Texas Water
Development Board

Flat Creek Flood Protection Plan -Draft Report

Submitted to:
Texas Water Development Board
Contract Administration
1700 North Congress Avenue
Austin, TX 78701

Submitted by:
Walker Partners
600 Austin Avenue, Suite 20
Waco, TX 76701

HDR, Inc.
600 West Sixth Street, Suite 20
Fort Worth, TX 76102

August 2017

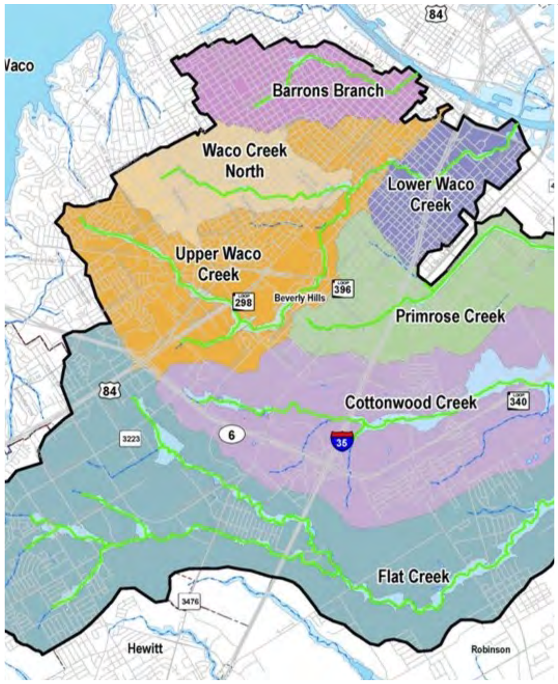
STATE OF TEXAS
GEORGE E. WALKER, JR.
65360
REGISTERED
PROFESSIONAL ENGINEER

George E. Walker, Jr.
25AUG17

STATE OF TEXAS
CURTIS BLANE BEITEL
83213
LICENSED
PROFESSIONAL ENGINEER

8/25/17

Flat Creek Flood Protection Plan - Final Report



August 25, 2017

CITY OF WACO

in conjunction with:

Texas Water Development Board

City of Robinson

HEWITT TEXAS

McLennan County 1850

City of Woodway Texas

City of WOODWAY

official website of the City of Woodway

Walker Partners

engineers ★ surveyors

HDR

Flat Creek Flood Protection Plan -Draft Report

Submitted to:
Texas Water Development Board
Contract Administration
1700 North Congress Avenue
Austin, TX 78701

Submitted by:
Walker Partners
600 Austin Avenue, Suite 20
Waco, TX 76701

HDR, Inc.
600 West Sixth Street, Suite 20
Fort Worth, TX 76102

August 2017

STATE OF TEXAS
GEORGE E. WALKER, JR.
65360
REGISTERED
PROFESSIONAL ENGINEER

George E. Walker, Jr.
25AUG17

STATE OF TEXAS
CURTIS BLANE BEITEL
83213
LICENSED
PROFESSIONAL ENGINEER

Curtis B. Beitel
8/25/17

(This Page Intentionally Left Blank)

Figures

Tables

Appendices

List of Acronyms Used

Acronyms

ACE	Annual Chance Exceedance
AEP	Annual Exceedance Probability
BCA	Benefit-Cost Analysis
cfs	Cubic Feet per Second
CIP	Capital Improvement Program
CN	Curve Number
CWA	Clean Water Act
DS	Downstream
DTM	Digital Terrain Model
ESRI	Environmental Systems Research Institute
FCR	Flat Creek
FEMA	Federal Emergency Management Agency
FFE	Finished Floor Elevations
FIPS	Federal Information Processing Standard
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FPP	Flood Protection Plan
fps	feet per second
GIS	Geographic Information System
GPS	Global Positioning Systems
HEC	USACE Hydrologic Engineering Center
HMS	Hydraulic Modeling System
HPIDS	High Priority Imagery and Data Sets

ICM	Integrated Catchment Modeling
IFA	Ineffective Flow Area
LEDPA	Least Environmentally Damaging Practicable Alternative
LiDAR	Light Detection and Ranging
LOB	Left Over Bank
MBTA	Migratory Bird Treaty Act
MCAD	McLennan County Appraisal District
MFT	Flat Creek - Main
NAD 83	North American Datum of 1983
NAIP	National Agriculture Imagery Program
NAVD 88	North American Vertical Datum of 1988
NFIP	National Flood Insurance Program
NFT	North Flat Creek Tributary
NGVD	National Geodetic Vertical Datum
NHPA	National Historic Preservation Act
NLCD	National Land Cover Database
NPV	Net Present Value
NRCS	Natural Resources Conservation Services
NRHP	National Register of Historical Places
NWP	Nationwide Permit
OB	Over Bank
OHWM	Ordinary High Water Mark
PCN	Pre-Construction Notification
RAS	River Analysis System
RCBC	Reinforced Concrete Box Culvert
ROB	Right Over Bank
ROW	Right of Way
RS	River Station (Cross Section)
SB	Sub-basin
SCS	Soil Conservation Service
SFT	South Flat Creek Tributary
SSURGO	Soil Survey Geographic Database
THC	Texas Historical Commision
TIN	Triangulated Irregular Network
TNRIS	Texas Natural Resources Information System
TR-55	USDA Technical Release 55: Urban Hydrology for Small Watersheds
TWDB	Texas Water Development Board
TxDOT	Texas Department of Transportation
TXNDD	Texas Natural Diversity Database
TXRAM	Texas Rapid Assessment Method
URS	URS Corporation (formerly United Research Services)
US	Upstream
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WOTUS	Waters of the U.S.
WS	Water Surface
WSEL	Water Surface Elevation
WWF	Welded Wire Fabric
XS	Cross Section

(This Page Intentionally Left Blank)

Executive Summary

On the night of June 13, 2014, 18-year old LaCharles Montgomery was driving home from work when his car was swept off of Panther Way/Old Hewitt Road by the raging floodwaters of Flat Creek. This event, coupled with historical property damage caused by Flat Creek flooding, prompted swift, methodical action by the City of Waco (City). As a result, the City retained the Team of Walker Partners, HDR, and Morrison Hydrology (Team) to prepare a flood protection plan for Flat Creek.

Due to the fact that Flat Creek flows through multiple jurisdictions, the City and the project Team organized a consortium consisting of each jurisdiction which contains Flat Creek (Robinson, Hewitt, Woodway, and McLennan County) to participate in a regional drainage and flood protection plan for the Flat Creek watershed. Each entity expressed a genuine interest in participating in the regional plan and this became the catalyst for the City of Waco to apply for a Flood Protection Planning Grant (Grant) from the Texas Water Development Board (TWDB). The grant was approved and funded, in part, by the TWDB.

The purpose of this regional flood protection planning effort was multi-fold:

- Gather and record historical information regarding flooding within the Flat Creek drainage basin;
- Analyze the watershed to determine the current flooding conditions;
- Establish accurate mapping of the limits of the 100-year floodplain of Flat Creek;
- Create regional floodplain regulations and drainage design criteria;
- Assure the adequacy and safety of existing drainage infrastructure including bridges, culverts, channels, and other facilities/structures;
- Explore regional approaches to flood protection planning, funding, and implementation;
- Identify local and regional (structural and non-structural) flood mitigation projects to provide long-term, sustainable flood protection measures;
- Recommend a Capital Improvement Program to plan and construct new improvement projects to protect the public against flood damage and injury, including loss of human life.

"State-of-the-art" computerized hydrologic and hydraulic modeling techniques were utilized to create new floodplain maps based upon modern-day urbanization and land use. This floodplain analysis revealed five major flood-prone areas:

- 12th Street and Woodcock Drive (State Highway 77)
- Robinson Drive and Old Robinson Road
- Panther Way and Old Hewitt Road
- Hewitt Elementary School and Applewood/Lindenwood Streets
- Venture Drive/Imperial Drive

For each of these problem areas, both structural and non-structural mitigation strategies were analyzed to protect public safety and property. The non-structural mitigation strategies considered by the project Team include the following:

- Property acquisition (buy-outs);
- Flood warning systems; and
- Regional Drainage Criteria

The structural mitigation strategies considered for each identified flooding area include the following:

- Regional Detention;
- Conveyance Improvements –
    - o Channelization Improvements
    - o Bridge/Culvert Improvements

Benefit-cost analyses were conducted for the various mitigation strategies analyzed for each flood-prone area and the "best value" solution has been recommended at each site. A summary of the recommended flood mitigation solutions, along with the estimated project costs, are shown below:

Flood-Prone Area	Recommended Solution	Estimated Cost	Responsible Entity	Funding Source
Woodcock Drive & 12th Street	Elevate 5 residential properties	$392,425	Homeowners City of Robinson	FEMA hazard mitigation grant
Robinson Drive & Old Robinson Road	Acquire 3 houses and adjacent lots	$506,172	City of Robinson	FEMA hazard mitigation grant
Panther Way & Old Hewitt Road	Remove culvert, add cul-de-sac on Panther Way; Revise operations of Old Hewitt Add culverts at Ava Drive	$760,185	City of Waco; City of Hewitt; McLennan County	CIP
Hewitt Elementary & Applewood/Lindenwood Streets	Regional detention pond behind Hewitt Elementary	$5,065,250	City of Hewitt	CIP
Venture Drive & Railroad	Verify that the finished floor elevations are above the 100-year WSEL	$0	City of Waco	General
Entire Watershed	Develop Regional Drainage Criteria	$100,000	City of Waco	General
Total Estimated Mitigation Cost		$6,824,032		

1.0 Introduction

The Brazos River, flowing through the heart of the City of Waco, has been a major catalyst for the economic prosperity and growth of Waco since it was founded. The economic boom years of the late 19th century and early 20th century were oftentimes stymied by the floodwaters of the Brazos. The City of Waco experienced most of its growth from 1920 (38,500) to 1970 (95,326), before the NFIP floodplain regulations were put in place in the mid-1970's.

Sound, regional planning brought forth Lake Possum Kingdom and Lake Whitney – flood control lakes along the Brazos which have tamed the River for almost 70 years. Now, however, planning is needed for the urbanized watersheds, streams, and tributaries that flow into the River. Waco, like most major cities, has experienced urban sprawl and growth of surrounding suburbs since the early 1960's. Coincidentally, these suburbs are predominantly located upstream of Waco and therefore contribute to and exacerbate the adverse effects that urbanization has on stormwater runoff.

The City of Waco contains portions of four major, regional watersheds, all within the Brazos River Basin. Three of these watersheds, the North Bosque River, the Middle Bosque River, and the South Bosque River all converge into the City's primary water supply reservoir – Lake Waco. Lake Waco is a U.S. Army Corps of Engineers reservoir which is intended to provide flood control to the Waco area in addition to boating, fishing, recreation, and water supply. The remaining areas of Waco drain into the Brazos River, as does the discharge from the Lake Waco Dam. Contributing to these four rivers, are 15 major creeks comprising over 53 miles of waterways all within the city limits. Of these 15 creeks, the Flat Creek watershed is unique, in that it includes portions of Waco, Robinson, Hewitt, Woodway, and McLennan County, which requires a regional stormwater management and flood protection plan to:

1. Mitigate the existing dangers of flooding;
2. Protect the lives and property of citizens living and working in the region; and
3. Prevent future flood losses from occurring through sound, regional planning.

Planning efforts in the Flat Creek watershed considered both structural and nonstructural mitigation measures. Regional structural mitigation efforts were identified to provide long-term, sustainable flood protection measures that will benefit multiple jurisdictions within the watershed. An example of this type of regional flood control mitigation would be a regional stormwater detention facility.

Each entity within the planning area – Waco, Robinson, Hewitt, Woodway, and McLennan County expressed a genuine interest in participating in a regional stormwater management/flood protection plan whereby each jurisdiction's ordinances, policies, drainage criteria, and development design guidelines would be complimentary and based upon regional practices and principles. Such planning and coordination are essential in the development and implementation of such a robust, regional effort.

1.1 Purpose

The City of Waco applied for a Flood Protection Planning Grant from the Texas Water Development Board and retained the Team of Walker Partners, HDR, and Morrison Hydrology to evaluate the City of Waco's major "riverine" drainage systems and publish Waco's first Drainage Master Plan. The purpose of this flood protection planning effort for the Flat Creek watershed is to:

1. Gather and record historical information regarding flooding within the Flat Creek drainage basin, particularly flooding which jeopardizes public safety (including loss of human life) and causes financial damage to private properties;
2. Analyze the watershed to determine the current flooding conditions;
3. Establish accurate mapping of the limits of the 100-year floodplain of Flat Creek within the city limits of Waco, Robinson, Hewitt, Woodway, and McLennan County based upon urbanization as is exists today;
4. Create regional stormwater management regulations and drainage design criteria in an effort to reduce the loss of human life caused by flooding and to reduce flood damage to property.
5. Assure the adequacy and safety of existing drainage infrastructure including bridges, culverts, channels, and other facilities/structures;
6. Explore regional approaches to stormwater management planning, funding, and implementation;
7. Identify local and regional (structural and non-structural) flood mitigation projects to provide long-term, sustainable flood protection measures;
8. Recommend a Capital Improvement Program in order to maintain and manage the existing drainage infrastructure as well as to plan and construct new improvement projects to protect the public against flood damage and injury, including loss of human life.

1.2 Scope of Work

The Flat Creek Flood Protection Plan was structured to address the flooding issues that exist within the planning area; to develop updated hydrologic and hydraulic models in order to evaluate potential structural and non-structural flood protection measures; and to involve the affected jurisdictions and the general public in the development of a regional flood protection plan. The scope of work is divided into ten primary tasks, as described below.

Task 1 – Project and Grant Management

A kickoff meeting was conducted with the TWDB FPP Grant project manager, the City's project manager, and the consultant's project team to discuss the goals and objectives of the study, the project schedule, responsibilities of each party, reporting protocol, and deliverables. Monthly progress reports describing tasks accomplished that month, discussion of issues to be resolved, tasks to be performed next month, and project schedule updates were prepared and distributed among the Team members.

Task 2 – Field Survey

The Project Team conducted an initial field reconnaissance of each specific study reach to determine conditions along the floodplains, types and numbers of hydraulic and/or flood-control structures, apparent maintenance (or lack thereof) of existing hydraulic structures, locations of cross sections to be surveyed, and other parameters needed for the hydrologic and hydraulic analyses. Based on the initial field reconnaissance, a map was developed depicting the preliminary cross section layout. Based on this preliminary cross section layout, field surveys were conducted to obtain channel cross sections, establish horizontal and vertical control datums, and obtain the physical dimensions of hydraulic and flood-control structures.

Task 3 – Hydrology

For the Flat Creek watershed, drainage sub-areas were determined at key points of interest along with hydrologic parameters, soil conditions, and impervious cover in order to calculate peak runoff rates and volumes for selected return period storm events. The FEMA standard HEC HMS software was used for hydrology modeling, with the GIS interface HEC-GeoHMS as a pre-processor to increase efficiency. The hydrograph routing method for rainfall-runoff modeling was the SCS unit hydrograph method used to perform hydrograph routing through existing and proposed detention facilities and hydraulic reaches. The resulting peak flows were compared to the effective “published” discharges and the regional regression equations developed by TxDOT. The updated peak flows were presented at Workshop and Public Meeting #1.

Task 4 – Hydraulic Analysis

A hydraulic analysis was performed for Flat Creek from the Brazos River to the headwaters. Cross sections were developed from the TNRIS 2011 topographic data and combined with surveyed cross sections to create the digital terrain model necessary for the computerized hydraulic analysis. The hydraulic model included the 10-, 2-, 1-, and 0.2-percent-annual-chance events based on peak discharges computed in Task 2. The FEMA standard HEC-RAS model was used for hydraulic analysis, with the GIS interface HEC-GeoRAS used as the pre- and post-processors to increase efficiency. Hydraulic analyses included the determination of water surface profiles for creeks and hydraulic capacities of culverts, bridges, and other hydraulic structures as needed at selected locations.

Task 5 – Identify Problem Areas

The 1- and 0.2-percent-annual-chance floodplain boundaries were delineated for each specific study reach. The results of the new, or revised, hydraulic modeling was used with the TNRIS 2011 topographic data to delineate the floodplain boundaries on a digital work map. This task did not included development of floodway hydraulic models or any modifications to regulatory floodway boundaries.

Workshop and Public Meeting #2 was conducted with City public works, maintenance, and emergency management staff to identify and discuss known problem areas. Problem areas were identified based on the floodplain boundaries, from flooding reports or field assessments of drainage infrastructure. In the meetings, Hydraulic restrictions such as undersized bridges or culverts; reaches where channel modifications could provide additional conveyance; and/or open land opportunities for regional detention were identified for each problem area.

Task 6 – Solution Development

Known problem areas were identified through a regional workshop with City engineering, maintenance, and emergency management staff. The majority of the problem areas were identified initially in the data collection phase and through discussions with City staff. Other problem areas were identified based on updated floodplain mapping and modeling, or from field assessments of drainage infrastructure. Regional detention facilities to reduce the peak discharges for downstream reaches were considered for each problem area.

Conceptual solutions were prepared for each identified problem area. Next, GIS shapefiles and a map of the proposed planning area were prepared to show the extents of each conceptual solution along with tabular data describing each CIP project for the Flood Protection Plan. The conceptual solutions and CIP were presented at Workshop and Public Meeting #3.

Task 7 – Environmental / Cultural Assessment

For each conceptual solution, a site visit was conducted to identify potential environmental and cultural resources that could be impacted.

Task 8 – Economic Analysis

An economic analysis was conducted for each conceptual solution. The economic analysis included development of potential cost estimates and estimates of flood reduction benefits using data from the McLennan County Appraisal District (MCAD). Benefits included reduction in damages for structures, reduction in frequency and severity of overtopping at low water crossings, and reduction in economic losses (business interruptions and job losses). Those cost estimates included construction costs, right-of-way acquisition costs, and soft costs such as engineering, surveying, and permitting. Cost-benefit ratios for each conceptual solution were prepared in order to determine the "best value" solution. The results of the economic analysis were presented at Workshop and Public Meeting #4.

Task 9 – Flood Protection Planning Report

This report has been drafted to document the analysis methods used and conclusions reached regarding potential CIP projects. Preliminary opinions of project costs; other project prioritization factors for each project; and a recommended Capital Improvement Program are included in this report. The Draft Report was presented at Workshop and Public Meeting #5.

Task 10 – Workshops and Public Meetings

Five project workshops were conducted with the representatives of the participating political subdivisions above, in an effort to solidify a regional flood protection plan.

1.3 Study Area Delineation

The Flat Creek watershed is shown in **Figure 1-1** below. This figure also shows the boundaries of the municipalities adjacent to the City of Waco including the cities of Hewitt, Robinson, and Woodway, as well as unincorporated areas of McLennan County.

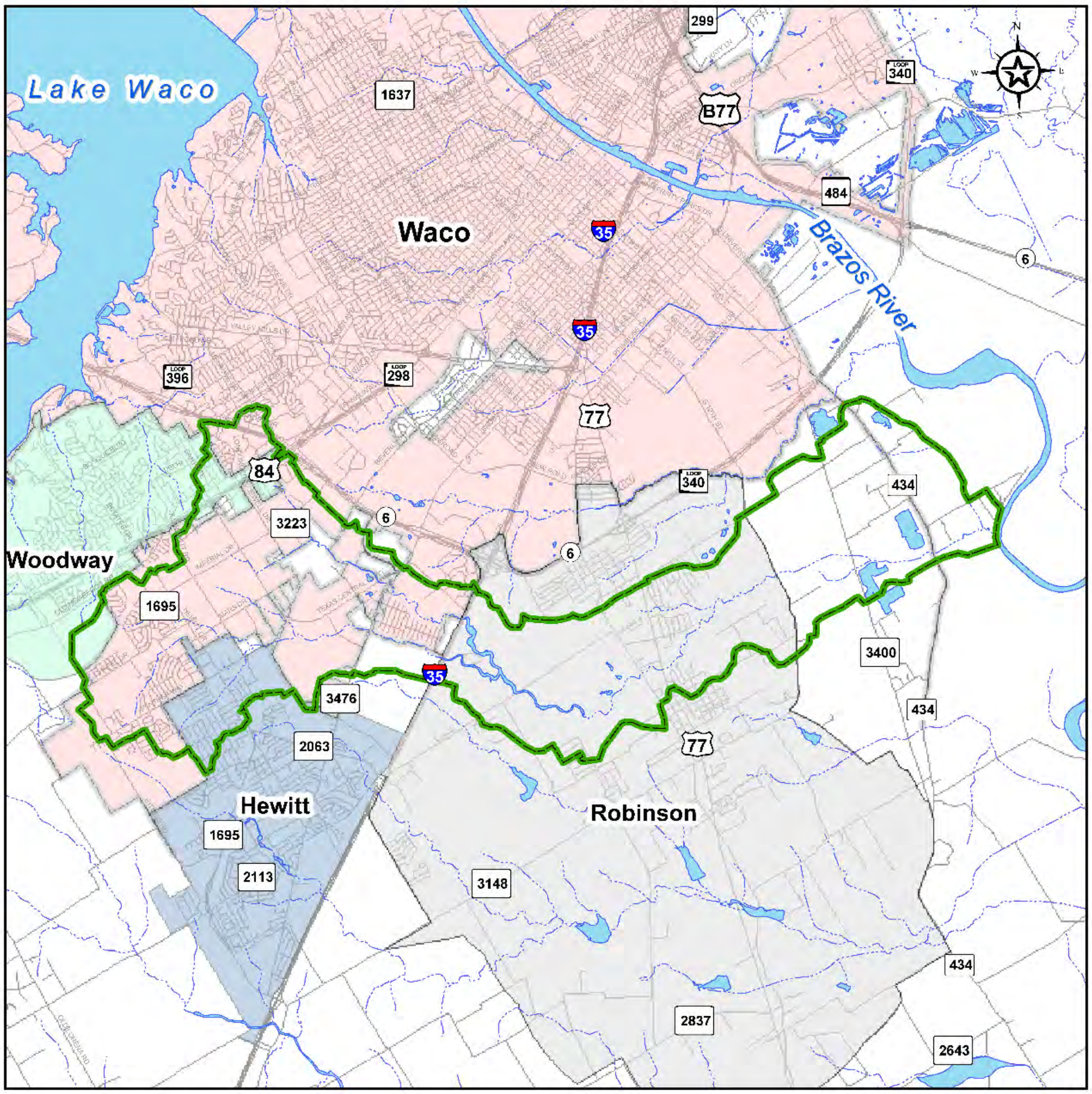


Figure 1-1: Flat Creek Watershed

(This Page Intentionally Left Blank)

2.0 Data Collection

Available existing reports and studies regarding the Flat Creek watershed were gathered and summarized. These sets of data and reports span the timeframe from 1970 to the present.

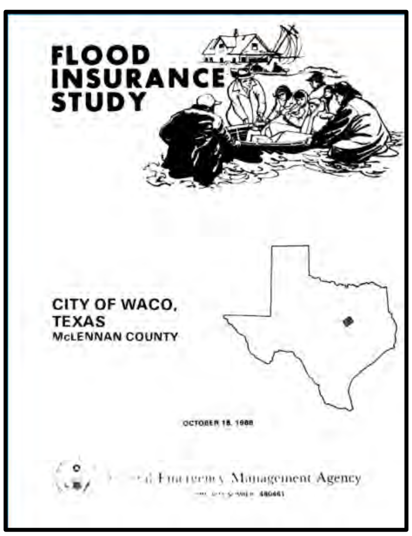
2.1 Previous Studies and Reports

Table 2-1 lists the previous studies / reports that were reviewed as part of our data mining efforts. Both City of Waco staff and Team members attempted to locate copies of the 1970 USACE report and 2003 Wallace Group Stormwater Master Plan, but no copy of these reports was able to be located.

Table 2-1: Summary of Previous Studies / Reports

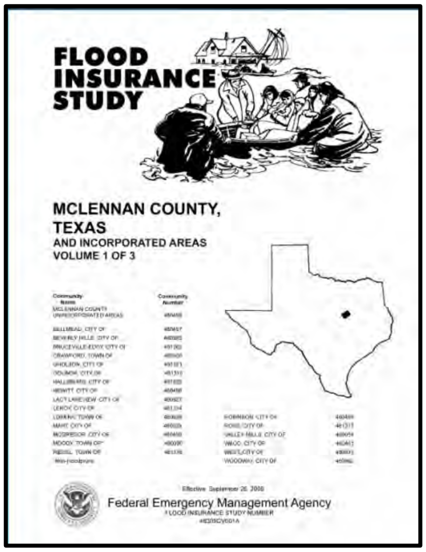
Date	Title	Author
May 1970	Flood Plain Information Report – Brazos and Bosque Rivers, McLennan County TX	USACE
Oct 1988	Flood Insurance Study – City of Waco, McLennan County, Texas	FEMA
2003	Stormwater Master Plan	Wallace Group
Sept 2008	Flood Insurance Study – McLennan County, Texas	FEMA
Jan 2015	Discovery Report – Middle Brazos Watershed Below Lake Whitney	FEMA

2.1.1 FEMA Effective Study



Oct 1988: FEMA *Flood Insurance Study – City of Waco, McLennan County, Texas*

The hydrologic and hydraulic analysis for this study represents a revision of the original analyses that were prepared by Lockwood, Andrews and Newman, Inc. for FEMA under Contract No. H-3730. The work for the original study was completed in November 1975. The hydrologic and hydraulic analysis of the Brazos and Bosque Rivers was updated by Caffey and Morrison, Inc. in March 1987.



Sept 2008: FEMA *Flood Insurance Study – McLennan County and Incorporated Areas, Texas*

In 2008 FEMA issued an updated Flood Insurance Study for McLennan County and Incorporated Areas. The effort was largely a modernization of the FIRM maps to a digital countywide format, and some of the floodplain boundaries were redelineated onto the latest available topography, which was the City of Waco's 2004/2005 contours.

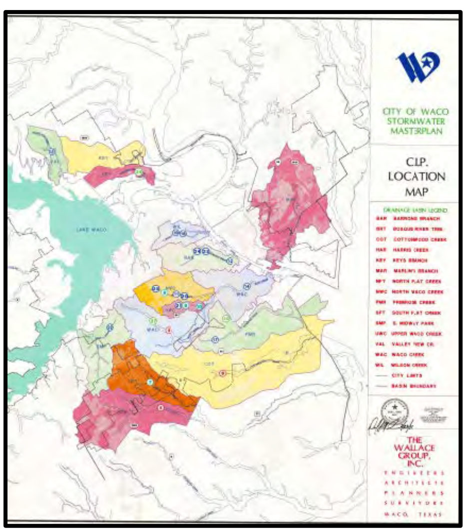
For streams in the unincorporated areas of McLennan County, the hydrologic and hydraulic analysis for this study represents a revision of the original analyses prepared by URS/Forrest and Cotton, Inc. for FEMA under Contract No. H-3972 in November 1978. For streams in Waco, the hydrologic and hydraulic analysis for this study remained the same as the original analyses prepared by Lockwood, Andrews and Newman, Inc. for FEMA under Contract No. H-3730 in November 1975.

2.1.2 Previous Studies / Reports

The listing of reports below is not considered to be all inclusive, but rather a listing of all available reports provided by the City of Waco staff.

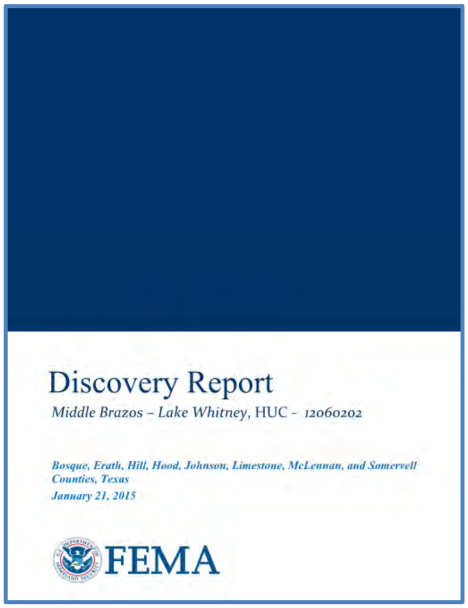
May 1970: Fort Worth District USACE *Flood Plain Information Report – Brazos and Bosque Rivers, McLennan County TX*

This report documented the development of the original hydrology and hydraulic model of Flat Creek, but a copy of it was not available.



2003: Wallace Group, Inc. *Stormwater Master Plan*

In 2002 an effort was made to update the hydrology and hydraulic models for most of the streams in Waco, along with modeling of the major storm drain systems. According to City of Waco Staff, this report was never completed. While no records exist for the hydrologic or hydraulic modeling efforts, a "Capital Improvements Program" map does exist along with cost estimates and prioritization of each capital project.



Jan 2015: FEMA *Discovery Report for the Middle Brazos Watershed Below Lake Whitney*

As part of their RiskMAP program, FEMA initiated a Discovery project to evaluate the Middle Brazos River from Lake Whitney downstream to Waco. This project is still underway (as of the date of this Report) and is scheduled for completion in 2018.

2.2 Topographic Data

In 2011 the Texas Natural Resource Information System (TNRIS) acquired Light Detection and Ranging (LiDAR) topographic data for Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties under a HPIDS Project. The Quality Assurance report by URS covers data deliveries received between July 14, 2011 and February 17, 2012, as well as 4 redeliveries of corrections, the last being delivered on March 13, 2012.

HDR reviewed the LiDAR data collected over McLennan County, TX in 2011 by Photo Science and compared that LIDAR data to an independent 2-foot contour data set created in 2005. The geographic footprint of these 34 tiles of high resolution aerial Infrared (IR) LiDAR data covers approximately 86,000 acres.

A copy of the HDR LiDAR Quality Inspection Report is included as **Exhibit A-1** in **Appendix A**. The assessments discussed in this report found that there is significant variance between the 2011 LiDAR data and the 2005 contour data, which was determined by a statistical comparison between the two datasets. Based on all the available information it was recommended that the 2011 LiDAR data be used for subsequent modeling efforts and not the existing 2004/2005 contour data. The LiDAR data was determined to meet industry standards and guidelines to support 1-foot contours in flat open terrain and 2-foot contours in sloped and heavily vegetated areas to the corresponding FEMA standards.

The 2011 LIDAR data was determined to be properly calibrated and despite some minor classification errors, classified within industry standards. The data was analyzed to determine Nominal Pulse Spacing, Ground Sample Distance, Vertical Accuracy, and Spatial Distribution and met industry standards in all regards. Vertical accuracy was assessed by information obtained in a report by URS Corporation. Because the report by URS did not contain information regarding accuracies in multiple land categories, the vertical accuracy outside of flat and open areas could not be determined with sufficient confidence to recommend 1-foot contours in context of the FEMA standard. It is likely that with minimal traditional survey in a variety of land cover areas, 1-foot FEMA compliant contours could be created throughout the study area.

2.3 Field Survey

The study extents for Flat Creek included the limits of the regulatory floodplain on the FEMA FIRM maps (and beyond) from the Brazos River to its headwaters. Strategic survey planning sessions were conducted to determine the optimum locations for the field surveys.

First, a Base Map with aerial photography as a background was created and the FEMA FIS cross-section locations were plotted. Next, new cross-section locations were determined and placed on the Base Map. These sections were intended to supplement the FIS cross-sections and have a maximum spacing of 500 feet. Finally, all of the drainage and bridge structures crossing Flat Creek were identified and the appropriate number and location for upstream and downstream cross-sections were planned and plotted on the Base Map. The field survey procedures comply with FEMA guidance.

Field survey crews were deployed to gather and collect topographic data at each creek cross-section locations; conduct an “as-built” survey of each bridge and culvert crossing; and locate the aerial pipeline crossings. Ground control was established on NAD 83, Texas State Plane horizontal datum and NAVD 88 vertical datum. Both Global Positioning Systems (GPS) and conventional survey methods were used to collect the cross-section data collected was from top-of-creek bank to top-of-creek bank. All of the overbank portions of the cross-sections were generated from the 2011 LIDAR data. Locations of the survey points collected are shown in **Exhibit A-2** in **Appendix A**, and locations of the photographs taken during the field survey are shown in **Exhibit A-3** in **Appendix A**.

2.4 Identification of Flooding Hot Spots

The current database of NFIP flood insurance claims was requested from FEMA, and the locations of each claim were geocoded to establish an initial set of flooding hot spots in the Flat Creek watershed, as shown in **Exhibit A-5** in **Appendix A**. The Team and City staff participated in a series of meetings with Waco Public Works staff to discuss the staff's historical / institutional knowledge of both system structural deterioration/failures and inadequate hydraulic capacity "hot spot" areas that have been identified.

(This Page Intentionally Left Blank)

3.0 Study Methodology

Developing a current understanding of the flood risk in the Flat Creek watershed required updating the hydrology and hydraulic models of the watershed using the current state of the practice techniques, as well as an economic analysis of the benefits and costs of each mitigation alternative, along with an assessment of the potential environmental and cultural impacts. The methodology used for each of these efforts is described in the sections below.

3.1 Hydrology

Peak flow rates were calculated at key discharge points within the Flat Creek watershed using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), Version 4.2. HEC-HMS is a rainfall-runoff model that simulates a watershed's response to precipitation and computes runoff hydrographs, peak discharges, and cumulative runoff volumes for the receiving watershed. Discharge points were established within the Flat Creek watershed at locations where peak runoff calculations were necessary to evaluate flooding hazards for insurable structures, as well as at locations where significant changes in the flow regime occur. This section describes the methods and assumptions used to calculate peak flow rates for each discharge point.

3.1.1 Drainage Area Delineation

Sub-basins describing the area that drains to each discharge point were delineated using the 2011 LiDAR elevation data. The City of Waco provided the previous watershed delineation for Flat Creek, which was used as a point of reference for the new sub-basin delineations. The more recent elevation data and higher level of detailed analysis resulted in modifications to the watershed drainage divides, but substantial differences were not observed. The Flat Creek watershed drains a total of 12,000 acres, or 18.8 square miles.

3.1.2 Precipitation

The hydrologic model, HEC-HMS, is a rainfall-runoff model that simulates a watershed's response to precipitation and computes runoff hydrographs, peak discharges, and cumulative runoff volumes for the receiving watershed. In order to develop flood hydrographs for storm events with various return periods, rainfall depths corresponding to the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals were used.

Time incremental rainfall depths for each recurrence interval were interpolated from contour maps published in the U.S. Geological Survey (USGS) Scientific Investigations Report 2004-5041, titled "Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas" (USGS, 2004), and entered into HEC-HMS as rainfall depth-duration, as shown in **Table 3-1** on the next page. Because the majority of the flood hydrograph is generated by the upper 10 square miles of drainage area, no additional areal reduction adjustment was applied to the precipitation.

Table 3-1: Depth-Duration-Frequency Data for Flat Creek

Duration	Rainfall Depth (in) Storm Return Period						
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
15 Minutes	0.85	1.20	1.45	1.65	1.90	2.20	2.90
1 Hour	1.65	2.15	2.50	2.95	3.35	3.75	4.90
2 Hours	2.05	2.70	3.25	3.95	4.60	5.30	7.10
3 Hours	2.20	3.00	3.60	4.40	5.20	6.00	8.20
6 Hours	2.60	3.55	4.25	5.20	6.20	7.25	10.20
12 Hours	2.95	4.00	4.80	5.85	7.00	8.10	11.90
1 Day	3.40	4.75	5.75	7.25	8.35	9.50	12.90

3.1.3 Soils and Land Use

The Soil Conservation Service (SCS) runoff curve number procedure is an accepted method for computing abstraction for storm rainfall, which effectively reduces the volume of precipitation that falls on a watershed and then becomes runoff. The rainfall that is in excess of the abstractions and becomes runoff is referred to as the excess rainfall. The SCS runoff curve number method relates soil types, antecedent soil moisture, and land use to precipitation abstractions.

Local soils data were downloaded from the SSURGO database through the U.S. Department of Agriculture's (USDA) Web Soil Survey online. The hydrologic soil group classification of a soil, as recorded in the SSURGO database, estimates runoff potential and was used in part to determine SCS curve numbers.

Land use classifications were determined from a high level of analysis by using the latest aerial imagery in GIS (2014 Aerial NAIP for McLennan County). Undeveloped land was assigned a land use classification of open space, wooded, meadow, brush, or agricultural. Developed areas were assigned a land use classification of open space in anticipation that impervious cover was going to be assigned directly to each sub-basin in HEC-HMS, rather than being accounted for in a general developed land use curve number. Each land use classification was assigned a base curve number, which does not presume an average percent impervious cover, according to guidance in the USDA TR-55, "Urban Hydrology for Small Watersheds" (NRCS,1986).

The National Land Cover Database 2011 (NLCD, 2011) was available in GIS format for McLennan County as feature class polygons, depicting impervious cover percentages for the Flat Creek watershed in 100 foot by 100 foot squares. These impervious cover percentages were reviewed and compared in detail with the latest aerial imagery, and were determined to be acceptable and generally in accordance with the current land uses.

A base curve number for each Flat Creek sub-basin was developed in GIS based on existing open space land use conditions and soil types, and percent impervious cover was applied to represent developed conditions. The runoff volumes were computed in HEC-HMS as a function of the base curve number and impervious cover percentage. For each storm event recurrence interval, average antecedent moisture conditions (AMC-II) were assumed.

3.1.4 Time of Concentration

The unit hydrograph method was used to transform the rainfall excess into a surface runoff hydrograph. The unit hydrograph for a watershed is defined as a direct runoff hydrograph that results from one inch of excess rainfall generated uniformly over the drainage area at a constant rate for an effective duration (Chow, *et al*, 1988).

The SCS unit hydrograph method relates hydrograph characteristics to a physical characteristic of the watershed, the basin time to peak (t_p). The parameter t_p is defined as the time from the beginning of the rainfall event to the time at which the peak runoff rate is observed at the watershed outlet. The time to peak of a basin can be estimated using the following empirical equation:

$$t_p = 0.6\ T_c$$

where:

T_c = Time of concentration for the watershed.

The time of concentration is defined as the time it takes for a drop of rain that falls on the most hydraulically remote point in the watershed to contribute to the flow at the drainage basin outlet. The time of concentration for each sub-basin was computed using 2011 LiDAR elevation data to delineate longest flow-path lines. Each flow-path line was broken into sheet flow, shallow concentrated flow, and channel flow due to the different characteristics of the flow in these regimes. The Kerby-Kirpich method was used to calculate travel time for overland sheet flow, which was limited to 300 linear feet for undeveloped surfaces and 100 linear feet for developed areas. Shallow concentrated flow and channel flow travel time calculations utilized the velocity method as described in the USDA National Engineering Handbook Part 630, Chapter 15.

3.1.5 Hydrologic Channel Routing

Routing simulates the movement of a flood-wave through a stream reach, to account for valley storage and flow resistance within the channel and its floodplain. Routing of flood flows from the outlet of an upstream sub-basin to the next sub-basin outlet downstream was accomplished using the Modified Puls method in HEC-HMS using Normal Depth Storage techniques. The Modified Puls method treats each routing reach as a storage pool with a user-specified storage-discharge relationship, which was obtained from a concurrently developed HEC-RAS model. The average flow velocity from the HEC-RAS model was also used to calculate the number of routing sub-reaches by dividing the length of the routing reach by the average velocity and rounding up to a whole number.

3.2 Pilot Study

During the initial stages of the Flat Creek hydrologic analysis, it was important to perform a "pilot study" to calibrate the hydrologic parameters of lag time and curve number. The study results would indicate the ideal equations and methods to follow for the rest of the Flat Creek hydrologic analysis based on the data available. The study focused mainly on the three upper sub-basins contributing to the upper reaches of the South Tributary of Flat Creek. **Figure 3-1** shows the location of the three sub-basins evaluated and the flow paths used to determine the lag time.

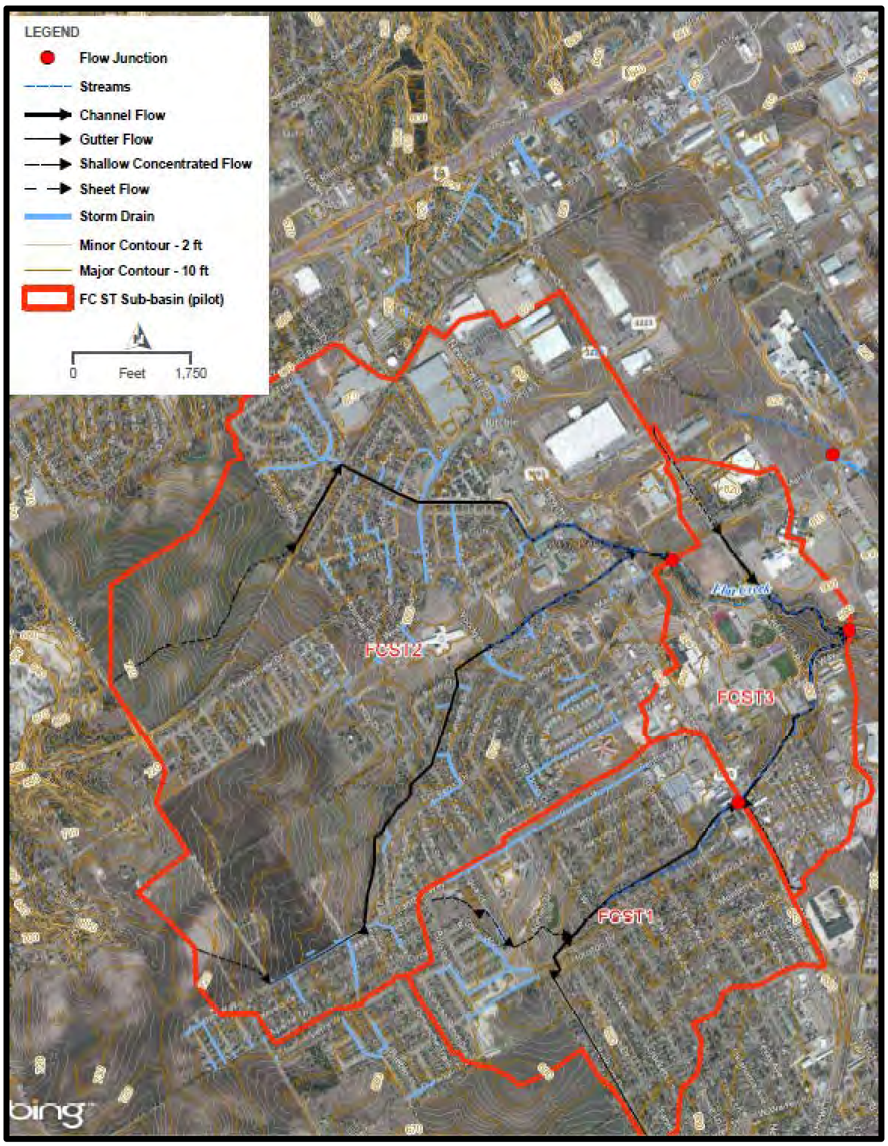


Figure 3-1: Pilot Study Sub-basins

The three sub-basins were re-labeled for the final hydrologic analysis as follows:

- ST1 = SB-SFT-11 (Final Flat Creek Study)
- ST2 = SB-SFT-06 & 07 (Final Flat Creek Study)
- ST3 = SB-SFT 04, 05, 10 (Final Flat Creek Study)

For lag time (time of concentration), the main parameters (for overland, sheet flow and channel flow paths) compared were a combination of the Kerby-TR55 Methods (see **Chapter 10** for references) versus the TR-55 Methods. The Kerby-TR55 Method uses the Kerby equation for overland sheet flow and the TR-55 Method for shallow concentrated and channel flow.

The Kerby overland flow assumes that the sheet flow does not exceed 100 feet in length for urbanized areas and 300 feet in length for rural areas. The TR-55 Method assumed that overland flow cannot exceed 100 feet in length at any condition. Channel flow was assumed once flow entered a drainage-way, storm drain system, open channel, or natural watercourse. **Table 3-2** shows the comparison results of the two methods.

Table 3-2: Overland Flow Comparison

Sub-basin	**Area**	**Overland (TR55)**		**Overland (Kerby)**	
	Acres	Length (ft)	T_c (mins.)	Length (ft)	T_c (mins)
ST1	477	90	11.05	140	11.25
ST2	1402	88	11.89	138	11.12
ST3	295	98	12.24	148	11.78

Results show that concentration times are similar for both methods although the Kerby method allows for longer distances. The sheet flow for the TR-55 Method exaggerates the T_c for distances over 100 feet. The Kerby method was selected since the longer distances do not significantly alter the results and allows to differentiate between rural and urban land uses.

Three curve number (CN) methods were compared for the Pilot Study sub-basins. Each approach can generally be described as:

1. Base CN - assumes that all developed land use in the sub-basin is entirely urban open space with good hydrologic condition. The impervious cover percentage for each sub-basin was determined and input directly into HMS, which assigns zero precipitation loss to the allotted area. Other agricultural and open areas were assigned appropriate CN values for straight row crop with crop residue – good condition, meadow, brush – good condition, or woods – good condition. This is a standard and typical approach that is consistent with the City of San Antonio requirements.

2. Simplified Composite CN - This approach is different from the Base CN method in that it distinguishes developed areas into two different categories. Based on the

aerial imagery and engineering judgment, developed areas where assigned CN values for either urban open space – good condition or urban open space – fair condition. Urban centers that appeared more intensely developed were assumed to have degraded hydrologic soil and were assigned the open space – fair condition CN, while residential and open urban areas were assigned the open space good condition CN. The impervious cover percentage for each sub-basin was still calculated and entered directly into HMS. Other agricultural and open areas were assigned appropriate CN values as described above. The City of Austin hydrologic and hydraulic guidance is similar to this approach in that urban areas are assigned either fair or good hydrologic conditions for CN determination, however this distinction specified by the City of Austin in their existing land use planimetrics shapefile.

3. Composite CN - This approach utilized CN values published in TR-55 Table 2-2a (see **Chapter 10** for references) that have an assumed percent imperviousness for urban land use types already associated with them, which is accounted for in a higher CN value. Average percent imperviousness in each sub-basin was not necessary for entry into HEC-HMS. Aerial imagery was used to identify and distinguish urban districts into various GIS polygon features. Residential areas comprised of approximately 1/3 acre lots and were assigned a composite CN value accordingly. More industrial/commercial urban development was identified and assigned a respective CN value. Agricultural and open areas were evaluated the same as in the previous methods. The Composite CN method described herein is widely accepted as common practice, but may be more laborious to identify each land use type and develop detailed polygon features.

The purpose of comparing three different CN value calculations was to assess the amount of effort that is required by each, and compare how well the resulting peak runoff discharges matched each other. See **Table 3-3** for a summary of computed CN values for each sub-basin using the three methods.

Table 3-3: Computed CN Values for Pilot Study Sub-basin Areas

Basin Name	Area (mi^2)	Area (ac)	Base CN	Simplified Composite CN	Composite CN
FCST 1	0.75	477	77	82	83
FCST 2	2.19	1402	80	85	86
FCST 3	0.46	296	79	85	87

Based on the data available for this study and per the reliable results obtained, the base CN method was selected for the remainder of the study. It relies more heavily on the impervious cover data than the other two methods. The available impervious data from TNRIS for the County was very detailed, as explained in Chapter 3.1. The Simplified and Composite CN methods were more laborious to identify the degree of urbanization and each land use type and the data was not readily available.

3.3 Study Methodology - Hydraulics

The hydraulic analysis incorporates the peak discharge values into a hydraulic model of the channel based on existing geometric conditions of Flat Creek. The model output is used to delineate the floodplains for storm events with annual exceedance probabilities (AEP) of 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% (2-, 5, 10-, 25-, 50-, 100-, and 500-yr storm events respectively). This delineation aids in determining the extents and severity of flood prone areas along Flat Creek. The Hydrologic Engineering Center-River Analysis System (HEC-RAS Version 5.0.3) computer program was used to calculate the floodplain extents and other parameters at various locations throughout the studied channels. ESRI's ArcGIS 10.3 was used for mapping and topographic analysis. The HEC-GeoRAS was used to develop various hydraulic parameters (including the cross-sectional geometry) inputs to HEC-RAS. HEC-GeoRAS is an ArcView GIS extension which was designed to manage geospatial data for use in HEC-RAS.

There are three main reaches that comprise the Flat Creek analysis. The Main Flat Creek channel runs from the confluence at the Brazos River up to the tributary split located upstream of Greig Road. The Northern Tributary runs along the northern side of the watershed up to Imperial Drive. The Southern Tributary splits into various branches (smaller tributaries) at approximately 500 feet upstream of the Gateway Boulevard crossing. All reaches and tributaries are labeled in **Exhibit C-2** in **Appendix C**.

3.3.1 Cross Section Development

Ground-based topographic survey data from Walker Partners were used to define the channels geometry (including the thalweg elevation and stream centerline) at key stream locations. These included all the bridge and culvert crossings, significant hydraulic structures and stream cross sections at various locations throughout the Flat Creek main channel. In total there were 179 cross sections and 22 culvert/bridge crossings that were surveyed. The topography was tied using surface coordinates (NAD 1983 State Plane Texas Central FIPS 4203 feet). Cross sections extended one channel width past the top of bank (or property line if in close proximity). As a general guideline, spacing between cross sections was set to an average of 2,000 feet. Surveyed shots included stream invert(s), left and right toe and top of bank among other grade break locations.

The ground survey was complemented with the 2011 TNRIS LiDAR points (as previously mentioned). Surveyed cross sections were extended as necessary to fully contain the 0.2% AEP (500-yr) flows. Additional cross sections were added as necessary at locations where further detail in channel geometry was required (these were strictly based on LiDAR information). The ground survey topo and the LiDAR data were combined using the GIS interface and HEC-GeoRAS. A digital terrain model (DTM) in the form of a triangulated irregular network (TIN) was created with this information (as required by GeoRAS). The TIN is a surface representation derived from irregularly spaced points and break-line features. Each sample point of a TIN has an x, y coordinate and a z value (elevation). The cross section data for the hydraulic model is extracted from the TIN surface in order to define the channel and overbank areas. To accomplish this, the user creates a series of line themes including cross section cut lines, stream centerlines, main channel banks, and flow and flow path centerlines which are necessary to develop the required HEC-RAS hydraulic inputs. **Figure 3-2** shows a portion of the TIN surface used to create cross sections for the hydraulic model and for floodplain delineation.

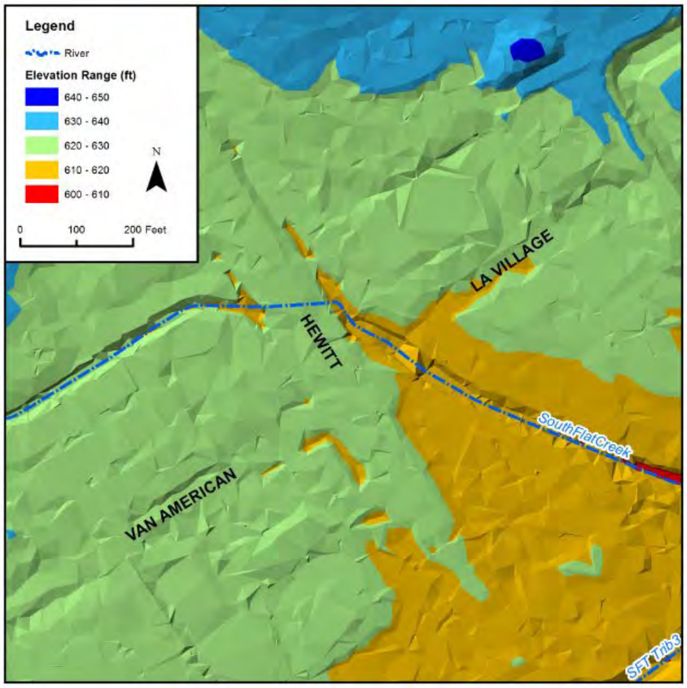


Figure 3-2: TIN used to Cut Cross Sections

The hydraulic work map in **Exhibit C-2** in **Appendix C** reflects the cross sections layout for Flat Creek as well as the contours and major intersecting structures.

3.3.2 Hydraulic Structures

The hydraulic structures crossing Flat Creek are critical to the flow conveyance and mapping of the floodplain. Each structure can impact the tailwater or headwater condition of a hydraulic model as well as the extents of flooding. Therefore, it was critical that good geometry was used to better represent each structure. Geometry data for bridges and culverts were developed using a combination of on-the-ground survey data, surveyor sketches, and ‘as-built’ drawings of the structures provided by the City. The ‘as-built’ drawings were reviewed where available, and the geometry of each structure was verified with the field survey and effective FIS model. Structures within Flat Creek include culverts, bridges, natural, and constructed weirs that are large enough to significantly affect the hydraulics of the system. A total of 22 culvert/bridge structures were field surveyed to define the structures dimensions and establish the opening sizes. This also included an upstream and downstream cross section and photographs at each face of structure, the abutment, deck, and piers dimensions and locations of bridges, as well as culvert and headwalls’ dimensions. The roadway width and profile was also tied at its highest elevations for at least 200 feet in each direction (from the stream crossing). This was important to identify which structures would be overtopped and by which storm event. The roadway embankment could also be important in defining which properties may be flooded as a result of backwaters. Modelers also field checked the structure crossings (after the field survey) to note any discrepancies with the field survey or record drawings and to better assimilate the actual geometry. The visit noted major debris or blocked obstructions that would impact the hydraulic model. Expansion and contraction coefficients are set to 0.1 and 0.3 for gradual transitions between sections, and 0.3 and 0.5, respectively for bridge sections. The bridge modeling approach used the greater of the energy and momentum solutions at each bridge.

3.3.3 Boundary Conditions

The accuracy of the hydraulic modeling results for Flat Creek are dependent on the downstream boundary conditions used in the model. In this study, the downstream limit of the model is located at the Brazos River, for which normal depth conditions were used for each flood frequency. A normal depth energy slope of 0.0036 ft/ft was calculated at the downstream most reach. Although the Brazos River backwater elevation of 388 feet NGVD impact the lower 6,000 feet of the Flat Creek floodplain, FEMA requires normal depth for the hydraulic models and enforces the Brazos River 1% AEP water surface elevations on the FIS profile and floodplain mapping only.

3.3.4 Manning's Roughness Coefficients

Cowan's Method (see **Chapter 10** for Reference) was used to determine the Manning's roughness (n) values within the channel areas. Floodplain (overbank) n-values were determined independently using a GIS land use polygon. Data collected during the field investigation, coupled with aerial photographs and contours from 2011, were used for reference in determining n values.

The Cowan's Method specifies the n-values to be based upon the summation of various channel characteristics. These factors are channel irregularity, variation in cross section, obstruction, vegetation, and thalweg meandering. In general, the channel roughness coefficients varied from 0.035 (for heavily mowed and straight channels) to 0.075 (for channel areas with dense vegetation, heavy irregularities in geometry and intense meandering).

A land use polygon shapefile was used to determine the left and right overbank n-values (floodplain). GeoRAS was used to incorporate the shapefile into the HEC-RAS model. Floodplain values were assigned per general observed land use conditions as noted in **Table 3-4** on the next page. In general, values varied from 0.03 for smooth surfaces to 0.09 for areas heavily wooded or residential areas with fences. Any structures that could be subject to flooding are modeled as either a high n-value of 0.17 or a blocked obstruction in HEC-RAS.

Table 3-4: Overbank Land Use Manning's n-Values

Land Use	n-value
Pond	0.01
Railroad	0.03
Roadway – paved areas	0.04
Short grass	0.04
Cultivated Fields	0.06
Brush – lightly wooded	0.07
Heavily Wooded	0.09
Residential	0.09
Buildings	0.17
Main Channel	Cowan's Method

Refer to the hydraulic work map in **Exhibit C-2** in **Appendix C** to see the various land-use types assigned for the overbank locations.

3.3.5 Ineffective Flow Areas

Ineffective flow areas (IFA) were added at bridge and culvert sections following a standard contraction ratio of 1 to 1 and expansion ratio of 2 to 1. They are not set to permanent as recommended in the HEC-RAS Technical Manual (see **Chapter 10** for Reference). Ineffective flow areas were also added in off-channel areas that store water where the active conveyance is assumed to be zero and at locations in and around homes or buildings (set as blocked obstructions) where the active conveyance is very limited. These locations are mainly at channel overbanks. Various gravel pit ponds or flat storage areas were observed along the main reach of Flat Creek, downstream of Robinson Road. The floodplain area between 3rd Street and 12th Street (RS 4772 and 15244) contains multiple offline ponding locations that were modeled with ineffective flow. Other locations in this vicinity had small islands along the main channel that also impeded the regular conveyance of flow. The IFA elevations were set to contain flows at the roadway profiles, but also allow effective passage for overflow conditions.

3.4 Economic Analysis

The potential cost effectiveness of proposed flood protection measures were determined by calculating the cost of the proposed solutions and comparing it to the expected flood reduction benefits. The flood reduction benefits were estimated by estimating the cost of repair or restoration of property that would be damaged by various levels of flooding. Property damage includes residences, businesses, streets and roadways, crop land and other associated improvements, as well as the "soft costs" such as interruption of businesses.

Property values were based on property maps and appraised values from the McLennan County Appraisal District. Estimates were prepared for flood events ranging from a 2-

year to 500-year return interval, and the percent chance of each flood occurring will be used to develop an annualized benefit, to compare to the annualized costs.

A benefit-cost analysis (BCA) was also performed. The analysis includes estimating the monetary amount of flood damage to a residential structure and contents by using a USACE generic depth-damage curve as mentioned in: Economic Guidance Memo 01-03: Generic Depth-Damage Relationships (USACE, 2000). The procedure relates flooding depth to damage as a percentage of structure value. The damage estimates are based on comprehensive accounting of losses from flood victims' records from 1996 to 1998. It accounts for damages to both structures and contents.

Various assumptions were used based on the Guidance's limitations and to better represent the impact of each mitigation alternative. In general, these included:

- Structures were assumed to be 1 story w/out basements.
- Industrial and commercial properties referenced the USACE New Orleans District Depth-Damage Relationships for Structures, Contents, and Vehicles and Content-to-Structure Value Ratios (CSRV) in Support of the Donaldsonville to the Gulf, Louisiana, Feasibility Study (USACE, March 2006). These properties were also assumed to have no basement as the procedure does not contain specific data for such structures. The assumption was made that all commercial and industrial structures fall into the category of wood or steel frame structures with a short flood duration per the document's Table 30. The structure contents are assumed to fit the warehouse and contractor services curve as defined in Table 51 of the same document.
- Microsoft Excel was used to develop a polynomial best-fit line and equation for the USACE depth-damage tabular relationships. This equation was used for ease of calculation in the spreadsheet rather than a linear interpolation straight from the tabular values.
- Displacement costs for residential and commercial properties are both calculated using the FEMA standard value of $1.44 per square foot per month of displacement.
- Benefit of raising the level of service of a roadway is not accounted for in the BCA analysis. Roadway damage is assumed to be negligible from the overtopping of flood waters.

A step by step procedure of the benefit calculations is as follows:

- GIS tools were used to compare structure finished floor elevations (FFE) to the resulting water surface elevations from the InfoWorks ICM model. Where surveyed elevations were not available, the lowest adjacent elevation (per 2009 TNRIS LiDAR data) was assumed as the structure's FFE.

- A Microsoft Excel spreadsheet was created to synthesize the data received from GIS and compute the flooding depths at each structure. This spreadsheet can be found in Appendix D (BCA_Calculations.xlsx).
- Using each structure's flood depth, the percent of damage to the structure, percent damage to contents, and displacement costs could all be calculated using the aforementioned best-fit equations.
- These damage calculations were performed on flooding depths resulting from the 2-, 5-, 10-, 25-, 50-, and 100-year storm events. The value of property damages were annualized assuming the corresponding Annual Exceedance Probability (AEP) for each storm event (e.g., 100-year is the 1% AEP) and then converted to Net Present Value (NPV) assuming the FEMA standard of 7% return over a 50 year period.
- The structures benefited (i.e., reduction in flood depth) by each mitigation alternative were monetarily quantified by taking the difference in NPV damage under existing flood depths versus NPV damage due to the proposed mitigated flood depth.

The benefit/cost ratio was finally calculated by dividing the benefit cost by the opinion of probable construction cost.

3.5 Environmental and Cultural Assessments

Once the conceptual mitigation solutions were developed, an environmental constraints report was planned for the problem areas that include disturbance of channel areas. The proposed project area was reviewed using publicly available data and aerial photographs to identify potential environmental constraints, including potential waters of the U.S. and habitat for threatened and endangered species. The project area appears to be primarily vegetated with species typical of disturbed and regenerative areas including invasive, non-native and native species. Small portions of the project area contain woody vegetation such as pecan, oak, western soapberry, hackberry, and green ash trees, some of which are mature and have a 30-inch plus diameter at breast height.

The federally-listed threatened/endangered species for McLennan County, Texas include the bald eagle (recovery) (*Haliaeetus leucocephalus*), whooping crane (endangered) (*Grus americana*), black-capped vireo (endangered) (*Vireo atricapilla*), and the golden-cheeked warbler (endangered) (*Dendroica chrysoparia*). A request has been made for information from the Texas Natural Diversity Database (TXNDD) (maintained by Texas Parks and Wildlife Department) but the report has not yet been received. However, once received, it should be noted that a lack of records in this database does not indicate nor guarantee the absence of listed threatened and endangered species, but no suitable habitat for federally-listed threatened and endangered species likely exists in the proposed project area.

In addition to the above species, there are federally-listed threatened fish, the Sharpnose shiner (*Notropis oxyrhynchus*) and Smalleye shiner (*Notropis buccula*). Also, there are state-listed threatened mussel Smooth pimpleback (*Quadrula houstonensis*), and the Texas fawnsfoot (*Truncilla macrodon*). The Texas horned lizard (*Phrynosoma cornutum*) and Timber rattlesnake (*Crotalus horridus*) are state-listed threatened species listed for McLennan County.

Based on desktop review, HDR performed a general habitat assessment to evaluate any potential threatened/endangered species habitat, and conducted a baseline environmental review of native vegetation areas that are potential migratory bird nesting and foraging habitat for which special clearing requirements may be applicable. The general habitat evaluation found that no suitable habitat for federally-listed threatened/endangered species likely occurs in the project area. However, scattered woody vegetation (trees and shrubs) in the proposed project area could serve as nesting habitat for migratory birds.

The Migratory Bird Treaty Act (MBTA) states that it is unlawful to kill, capture, collect, possess, buy, sell, trade, or transport any migratory bird, nest, young, feather, or egg, in part or in whole, without a federal permit issued in accordance within the Act's policies and regulations. The MBTA prohibits disturbance to active nests with eggs present unless expressly authorized by regulation or permit. Since trees and shrubs in the proposed project area could serve as nesting habitat for migratory birds, the proposed project may require best management practices for clearing (see recommendations below) to avoid impacts to migratory birds for compliance with the MBTA. Otherwise, coordination with the U.S. Fish and Wildlife Service for a "take" permit may be required.

HDR reviewed the Texas Historical Commission (THC) Texas Archeological Site Atlas (Atlas) to search for previously documented cultural resources within a one-mile radius of the proposed project area. Although there are no previously recorded archaeological sites within the proposed project area, there is some potential for buried cultural resources to be encountered in the project area. There are previously recorded archaeological sites within a one–mile radius of the project area which may need to be reviewed for consideration for eligibility for inclusion in the National Register of Historic Places (NRHP). The proposed project area has not been previously surveyed for cultural resources, but due to the presence of archaeological sites previously found in similar settings within the region, the potential for subsurface archaeological sites should be considered.

Under Section 404 of the Clean Water Act (CWA), the USACE regulates the discharge of excavated or fill material into waters of the U.S. The lateral limit of the USACE jurisdiction over non-tidal water bodies extends to the ordinary high water mark (OHWM) in the absence of adjacent wetlands. If the stream crossing is constructed with an open trench, the proposed project would likely cause fill within the OHWM and require a Section 404 permit from the USACE. Nationwide Permit 14 for linear projects could be used to authorize activities associated with the construction of this project if the planned activities result in a discharge in a water of the U.S. so long as the criteria and general conditions of the Nationwide Permit are met.

A Regulatory Data Report can be ordered to review the project site for any potential hazardous or other environmental concerns listed in federal and state databases.

4.0 Hydrology

The Flat Creek watershed drains a total of 12,000 acres, or 18.8 square miles.

4.1 Watershed Parameters

Rainfall-runoff responses of the Flat Creek watershed to a range of rainfall depths were calculated using HEC-HMS to determine peak discharges from each sub-basin. The following watershed parameters were used to represent existing watershed conditions in the HEC-HMS hydrologic model.

4.1.1 Drainage Area Delineation

As shown on **Exhibit B-1A** and **Exhibit B-1B** in **Appendix B**, the Flat Creek drainage area was subdivided into 22 new sub-basins to calculate peak discharge rates at points of interest along Flat Creek and its tributaries. Sub-basin delineation was done by using the 2011 LiDAR elevation data. Points of interest were evenly spaced throughout the drainage area in attempt to maintain a consistent sub-basin size, resulting in an average sub-basin drainage area of 550 acres, with the smallest sub-basin at 186 acres and the largest at 1,460 acres.

4.1.2 Soils and Land Use

Flat Creek cuts through the Blackland Prairie eco-region, which is largely categorized as having clayey soil types. The USGS SSURGO database was used to obtain soils for Flat Creek and classify the hydrologic soil type for each sub-basin, as illustrated in **Exhibit B-2** in **Appendix B**. Soil types in the Flat Creek drainage basin were categorized as predominately hydrologic soil types D and C, with very small pockets of types A and B soils. Land use classifications were assigned based on aerial imagery, as shown on **Exhibit B-3** in **Appendix B**. The upper reaches of Flat Creek were categorized as mostly developed space, while the remaining lower portion of the basin is largely comprised of agricultural lands. Land uses and soil types for each sub-basin were processed in GIS and used to determine a base curve number. Base curve numbers for sub-basins ranged from 70 to 84, and had average value of 78 across the entire drainage area. Base curve numbers were entered into HEC-HMS as part of the sub-basin's initial abstraction parameter.

The other component to the initial abstraction parameter in HEC-HMS is the amount of impervious cover that reduces infiltration. Percent impervious cover for each sub-basin was calculated in GIS with use of the NLCD2011, as shown on **Exhibit B-4** in **Appendix B**. The average percent impervious cover for sub-basins in Flat Creek drainage area was 21 percent with the maximum impervious cover being 53 percent for a sub-basin. These values were entered directly into the hydrologic model for each sub-basin.

4.1.3 Time of Concentration

The Time of Concentration was calculated using the Kirby-Kirpich equations for sheet flow, and using the velocity method for shallow concentrated flow and channel flow calculations. For each sub-basin, the longest flowpath was identified and broken into runoff flow types, as shown on **Exhibit B-1** in **Appendix B**. The length of overland flow was limited to 300 feet for undeveloped areas and 100 feet for developed areas. The time of concentration calculations are shown in **Exhibit B-5** in **Appendix B**.

4.1.4 Hydrologic Channel Routing

The initial HEC-RAS model was used to develop flow and volume relationships for each routing reach. These tables were entered into HEC-HMS, and the Modified Puls routing procedure. The average flow velocity from the HEC-RAS model was also used to calculate the number of steps variable – by dividing the length of the routing reach by the average velocity and rounding up to a whole number.

4.2 Peak Flow Rates

Once the peak discharges were calculated, they were input into a hydraulic model to calculate the resulting water surface profiles. **Exhibit B-6** in **Appendix B** contains peak discharges entered into the hydraulic model for a steady state flooding evaluation.

The resulting peak discharges are shown in Table 4-1 below as the Flood Protection Plan (FPP) discharges, along with a comparison to the FEMA FIS effective peak discharges where available. **Exhibit B-6** in **Appendix B** contains all the peak discharges entered into the hydraulic model.

Table 4-1: FIS Peak Discharge Comparison

Study Cross Section	FIS Lettered Section Location	Description	Discharge (cfs)	
			FPP	FEMA FIS**
74	A	At Brazos River	14,450	14,639
1999	B		13,940	13,066
4675	C	At 3rd Street	13,940	13,066
9981	D		14,410	12,366
15244	E	At 12th Street	14,770	10,702
18895	F		14,770	10,136
21992	G		14,900	10,136
24707	H		14,900	10,136
28395	I	At Robinson Drive	14,900	10,136
30219	J	At Old Robinson Road	15,050	9,761
31113	K		15,050	9,761

*Section was approximated to FIS Lettered Section, but not at exact location.
**Approximated per FIS Table 3 Discharge Location.

5.0 Hydraulics and Floodplain Mapping

Once the peak discharges were calculated, the existing conditions model was used to simulate the various storm events with the hydraulic parameters and floodplain geometry discussed in Chapter 3, Section 3.3.

5.1 Hydraulic Model Results

The HEC-RAS (Version 5.0.3) hydraulic model calculated the water surface elevations used to determine the extent of flooding among the various reaches of Flat Creek. The resulting water surface profiles are shown on **Exhibit C-1** in **Appendix C**. The hydraulic work map in **Exhibit C-2** in **Appendix C** shows the reach name, cross section layout, roadway crossings, contours, bank stations, and the land use types used to select the overbank Manning's n-values. **Table 5-1** provides a comparison of the FPP results with the FEMA FIS at Flat Creek's Main Reach only. The FIS detailed study ends at FEMA Lettered Section K which is located just upstream of Old Robinson Road.

Table 5-1: FIS Comparison

Study Cross Section	FIS Lettered Section Location	Description	Discharge (cfs)		WSEL (ft)	
			FPP	FEMA FIS**	FPP	FEMA FIS
74	A	At Brazos River	14,450	14,639	370.6	383.3
1999	B		13,940	13,066	379.9	386.6
4675	C	At 3rd Street	13,940	13,066	390.6	389.8
9981	D		14,410	12,366	406.0	406.0
15244	E	At 12th Street	14,770	10,702	422.1	422.0
18895	F		14,770	10,136	434.6	435.4
21992	G		14,900	10,136	441.3	441.7
24707	H		14,900	10,136	448.3	447.9
28395	I	At Robinson Drive	14,900	10,136	459.1	457.5
30219	J	At Old Robinson Road	15,050	9,761	465.1	465.4
31113	K		15,050	9,761	466.6	468.4

*Section was approximated to FIS Lettered Section, but not at exact location.
**Approximated per FIS Table 3 Discharge Location.

Overall, the FPP peak discharges are greater than the FIS peak discharges due to the urbanized condition at the upper areas of the watershed. The base flood elevations are lower near the confluence with the Brazos River at lettered sections A and B due to the different boundary conditions used for the analyses. The base flood elevations are similar at lettered sections C through G. They vary slightly from H through K due to the updated topography and higher discharges.

5.2 Floodplain Mapping

As explained in Chapter 3 Section 3.3.1, model cross sections were created within GeoRAS from a TIN file derived from a combination of surveyed spot elevations and 2011 TNRIS LiDAR data. This TIN file was also used for the delineation of existing and fully developed floodplains. GeoRAS was used to create a water surface elevation TIN from the HEC-RAS model results, and compare that TIN to the ground surface TIN to delineate the floodplain. The resulting floodplain was reviewed and manually revised and polished within the GIS platform where necessary.

Since the data used to develop this analysis was mainly dependent on the 2011 TNRIS Study, the evaluated 1% AEP floodplain is referred to as "FPP Floodplain". A comparison of the existing conditions and FEMA effective 1% ACE (100-year) floodplains is shown in **Exhibit C-3** in **Appendix C**. The FPP Floodplain shows a significant widening upstream of University Parks. The terrain in this area reflects flat and ineffective terrain such as the large gravel pits excavated in this area. The main reach of Flat Creek overall shows a slight increase in the floodplain width due to an increase in WSEL. The terrain at Greig Road shows a significant overflow due to a flat road and the terrain downstream of the road sloping parallel to the channel. This area was evaluated in more detail and additional survey was obtained to further refine the accuracy of the delineated floodplain. The North Tributary floodplain is similar with a significant widening upstream of the railroad crossing (east of Imperial) due to the high track embankment and backwater conditions. For the South Tributary, the area upstream of the railroad tracks (by Panther Way) shows a wide and complex floodplain with several commercial buildings inundated. Significant inundation of homes was also confirmed at the headwaters at Lindenwood Drive and there are various commercial properties flooded near Hewitt and Van American Drive.

A complete summary of hydraulic results including a summary of water surface elevations for the 1% AEP is provided in **Exhibit C-4** in **Appendix C.**

6.0 Problem Areas

Once the FPP Floodplain for existing conditions was finalized, it was used to identify areas of potential flooding during the 1% ACE event.

6.1 Problem Area Identification

Several categories of damage during flooding events were considered.

The primary category of flood damages is inundation of residential and commercial insurable structures. In some areas along Flat Creek, the FPP Floodplain is wider than the FEMA's current effective floodplain.

Due to the tragic loss of life in June 2014 when LaCharles Montgomery's car was washed off a low water crossing, overtopping of roadways was also evaluated. Both the depth of overtopping and the flow velocity were calculated by the hydraulic models.

6.2 Flat Creek Problem Areas

Flooding problems were concentrated in 5 areas of the Flat Creek watershed.

6.2.1 FCR-001 Woodcock Drive & 12th Street

Problem area FCR-001 is located in Robinson near Woodcock Drive and the Flat Creek crossing at S. 12th Street. This location contains six homes upstream of the 12th Street bridge crossing which were not in the previous FEMA 1% floodplain and are in the new FPP Floodplain. As shown on **Exhibit D-1** in **Appendix D**, the existing conditions floodplain upstream of 12th Street is significantly wider than the FEMA effective floodplain, and it results in 6 residential structures located inside the floodplain.

6.2.1.1 Structures At Risk

Within the problem area boundaries on **Exhibit D-1**, there are 6 residential and no commercial properties inundated by the FPP Floodplain.

6.2.1.2 Inundated Roadways

The 12th Street bridge crossing can only pass up to the 5-year (20% AEP) event. During the 100-year (1% AEP) storm event, 12th Street will be overtopped by 2.85 feet with a velocity of 3.1 feet per second (fps).

6.2.2 FCR-002 Robinson Drive & Old Robinson Road

Problem Area FCR-002 is located in Robinson near the Flat Creek crossing of N. Old Robinson Road and Robinson Drive (U.S. Highway 77).

6.2.2.1 Structures At Risk

Within the problem area boundaries on **Exhibit D-2**, there are 5 residential and 24 commercial buildings inundated by the FPP ACE Floodplain.

6.2.2.2 Inundated Roadways

The Robinson Road bridge over Flat Creek passes the 25-year (4% AEP) storm event. During the 100-year (1% AEP) storm event, Robinson Road will be overtopped by 1.19 feet with a velocity of 2.4 fps.

6.2.3 FCR-003 Panther Way & Old Hewitt Road

Problem Area FCR-003 is located near the intersection of Panther Way and Old Hewitt Road, just south of Midway High School, and encompasses multiple jurisdictions (Waco, Hewitt, and McLennan County).

6.2.3.1 Structures At Risk

Within the problem area boundaries on **Exhibit D-3**, there are 2 residential and 9 commercial buildings inundated by the FPP ACE Floodplain.

6.2.3.2 Inundated Roadways

In addition to the flooded structures, water frequently overtops the roadway at three stream culvert crossings (two along Panther Way and one along Old Hewitt Drive). The Old Hewitt Drive crossing and both the Panther Way crossings overtop for a 2-year (50% AEP) event. During the 100-year (1% AEP) storm event, Old Hewitt Drive will be overtopped by 2.61 feet with a velocity of 1.6 fps; Panther Way at the Southern Flat Creek Tributary (SFT 04) will be overtopped by 11.96 feet with a velocity of 0.7 fps; and Panther Way at the Southern Tributary 2 of Flat Creek (SFT 10-11) will be overtopped by 2.40 feet with a velocity of 3.4 fps.

6.2.4 FCR-004 Hewitt Elementary and Applewood / Lindenwood

Problem Area FCR-004 is located in Hewitt between Applewood Lane and Lindenwood Lane from North Hewitt Drive to Hewitt Elementary.

6.2.4.1 Structures At Risk

Within the problem area boundaries on **Exhibit D-4**, there are 42 residential structures and 7 commercial buildings inundated by the FPP Floodplain.

6.2.4.2 Inundated Roadways

The North Hewitt Drive culverts crossing the Southern Tributary 2 of Flat Creek (SFT 10-11) pass the 25-year (4% AEP) storm event, while the Lindenwood Lane culverts overtop for even the 2-year (50% AEP) event. During the 100-year (1% AEP) storm event, North Hewitt Drive will be overtopped by 0.51 feet with a velocity of 1.8 fps; Lindenwood Lane will be overtopped by 2.30 feet with a velocity of 3.0 fps.

6.2.5 FCR-005 Venture Drive and Railroad

Problem Area FCR-005 is located in Waco just north of Imperial Drive and west of Venture Drive. This location contains nine commercial buildings that are shown to be within the FPP Floodplain.

6.2.5.1 Structures At Risk

Within the problem area boundaries on **Exhibit D-5**, there are no residential and nine commercial properties inundated by the FPP Floodplain.

6.2.5.2 Inundated Roadways

The Imperial Drive culvert crossing the Northern Tributary of Flat Creek passes the 2-year (50% AEP) event. During the 100-year (1% AEP) storm event, Imperial Drive will be overtopped by 2.30 feet with a velocity of 3.3 fps.

In addition to the inundated roadways at the five problem area locations described above, roadway overtopping occurs at other locations throughout the Flat Creek watershed. **Exhibit D-6** in **Appendix D** lists all roadways that cross Flat Creek and its Tributaries. It shows the passing storm frequency (meaning the storm event that does not overtop the road). The Exhibit also reflects the depth of flooding over the lowest road elevation for the 1% AEP or the 100-year storm event. Except for the 3rd Street bridge crossing, the Main reach crossings can only pass between a 10-year and 25-year event. The North Tributary crossings all have a high storm event passing except for Imperial Drive, which can only pass the 2-year event. The South Tributary crossings are not as effective since various crossings (such as Mars Drive and Hewitt Drive) are not able to pass any storm event.

(This Page Intentionally Left Blank)

7.0 Mitigation Solutions

This plan offers a unique opportunity to examine and plan for regional projects to address flooding problems on a watershed-wide basis in a systematic approach, rather than each city constructing its own "isolated" project.

7.1 Mitigation Strategies

Three structural and three non-structural mitigation strategies were considered. Structural mitigation strategies included regional detention to reduce the peak flow rates, channel improvements to pass existing flows at a lower water surface elevation, and bridge or culvert improvements at locations where upstream flooding is the result of undersized roadway crossings. Non-structural strategies included property acquisitions, flood warning systems and strengthening regional drainage criteria.

7.1.1 Regional Detention

The first structural strategy considered at each problem area was regional detention, to store the incoming flows and release them at a safer rate. To evaluate the potential for regional detention, a non-damaging flow was determined, such as the 2-year, 5-year or 10-year event – and the percent flow reduction was calculated to establish the required storage volume. This volume was then divided by the available height (embankment tie-in minus flowline) to calculate the required open area. This was used to establish the area of open space required for detention.

7.1.2 Channel Improvements

The second strategy considered at each problem area was channel improvements to increase the conveyance capacity to reduce the water surfaces during peak flows. A non-damaging elevation was identified – below which all of the flow has to pass – and the additional flow area required was calculated, along with a percent increase and/or top width required. If feasible, the conceptual solution design was modeled with the channel improvement tool in RAS. For a given flow depth, a trapezoidal section was applied to estimate top width, and the easement required to determine if the channel improvements were feasible.

7.1.3 Bridge and Culvert Improvements

The third strategy considered at each problem area was bridge or culvert improvements to increase the capacity of the crossing. In some areas, flooding is caused by undersized roadway crossings, which cause flow to back up into structures upstream. The best solution that could be achieved would be no head loss across the crossing – although the downstream impacts of the additional flow must be evaluated as well. The difference between headwater and tailwater was calculated and if the difference was not large enough to solve the problem this strategy was not viable. If this strategy was selected, the solution configuration would be modeled in HEC-RAS to verify the reduction in the upstream WSEL.

7.1.4 Property Acquisitions

The first non-structural strategy considered for each problem area was property acquisition, in which the local jurisdiction purchases residential or commercial structures and demolishes the buildings to return the property to an open space use that is more consistent with the floodplain. Often property acquisitions are accomplished with federal or state grants, typically at a 75% federal / 25% local cost share. The BCA spreadsheet in **Appendix D** includes a column to the right for the B/C Ratio of each structure in the problem area, calculated as net present value over 1.5 * appraised value to include acquisition and demolition costs.

7.1.5 Flood Warning Systems

The second non-structural strategy considered for each problem area where bridge and culvert improvements were not feasible and overtopping of the roadway will continue to occur was installation of flood warning systems.

7.1.6 Regional Drainage Criteria

The third non-structural mitigation strategy is developing regional drainage criteria throughout the watershed. By each jurisdiction in the watershed requiring no "adverse" impact (upstream and downstream) after development, the effects of urbanization can be minimized in the Flat Creek watershed. Further, with each jurisdiction adopting the same floodplain management strategy (e.g. no alterations of the floodplain can increase the 100-year water surface elevation upstream or downstream of the alteration), the Flat Creek floodplain can be managed consistently by each jurisdiction from its headwaters to the Brazos River.

7.2 Flat Creek Solutions

Conceptual mitigation solutions were developed in multiple jurisdictions for the five problem areas in the Flat Creek watershed. Each area was investigated to determine which mitigation strategy should be pursued to produce the greatest benefit at the most economical cost. The areas were then analyzed to determine the effectiveness of each solution.

7.2.1 FCR-001 Woodcock Drive & 12th Street

The first mitigation option considered for this problem area was property acquisition. After reviewing the cost benefit ratio for each structure, it was determined that none of the six homes would have a positive ratio to warrant this strategy. The second option considered was widening the bridge at 12th Street to increase flow and reduce the upstream water surface elevation near the homes. Although this option had a positive impact just upstream of the bridge, the improvements did not provide any benefit to the flooded structures. Due to this, extensive channel overbank excavation was added in combination with the 12th Street bridge improvements. With the additional excavation, the water surface elevation of the 1% floodplain was lowered to at least one foot below the finished floor elevation of each structure.

After performing the cost analysis to implement the option of bridge improvements and excavation, it was found that the cost would be prohibitive and the project would not be feasible. To reduce costs, a modified option was considered that would include demolition of the 12th Street bridge, addition of cul-de-sacs on the resulting dead-end streets, and a permanent closing of 12th Street. This alternative reduces costs by not reconstructing the bridge, but still proved to be cost prohibitive and not a feasible option.

After eliminating the previous strategies, it was decided that the most feasible and economical option would be to raise the finished floor elevation of each structure above the 2011-1% water surface elevation. This could be accomplished by either leaving the houses in their current location to utilize the existing foundation or by shifting the houses to a new location on the property and incorporating a new foundation.

See **Exhibit E-1A** and **Exhibit E-1B** in **Appendix E** for a location map and opinion of probable cost for the selected mitigation strategy to elevate the existing finished floors.

7.2.2 FCR-002 Robinson Drive & Old Robinson Road

After review of the cost-benefit analysis, it was determined that more than 70% of damages for this problem area originate from three residential structures along N. McLendon Drive. It was also found that property acquisition of these structures combined with the surrounding empty lots would result in a positive overall cost-benefit ratio. Due to the remainder of impacted structures in the problem area being commercial, it was decided that property acquisition of only the residential structures and surrounding empty lots would be the most feasible and economical option in this location. Channel and bridge improvements were considered in this area, but were abandoned due to minimal potential benefits to the highest risk structures, and concerns of increasing flow in critical downstream locations.

See **Exhibit E-2A** and **Exhibit-2B** in **Appendix E** for a location map and opinion of probable cost for the selected property acquisition mitigation strategy.

7.2.3 FCR-003 Panther Way & Old Hewitt Road

Property acquisition was considered in this location, but was quickly abandoned due to the residential properties having benefit-cost ratios less than one, and the lack of addressing the overtopping issue at each culvert crossing.

It was found that a significant portion of the flooding at each culvert was due to an undersized railroad arch-bridge crossing acting as a “dam” just downstream of the area in question. Increasing the capacity of the railroad crossing to lower the upstream water surface elevation was considered, but abandoned due to concerns over the feasibility of adding capacity to the crossing and increasing the amount of flow at critical areas downstream. After eliminating the option of improvements at the railroad crossing, each culvert crossing was approached individually to determine potential solutions.

For the first crossing location of Panther Way near the intersection of Panther Run Road, the decision was made to completely remove the existing culvert and install a cul-de-sac on the resulting dead-end portion of the road. This would eliminate the chance of any vehicles being washed away in a large storm event while still maintaining access for all residences and commercial buildings in the area. In addition, this would decrease the number of vehicles at the second culvert crossing on Panther Way by removing the "traffic loop" between Mars Drive and Old Hewitt Drive. Structural improvements were considered at this crossing, but abandoned due to limited benefits.

At the second culvert crossing on Panther Way near Ava Drive, the strategy of increased culvert capacity was pursued to decrease the overtopping water surface elevation and increase safety. Currently this location contains an existing 72-inch metal culvert which passes only the 50% storm event and produces a 1% water surface elevation approximately 1.75 feet above the intersection of Panther Way and Ava Drive. Proposed improvements would include replacement of the exiting 72-inch culvert with three 10-foot by 7-foot box culverts. This would provide capacity in the culvert to pass the 4% storm below the road and reduce the 1% water surface elevation to 1-foot above the intersection of Panther Way and Ava Drive.

The third overtopping culvert crossing is located along Old Hewitt Road near Midway High School and the Midway athletic complex. Traffic at this crossing is controlled by two sets of manual gates running across separate portions of the roadway. While gating off the road is an effective solution to eliminate traffic at the overtopping crossing, currently the default position of the gates is to remain open and only be closed when needed. This leads to a high probability of the gates accidentally being left open or closed too late during a large storm event and vehicles having the opportunity to access the stream crossing. The recommended solution for this area is to replace the manual gates with an automated, permanent gate system that would be closed by default and open only for Midway sporting events. This should eliminate the chance of vehicles being swept away at the crossing and continue to provide the required access to Midway's sporting facilities.

See **Exhibit E-3A** and **Exhibit-3B** in **Appendix E** for a location map and opinion of probable cost on the three selected mitigation strategies in this area.

7.2.4 FCR-004 Hewitt Elementary and Applewood / Lindenwood

The first mitigation strategy approached was property acquisition. After analyzing property damage, it was concluded that none of the flooded properties had a benefit-cost ratio high enough to warrant a buyout. The second strategy considered was an increase in culvert capacity at North Hewitt Drive. Although this option did reduce water surface elevations upstream of the culvert, the effects did not have a beneficial impact on the flooded residences. The third strategy considered and chosen was addition of an upstream detention pond south of Hewitt Elementary. It was determined that if the 1% storm event could be reduced to approximately the 10% storm event, much of the residential flooding could be reduced or eliminated. After evaluating the potential storage capacity and release rates of the proposed detention area, it was found that the existing 1% flow rate could be reduced to a rate between the 10% and 4% storm events. Modification of the flow rate created a reduction in water surface extents that removed the majority of residences from the floodplain and reduced the water surface elevation for homes that remained in the floodplain. An added benefit of the flow reduction was a lowering of the 1% water surface at N. Hewitt Drive, negating the need for additional culvert capacity. In addition, any reduction of flow would create benefits downstream at Problem Area FCR-003. Construction of the detention facility would be contingent on removal of three existing baseball/softball fields that are currently behind Hewitt Elementary.

See **Exhibit E-4A** and **Exhibit E-4B** in **Appendix E** for a location map and opinion of probable cost for the detention facility mitigation strategy.

7.2.5 FCR-005 Venture Drive and Railroad

After visual inspection of the buildings, it appeared that several of the finished floor elevations may be above the 1% floodplain even though mapping shows the structures to be within the water surface extents. Because of this, the decision was made to survey each building's finished floor elevation prior to pursuing any additional mitigation strategies.

Surveyed finished floor elevations showed that eight of the nine structures were above the 1% water surface elevation and safe from flooding. In addition, the single structure that is below the 1% water surface elevation does not appear to be a primary building of operations for the commercial area in question. Based on this information, no additional mitigation strategies are recommended in this area.

See **Exhibit E-5A in Appendix E** for a location map of the area and buildings in question.

7.3 Environmental Permitting Considerations

The conceptual mitigation solutions that were developed in multiple jurisdictions for the problem areas in the Flat Creek watershed were reviewed with the intent to identify potential environmental constraints for each of the five solution areas. Site visits were made to all five locations July 25, 2017 by HDR environmental staff. Sites were assessed to establish what environmental constraints were present that would affect the proposed mitigation strategies pursued. The proposed mitigation strategy for each site described in **Section 7.2** above was developed to produce the greatest benefit at the most economical cost. The five areas were then evaluated to determine the effectiveness of each solution. The information presented in this section provides an overview of the constraints at each area.

Under the Clean Water Act (CWA), Section 404, the USACE regulates the discharge of excavated or fill material into waters of the U.S. Permit applications for projects anticipated to discharge dredged or fill material into waters of the U.S. (WOTUS), including wetlands will be evaluated by the U.S. Army Corps of Engineers (USACE) to confirm that permit actions are in compliance with Section 404 of the Clean Water Act (CWA). A permitted action must demonstrate that the proposed action meets the Section 404(b)(1) Guidelines' (Guidelines) requirement for consideration of alternatives, 40 CFR 230.10(a). The Guidelines emphasize the need for an Alternative Analysis to be conducted leading to the identification of a preferred alternative (Proposed Alternative) that is the "Least Environmentally Damaging Practicable Alternative" (LEDPA). The Flat Creek sites were evaluated for activities that could result in adverse impacts to waters of the U.S., including wetlands. Factors that are evaluated by the USACE for compliance to Section 404(b)(1) guidelines include the following.

- Compliance with regard to:
    - Section 401 of the Clean Water Act – Water Quality Certification
    - Endangered Species Act (ESA) of 1973 – Federally-listed threatened and endangered species
    - Migratory Bird Treaty Act of 1918
    - Section 106 of the National Historic Preservation Act of 1966 (NHPA) – Effects of Project on historic properties

If in unavoidable (adverse) impacts to WOTUS occur, a Conceptual Mitigation Plan will be required. The 2008 Mitigation Rule stipulates that compensation (mitigation) must be commensurate with the amount and type of aquatic resources affected and should occur within the same watershed. Coordination with USACE would be necessary on any required mitigation.

Sites were reviewed for known federally-listed threatened or endangered species or any designated critical habitat in the area. The USACE does not allow activity to be authorized under any Nationwide Permit (NWP) which is likely to directly or indirectly jeopardize a threatened or endangered species or a species proposed for such designation, as identified under the Federal Endangered Species Act (ESA), or which will directly or indirectly destroy or adversely modify the critical habitat of such species.

For this study, desktop reviews were conducted to identify historical and archeological sites previously documented in the five Flat Creek sites.

See **Exhibit F-1**, **Exhibit F-2**, and **Exhibit F-3** in **Appendix F** for a General Location Map, a Preliminary WOTUS Map, and Preliminary Map of Cultural Resources Sites in the Flat Creek watershed, along with the locations of the five mitigation solution areas.

7.3.1 FCR-001 Woodcock Drive & 12th Street

As described in **Section 7.2.1** above, the most feasible and economical option is to raise the finished floor elevation of each of five structures above the 2011-1% water surface elevation. This could be accomplished by either leaving the houses in their current location to utilize the existing foundation or by shifting the houses to a new location on the property and incorporating a new foundation. The locations of the structures are of sufficient distance from the stream that this activity, as proposed, would not result in any 404 permitting action. If the proposed solution approach undergoes modification, some additional evaluation would be needed.

Site FCR-001 has a number of historical and archeological sites identified either adjacent to or near the site study boundary. Prior to conducting any work in the area, a cultural resource survey may be required.

7.3.2 FCR-002 Robinson Drive & Old Robinson Road

As described in **Section 7.2.2** above, property acquisition of the residential structures and surrounding empty lots would be the most feasible and economical option in this location. Channel and bridge improvements were considered in this area, but were abandoned due to minimal potential benefits to the highest risk structures, and concerns of increasing flow in critical downstream locations. Based on this proposed action, removal of structures would not result in any 404 permitting action.

Site FCR-002 does appear to have undergone cultural resource surveys sometime in the past. No historical and archeological sites are identified in the nearby area. However, prior to conducting any work in the area, a cultural resource survey may be required.

7.3.3 FCR-003 Panther Way & Old Hewitt Road

As described in **Section 7.2.3** above, each culvert crossing was approached individually to determine potential solutions.

For the first crossing location of Panther Way near the intersection of Panther Run Road, the decision was made to completely remove the existing culvert and install a cul-de-sac on the resulting dead-end portion of the road.

At the second culvert crossing on Panther Way near Ava Drive, the proposed improvements include replacement of the existing 72-inch culvert with three 10-foot by 7-foot box culverts. This would provide capacity in the culvert to pass the 4% storm below the road and reduce the 1% water surface elevation to 1-foot above the intersection of Panther Way and Ava Drive.

The third overtopping culvert crossing is located along Old Hewitt Road near Midway High School and the Midway athletic complex. Traffic at this crossing is controlled by two sets of manual gates running across separate portions of the roadway. The recommended solution for this area is to replace the manual gates with an automated, permanent gate system that would be closed by default and open only for Midway sporting events. This should eliminate the chance of vehicles being swept away at the crossing and continue to provide the required access to Midway's sporting facilities.

The removal of the existing culvert and installation of a cul-de-sac at Panther Way near the intersection of Panther Run Road is expected to have minimal impact to waters of the U.S. However, it is expected that because the work conducted would be done within the OHWM of the stream, the use of a NWP 33 for Temporary Construction, Access, and Dewatering would be used. This would require some coordination with the USACE. The use of automatic gates along Old Hewitt Road would not have any impact or result in a 404 permit coordination effort.

Based on the proposed action for removal of an existing culvert and installation of a cul-de-sac on Panther Run and the replacement of the existing 72-inch culvert with three 10-foot by 7-foot box culverts on Panther Way near Ava Drive, permit coordination would be required. Under Section 404, a delineation for waters of the U.S. would be required as well as a Texas Rapid Assessment Method (TXRAM) (Version 2) Evaluation. Based on an USACE accepted Proposed Jurisdictional Determination, an application for review under a NWP 14 for Linear Transportation Projects could be made. Activities that result in permanent impacts less than 0.1 acre would be documented under a NWP 14 to the USACE in a 'No-Action Letter'. Impacts greater than a 0.1 acre and less than 0.5 acre would be permitted under NWP 14 using a Pre-Construction Notification (PCN).

There are two previously recorded archaeological sites located within the FCR-003 boundary. The USACE will make a determination if the permit action has the potential to cause effects to these properties. The permit will not be authorized, until the requirements of Section 106 of the National Historic Preservation Act (NHPA) have been satisfied. The USACE will require the applicant to provide the USACE with the appropriate documentation to demonstrate compliance with the permit requirements. This may require additional cultural resource surveys to be conducted.

7.3.4 FCR-004 Hewitt Elementary and Applewood / Lindenwood

As described in **Section 7.2.4** above, the most cost effective solution is construction of an upstream detention pond south of Hewitt Elementary. Construction of the detention facility would be contingent on removal of three existing baseball/softball fields that are currently behind Hewitt Elementary.

Based on the proposed action for FCR-004, a NWP 43 for Stormwater Management Facilities could be used to coordinate the permit action for a detention facility. Coordination with local county and city officials would be necessary to complete requirements for storm water management activities.

There are no known listed historical or archeological sites within the FCR-004 boundary and therefore no coordination would be anticipated. However, prior to conducting any work in the area, a cultural resource survey may be required.

7.2.5 FCR-005 Venture Drive and Railroad

As described in **Section 7.2.5** above, after visual inspection of the buildings, based upon the surveyed finished floor elevations, no additional mitigation strategies are recommended in this area.

Based on the above recommendation, it is not anticipated that environmental coordination will be required. If a new Solution approach to FCR-005 is determined to be needed, a review for impacts to waters of the U.S., including wetlands along should be coordinated.

(This Page Intentionally Left Blank)

8.0 Conclusions and Recommendations

The Flat Creek Flood Protection Plan is a set of structural and non-structural flood protection measures to reduce the flooding losses in the watershed, based on updated hydrologic and hydraulic models.

8.1 Public Meetings and Workshops

The jurisdictions in the watershed and the general public were involved throughout the planning process. Several public meetings were held as the Flat Creek Flood Protection Plan was developed, a list of which is shown in **Table 8-1** below.

Table 8-1: List of Public Meetings

Meeting	Date	Description
Workshop and Public Meeting #1	November 10, 2015	Presented scope of study and collected drainage concerns
Workshop and Public Meeting #2	August 4, 2016	Presented the results of the updated hydrology and updated peak flow rates
Workshop and Public Meeting #3	October 19, 2016	Presented the results of the updated hydraulics and FPP Floodplain
Workshop and Public Meeting #4	January 18, 2017	Presented the mitigation solutions and results of the economic analysis
Workshop and Public Meeting #5	March 22, 2017	Presented the Flood Protection Plan and Draft Report

8.2 Ranking of Solutions

Since the mitigation solutions are to be implemented by different jurisdictions, a formal ranking process to develop a prioritized order in which they should be implemented is not applicable.

8.3 Recommendations

The recommended flood mitigation solutions are shown on **Figure 8-1** on the following page. They are also summarized in **Table 8-2** below.

Table 8-2: Summary of Mitigation Solutions

Flood-Prone Area	Recommended Solution	Estimated Cost	Responsible Entity	Funding Source
FCR-001	Elevate 5 residential properties	$392,425	Homeowners City of Robinson	FEMA Hazard Mitigation Assistance Grant Programs
FCR-002	Acquire 3 houses and adjacent lots	$506,172	City of Robinson	FEMA Hazard Mitigation Assistance Grant Programs
FCR-003	Remove culvert, add cul-de-sac on Panther Way; Revise operations of Old Hewitt Add culverts at Ava Drive	$760,185	City of Waco; City of Hewitt; McLennan County	CIP
FCR-004	Regional detention pond behind Hewitt Elementary	$5,065,250	City of Hewitt	CIP
FCR-005	Verify that the finished floor elevations are above the 100-year WSEL	$0	City of Waco	General
FCR-006	Develop Regional Drainage Criteria	$100,000	City of Waco	General
Total Estimated Mitigation Cost		$6,424,032		

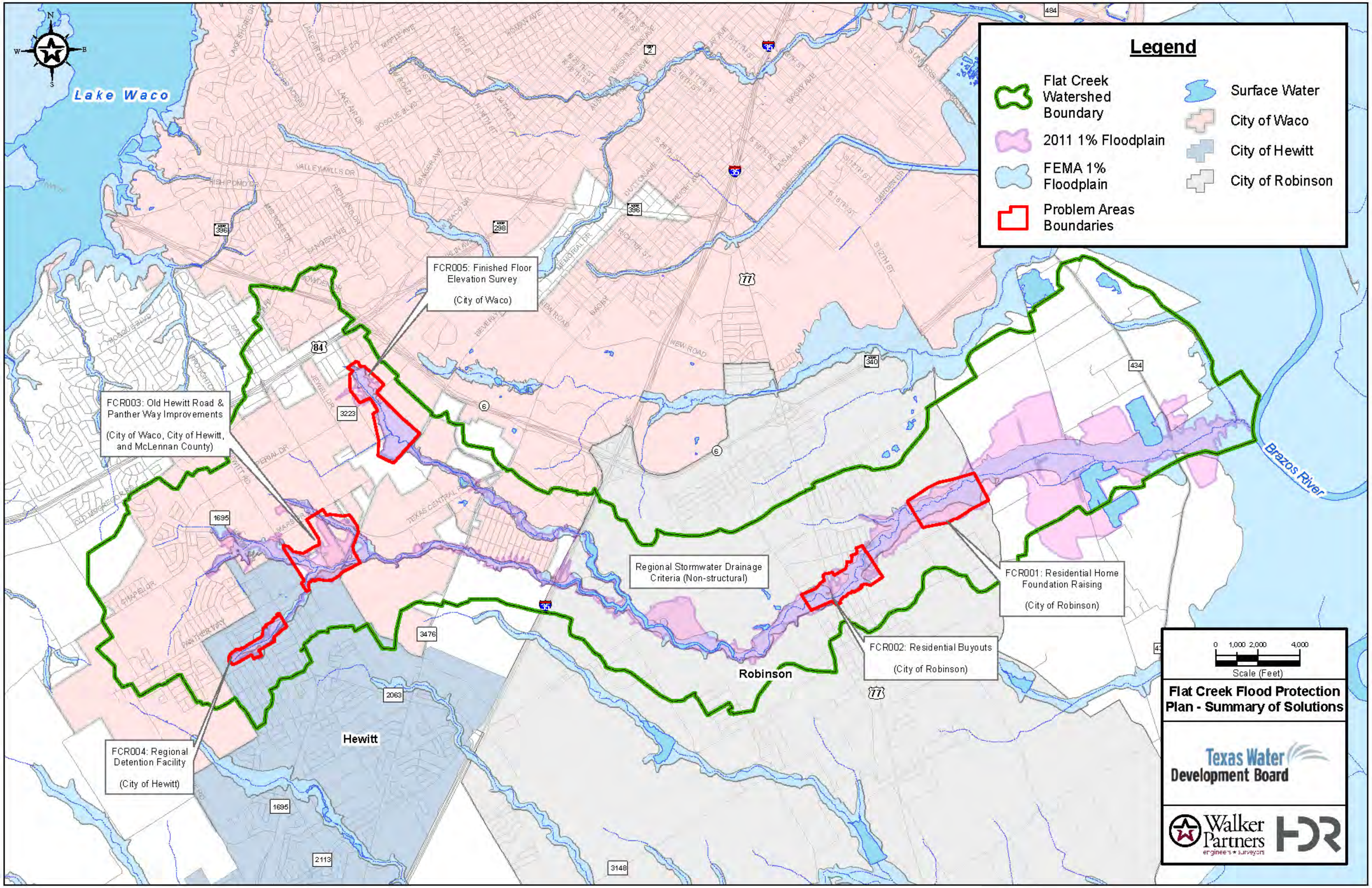


Figure 8.1: Summary of Solutions

(This Page Intentionally Left Blank)

9.0 Acknowledgements

We would like to thank the Staff of the City of Waco for their leadership and effort put forth to make this study possible. Likewise, we would like to thank the Staff's from the Cities of Robinson, Hewitt, Woodway, and McLennan County for participating financially and "in-kind" to create a collection of local entities committed to the implementation of a regional stormwater management alliance.

In addition, we appreciate Ivan Ortiz and the entire Team at the Texas Water Development Board for providing this Flood Protection Planning Grant to the City of Waco.

Finally, we would also like to thank FEMA Region 6 for their cooperation and support throughout this study.

(This Page Intentionally Left Blank)

10.0 References

Asquith, William H., Roussel, Meghan C., "Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas", United States Geological Survey Scientific Investigations Report 2004-5041, pp. 18-113, 2004.

Chow, Ven Te, *et al*., "Applied Hydrology," McGraw-Hill Book Co., 1988.

Federal Emergency Management Agency (FEMA). Flood Insurance Study #48XXXCV000A, McLennan County, Texas and Incorporated Areas, Washington, D.C., September 26, 2008.

Federal Emergency Management Agency (FEMA), Discovery Report for the Middle Brazos Watershed Below Lake Whitney, January 2015.

Hydrologic Engineering Center, U.S. Army Corps of Engineers. Hydrologic Modeling System, Version 3.5.

Hydrologic Engineering Center, U.S. Army Corps of Engineers. River Analysis System, Version 5.0, February 2016

Hydrologic Engineering Center, U.S. Army Corps of Engineers. HEC-RAS Hydraulic Reference Manual, Version 5.0, February 2016

Natural Resources Conservation Service, United States Department of Agriculture. "Urban Hydrology for Small Watersheds", Technical Release No. 55 (TR-55), 1986.

National Weather Service (NWS). "Rainfall Frequency Atlas of the United States, 30-Minute to 24-Hour Durations, 1- to 100-Year Return Periods", Technical Paper No. 40, U.S. Department of Commerce, 1961.

United States Department of Agriculture, Web Soil Survey, Accessed in April 2016, https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

United States Department of Agriculture. Part 630 Hydrology National Engineering Handbook, Ch. 15, Time of Concentration, 210-VI-NEH, 2010.

Texas Department of Transportation (TxDOT) Hydraulic Design Manual. Chapter 4 – Hydrology, Revised July 2016.

United States Geological Survey (USGS). "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains –Cowan's Method 1956" – Water-Supply Paper 2339, 1992.

URS, Independent Quality Control Report, "Bell, Burnet, Coryell, Falls, Lampasas and McLennan Counties of Texas", prepared for the Texas Natural Resources Information System, TWDB Task Order 19417169083, March 23, 2012.

Wallace Group, Inc., City of Waco Stormwater Master Plan, unpublished, 2003.

(This Page Intentionally Left Blank)

Appendix A – Data Collection

Exhibit A-1 LIDAR QC Report (Digital Data Only)

Exhibit A-2 Field Survey Points

Exhibit A-3 Field Survey Photo Locations

Exhibit A-4 Field Survey Photos (Digital Data Only)

Exhibit A-5 Hot Spot Locations

(This Page Intentionally Left Blank)

Legend

SURVEY POINT

0 200 400 800

Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners

HDR

Legend

SURVEY POINT

N
E
S
W

0 200 400 800

Scale (Feet)

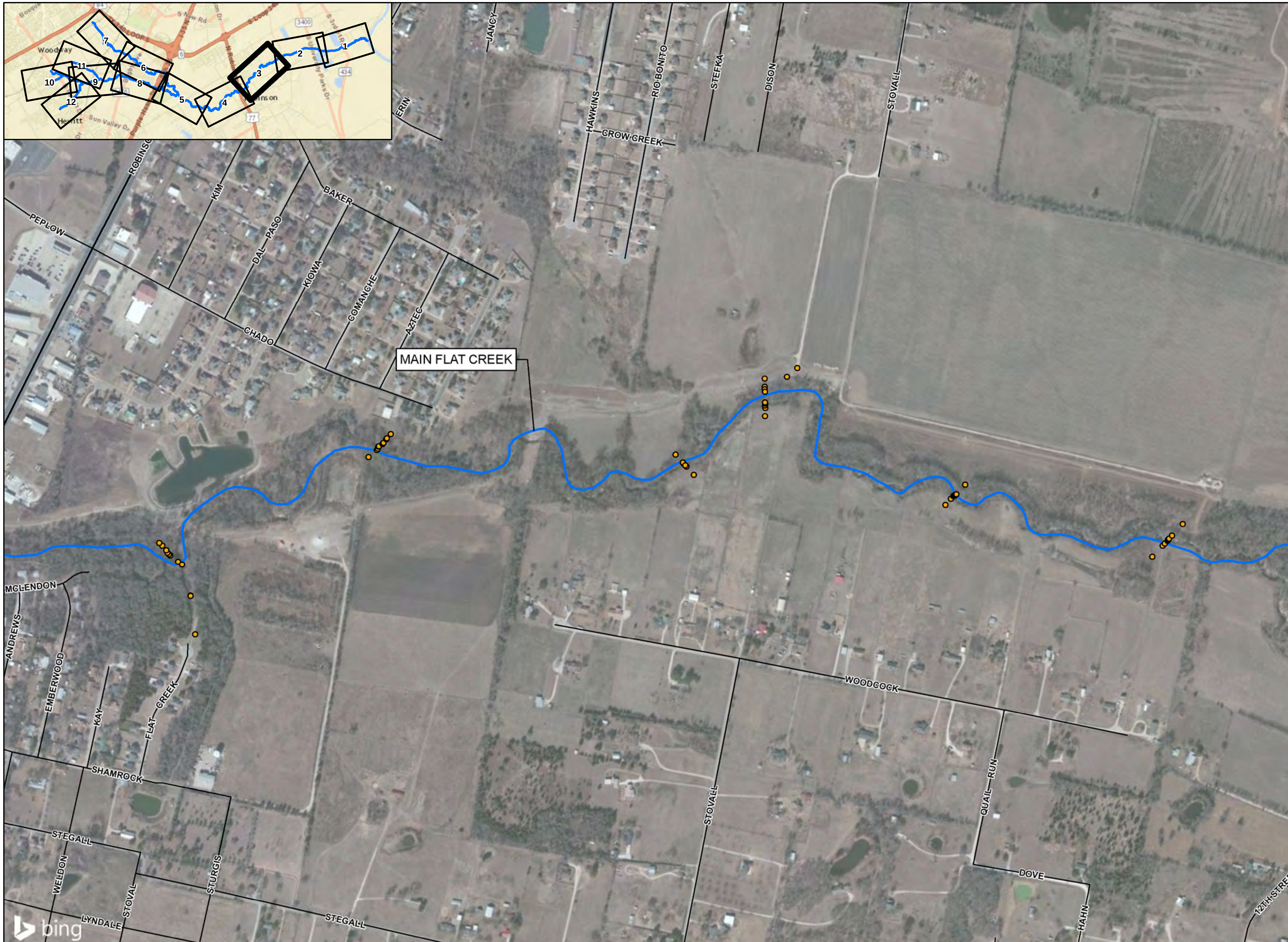
Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners

HDR



Legend

SURVEY POINT

0 200 400 800
Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners

HDR

Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

Legend

SURVEY POINT

0 200 400 800
Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners

HDR

Legend

SURVEY POINT

N E S W

0 200 400 800

Scale (Feet)

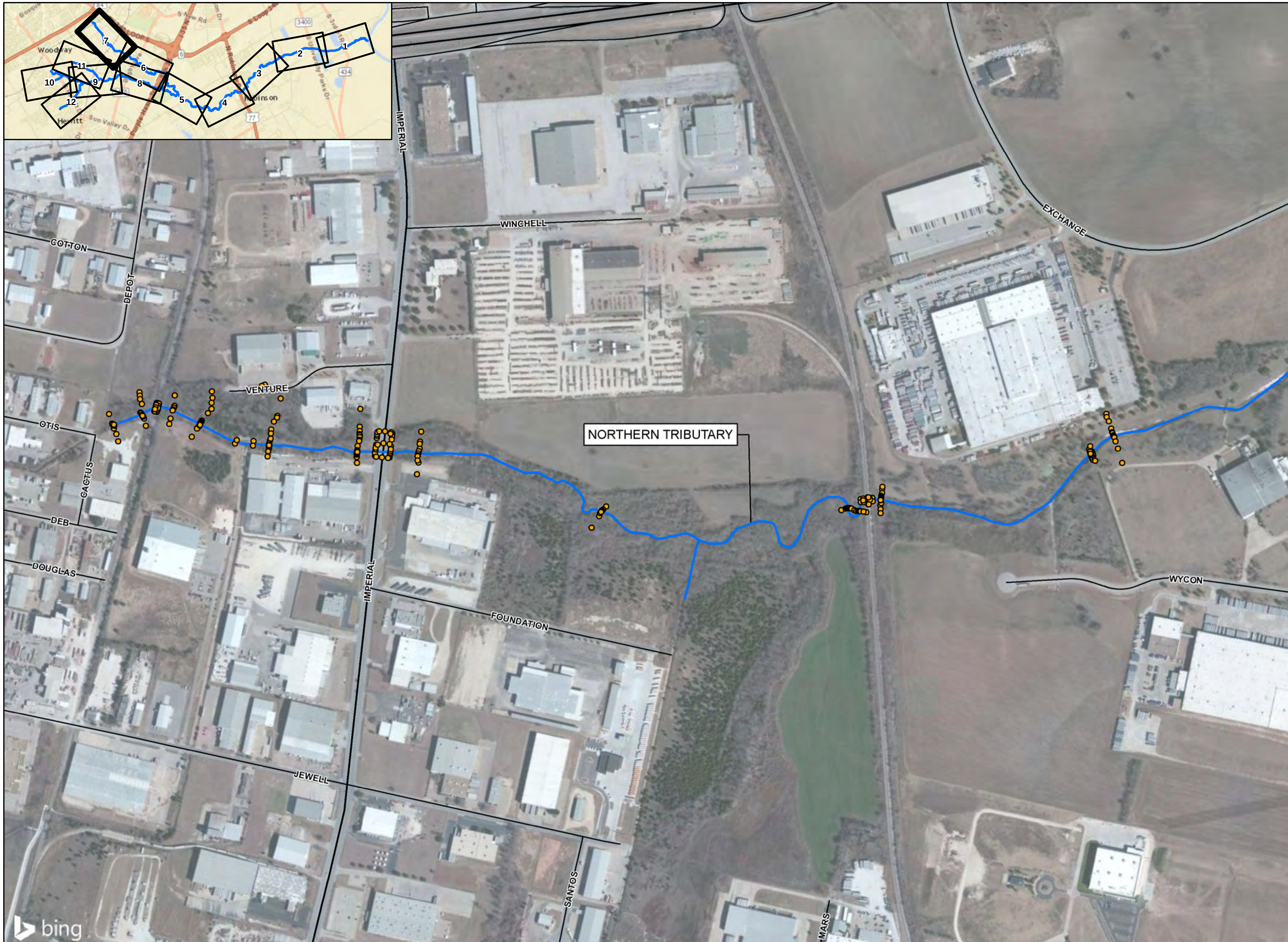
Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners

HDR



Legend

SURVEY POINT

N E S W

0 200 400 800

Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

Legend

SURVEY POINT

0 200 400 800
Scale (Feet)

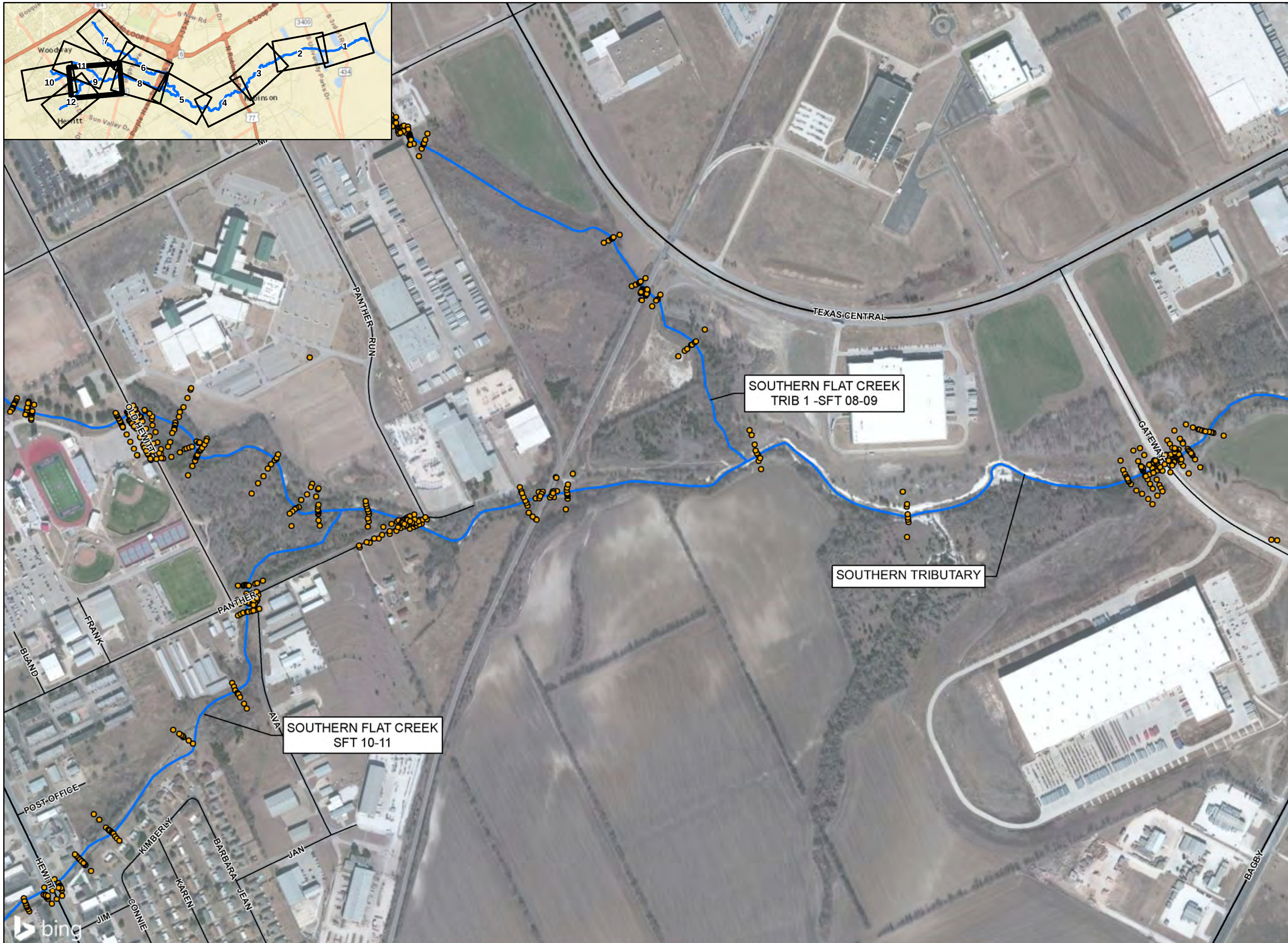
Flat Creek Flood Protection Plan

Exhibit A-2 Survey Points

Texas Water Development Board

Walker Partners

HDR



Legend

SURVEY POINT

N
W
E
S

0 200 400 800

Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners

HDR

Legend

SURVEY POINT

0 200 400 800

Scale (Feet)

N E S W

Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners

HDR

Legend

SURVEY POINT

0 200 400 800

Scale (Feet)

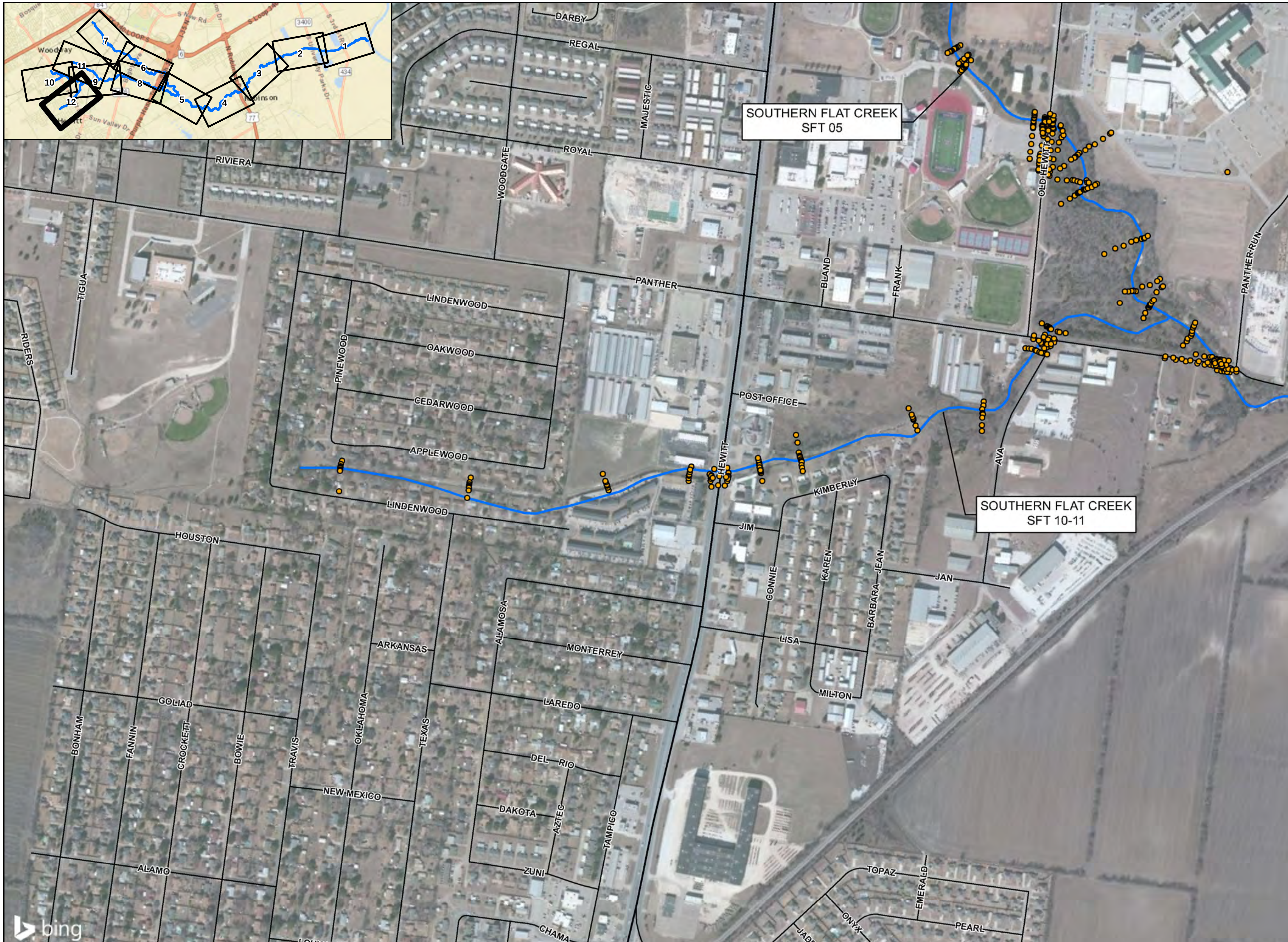
Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners

HDR



Legend

SURVEY POINT

0 200 400 800

Scale (Feet)

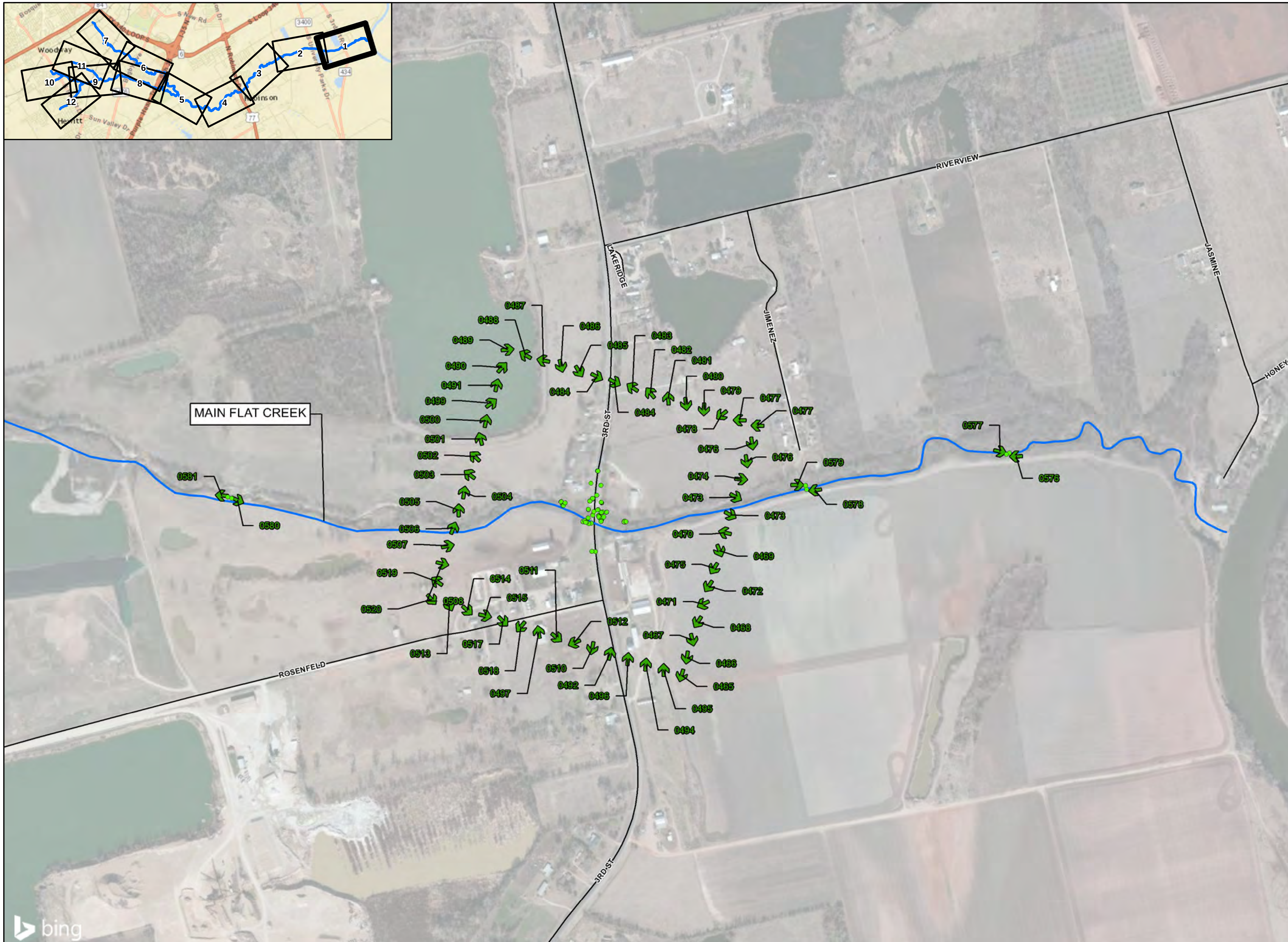
Flat Creek Flood Protection Plan

Exhibit A-2
Survey Points

Texas Water Development Board

Walker Partners

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

N
W
E
S

0 200 400 800

Scale (Feet)

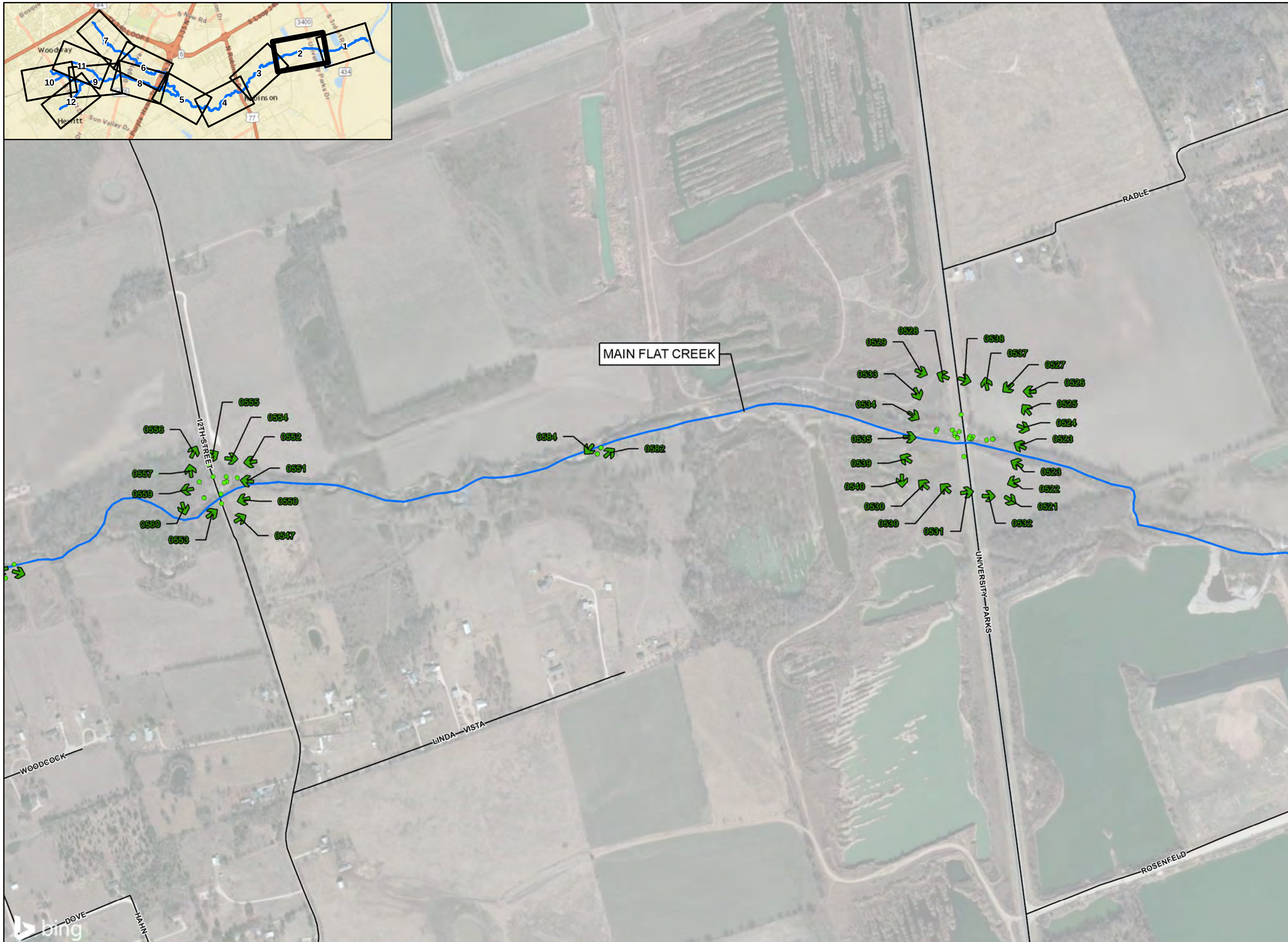
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

N
W
E
S

0 200 400 800

Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners
engineers • surveyors

HDR

Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

0 200 400 800

Scale (Feet)

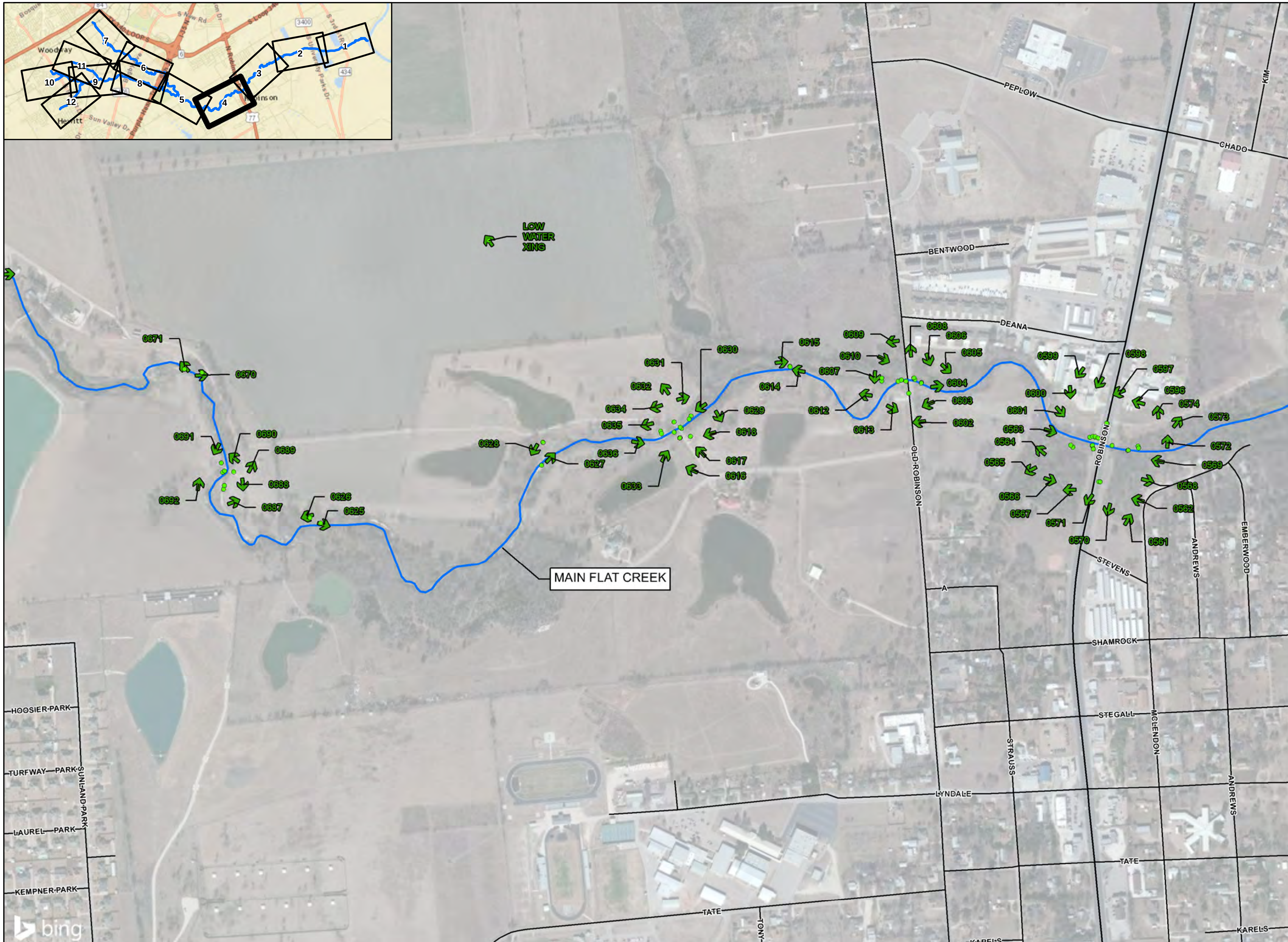
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

N W E S

0 200 400 800
Scale (Feet)

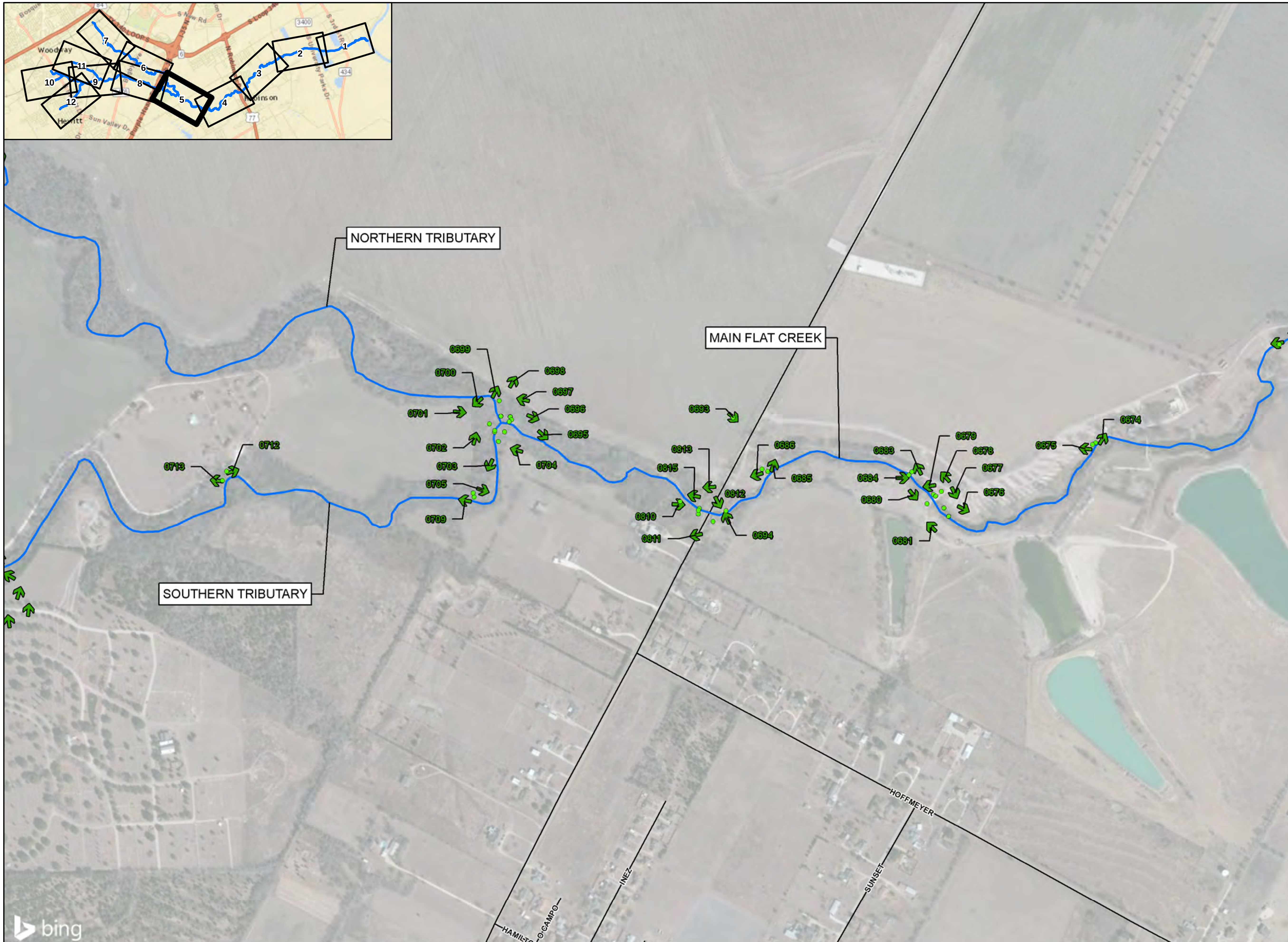
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

N E S W

0 200 400 800

Scale (Feet)

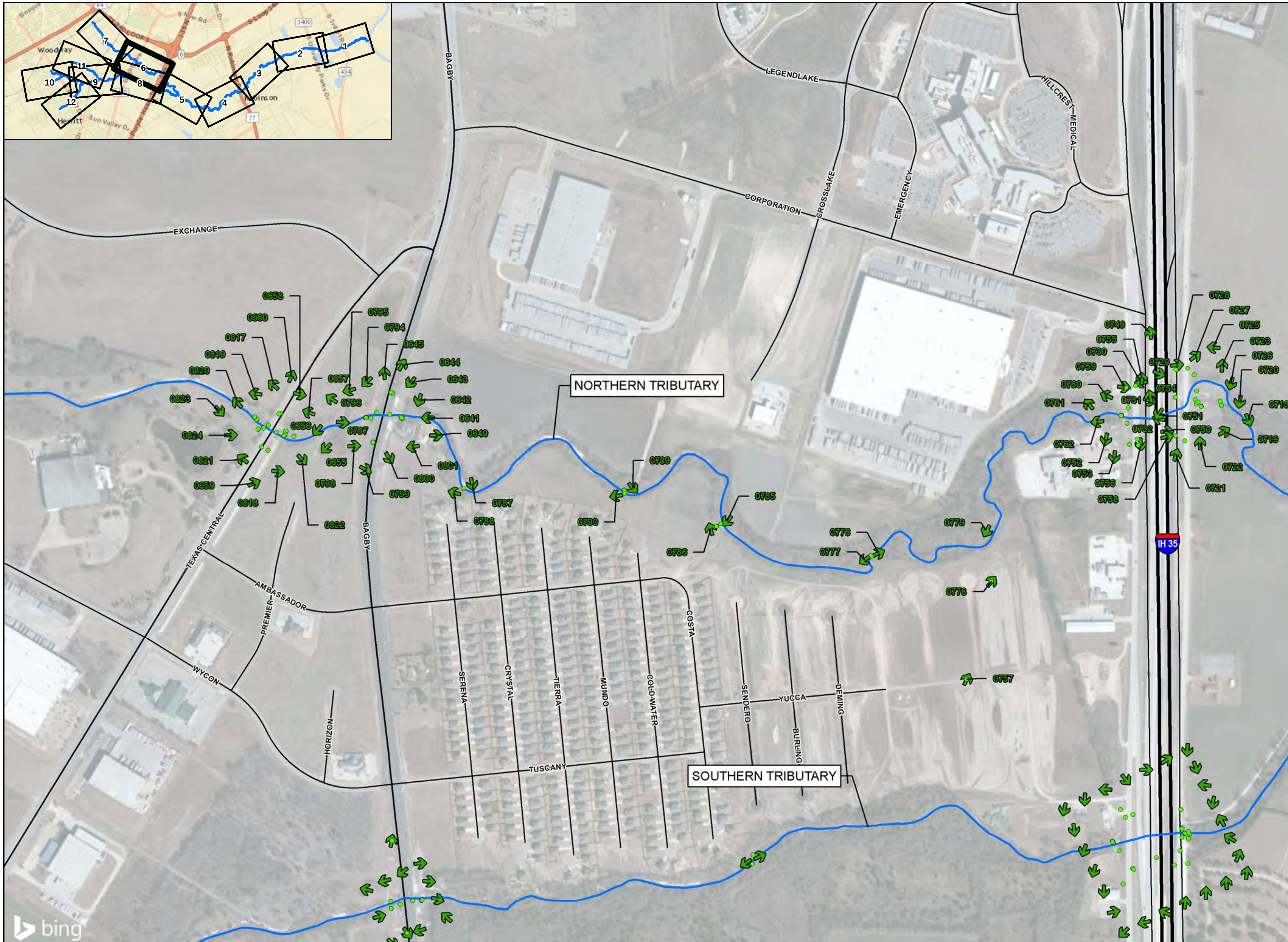
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

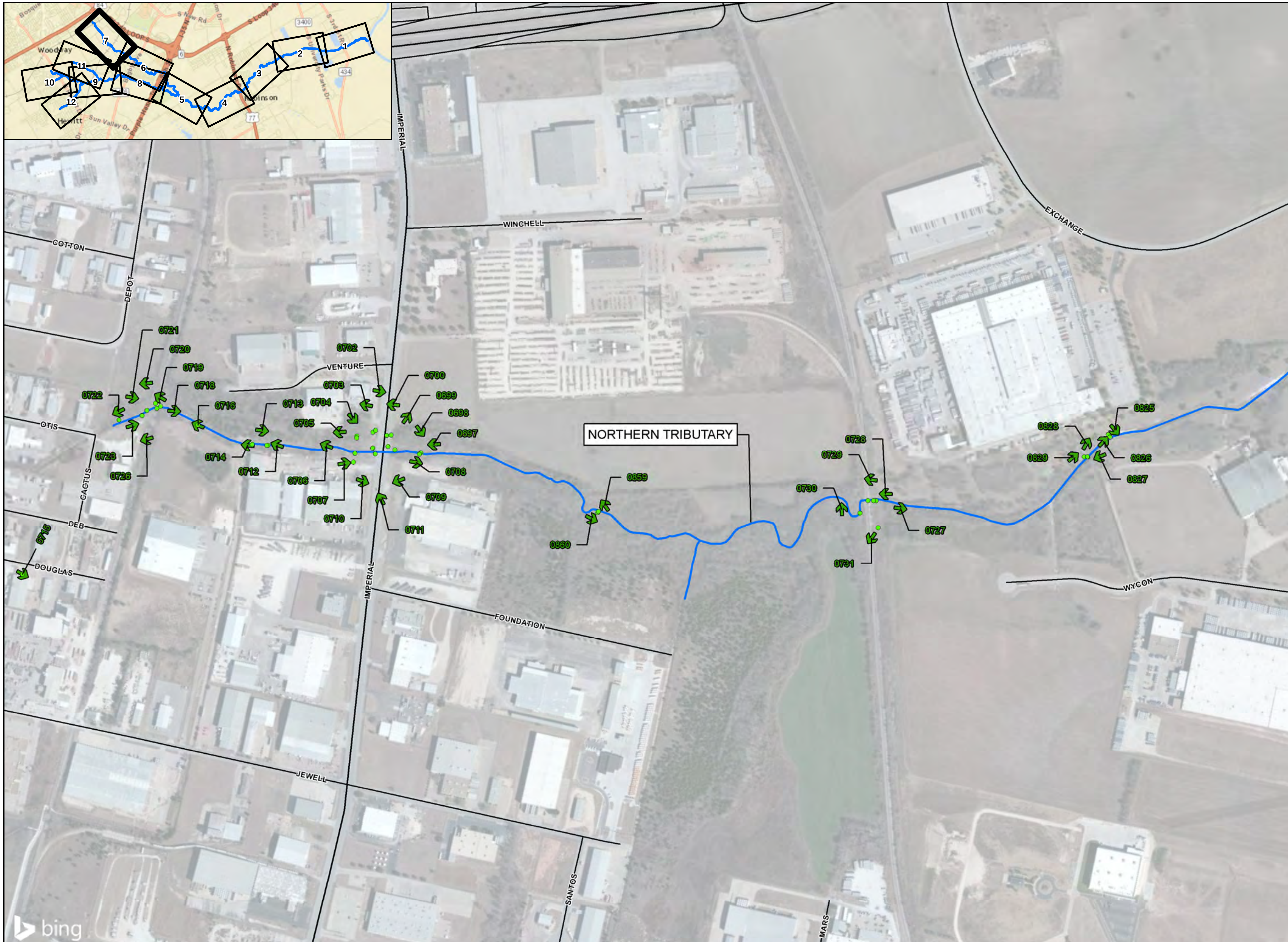
*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

0 200 400 800

Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

0 200 400 800

Scale (Feet)

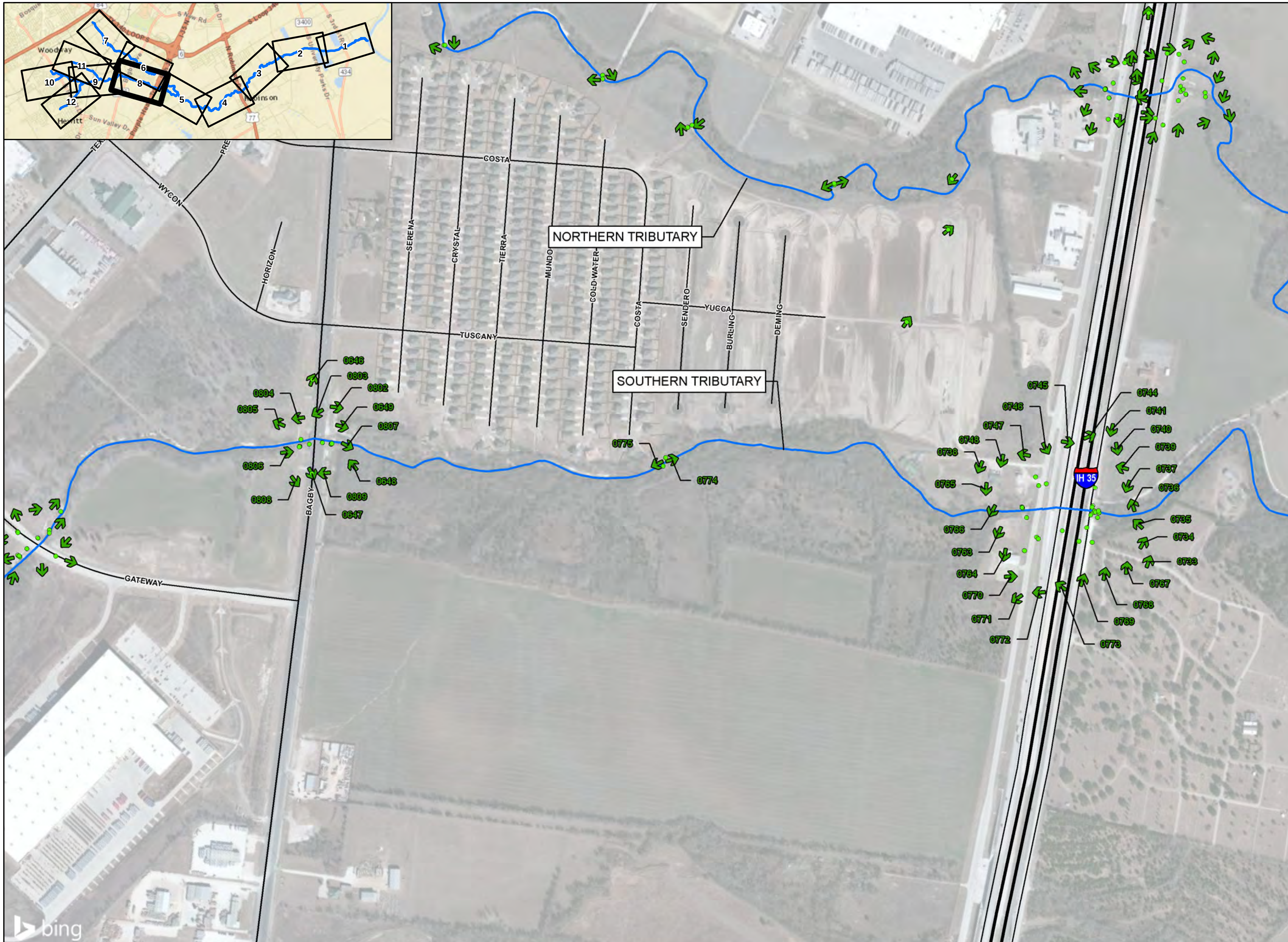
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

N E S W

0 200 400 800

Scale (Feet)

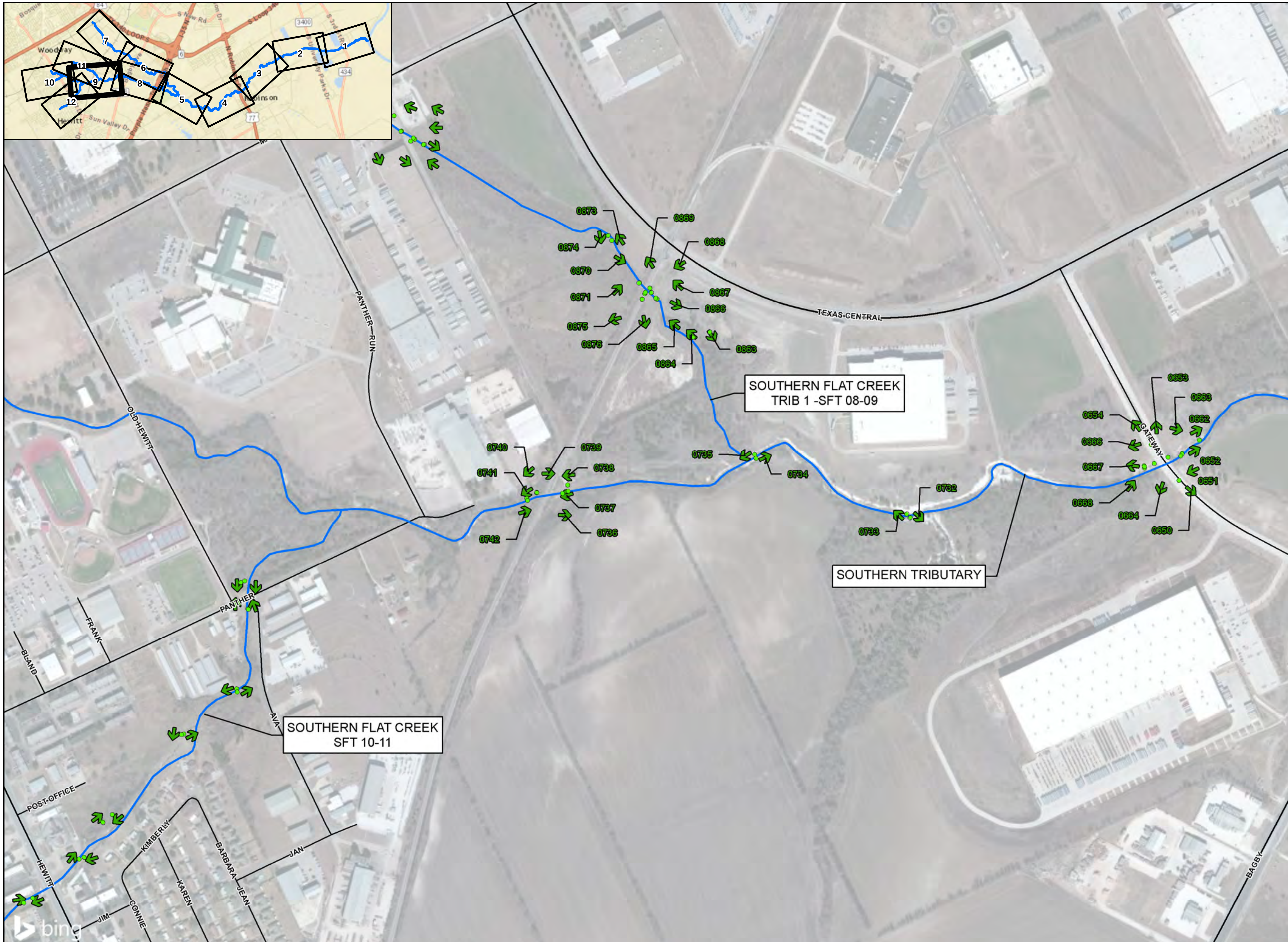
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

0 200 400 800

Scale (Feet)

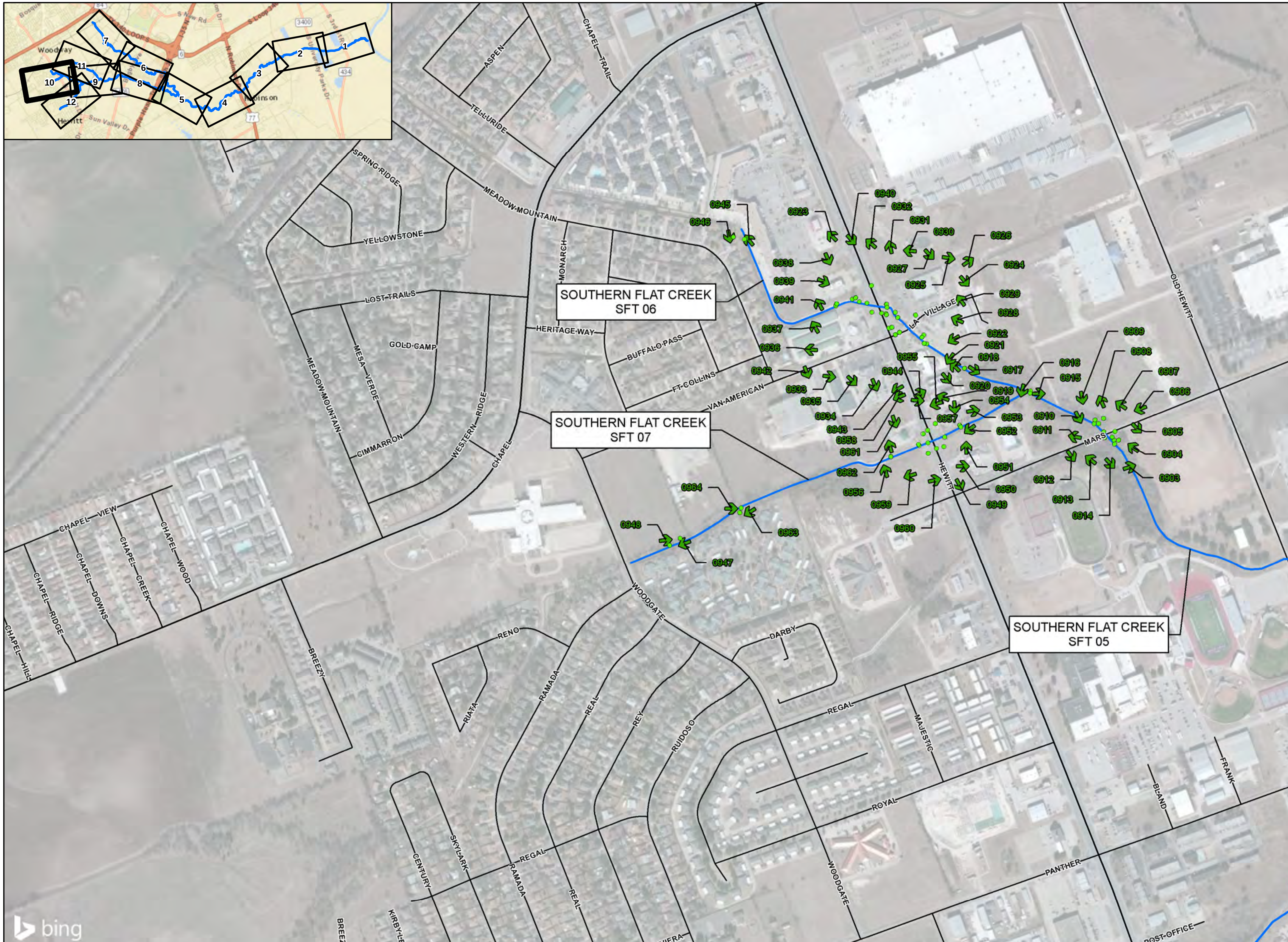
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

N
E
S
W

0 200 400 800

Scale (Feet)

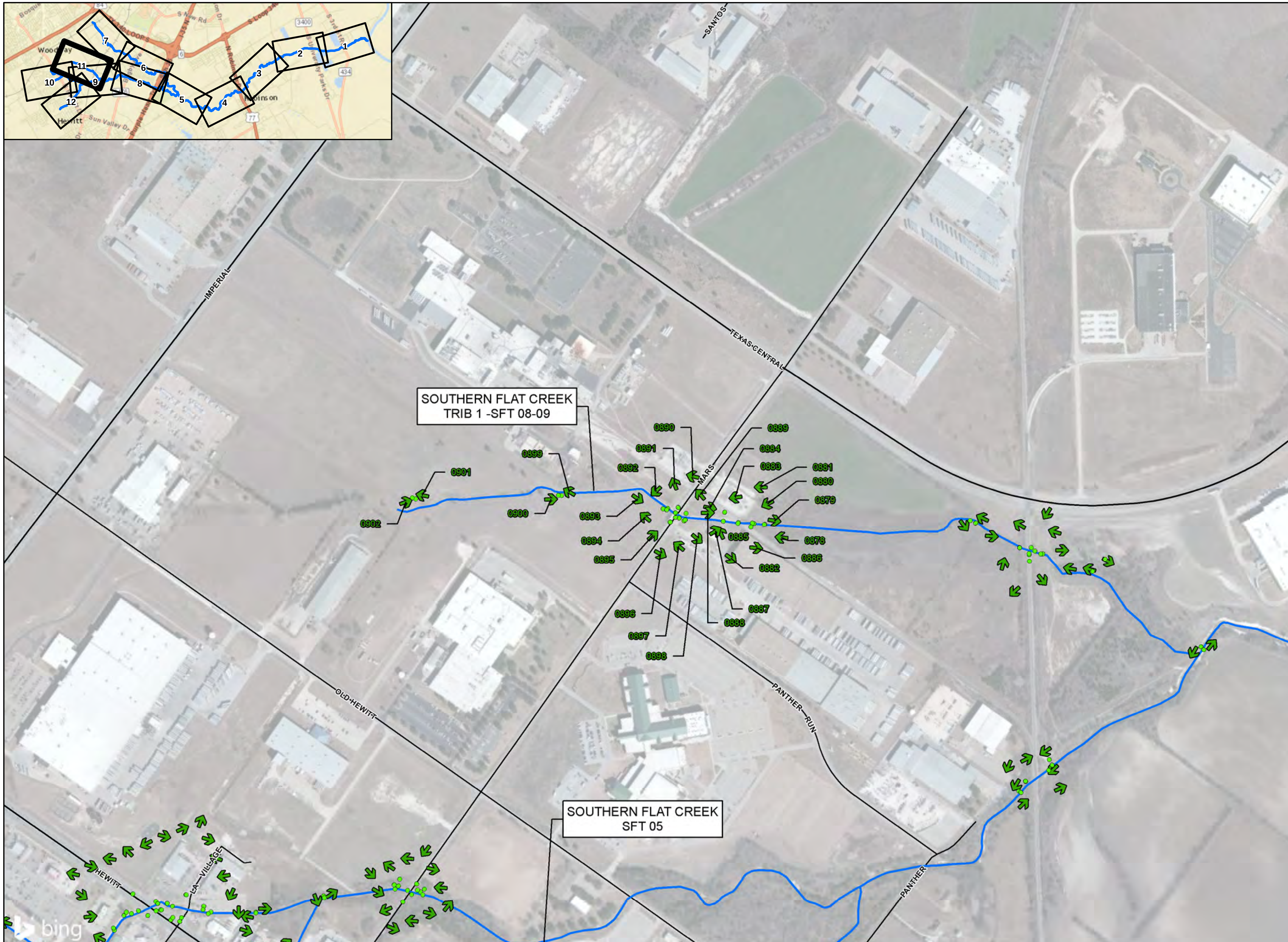
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

N E S W

0 200 400 800

Scale (Feet)

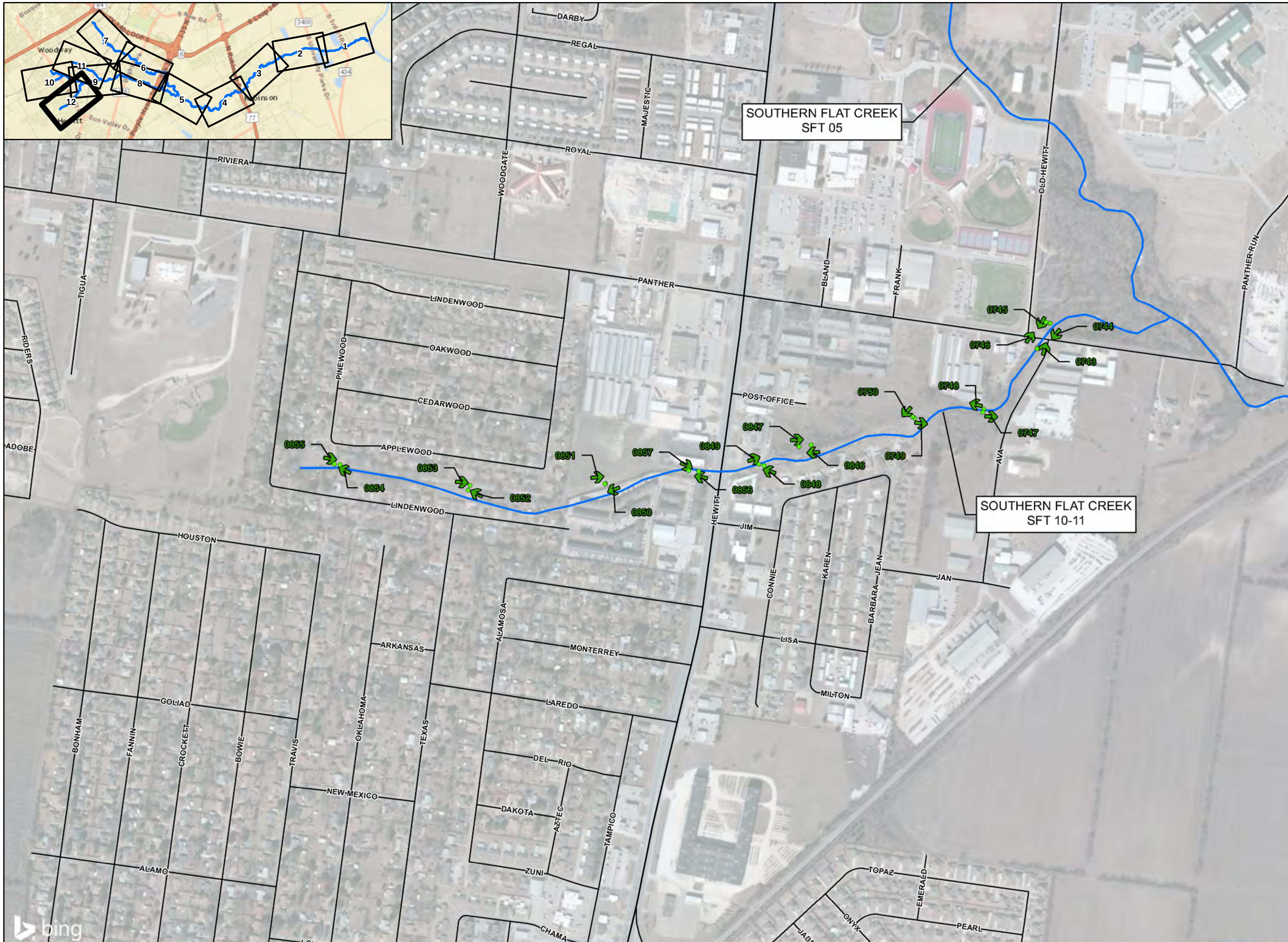
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

PHOTO POINT REPRESENTATION

ACTUAL PHOTO POINT

*PHOTO POINT SYMBOLOGY IS OFFSET FROM ITS TRUE GEOLOCATION IN A SQUARE PARAMETER FROM THE CLUSTER OF POINTS THAT WOULD NORMALLY BE SEEN AT THIS SCALE.

0 200 400 800

Scale (Feet)

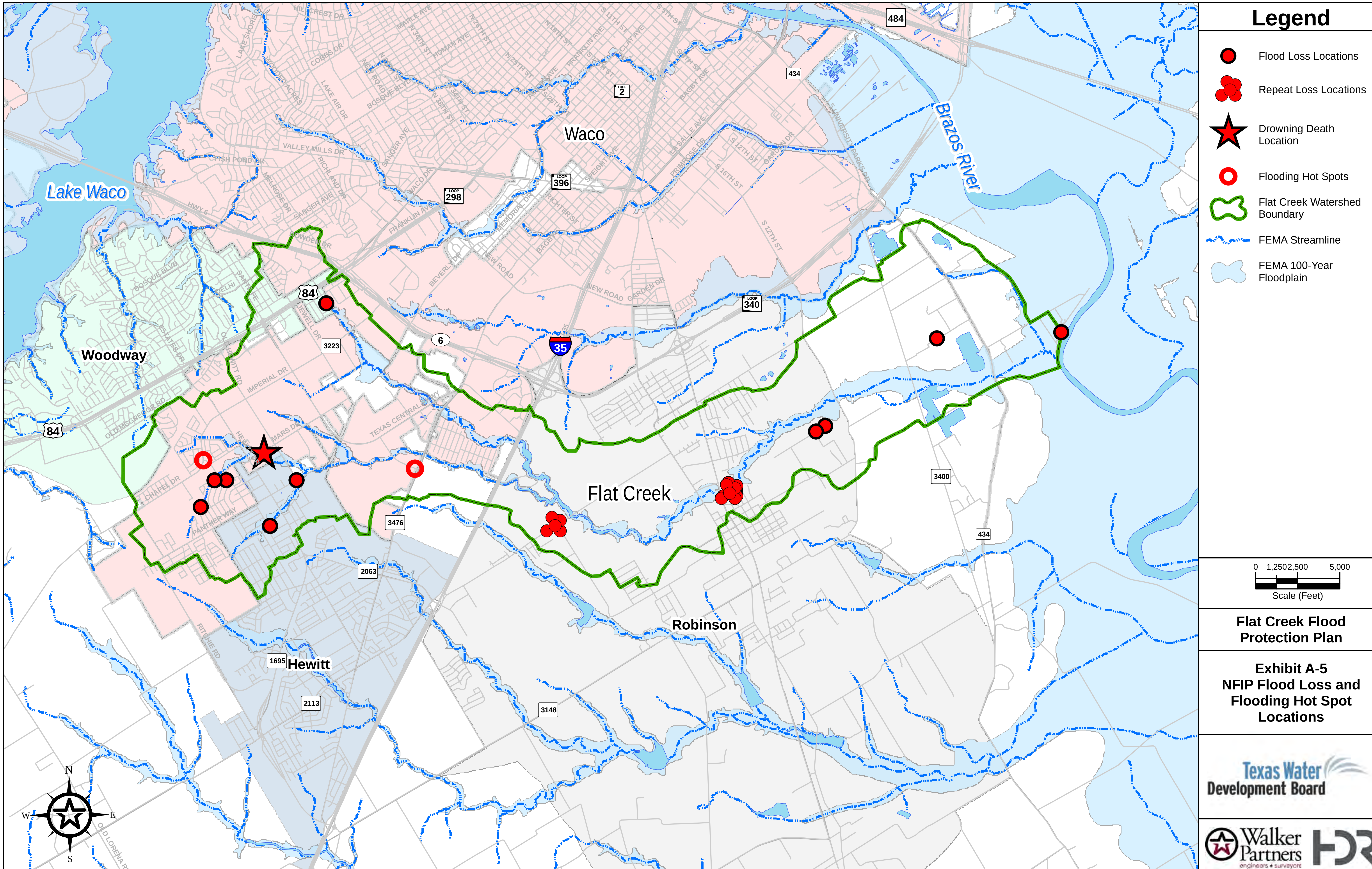
Flat Creek Flood Protection Plan

Exhibit A-3
Photo Locations

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Flat Creek Flood Protection Plan

Exhibit A-5
NFIP Flood Loss and Flooding Hot Spot Locations

Appendix B – Hydrology

Exhibit B-1A Sub-basin Delineations and Flow Paths (upper)

Exhibit B-1B Sub-basin Delineations and Flow Paths (lower)

Exhibit B-2 Soils

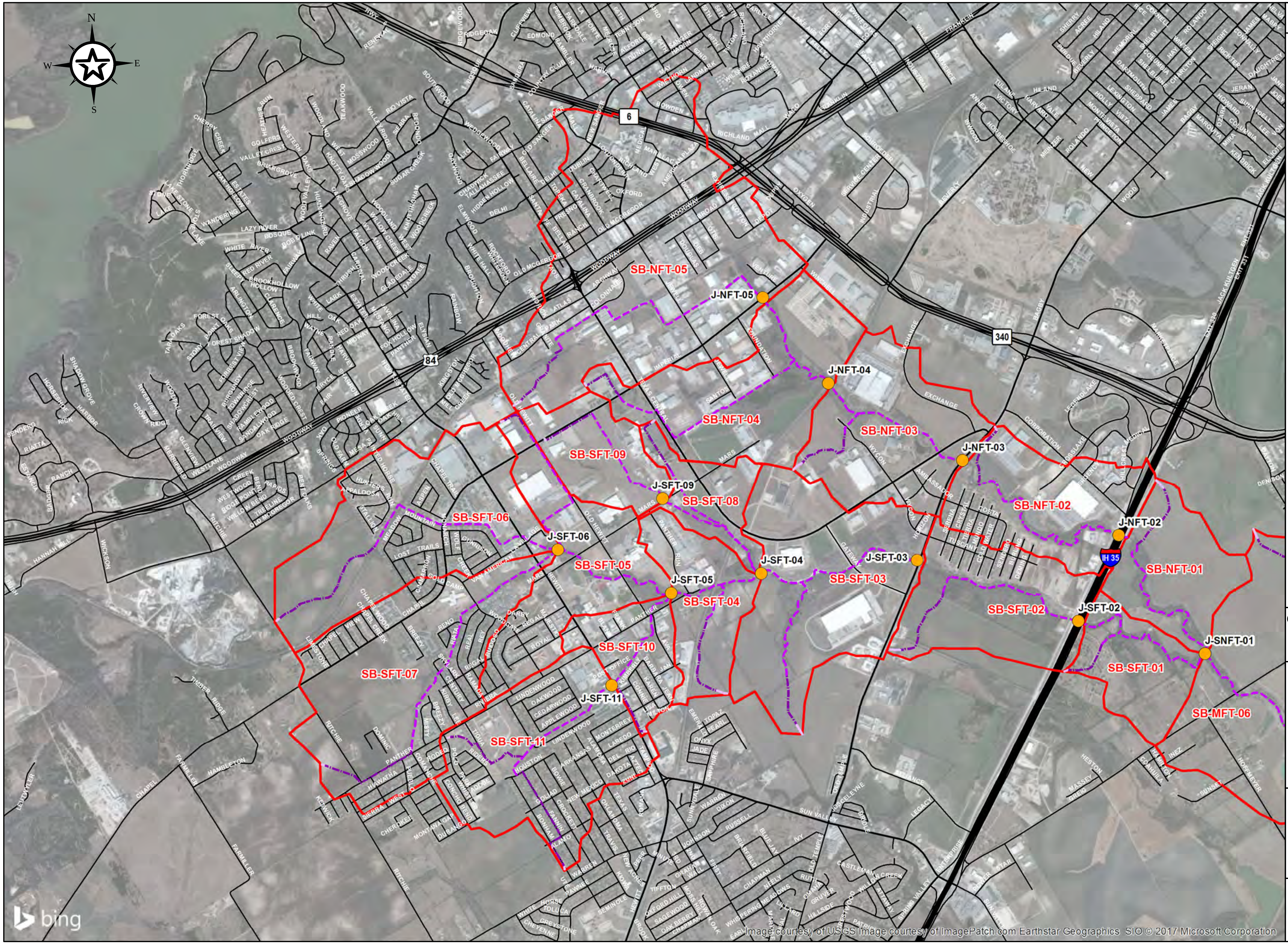
Exhibit B-3 Land Use

Exhibit B-4 Impervious Cover Percentage

Exhibit B-5 Time of Concentration Calculations

Exhibit B-6 Sub-basin Peak Discharge

(This Page Intentionally Left Blank)



Legend

Flow Junctions

H&H Flowpath

- Channel
- Overland
- Shallow-Conc
- River

Flat Creek Subbasins

DATA SOURCE:
H&H FLOWPATH : HDR
SUBBASINS : HDR
STREAMS : FEMA

0 | 1,250 | 2,500 | 5,000
Scale (Feet)

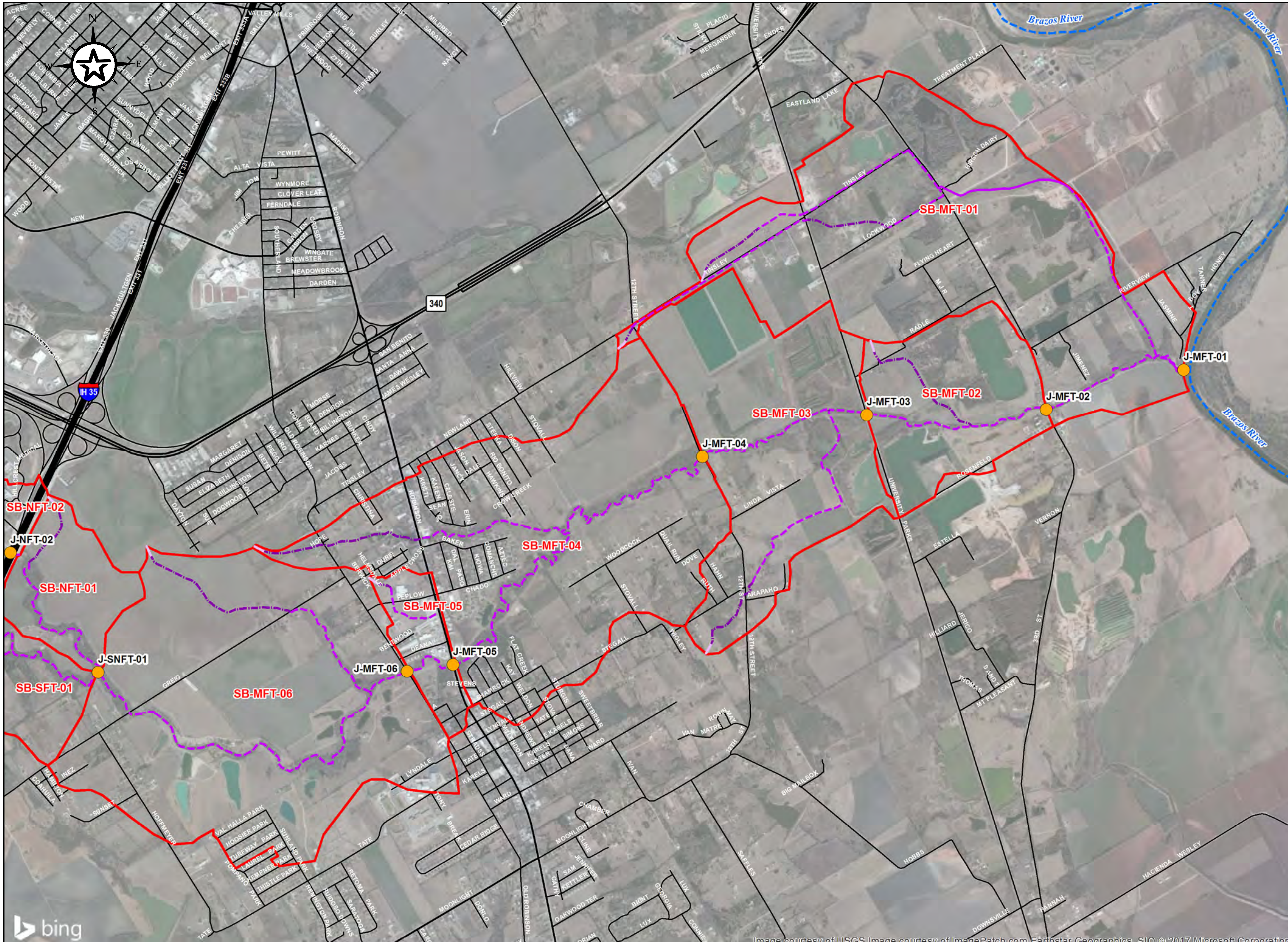
FLAT CREEK FLOOD PROTECTION PLAN

EXHIBIT B-1A : FLAT CREEK SUBBASIN DELINEATION AND FLOW PATHS

Texas Water Development Board

Walker Partners

HDR



Legend

Flow Junctions

H&H Flowpath

Channel

Overland

Shallow-Conc

River

Flat Creek Subbasins

DATA SOURCE:
H&H FLOWPATH : HDR
SUBBASINS : HDR
STREAMS : FEMA

0 1,250 2,500 5,000

Scale (Feet)

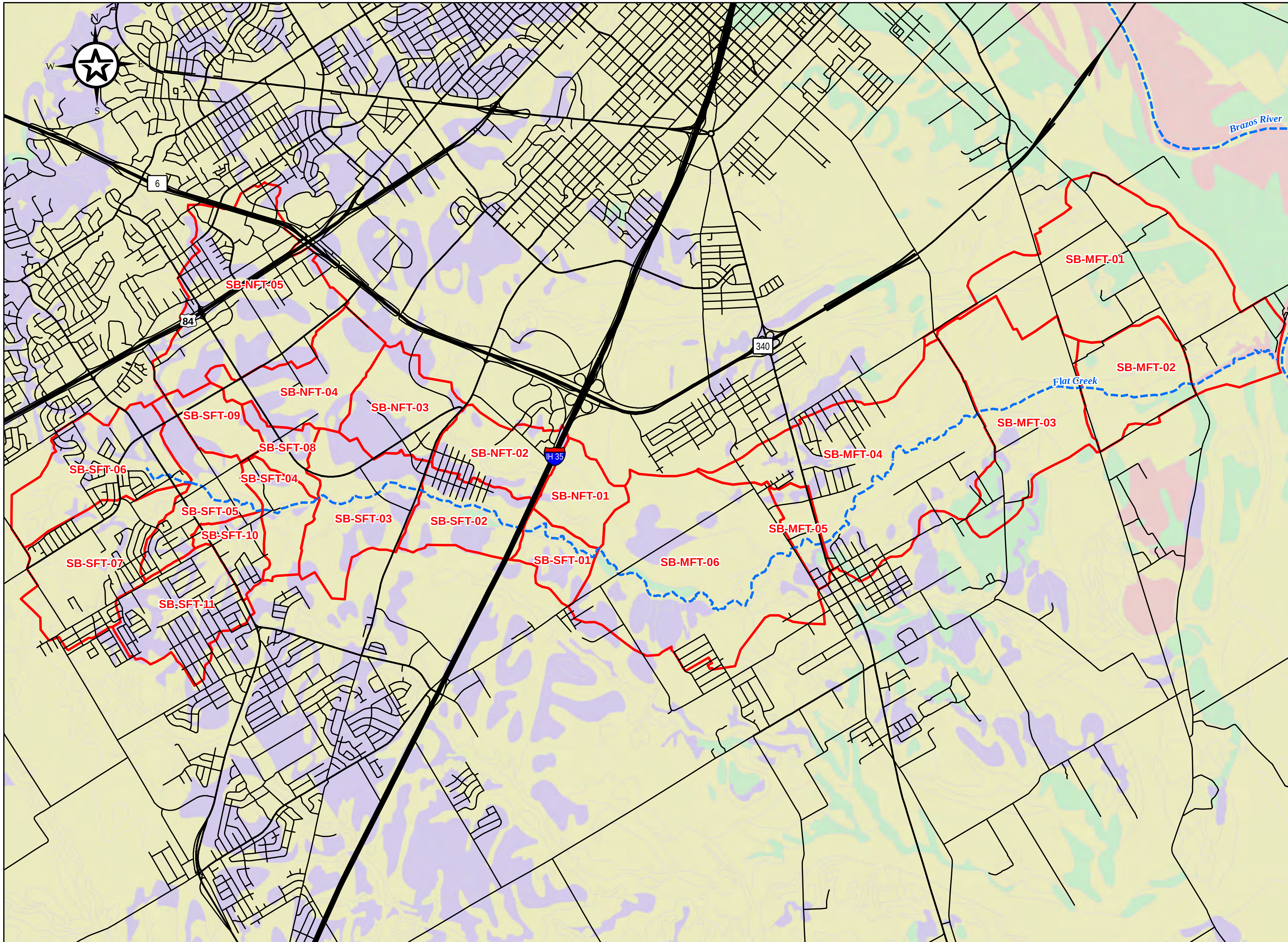
FLAT CREEK FLOOD PROTECTION PLAN

EXHIBIT B-1B : FLAT CREEK SUBBASIN DELINEATION AND FLOW PATHS

Texas Water Development Board

Walker Partners

HDR



Legend

Streams

Hydrologic Soils Group

A

B

C

D

Flat Creek Subbasins

DATA SOURCE:
SOILS : NRCS
STREAMS : FEMA 2008

0 2,000 4,000 8,000
Scale (Feet)

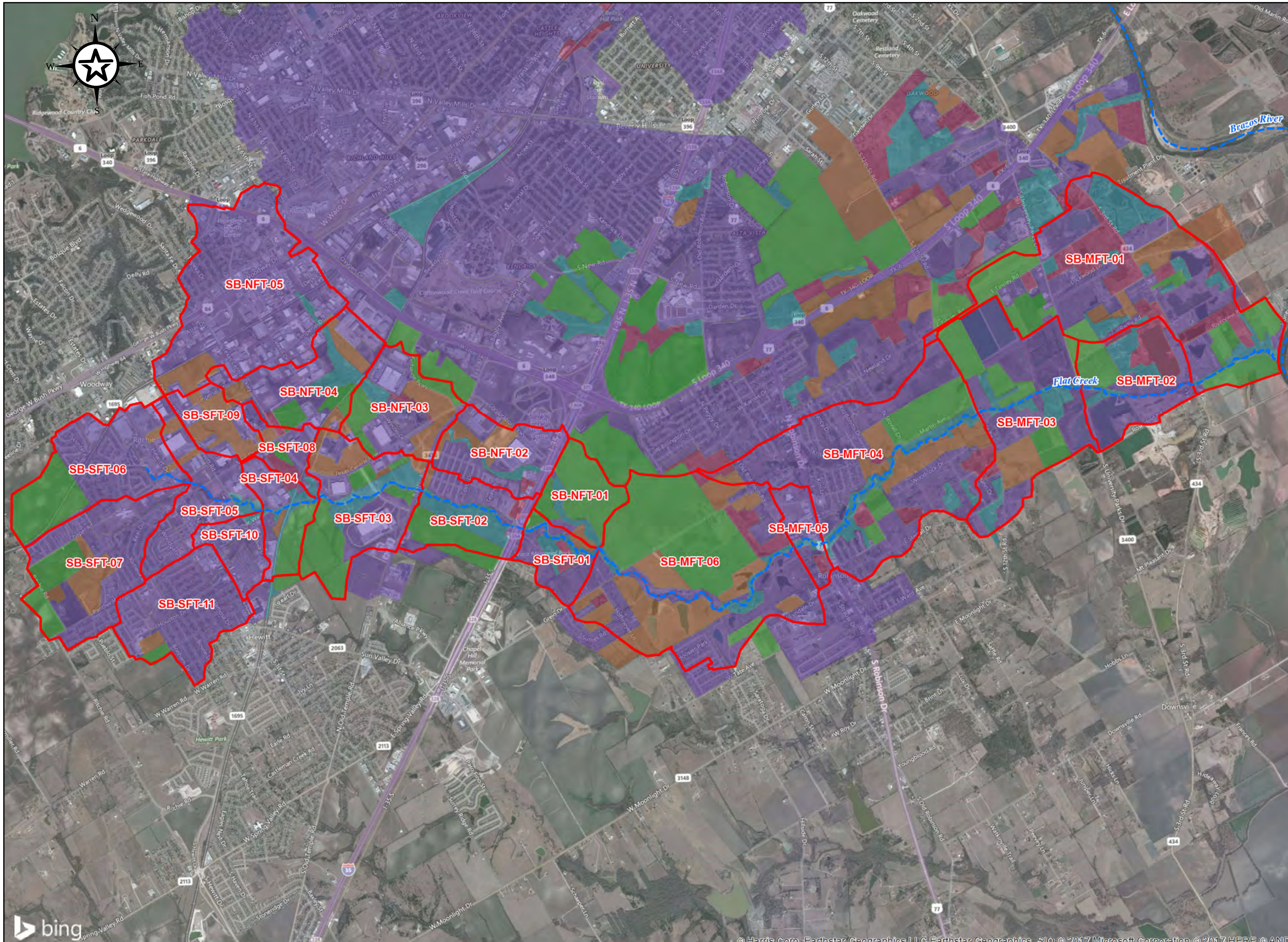
FLAT CREEK FLOOD PROTECTION PLAN

EXHIBIT B-2: FLAT CREEK SOILS

Texas Water Development Board

Walker Partners

HDR



Legend

Streams

Flat Creek Subbasins

Landuse Type

Agricultural

Brush

Meadow

Open

Woods

DATA SOURCE:
FLAT CREEK SUBBASINS : HDR
LANDUSE : HDR
STREAMS : FEMA

0 2,000 4,000 8,000
Scale (Feet)

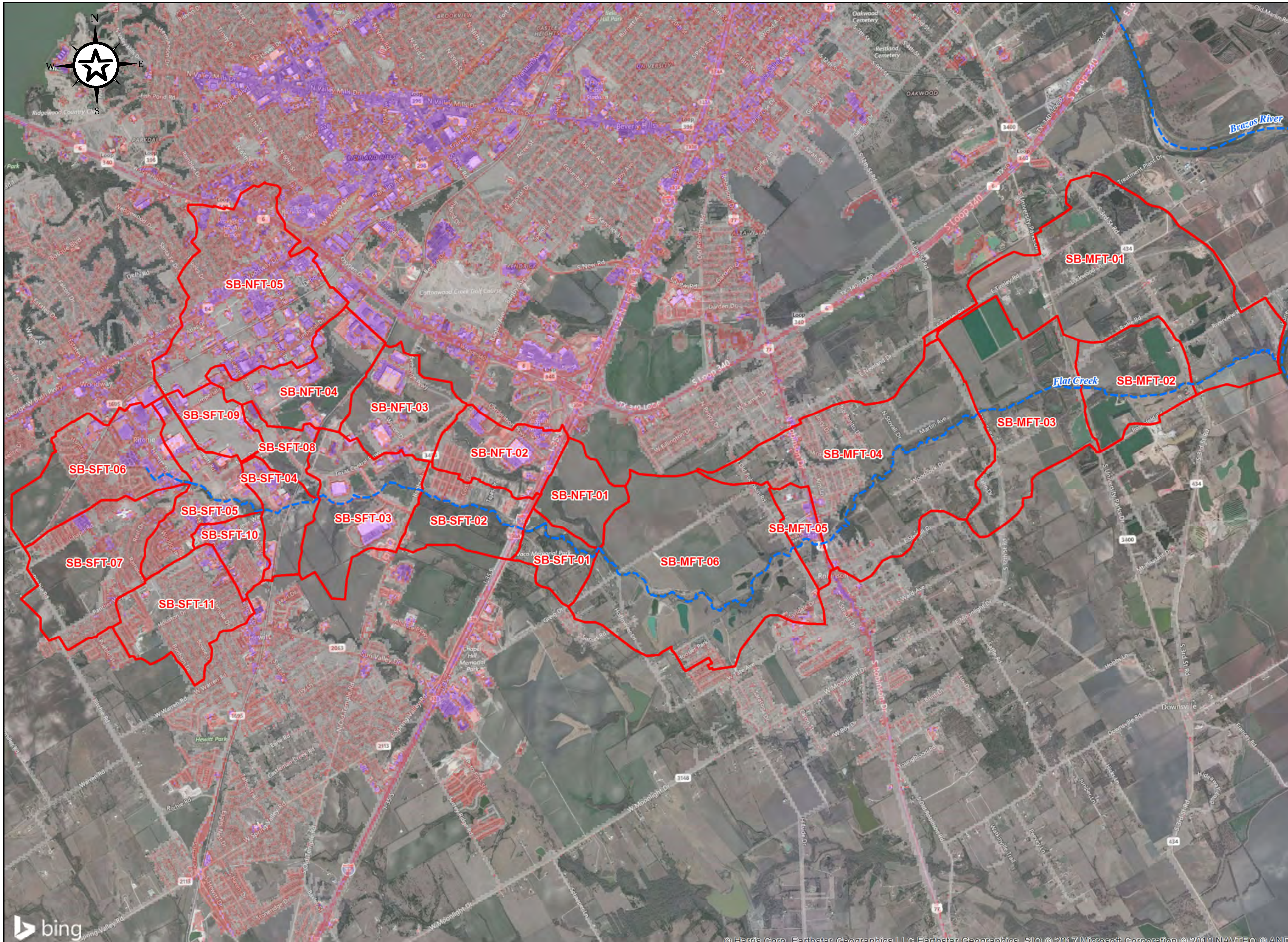
FLAT CREEK FLOOD PROTECTION PLAN

EXHIBIT B-3: FLAT CREEK LANDUSE

Texas Water Development Board

Walker Partners

HDR



Legend

Streams

Flat Creek Subbasins

Impervious Cover Percentage

0% 50% 100%

DATA SOURCE:
FLAT CREEK SUBBASINS : HDR
IMPERVIOUS COVER : NLCD 2011
STREAMS : FEMA

0 2,000 4,000 8,000

Scale (Feet)

FLAT CREEK FLOOD PROTECTION PLAN

EXHIBIT B-4: FLAT CREEK IMPERVIOUS COVER PERCENTAGE

Texas Water Development Board

Walker Partners

HDR

Flat Creek Flood Protection Plan

Exhibit B-5: Time of Concentration Calculations

Subbasin ID	Overland/Sheet Flow							Shallow Concentrated							Channel (Natural)														Total T_t	Total T_L
	Coefficient of Imperviousness		US Elev	DS Elev	Length (ft)	Slope	$T_{t\ (min)}$	Unique ID	Surface Condition	US Elev	DS Elev	Length (ft)	Slope	$T_{t\ (min)}$	Unique ID	US Elev	DS Elev	Length (ft)	Slope	V[2] (fps)	$T_{t\ (min)}$	Unique ID	US Elev	DS Elev	Length (ft)	Slope	V[2] (fps)	$T_{t\ (min)}$	(min)	(min)
SB-MFT-01	Poor Grass Surface	0.20	418.29	412.40	300.00	1.96%	**14.06**	SB-MFT-01-30	Unpaved	412.40	403.38	1,858.61	0.49%	**27.56**	SB-MFT-01-26	379.35	373.53	3,710.02	0.16%	2.00	30.92	SB-MFT-01-32	387.68	379.35	4,235.95	0.20%	2.00	35.30	**159.6**	95.8
								N/A		-	-	-	0.00%	**-**	SB-MFT-01-31	401.89	387.68	4,317.68	0.33%	2.00	35.98	SB-MFT-01-33	373.53	353.99	2,436.96	0.80%	8.30	4.89		
								N/A		-	-	-	0.00%	**-**	SB-MFT-01-124	403.38	401.89	1,306.46	0.11%	2.00	10.89									
SB-MFT-02	Poor Grass Surface	0.20	417.96	412.26	300.02	1.90%	**14.17**	SB-MFT-02-34	Unpaved	412.26	392.07	3,678.21	0.55%	**51.28**	SB-MFT-02-37	378.98	373.53	2,265.77	0.24%	5.30	7.13	N/A	-	-	-	0.00%		-	**72.7**	43.6
								SB-MFT-02-74	Unpaved	392.07	378.98	66.94	19.55%	**0.16**	N/A	-	-	-	0.00%		-	N/A	-	-	-	0.00%		-		
SB-MFT-03	Average Grass Surface	0.40	487.82	477.96	300.01	3.29%	**17.23**	SB-MFT-03-65	Unpaved	477.96	442.79	2,272.70	1.55%	**18.87**	SB-MFT-03-66	395.35	394.60	1,037.03	0.07%	2.10	8.23	SB-MFT-03-38	442.79	405.50	4,814.76	0.77%	3.00	26.75	**76.9**	46.1
								SB-MFT-03-73	Unpaved	403.66	395.35	36.30	22.87%	**0.08**	SB-MFT-03-122	405.50	403.66	1,749.81	0.11%	5.10	5.72	N/A	-	-	-	0.00%		-		
SB-MFT-04	Poor Grass Surface	0.20	529.25	526.66	300.06	0.86%	**17.04**	SB-MFT-04-43	Unpaved	526.66	469.00	4,499.01	1.28%	**41.05**	SB-MFT-04-39	427.22	409.47	6,331.73	0.28%	4.80	21.99	N/A	-	-	-	0.00%		-	**115.2**	69.1
								N/A		-	-	-	0.00%	**-**	SB-MFT-04-44	469.00	427.22	4,208.47	0.99%	2.00	35.07	N/A	-	-	-	0.00%		-		
SB-MFT-05	Poor Grass Surface	0.20	504.05	498.68	300.00	1.79%	**14.37**	SB-MFT-05-49	Unpaved	498.68	484.59	355.32	3.96%	**1.84**	SB-MFT-05-52	451.70	445.89	268.32	2.17%	8.50	0.53	SB-MFT-05-50	484.59	471.37	681.09	1.94%	6.30	1.80	**28.4**	17.0
								N/A		-	-	-	0.00%	**-**	SB-MFT-05-51	471.37	461.36	1,241.61	0.81%	2.10	9.85	N/A	-	-	-	0.00%		-		
SB-MFT-06	Poor Grass Surface	0.20	544.07	543.06	300.01	0.34%	**21.24**	SB-MFT-06-57	Unpaved	543.06	496.40	4,439.54	1.05%	**44.73**	SB-MFT-06-58	453.79	449.84	1,277.22	0.31%	4.40	4.84	N/A	-	-	-	0.00%		-	**80.7**	48.4
								SB-MFT-06-72	Unpaved	456.49	453.79	25.54	10.58%	**0.08**	SB-MFT-06-53	496.40	456.49	3,527.87	1.13%	6.00	9.80	N/A	-	-	-	0.00%		-		
SB-NFT-01	Poor Grass Surface	0.20	553.17	547.03	300.00	2.05%	**13.93**	SB-NFT-01-62	Unpaved	547.03	517.09	1,884.01	1.59%	**15.44**	SB-NFT-01-59	503.58	483.83	4,895.70	0.40%	7.38	11.06		-	-	-	0.00%		-	**40.6**	24.4
								SB-NFT-01-71	Unpaved	517.09	503.58	73.89	18.27%	**0.18**		-	-	-	0.00%		-		-	-	-	0.00%		-		
SB-NFT-02	Poor Grass Surface	0.20	576.99	572.99	100.02	4.01%	**7.13**	SB-NFT-02-76	Unpaved	572.99	540.15	1,690.16	1.94%	**12.53**	SB-NFT-02-75	533.87	503.88	6,522.81	0.46%	4.55	23.89		-	-	-	0.00%		-	**43.6**	26.2
								SB-NFT-02-77	Unpaved	540.15	533.87	35.93	17.50%	**0.09**		-	-	-	0.00%		-		-	-	-	0.00%		-		
SB-NFT-03	Average Grass Surface	0.40	615.68	606.12	300.00	3.19%	**17.36**	SB-NFT-03-71	Unpaved	606.12	575.34	1,805.31	1.71%	**14.28**	SB-NFT-03-70	552.92	536.89	3,494.11	0.46%	5.98	9.74		-	-	-	0.00%		-	**42.8**	25.7
								N/A		-	-	-	0.00%	**-**	SB-NFT-03-72	575.34	552.92	701.75	3.19%	8.00	1.46		-	-	-	0.00%		-		
SB-NFT-04	Poor Grass Surface	0.20	647.09	638.70	79.01	10.61%	**5.09**	SB-NFT-04-68	Unpaved	638.70	628.55	1,366.43	0.74%	**16.38**	SB-NFT-04-66	628.55	565.84	6,115.99	1.03%	3.81	26.75		-	-	-	0.00%		-	**56.6**	34.0
								N/A		-	-	-	0.00%	**-**	SB-NFT-04-67	565.84	559.04	1,660.52	0.41%	3.29	8.41		-	-	-	0.00%		-		
SB-NFT-05	Average Grass Surface	0.40	664.57	655.50	233.85	3.88%	**14.76**	SB-NFT-05-62	Unpaved	655.50	628.06	1,978.24	1.39%	**17.35**	SB-NFT-05-61	578.59	575.40	953.60	0.33%	4.59	3.46	SB-NFT-05-60	615.11	578.59	5,260.15	0.69%	14.72	5.96	**44.2**	26.5
								N/A		-	-	-	0.00%	**-**	SB-NFT-05-63	628.06	615.11	1,579.14	0.82%	9.83	2.68		-	-	-	0.00%		-		
SB-SFT-01	Poor Grass Surface	0.20	566.87	565.84	113.33	0.90%	**10.70**	SB-SFT-01-120	Unpaved	565.84	530.56	1,355.69	2.60%	**8.68**	SB-SFT-01-117	496.90	483.96	3,233.08	0.40%	8.62	6.25		-	-	-	0.00%		-	**27.2**	16.3
								N/A		-	-	-	0.00%	**-**	SB-SFT-01-121	530.56	496.90	649.11	5.19%	6.95	1.56		-	-	-	0.00%		-		
SB-SFT-02	Deciduous Timberland	0.60	596.20	591.50	300.01	1.57%	**24.76**	SB-SFT-02-56	Unpaved	591.64	547.73	2,219.47	1.98%	**16.30**	SB-SFT-02-55	531.45	504.33	4,199.34	0.65%	5.73	12.21		-	-	-	0.00%		-	**54.4**	32.6
								N/A		-	-	-	0.00%	**-**	SB-SFT-02-57	547.73	531.45	503.64	3.23%	7.49	1.12		-	-	-	0.00%		-		
SB-SFT-03	Poor Grass Surface	0.20	618.70	617.40	300.00	0.43%	**20.01**	SB-SFT-03-52	Unpaved	617.40	606.32	1,422.52	0.78%	**16.65**	SB-SFT-03-50	606.32	552.81	3,058.74	1.75%	6.80	7.50		-	-	-	0.00%		-	**53.3**	32.0
								N/A		-	-	-	0.00%	**-**	SB-SFT-03-51	552.81	533.06	3,937.86	0.50%	7.21	9.10		-	-	-	0.00%		-		
SB-SFT-04	Poor Grass Surface	0.20	643.88	638.97	300.00	1.64%	**14.67**	SB-SFT-04-45	Unpaved	638.97	608.15	2,363.45	1.30%	**21.38**	SB-SFT-04-46	569.03	562.67	1,114.89	0.57%	6.93	2.68		-	-	-	0.00%		-	**40.8**	24.5
								N/A		-	-	-	0.00%	**-**	SB-SFT-04-47	608.15	569.03	1,143.14	3.42%	9.10	2.09		-	-	-	0.00%		-		
SB-SFT-05	Average Grass Surface	0.40	671.50	670.60	98.40	0.91%	**13.80**	SB-SFT-05-33	Unpaved	671.03	662.41	939.63	0.92%	**10.13**	SB-SFT-05-8	662.41	634.85	2,442.04	1.13%	4.73	8.60	SB-SFT-05-32	634.85	605.87	2,110.92	1.37%	9.32	3.77	**49.7**	29.8
								N/A		-	-	-	0.00%	**-**	SB-SFT-05-30	605.87	579.43	3,613.34	0.73%	4.51	13.35		-	-	-	0.00%		-		
SB-SFT-06	Average Grass Surface	0.40	725.12	721.83	300.00	1.10%	**22.26**	SB-SFT-06-19	Unpaved	700.30	668.17	2,667.92	1.20%	**25.11**	SB-SFT-06-5	654.60	606.66	4,972.02	0.96%	11.81	7.02		-	-	-	0.00%		-	**60.5**	36.3
								SB-SFT-06-27	Unpaved	721.83	700.30	753.22	2.86%	**4.60**	SB-SFT-06-20	668.17	654.60	1,324.90	1.02%	14.17	1.56		-	-	-	0.00%		-		
SB-SFT-07	Average Grass Surface	0.40	723.91	718.91	300.00	1.67%	**20.19**	SB-SFT-07-16	Unpaved	718.91	700.68	972.28	1.87%	**7.34**	SB-SFT-07-6	677.60	606.01	7,360.14	0.97%	18.50	6.63		-	-	-	0.00%		-	**46.1**	27.6
								SB-SFT-07-17	Paved	700.68	677.60	1,695.65	1.36%	**11.91**		-	-	-	0.00%		-		-	-	-	0.00%		-		
SB-SFT-08	Paved	0.02	628.20	626.44	100.10	1.76%	**5.00**	SB-SFT-08-40	Unpaved	623.05	612.04	1,360.31	0.81%	**15.62**	SB-SFT-08-39	604.67	562.78	3,114.86	1.34%	5.67	9.16		-	-	-	0.00%		-	**32.7**	19.6
								SB-SFT-08-42	Paved	626.44	623.05	257.37	1.32%	**1.84**	SB-SFT-08-41	612.04	604.67	917.12	0.80%	14.15	1.08		-	-	-	0.00%		-		
SB-SFT-09	Paved	0.02	656.95	655.19	59.59	2.95%	**5.00**	SB-SFT-09-37	Unpaved	655.19	638.32	1,482.57	1.14%	**14.35**	SB-SFT-09-36	638.32	604.76	3,273.20	1.03%	3.34	16.33		-	-	-	0.00%		-	**35.7**	21.4
								N/A		-	-	-	0.00%	**-**		-	-	-	0.00%		-		-	-	-	0.00%		-		
SB-SFT-10	Paved	0.02	645.55	644.90	75.24	0.86%	**5.00**	SB-SFT-10-23	Paved	644.90	615.14	1,608.63	1.85%	**9.70**	SB-SFT-10-7	615.14	579.09	3,264.17	1.10%	4.97	10.95		-	-	-	0.00%		-	**25.6**	15.4
								N/A		-	-	-	0.00%	**-**		-	-	-	0.00%		-		-	-	-	0.00%		-		
SB-SFT-11	Average Grass Surface	0.40	682.21	680.86	89.91	1.51%	**11.78**	SB-SFT-11-26	Paved	680.86	674.80	1,228.17	0.49%	**14.34**	SB-SFT-11-3	657.86	617.50	3,220.55	1.25%	14.50	3.70		-	-	-	0.00%		-	**61.1**	36.7
								SB-SFT-11-10	Paved	674.80	667.69	2,143.83	0.33%	**30.53**	SB-SFT-11-11	667.69	657.86	642.93	1.53%	14.02	0.76		-	-	-	0.00%		-		

[1] *Velocities calculated using full capacity assumption for specified pipe size.*

[2] *Velocities calculated using Manning's equation in the Bentley FlowMaster software.*

Flat Creek Flood Protection Plan Exhibit B-6: HEC-HMS Junction Peak Discharges								
Contributing Sub-basins	Basin Junction	Drainage Area	Q_2	Q_{10}	Q_{50}	Q_{100}	Q_{500}	Junction Reference / Description
		(mi^2)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	
Flat Creek Main Stem								
SB-MFT-01	J-MFT-01	18.79	3,385	7,197	11,961	14,445	21,739	Outfall at Brazos River
SB-MT-02	J-MFT-02	16.48	3,336	7,063	11,572	13,941	21,166	FM 434
SB-MFT-03	J-MFT-03	15.78	3,377	7,206	12,050	14,410	22,441	Old railroad grade (Univ. Parks)
SB-MFT-04	J-MFT-04	14.43	3,530	7,784	12,150	14,767	21,794	12th Street
SB-MFT-05	J-MFT-05	12.30	3,845	7,816	11,657	14,896	19,959	U.S. Hwy. 77
SB-MFT-06	J-MFT-06	12.09	3,871	7,841	12,007	15,051	19,921	Old Robinson Road
SB-SFT-01 & SB-NFT-01	J-SNFT-01	9.80	3,916	7,554	10,842	12,353	17,274	At North & South Trib Junction
North Flat Creek								
SB-NFT-02	J-NFT-02	3.44	1,494	2,399	3,146	3,574	4,842	NFT at IH-35
SB-NFT-03	J-NFT-03	2.91	1,480	2,322	3,049	3,459	4,653	NFT at Bagby Avenue
SB-NFT-04	J-NFT-04	2.30	1,384	2,161	2,852	3,230	4,333	At Rail Road Tracks
SB-NFT-05	J-NFT-05	1.60	1,712	3,136	4,539	5,254	7,179	At Imperial Drive
South Flat Creek								
SB-SFT-02	J-SFT-02	5.68	2,857	5,307	12,237	8,472	12,237	SFT at IH-35
SB-SFT-03	J-SFT-03	5.13	2,792	5,012	11,651	7,827	11,651	SFT at Bagby Avenue
SB-SFT-04 & SB-SFT-08	J-SFT-04	4.26	2,429	4,347	10,848	6,583	10,848	SFT & Trib Junction U/S of Gateway Blvd.
SB-SFT-05 & SB-SFT-10	J-SFT-05	3.40	2,034	3,842	9,927	6,710	9,927	SFT & Trib Junction near Panther Way
SB-SFT-06 & SB-SFT-07	J-SFT-06	1.85	1,349	2,585	6,022	4,393	6,022	SFT & Trib Junction D/S of Hewitt Drive
SB-SFT-09	J-SFT-09	0.30	223	441	1,051	761	1,051	SFT at Mars Drive
SB-SFT-11	J-SFT-11	0.75	420	829	2,030	1,459	2,030	SFT at Hewitt Drive

Appendix C – Hydraulics and Floodplain Mapping

Exhibit C-1 Water Surface Profiles

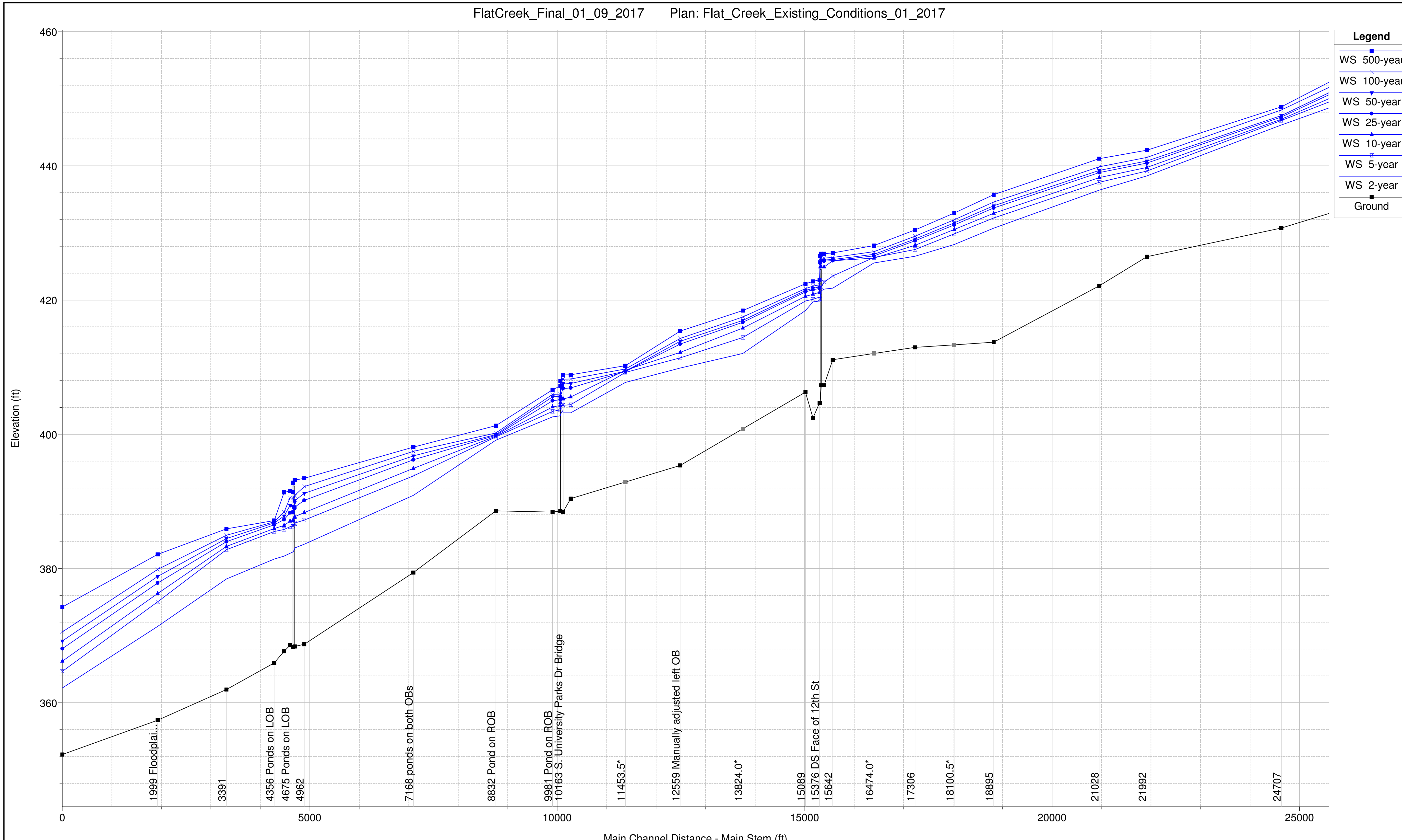
Exhibit C-2 Hydraulic Work Map

Exhibit C-3 FPP Floodplain vs. FEMA 1% Floodplain

Exhibit C-4 Hydraulic Model (HEC-RAS) 1% AEP (100-YR) Results

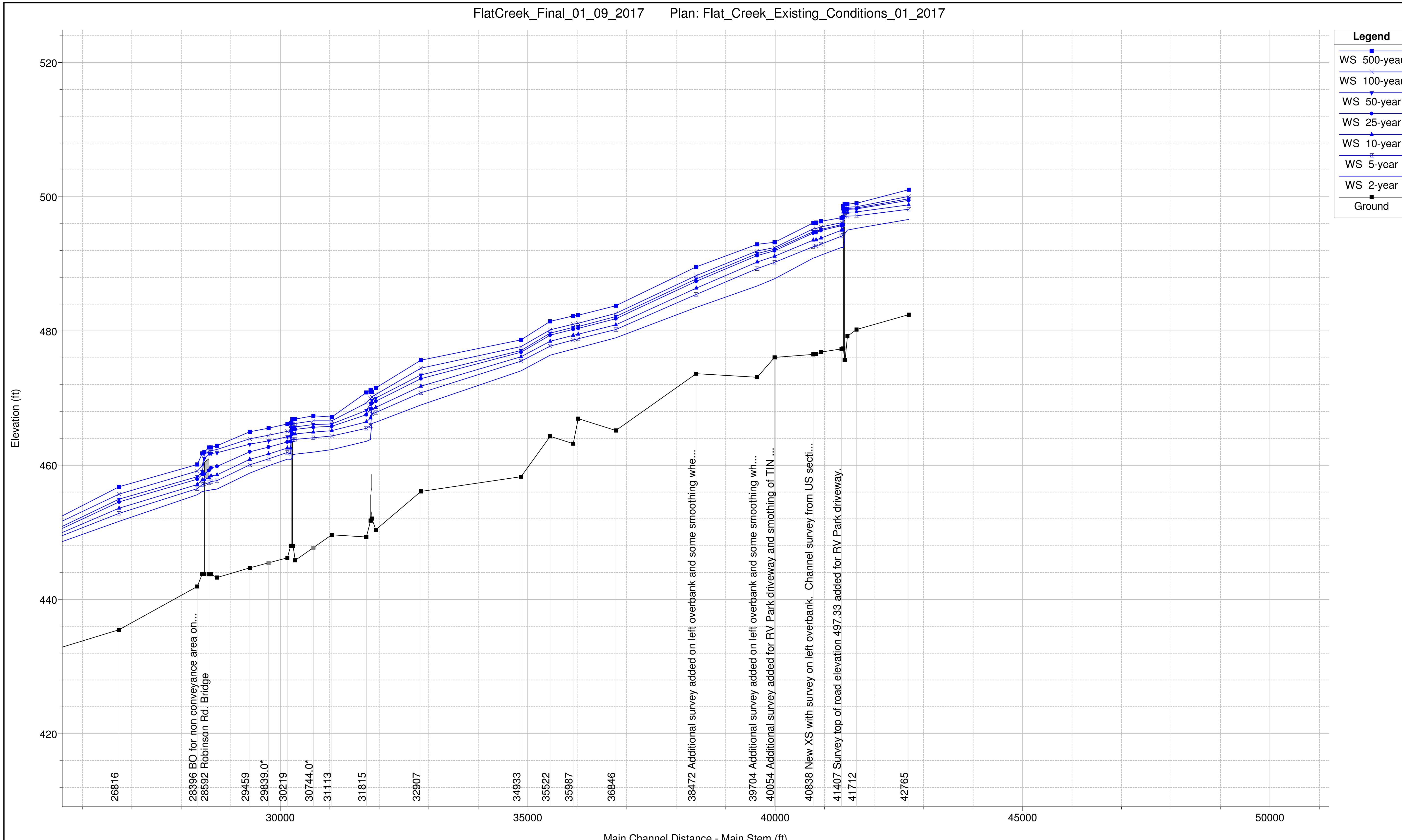
(This Page Intentionally Left Blank)

FLAT CREEK FLOOD PROTECTION PLAN
EXHIBIT C-1: WATER SURFACE PROFILES



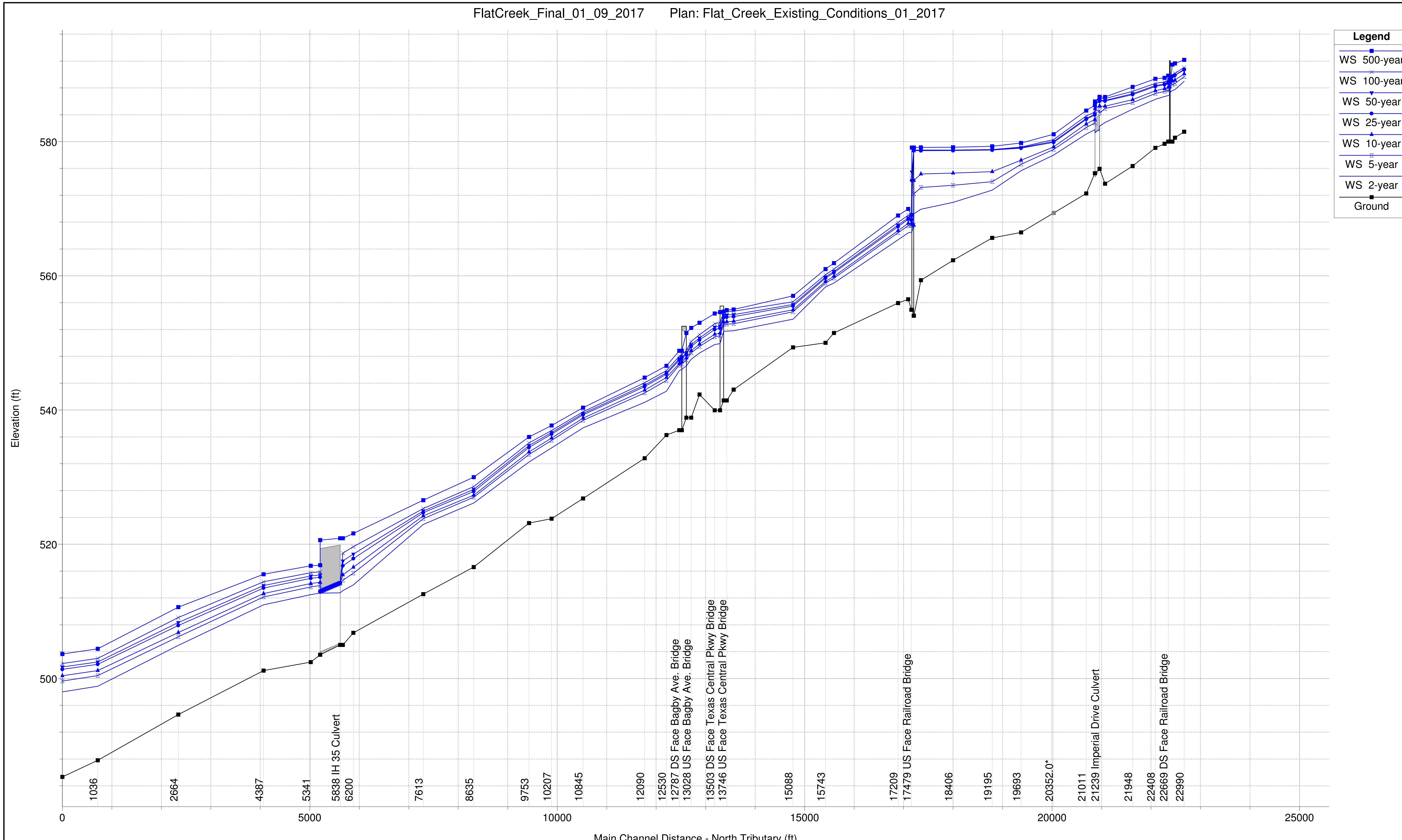
1 in Horiz. = 1900 ft 1 in Vert. = 14 ft

FLAT CREEK FLOOD PROTECTION PLAN
EXHIBIT C-1: WATER SURFACE PROFILES



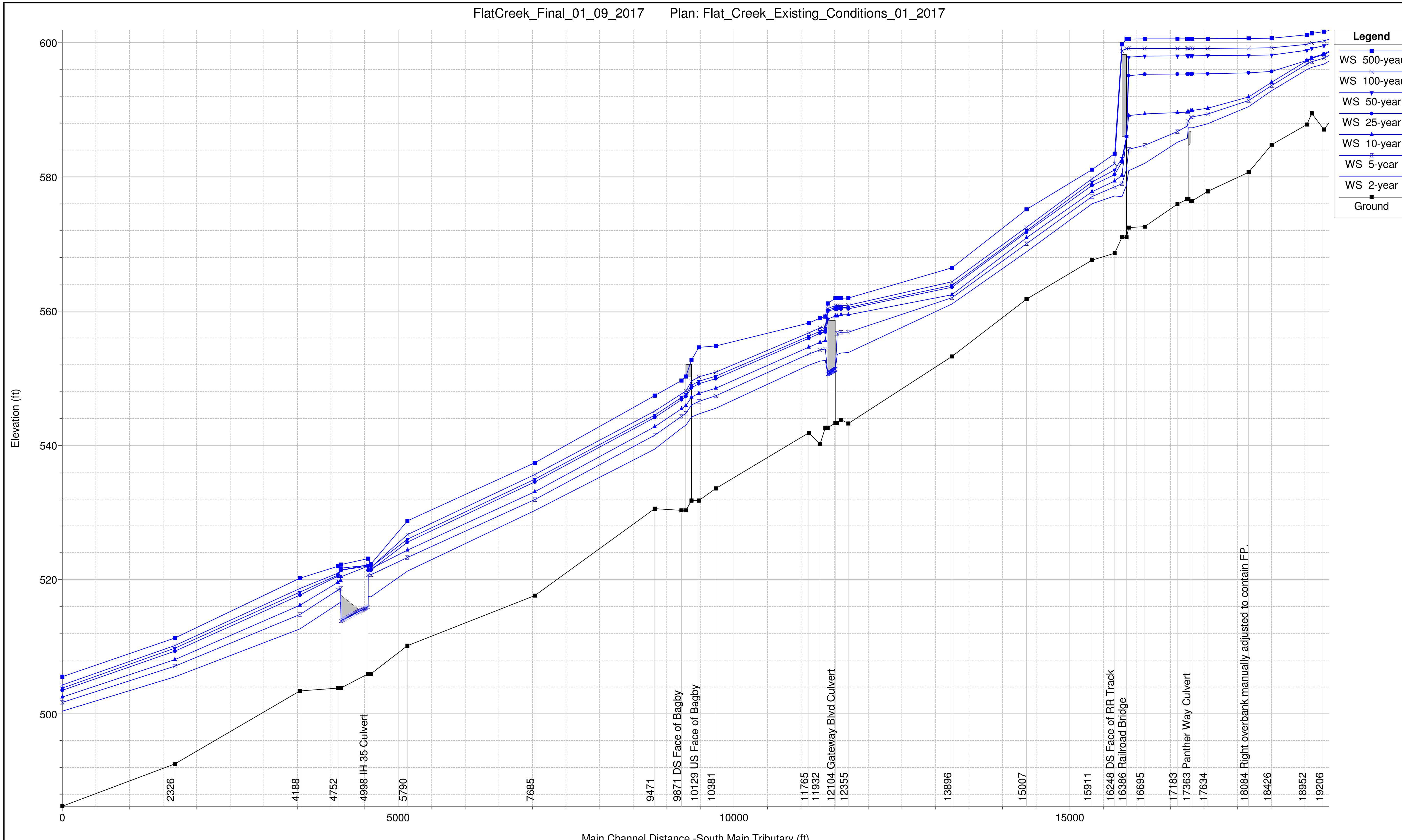
1 in Horiz. = 1900 ft 1 in Vert. = 14 ft

FLAT CREEK FLOOD PROTECTION PLAN
EXHIBIT C-1: WATER SURFACE PROFILES



1 in Horiz. = 1900 ft 1 in Vert. = 14 ft

FLAT CREEK FLOOD PROTECTION PLAN
EXHIBIT C-1: WATER SURFACE PROFILES

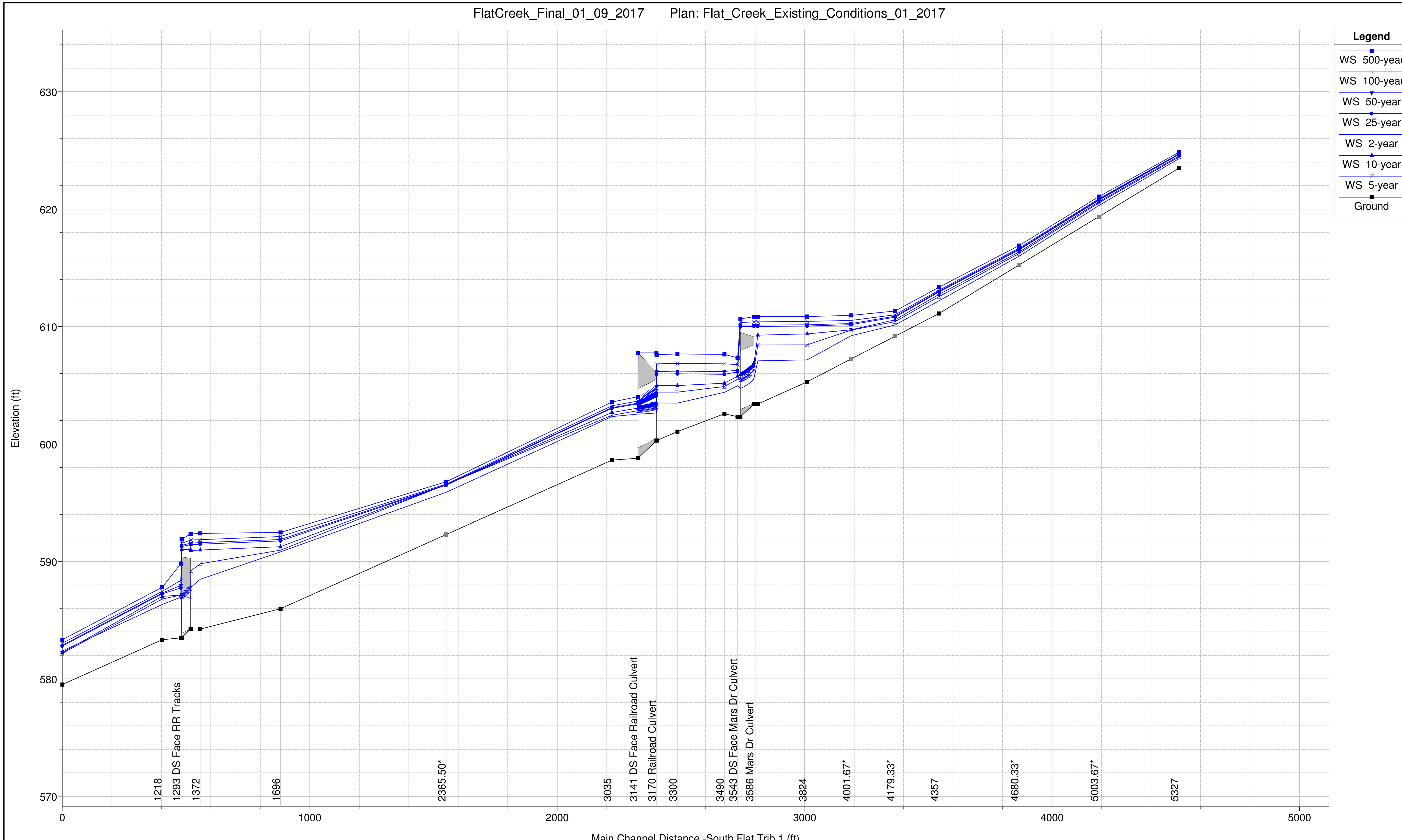


1 in Horiz. = 1400 ft 1 in Vert. = 14 ft

FLAT CREEK FLOOD PROTECTION PLAN
EXHIBIT C-1: WATER SURFACE PROFILES

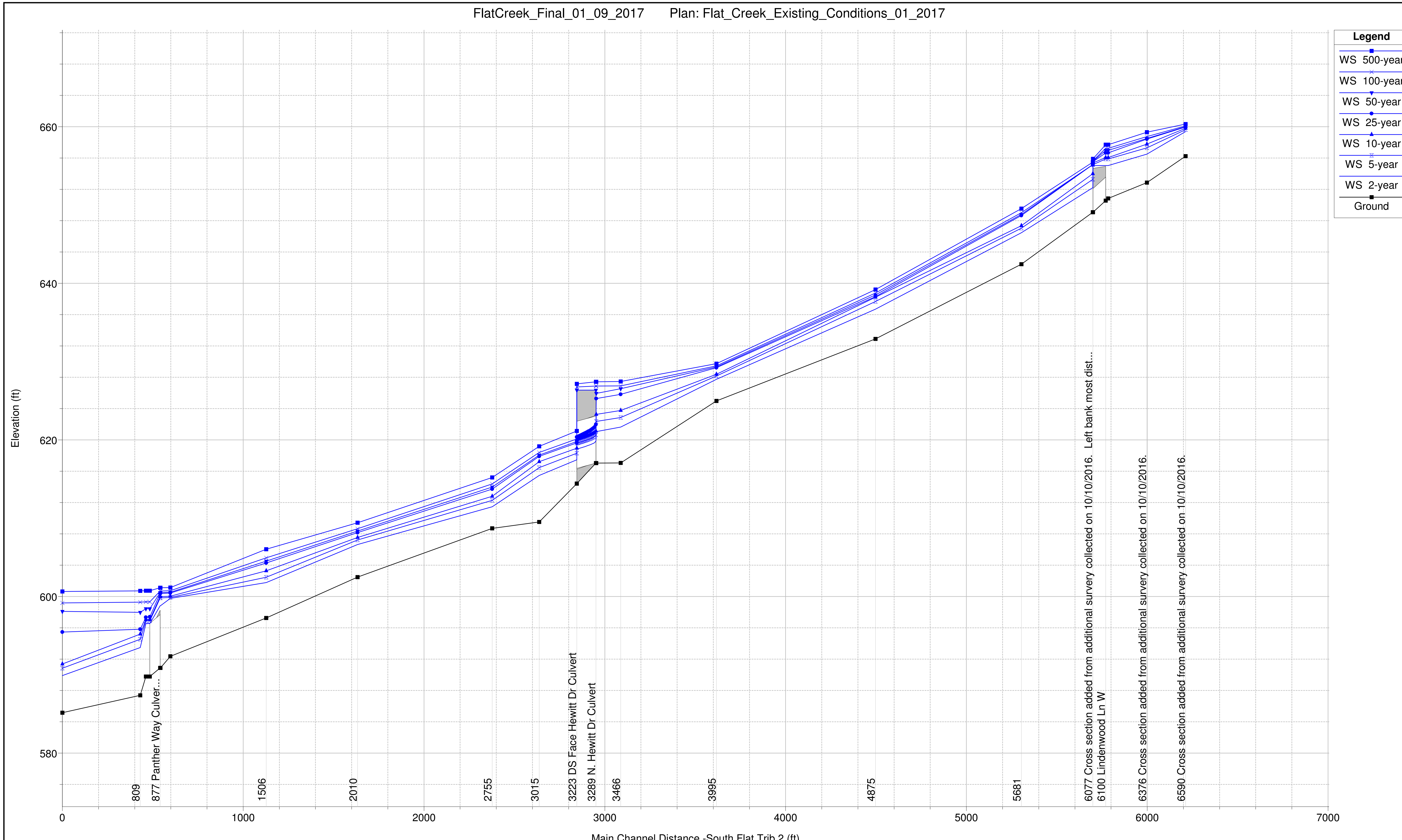
1 in Horiz. = 1400 ft 1 in Vert. = 14 ft

FLAT CREEK FLOOD PROTECTION PLAN
EXHIBIT C-1: WATER SURFACE PROFILES



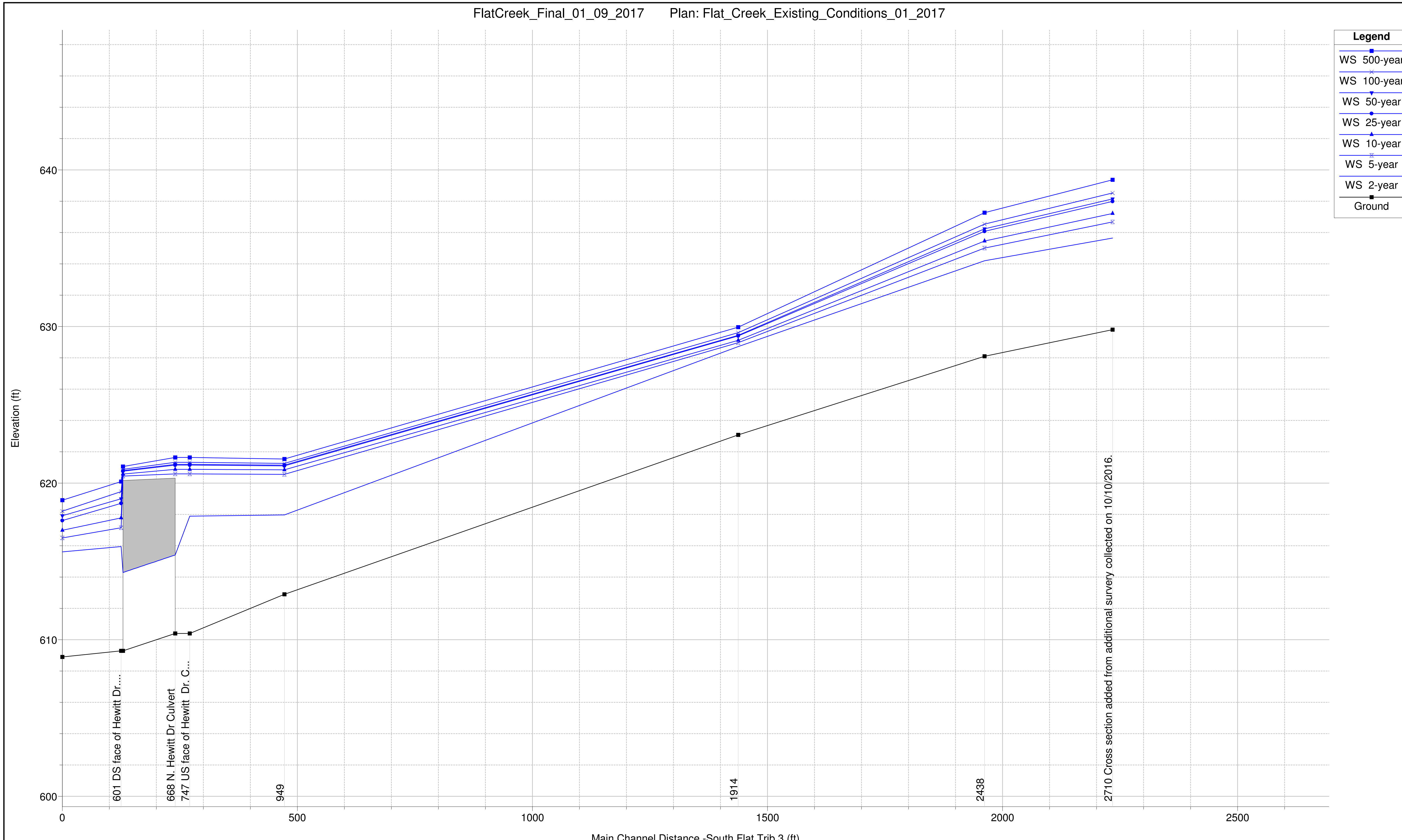
1 in Horiz. = 380 ft 1 in Vert. = 8 ft

FLAT CREEK FLOOD PROTECTION PLAN
EXHIBIT C-1: WATER SURFACE PROFILES

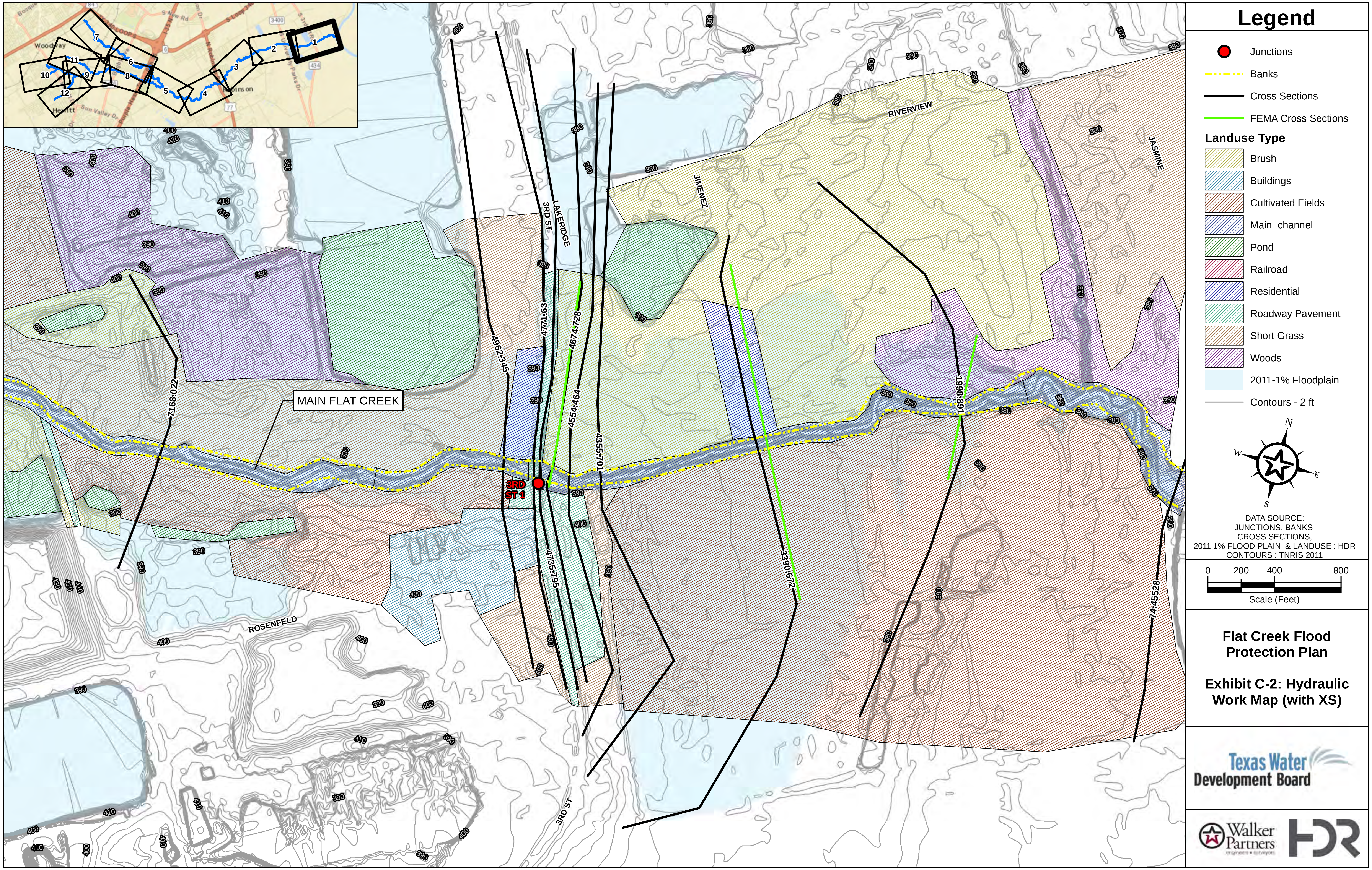


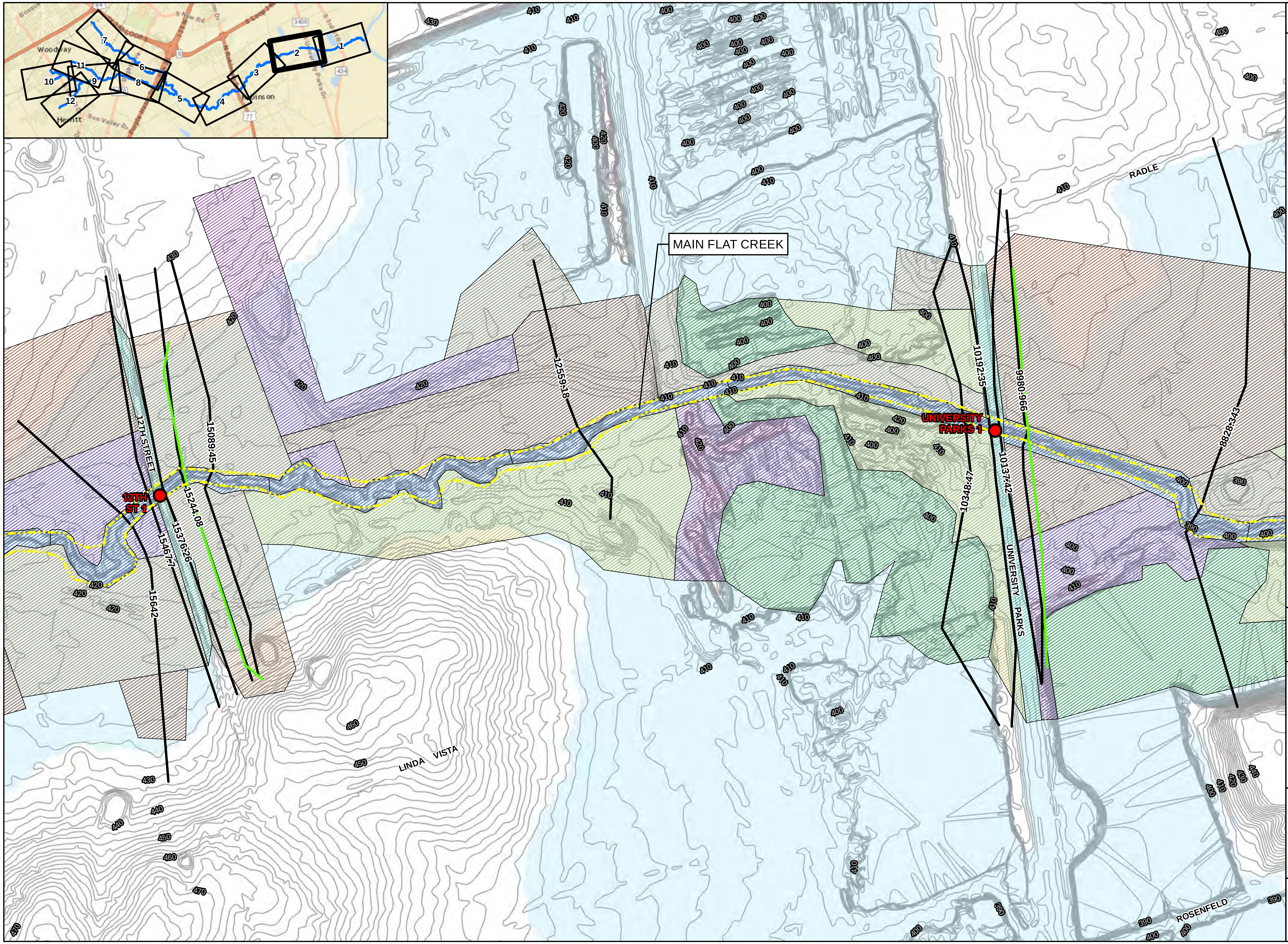
1 in Horiz. = 520 ft 1 in Vert. = 12 ft

FLAT CREEK FLOOD PROTECTION PLAN
EXHIBIT C-1: WATER SURFACE PROFILES



1 in Horiz. = 200 ft 1 in Vert. = 6 ft


Legend
Junctions
Banks
Cross Sections
FEMA Cross Sections
Landuse Type
Brush
Buildings
Cultivated Fields
Main_channel
Pond
Railroad
Residential
Roadway Pavement
Short Grass
Woods
2011-1% Floodplain
Contours - 2 ft
N
W
E
S
DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011
0 200 400 800
Scale (Feet)
Flat Creek Flood Protection Plan
Exhibit C-2: Hydraulic Work Map (with XS)
MAIN FLAT CREEK
3RD ST 1
RIVERVIEW
JIMENEZ
JASMINE
LAKERIDGE
3RD ST
ROSENFELD
7168.022
4962.345
4774.63
4674.728
4554.464
4355.701
4735.795
3390.672
1998.891
74.45528



Legend

Junctions
Banks
Cross Sections
FEMA Cross Sections

Landuse Type

Brush
Buildings
Cultivated Fields
Main_channel
Pond
Railroad
Residential
Roadway Pavement
Short Grass
Woods
2011-1% Floodplain
Contours - 2 ft

N
W E
S

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800
Scale (Feet)

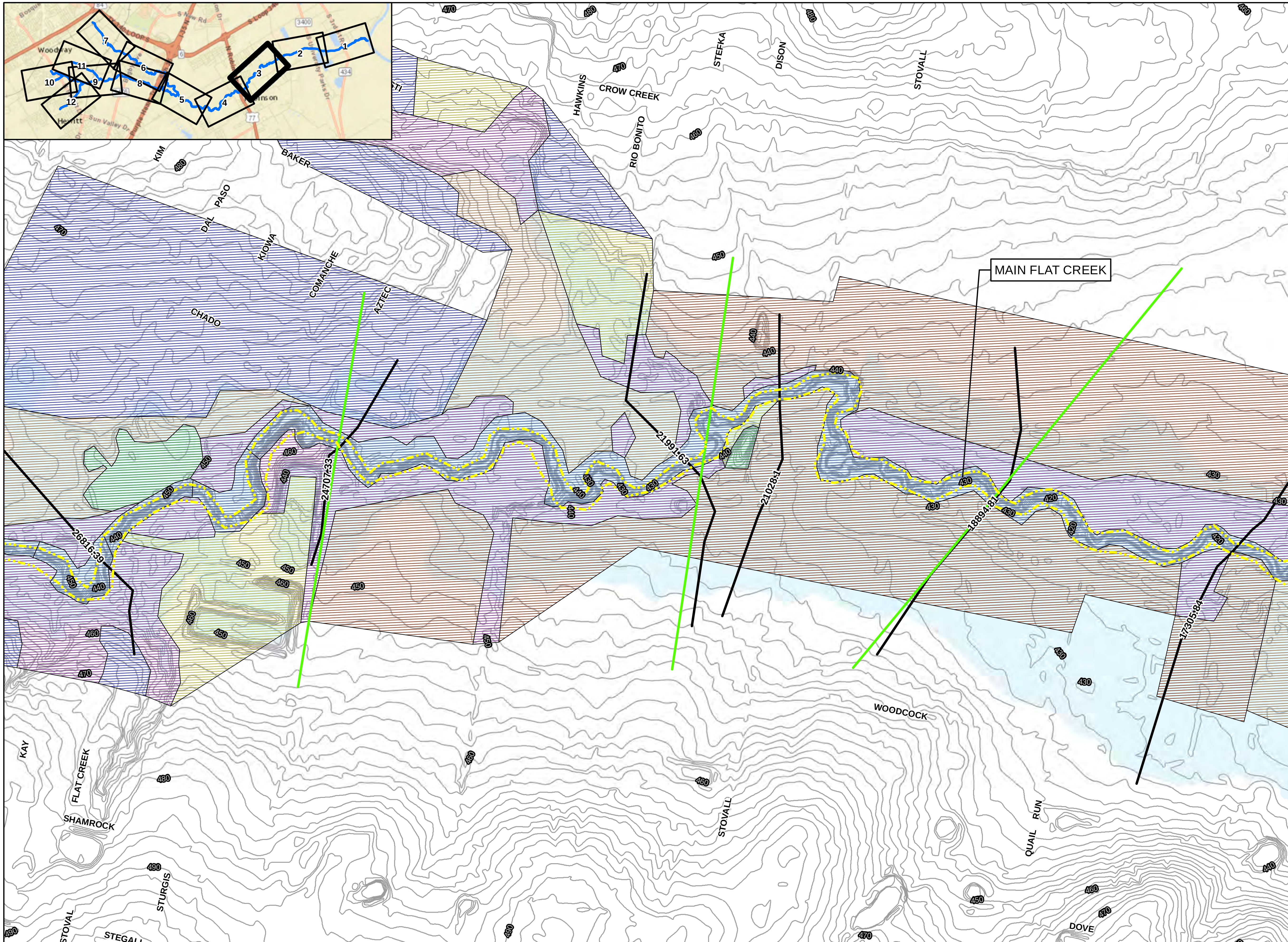
Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners

HDR



Legend

- Junctions
- Banks
- Cross Sections
- FEMA Cross Sections

Landuse Type

- Brush
- Buildings
- Cultivated Fields
- Main_channel
- Pond
- Railroad
- Residential
- Roadway Pavement
- Short Grass
- Woods
- 2011-1% Floodplain
- Contours - 2 ft

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800
Scale (Feet)

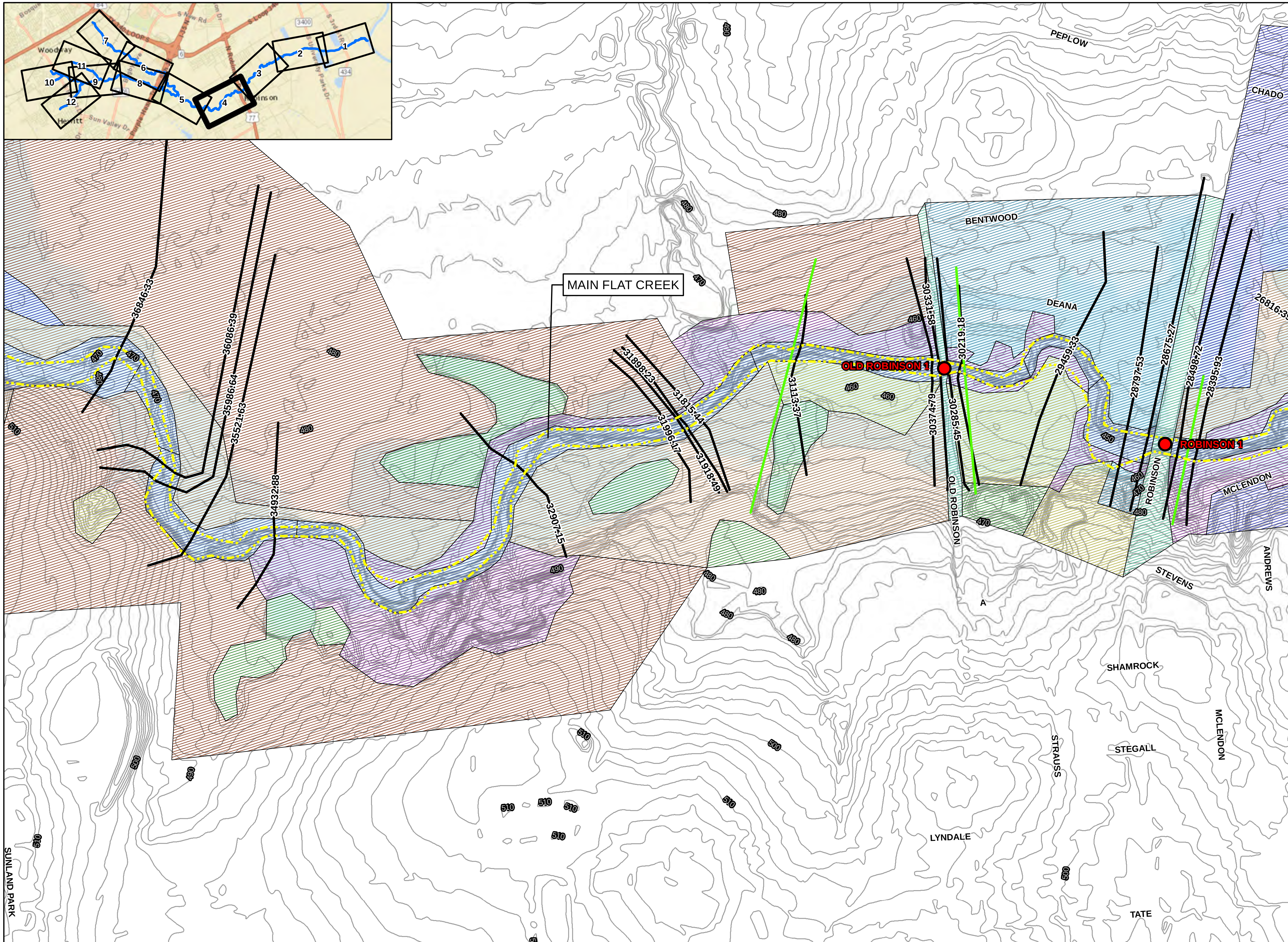
Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- Junctions
- Banks
- Cross Sections
- FEMA Cross Sections

Landuse Type

- Brush
- Buildings
- Cultivated Fields
- Main_channel
- Pond
- Railroad
- Residential
- Roadway Pavement
- Short Grass
- Woods
- 2011-1% Floodplain
- Contours - 2 ft

N W E S

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800
Scale (Feet)

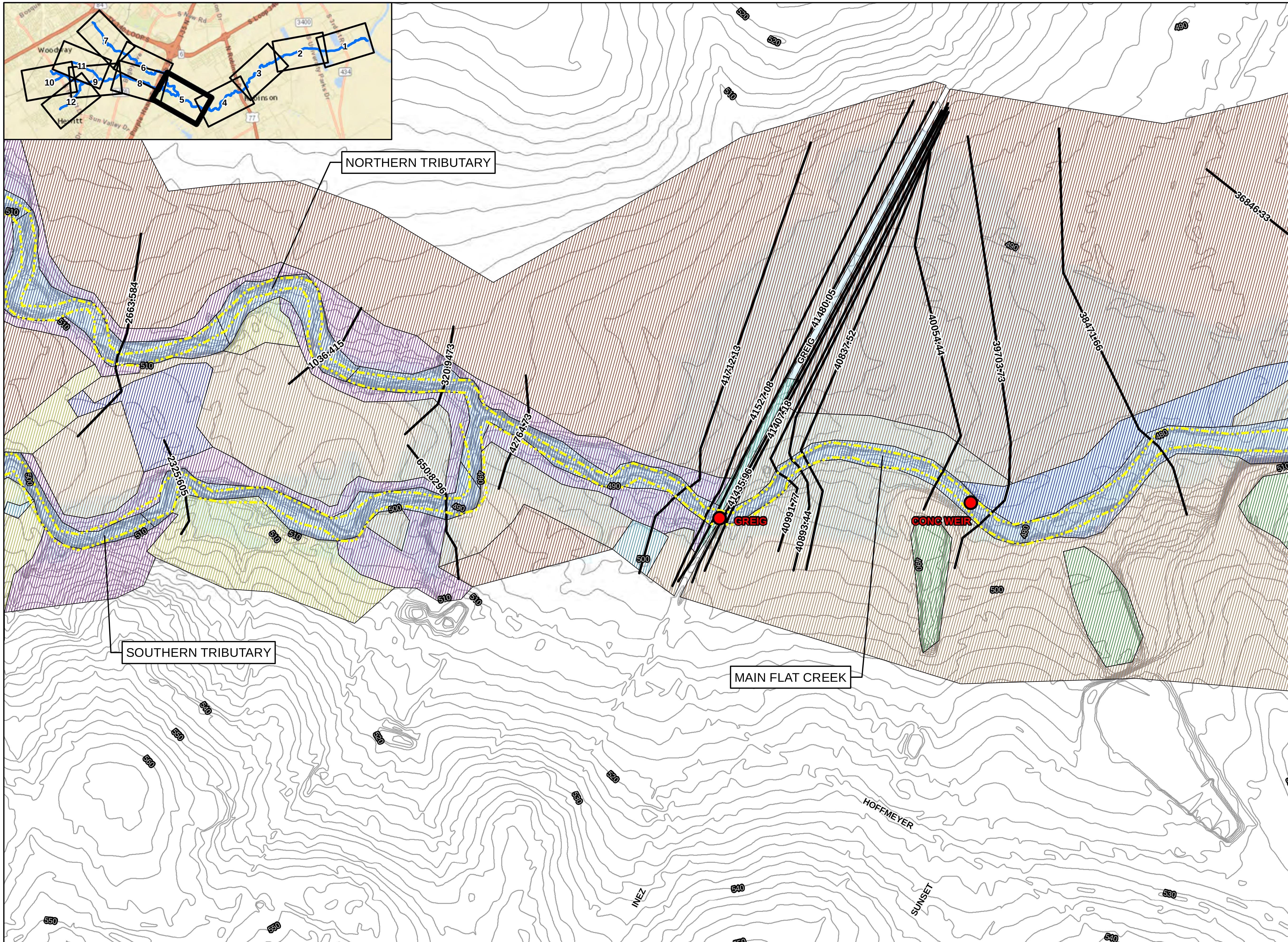
Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- Junctions
- Banks
- Cross sections

Landuse Type

- Brush
- Buildings
- Cultivated_fields
- Main_channel
- Pond
- Railroad
- Residential
- Roadway_pavement
- Short_grass
- Woods
- 2011-1% Floodplain
- Contours - 2 ft

N E S W

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800

Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

Legend

- Junctions
- Banks
- Cross sections

Landuse Type

- Brush
- Buildings
- Cultivated_fields
- Main_channel
- Pond
- Railroad
- Residential
- Roadway_pavement
- Short_grass
- Woods
- 2011-1% Floodplain
- Contours - 2 ft

N E S W

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800
Scale (Feet)

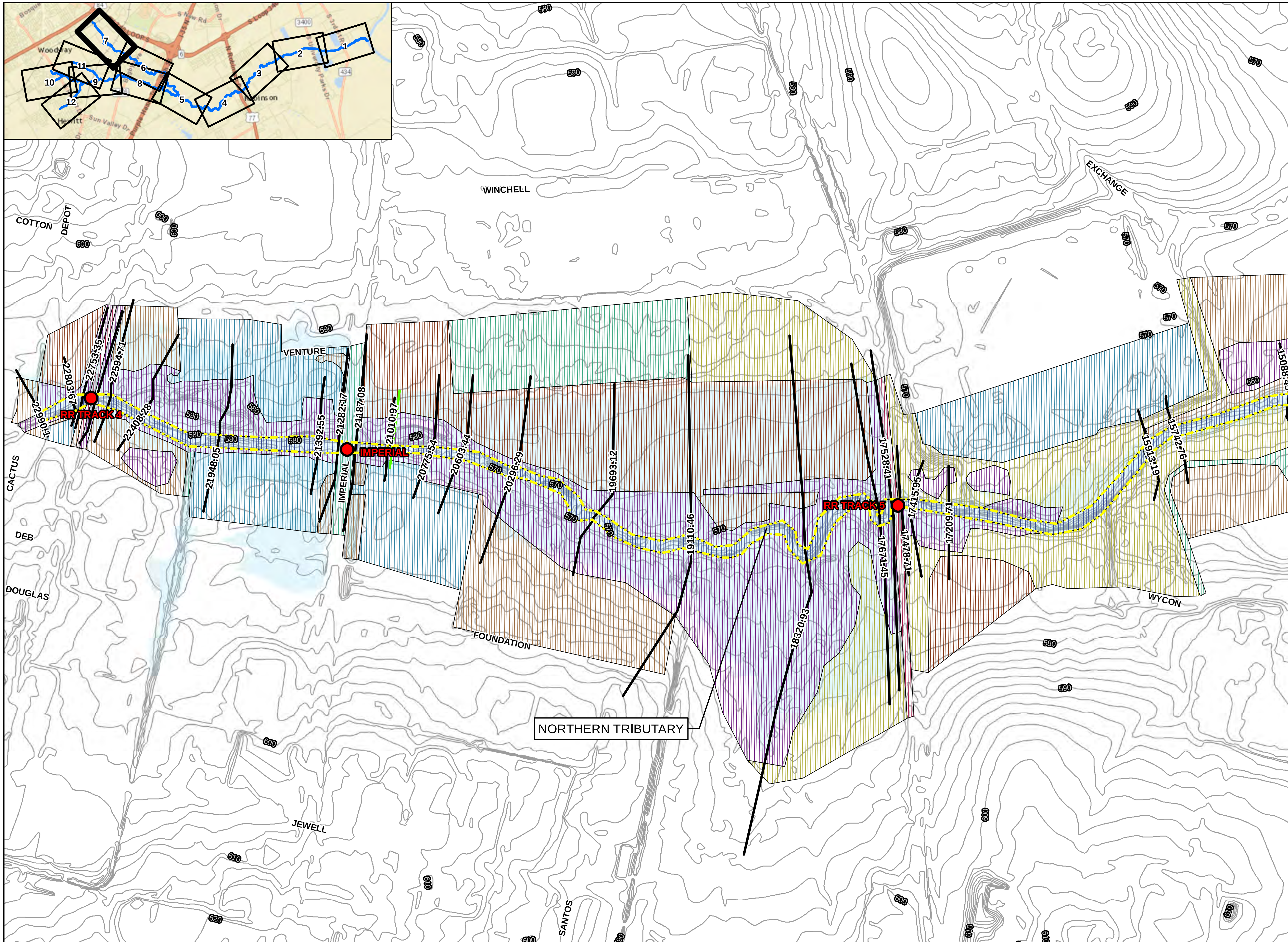
Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- Junctions
- Banks
- Cross Sections
- FEMA Cross Sections

Landuse Type

- Brush
- Buildings
- Cultivated Fields
- Main_channel
- Pond
- Railroad
- Residential
- Roadway Pavement
- Short Grass
- Woods
- 2011-1% Floodplain
- Contours - 2 ft

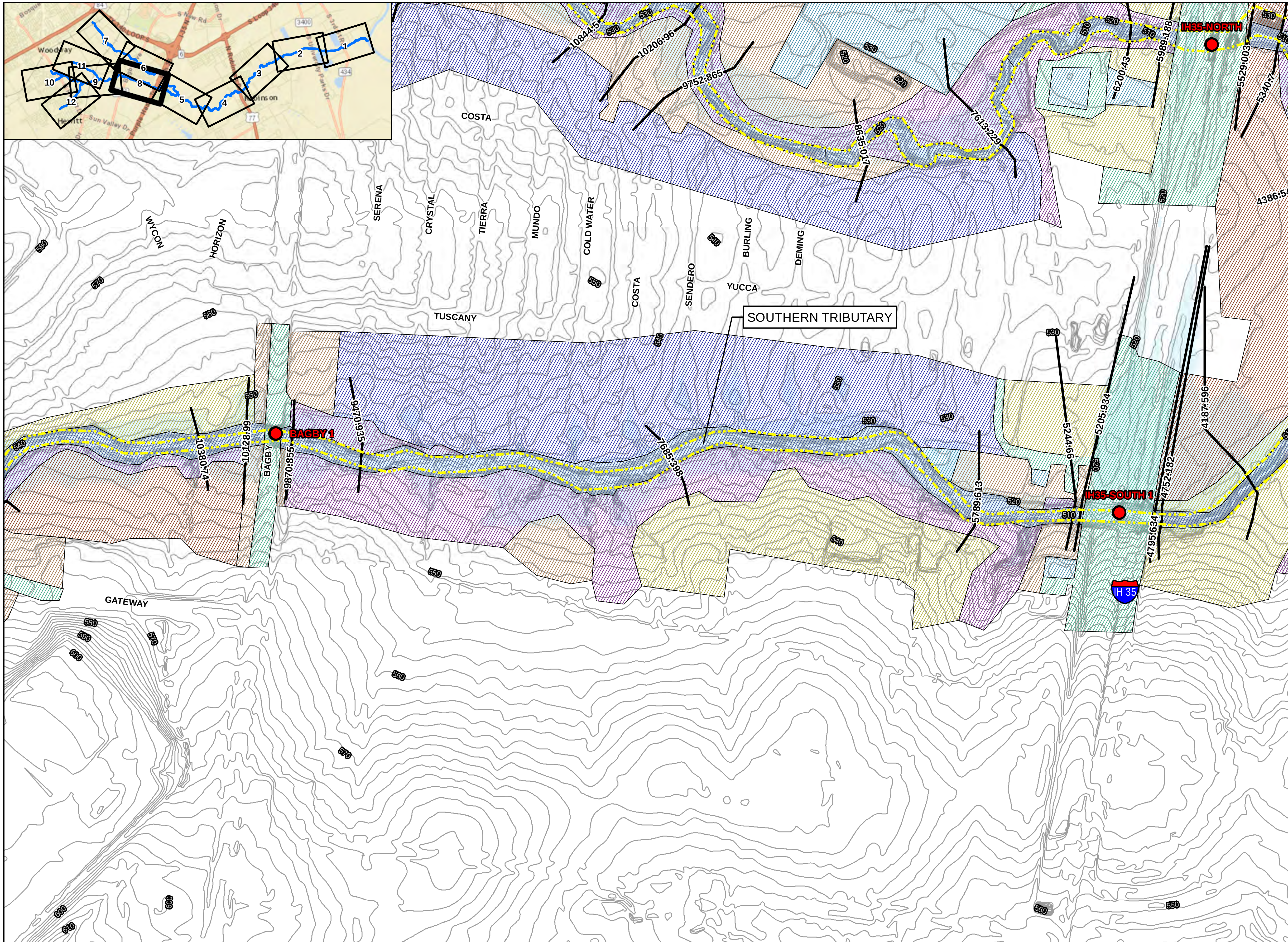
N E S W

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800
Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)



Legend

- Junctions
- Banks
- Cross sections

Landuse Type

- Brush
- Buildings
- Cultivated_fields
- Main_channel
- Pond
- Railroad
- Residential
- Roadway_pavement
- Short_grass
- Woods
- 2011-1% Floodplain
- Contours - 2 ft

N E S W

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800
Scale (Feet)

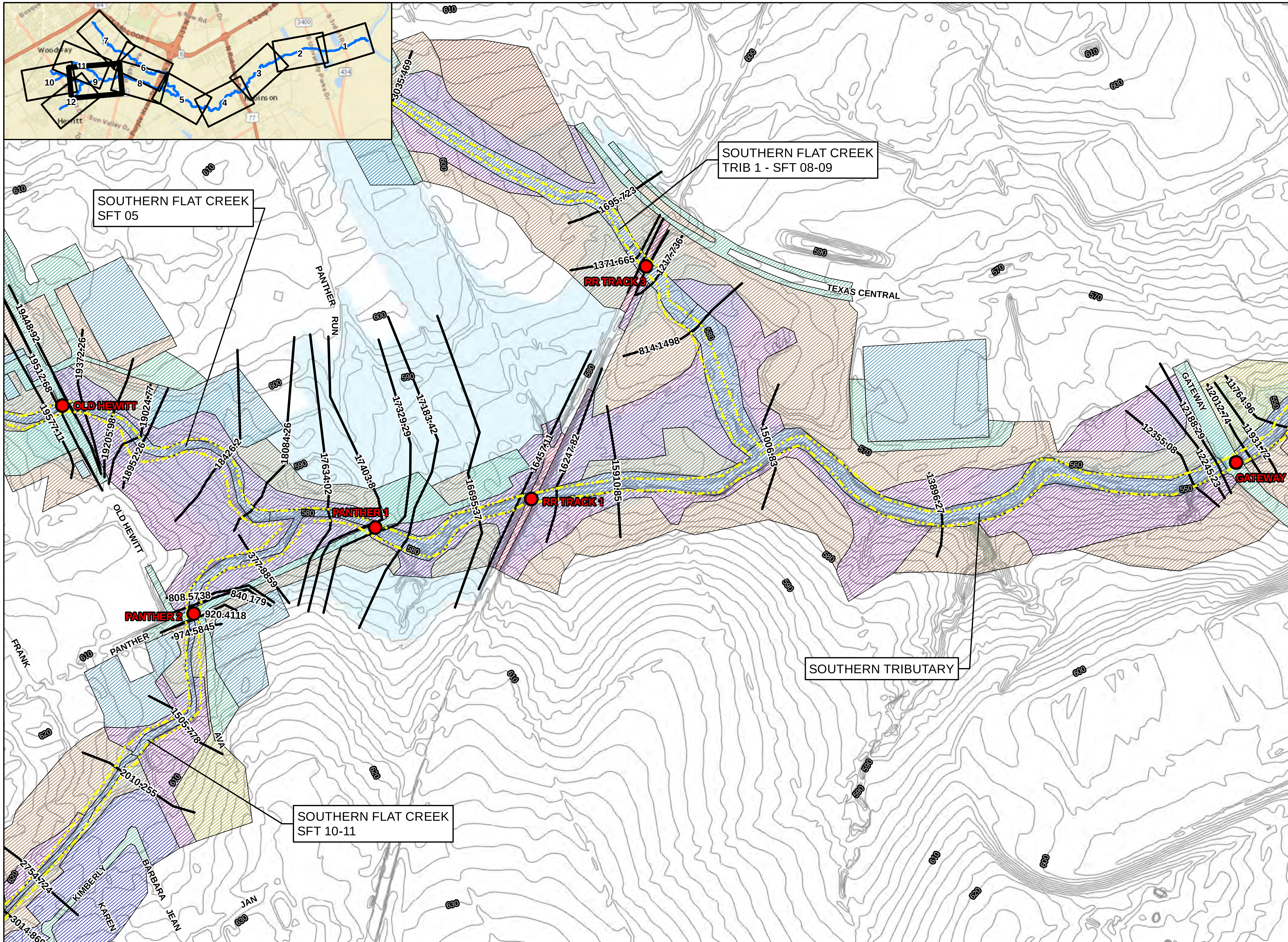
Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- Junctions
- Banks
- Cross sections

Landuse Type

- Brush
- Buildings
- Cultivated_fields
- Main_channel
- Pond
- Railroad
- Residential
- Roadway_pavement
- Short_grass
- Woods
- 2011-1% Floodplain
- Contours - 2 ft

N E S W

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800
Scale (Feet)

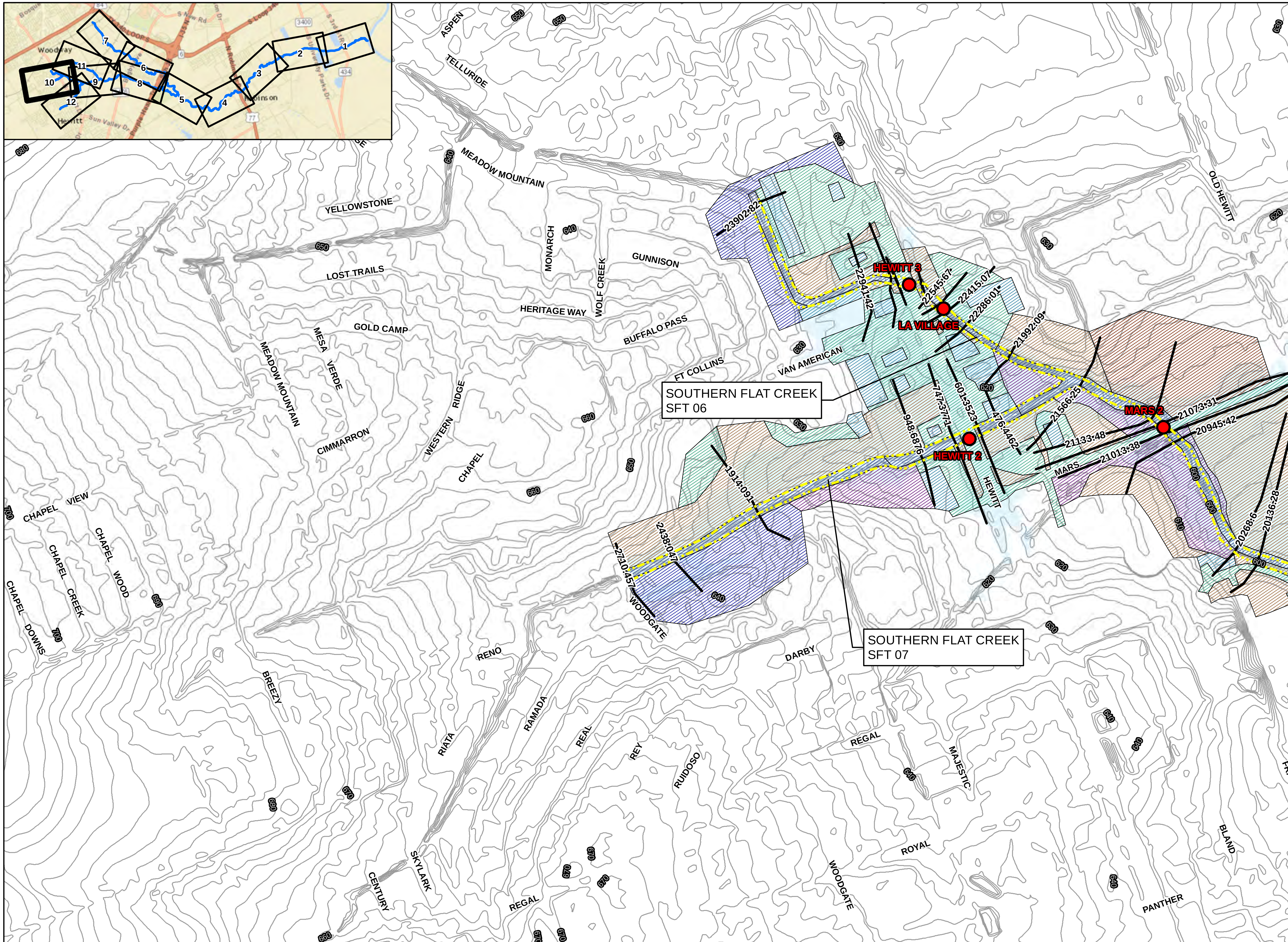
Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- Junctions
- Banks
- Cross sections

Landuse Type

- Brush
- Buildings
- Cultivated_fields
- Main_channel
- Pond
- Railroad
- Residential
- Roadway_pavement
- Short_grass
- Woods
- 2011-1% Floodplain
- Contours - 2 ft

N W E S

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800
Scale (Feet)

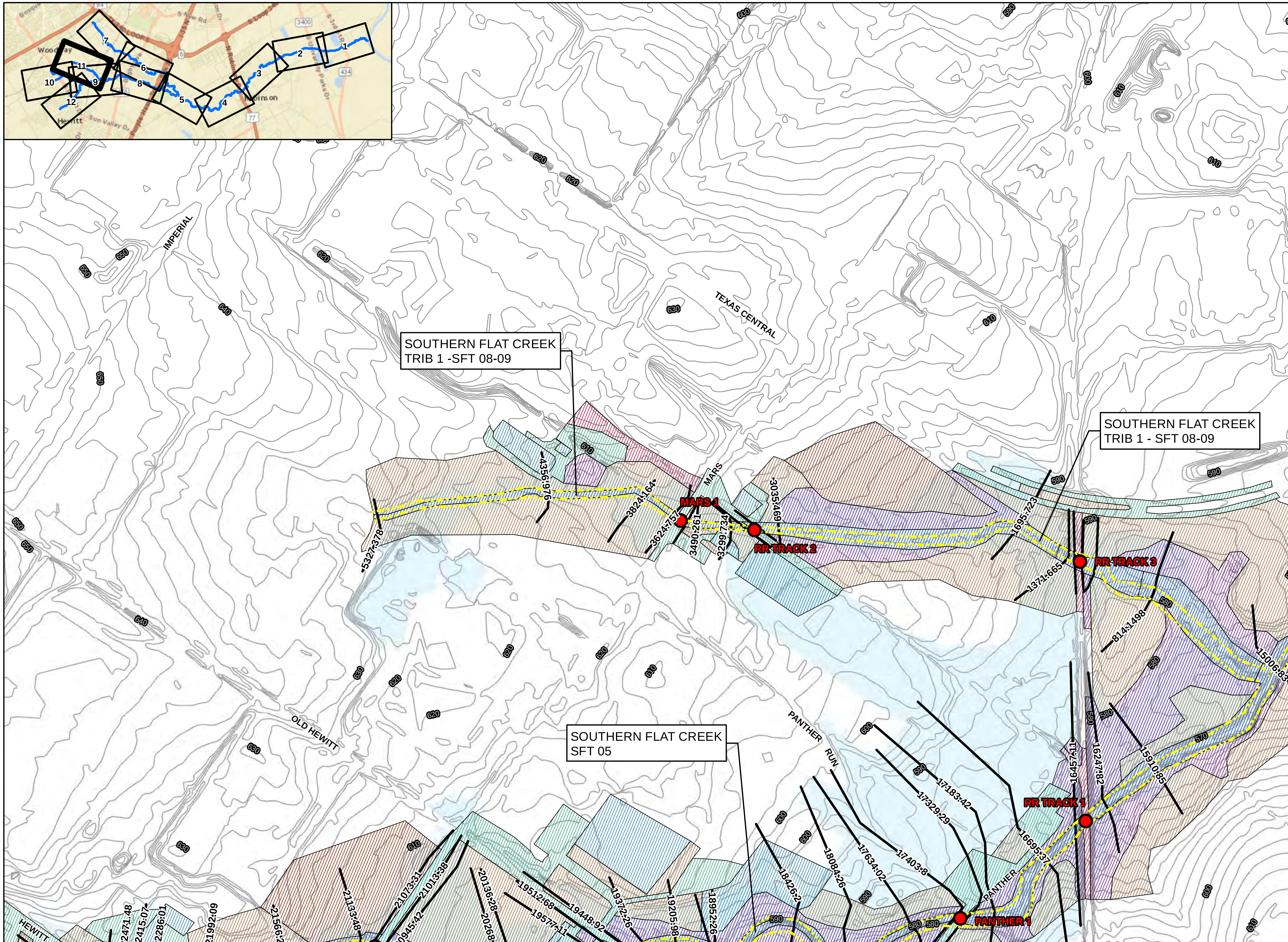
Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- Junctions
- Banks
- Cross sections

Landuse Type

- Brush
- Buildings
- Cultivated_fields
- Main_channel
- Pond
- Railroad
- Residential
- Roadway_pavement
- Short_grass
- Woods
- 2011-1% Floodplain
- Contours - 2 ft

DATA SOURCE:
JUNCTIONS, BANKS
CROSS SECTIONS,
2011 1% FLOOD PLAIN & LANDUSE : HDR
CONTOURS : TNRIS 2011

0 200 400 800
Scale (Feet)

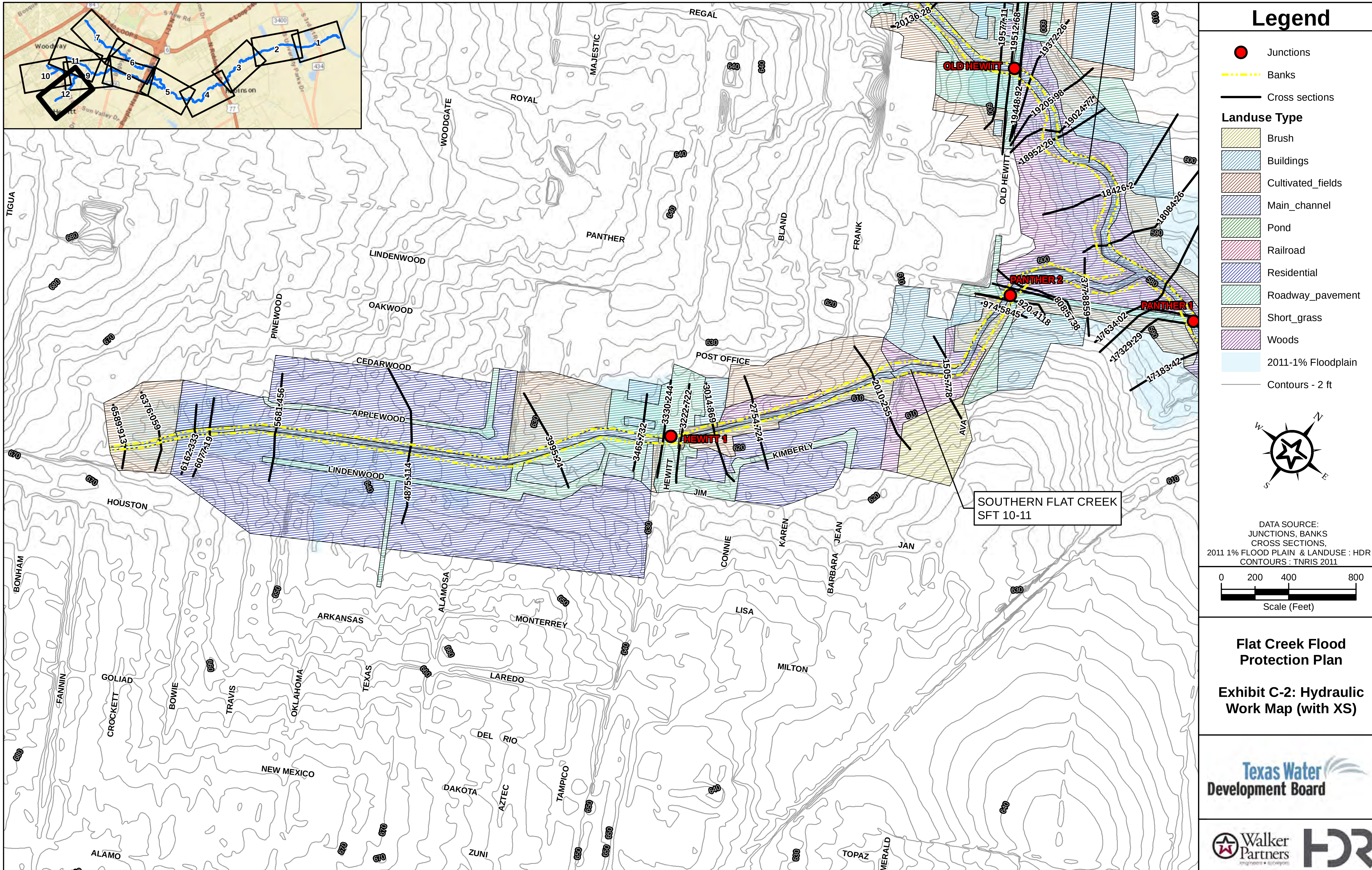
Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



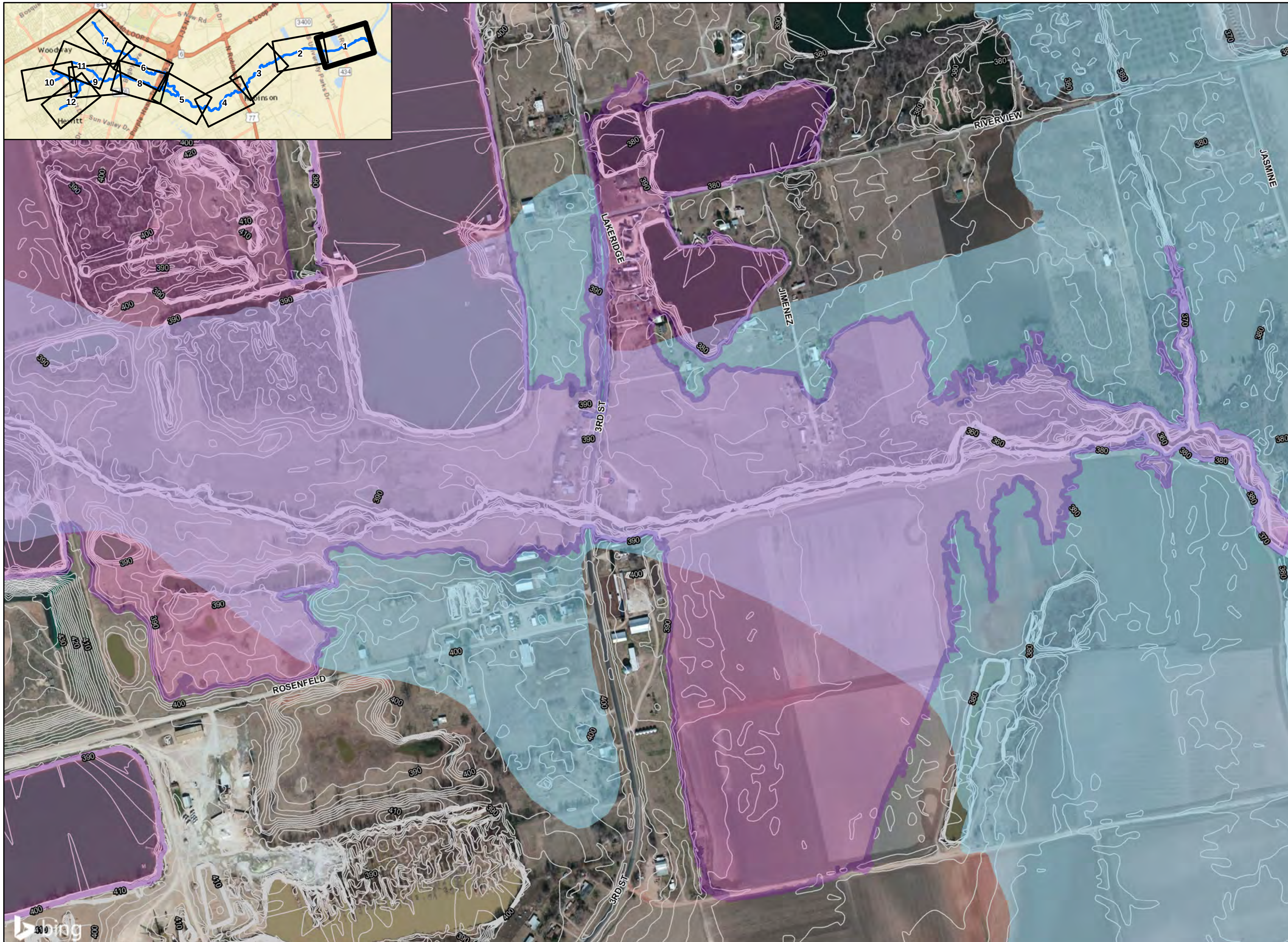
Flat Creek Flood Protection Plan

Exhibit C-2: Hydraulic Work Map (with XS)

Texas Water Development Board

Walker Partners

HDR



Legend

- 2011-1% Floodplain
- FEMA Floodplain
- 2FT INTERVAL CONTOUR

N
W
E
S

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

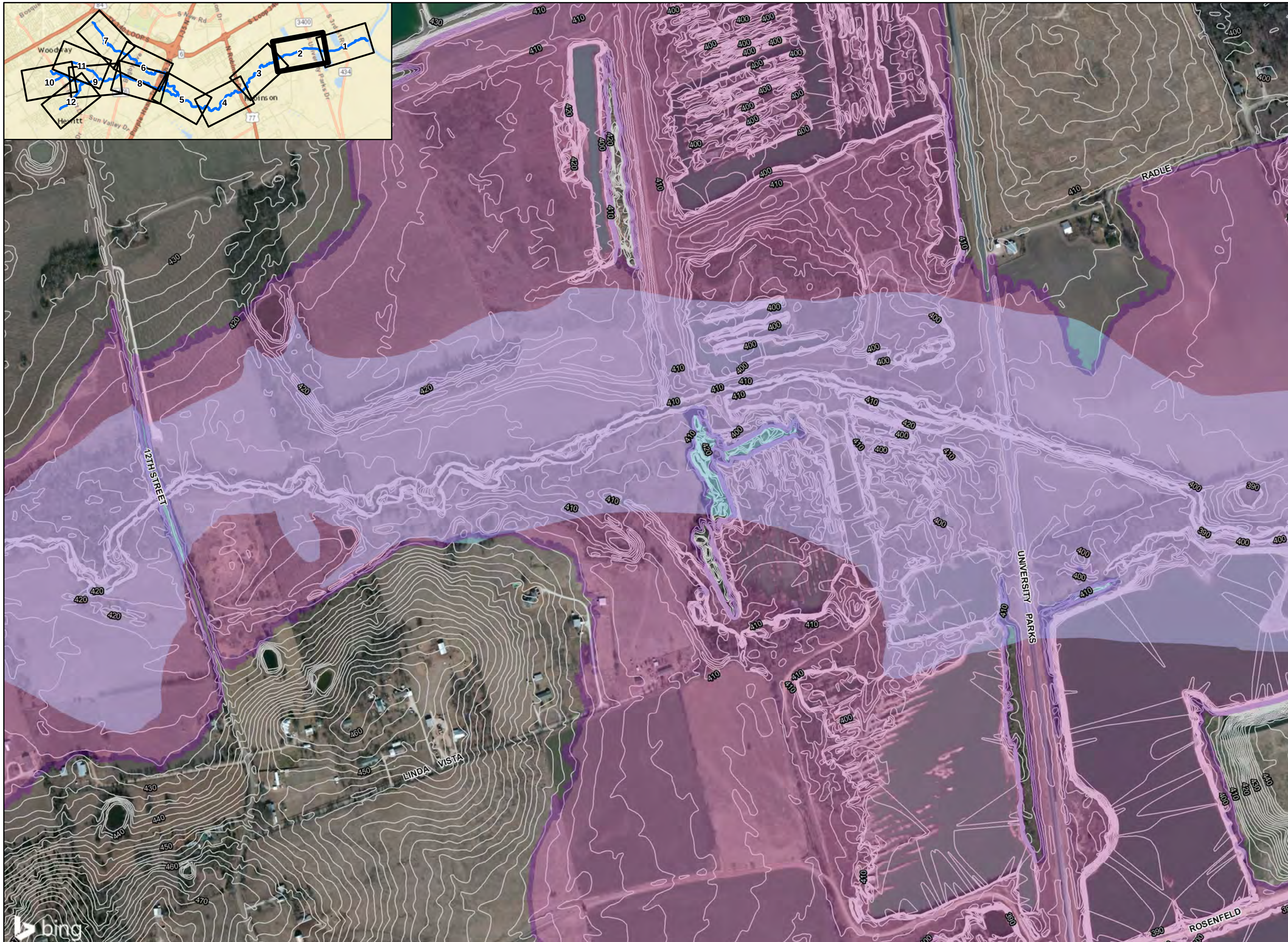
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners

HDR



Legend

2011-1% Floodplain

FEMA Floodplain

2FT INTERVAL CONTOUR

N
W
E
S

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

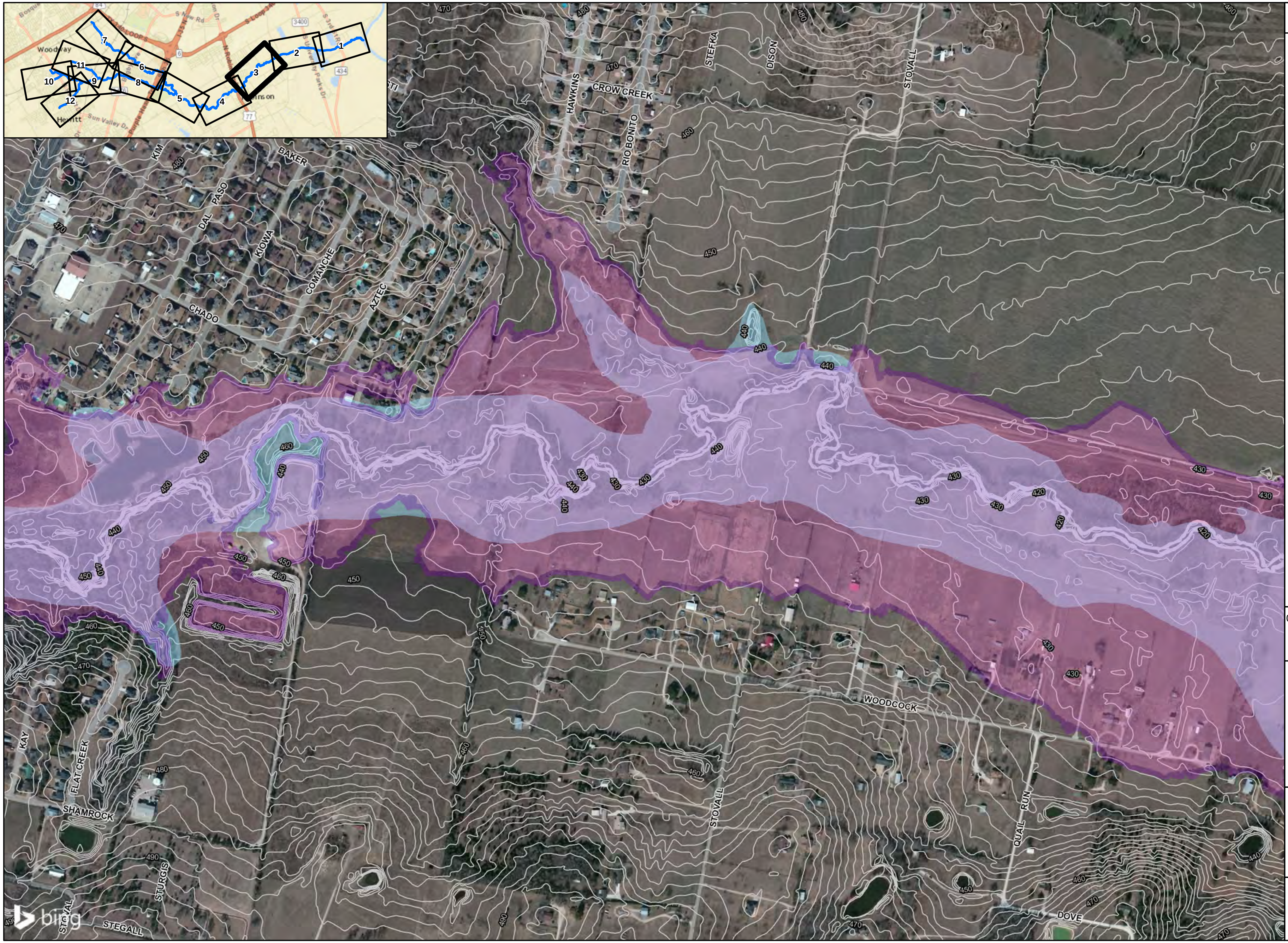
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- 2011-1% Floodplain
- FEMA Floodplain
- 2FT INTERVAL CONTOUR

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

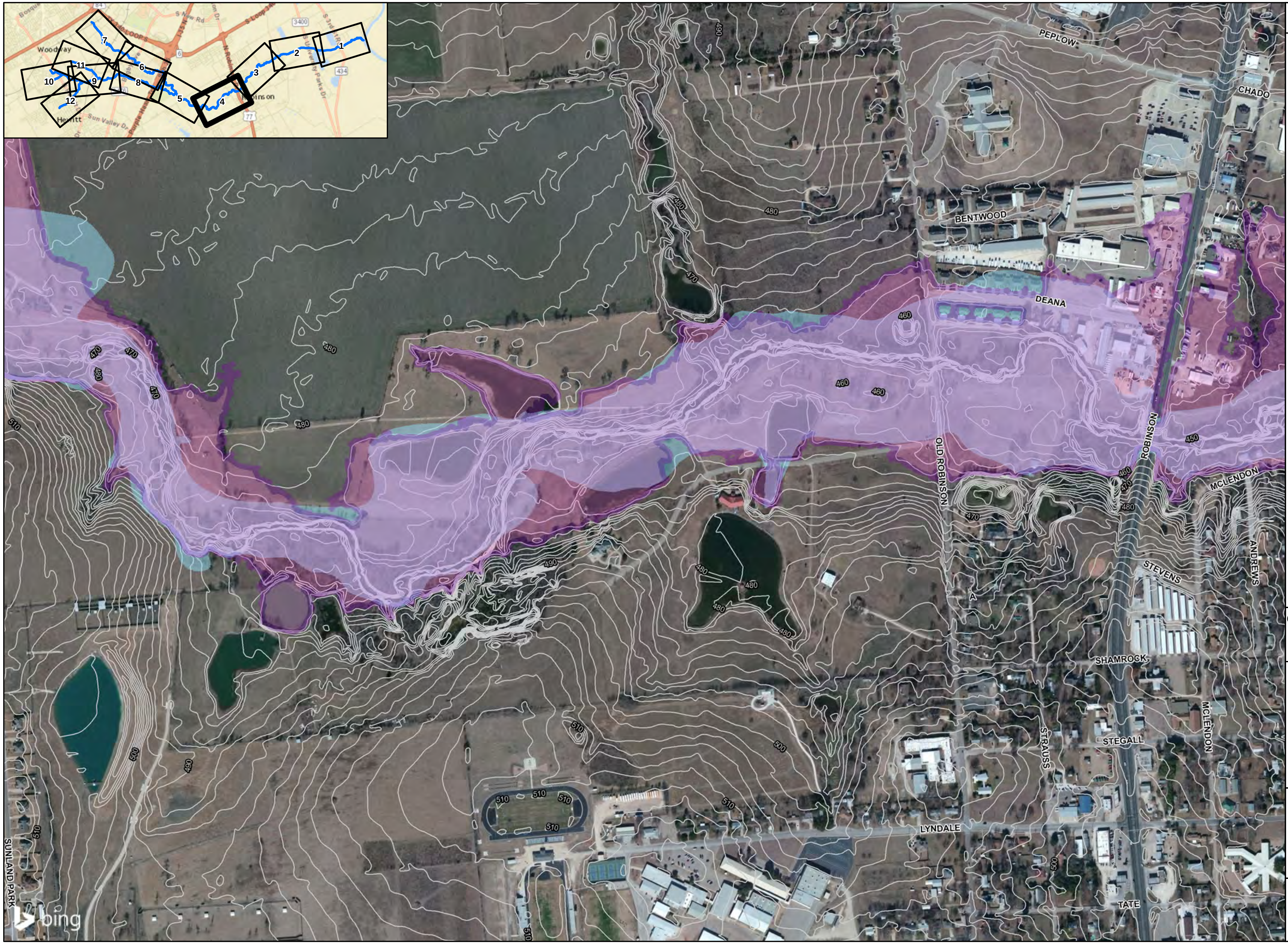
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners

HDR



Legend

- 2011-1% Floodplain
- FEMA Floodplain
- 2FT INTERVAL CONTOUR

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

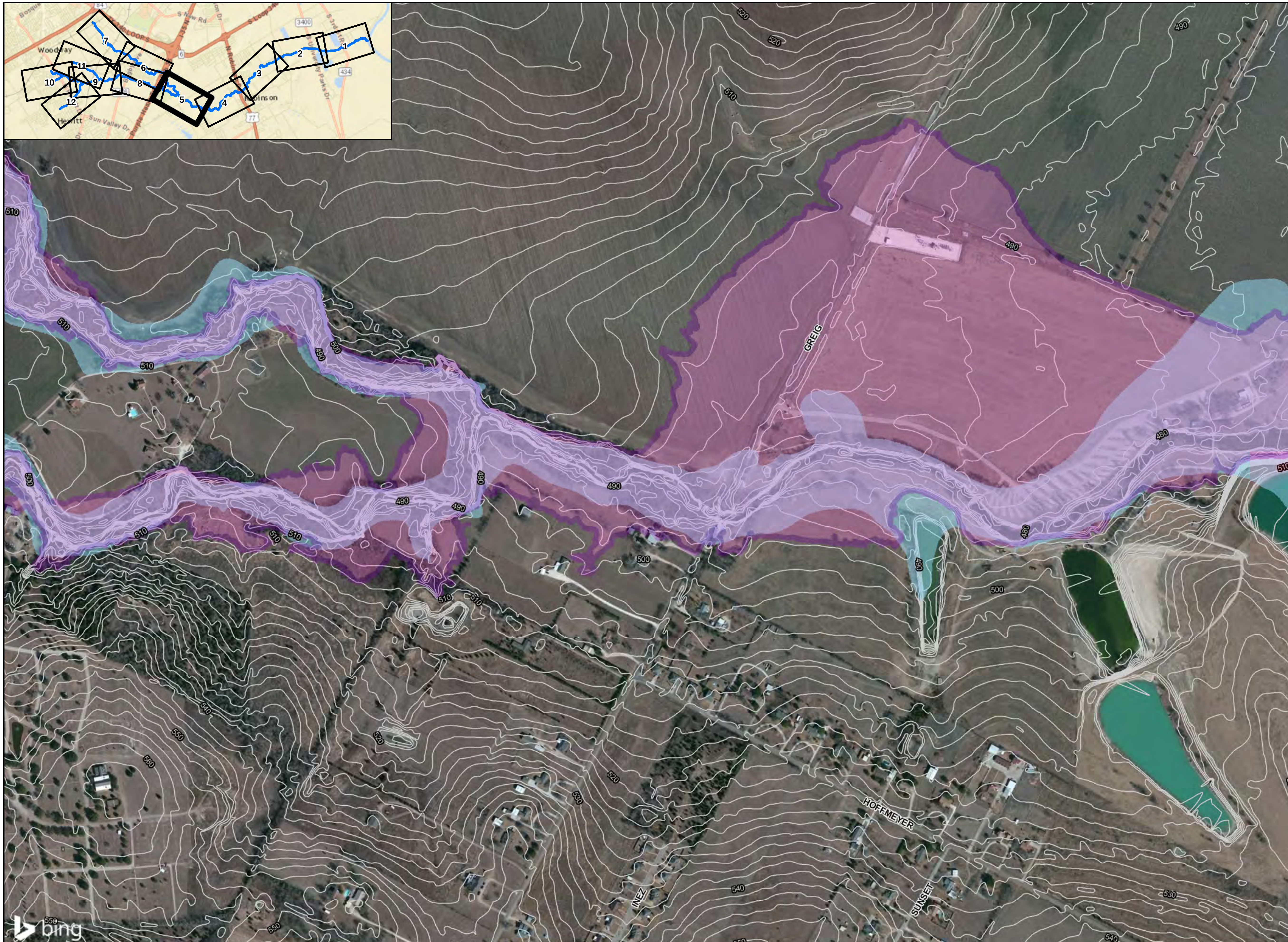
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners

HDR



Legend

2011-1% Floodplain

FEMA Floodplain

2FT INTERVAL CONTOUR

N E S W

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000

Scale (Feet)

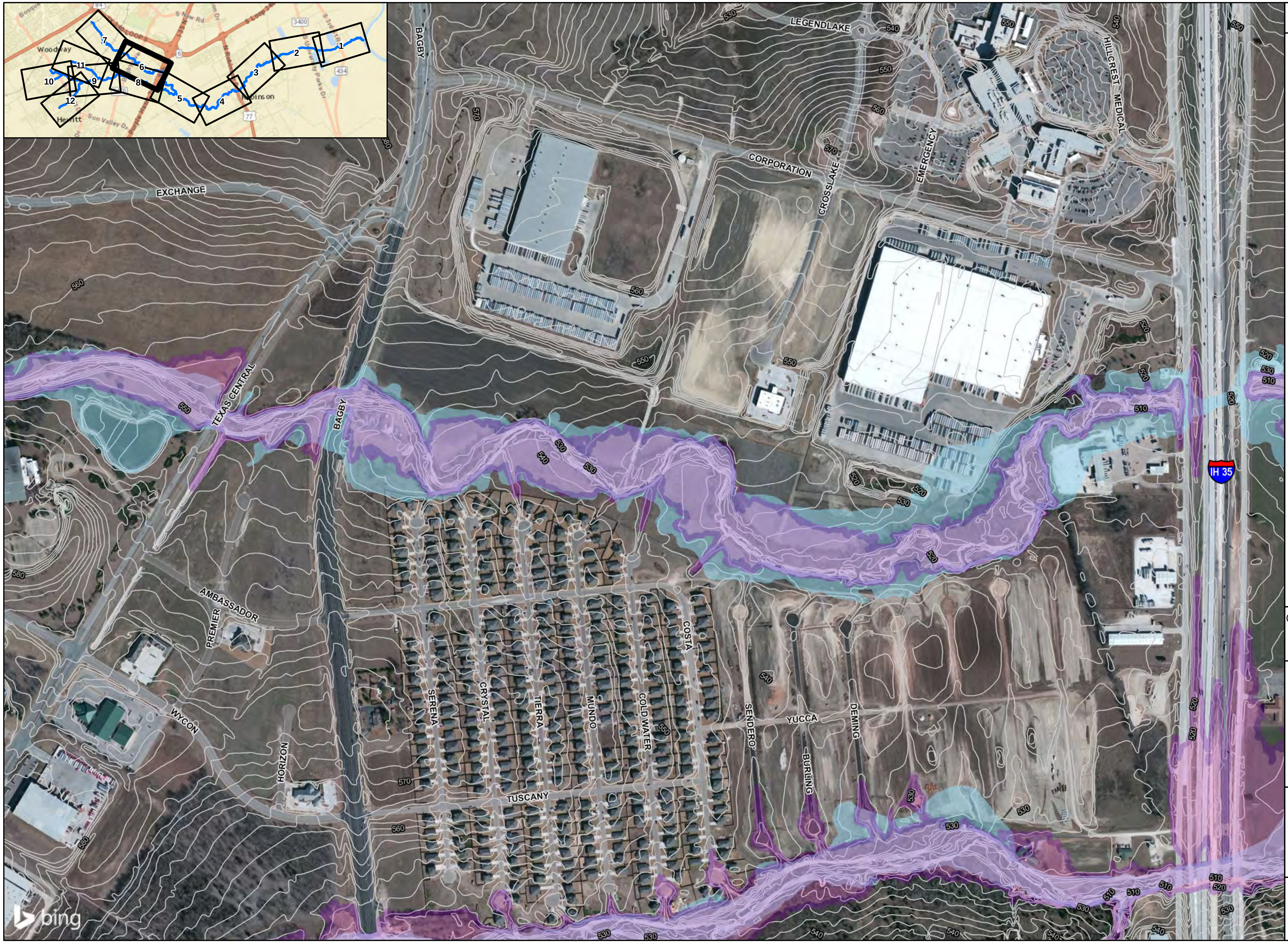
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- 2011-1% Floodplain
- FEMA Floodplain
- 2FT INTERVAL CONTOUR

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

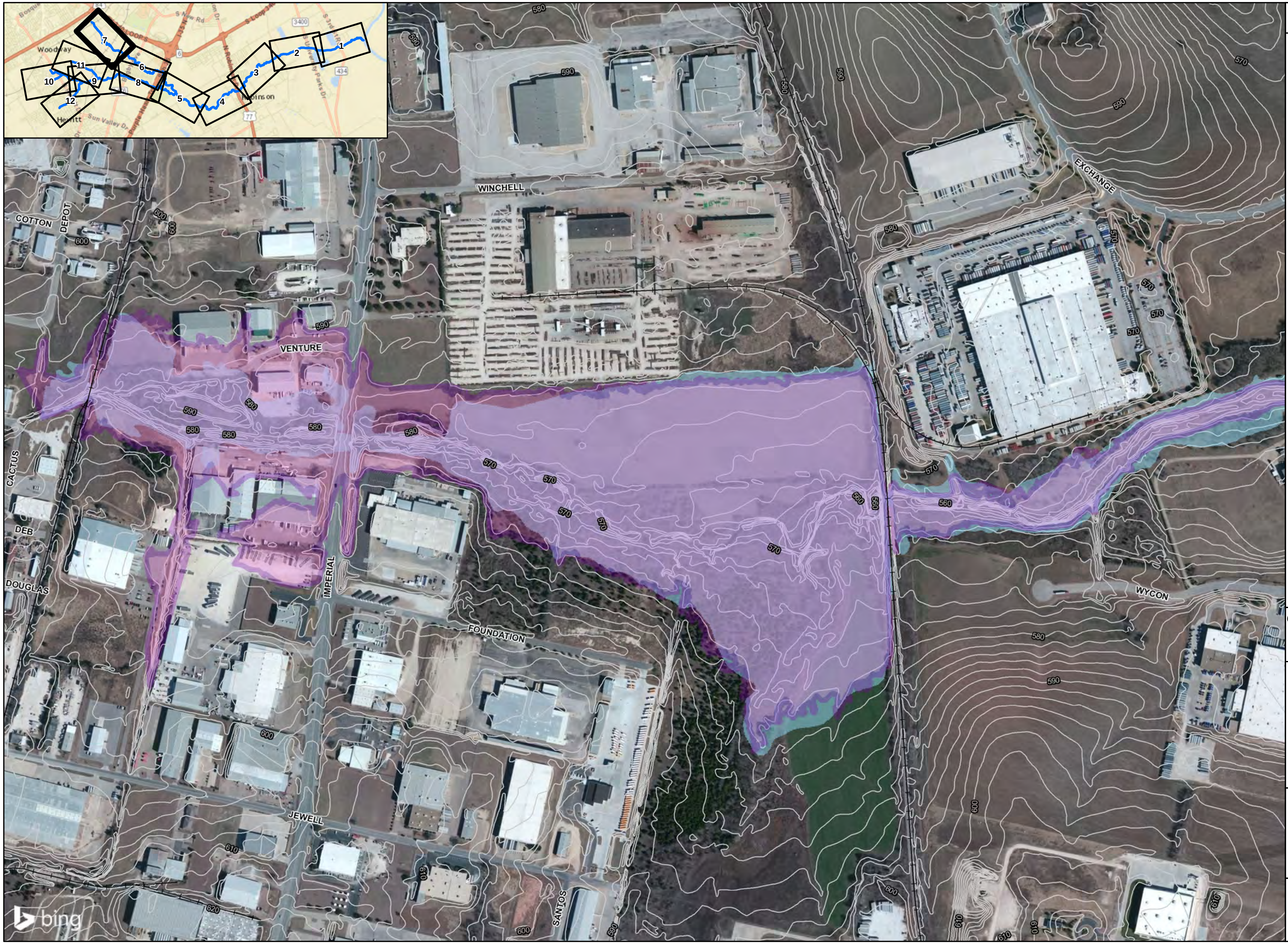
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- Railroad
- 2011-1% Floodplain
- FEMA Floodplain
- 2FT INTERVAL CONTOUR

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

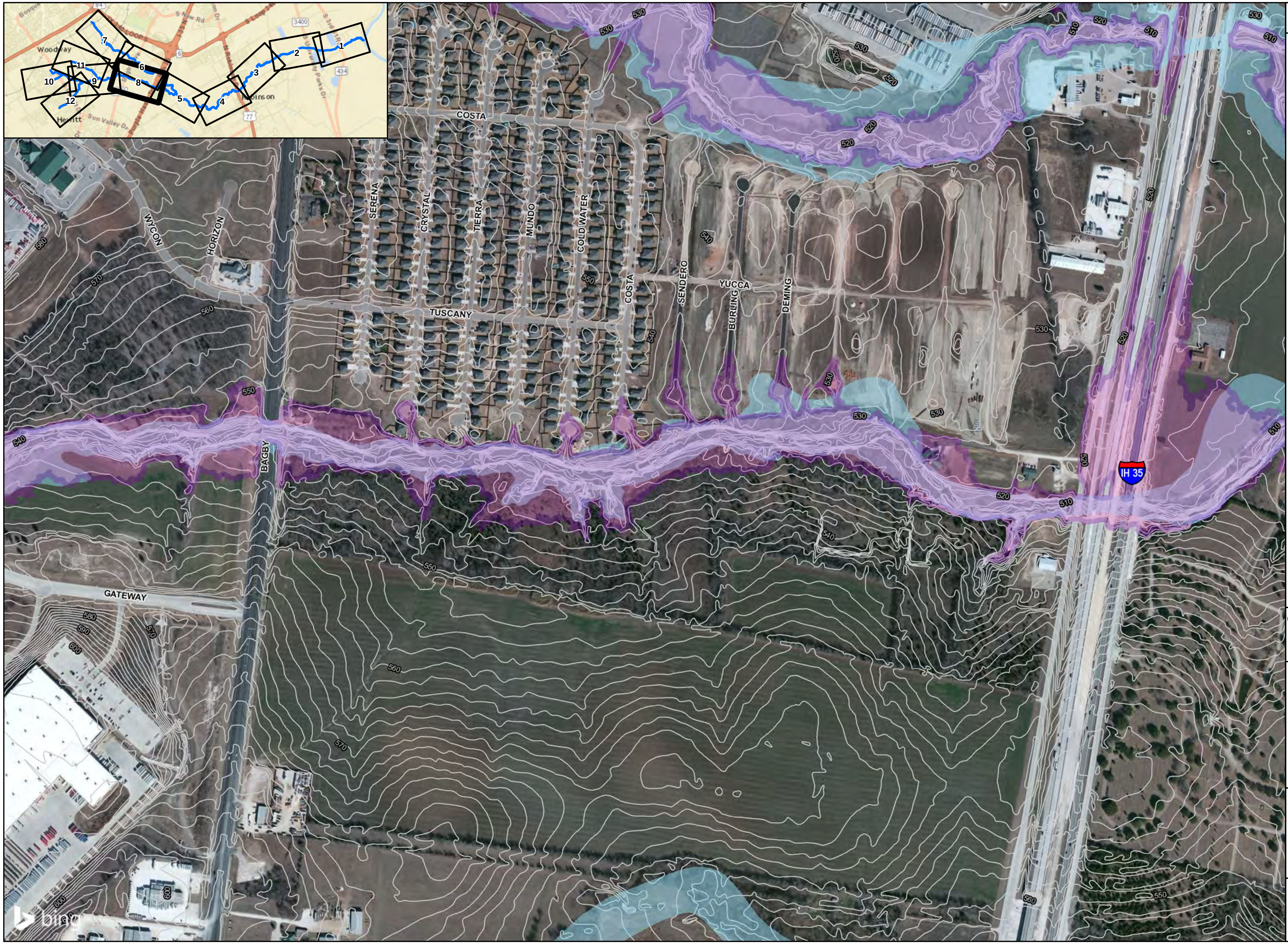
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners

HDR



Legend

2011-1% Floodplain

FEMA Floodplain

2FT INTERVAL CONTOUR

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

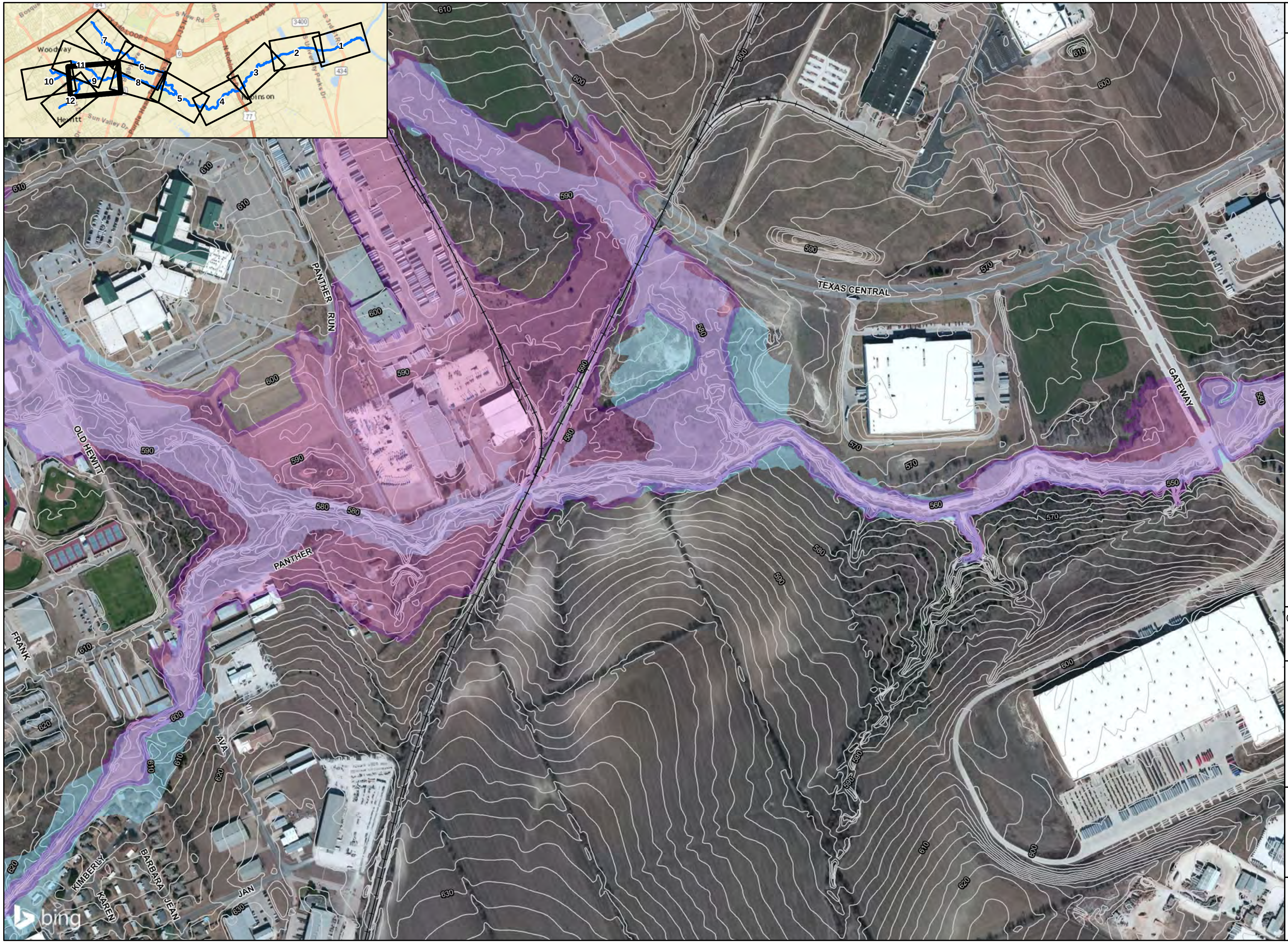
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- Railroad
- 2011-1% Floodplain
- FEMA Floodplain
- 2FT INTERVAL CONTOUR

N
W
E
S

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

Legend

- Railroad
- 2011-1% Floodplain
- FEMA Floodplain
- 2FT INTERVAL CONTOUR

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

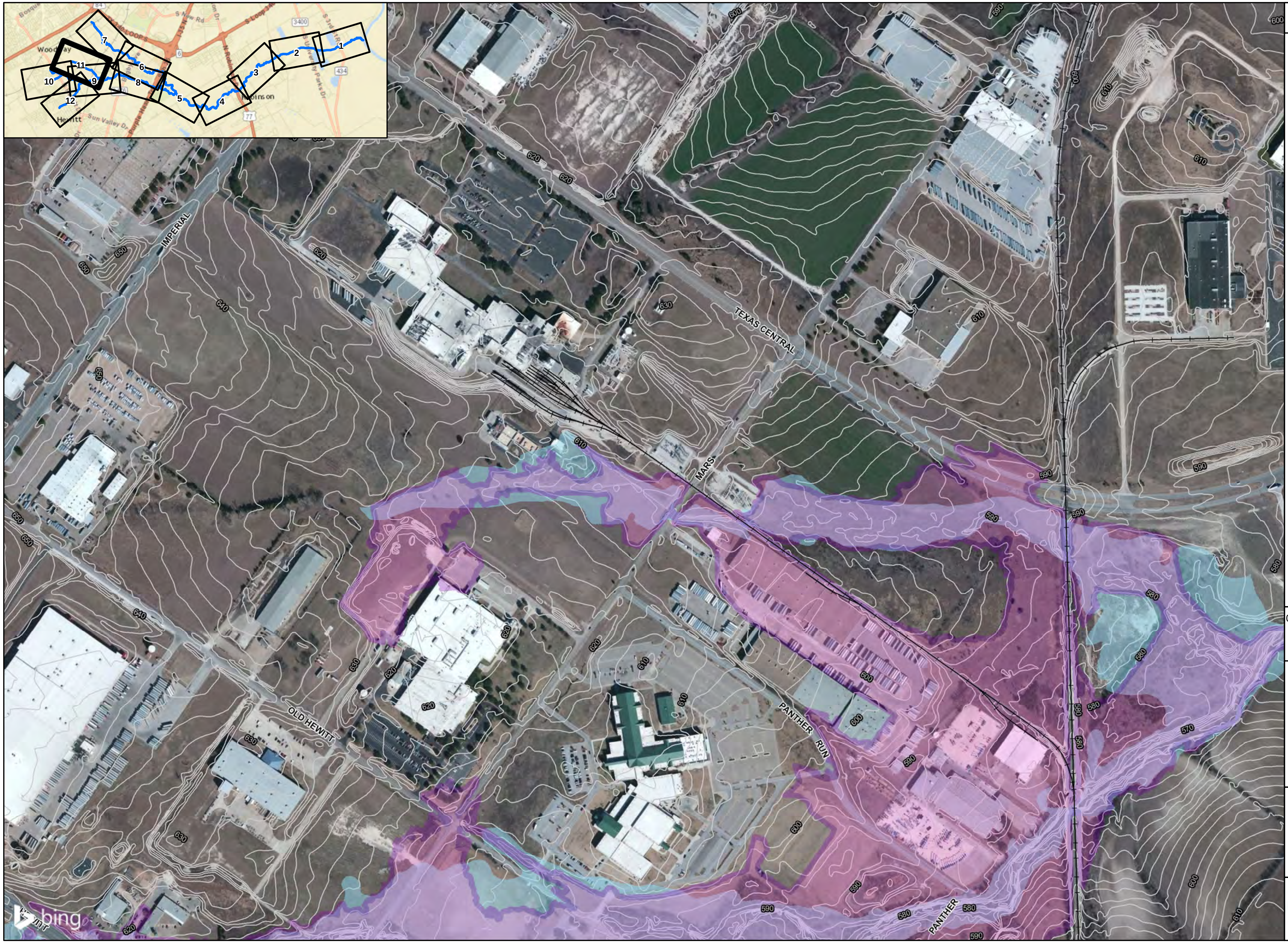
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

Railroad

2011-1% Floodplain

FEMA Floodplain

2FT INTERVAL CONTOUR

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000
Scale (Feet)

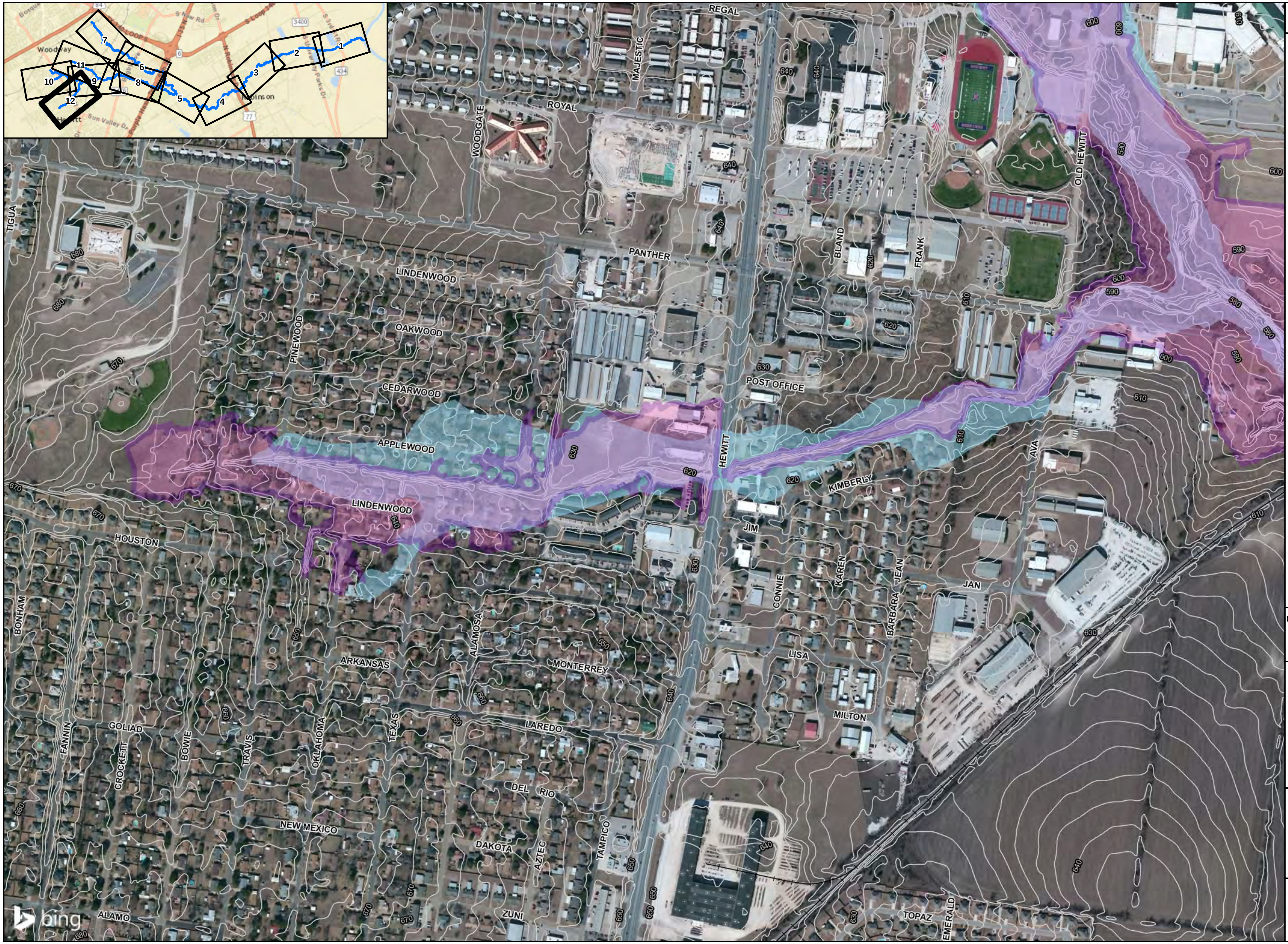
FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

Railroad

2011-1% Floodplain

FEMA Floodplain

2FT INTERVAL CONTOUR

N
E
S
W

DATA SOURCE:
2011 1% FLOODPLAIN : HDR
FLOODPLAIN : FEMA 2008
CONTOURS : TNRIS 2011

0 250 500 1,000

Scale (Feet)

FLAT CREEK FLOOD PROTECTION PLAN

Exhibit C-3: 2011 1% Floodplain VS FEMA 1% Floodplain

Texas Water Development Board

Walker Partners

HDR

EXHIBIT C-4: HYDRAULIC MODEL (HEC-RAS) 1% AEP (100-YR) RESULTS

HEC-RAS Plan: Flat_Ck_01_2017 Profile: 100-year

River	Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft/s)	(sq ft)	(ft)	
FlatCreek	Main	74	100-year	14450.00	370.55	6.37	2268.65	195.35	0.33
FlatCreek	Main	1999	100-year	14450.00	379.87	8.00	2283.75	936.58	0.48
FlatCreek	Main	3391	100-year	13940.00	384.94	4.73	7370.92	3160.18	0.23
FlatCreek	Main	4356	100-year	13940.00	386.97	9.64	1446.77	1953.56	0.51
FlatCreek	Main	4554	100-year	13940.00	388.41	10.86	1285.50	1001.83	0.54
FlatCreek	Main	4675	100-year	13940.00	390.55	4.96	4863.08	2259.17	0.25
FlatCreek	Main	4736	100-year	13940.00	390.45	8.04	2483.17	870.44	0.40
FlatCreek	Main	4754 3rd St.		Bridge					
FlatCreek	Main	4772	100-year	13940.00	390.91	8.95	1557.04	1180.38	0.44
FlatCreek	Main	4962	100-year	13940.00	392.21	9.75	1681.10	1001.50	0.54
FlatCreek	Main	7168	100-year	13940.00	397.45	3.92	6418.82	1674.74	0.19
FlatCreek	Main	8832	100-year	14410.00	400.18	7.79	3881.18	2861.03	0.59
FlatCreek	Main	9981	100-year	14410.00	405.95	4.23	4815.99	2176.96	0.26
FlatCreek	Main	10137	100-year	14410.00	405.98	9.38	1482.14	1622.10	0.57
FlatCreek	Main	10163 University Parks		Mult Open					
FlatCreek	Main	10192	100-year	14410.00	408.20	2.76	9517.11	2482.85	0.14
FlatCreek	Main	10348	100-year	14410.00	408.23	1.06	7297.37	2288.50	0.06
FlatCreek	Main	11453.5*	100-year	14770.00	409.72	9.50	2737.84	1440.57	0.57
FlatCreek	Main	12559	100-year	14770.00	414.29	6.59	4702.54	1868.32	0.33
FlatCreek	Main	13824.0*	100-year	14770.00	417.47	8.98	3296.24	1410.25	0.48
FlatCreek	Main	15089	100-year	14770.00	421.71	6.66	3912.27	1763.09	0.36
FlatCreek	Main	15244	100-year	14770.00	422.07	6.19	4287.93	1710.36	0.28
FlatCreek	Main	15376	100-year	14770.00	422.28	6.21	3858.66	1684.63	0.32
FlatCreek	Main	15398 12st St.		Bridge					
FlatCreek	Main	15468	100-year	14770.00	426.25	2.81	8852.98	2175.12	0.12
FlatCreek	Main	15642	100-year	14770.00	426.34	2.63	8032.40	1993.97	0.13
FlatCreek	Main	16474.0*	100-year	14770.00	427.21	5.73	5067.12	1758.66	0.31
FlatCreek	Main	17306	100-year	14770.00	429.51	6.40	5068.62	1689.27	0.33
FlatCreek	Main	18100.5*	100-year	14770.00	431.96	6.71	4406.13	1548.27	0.35
FlatCreek	Main	18895	100-year	14770.00	434.60	6.30	4148.31	1136.60	0.33
FlatCreek	Main	21028	100-year	14770.00	439.86	4.90	4998.48	1281.09	0.27
FlatCreek	Main	21992	100-year	14900.00	441.25	3.96	6645.61	1823.13	0.21
FlatCreek	Main	24707	100-year	14900.00	448.31	12.08	2816.59	869.66	0.63
FlatCreek	Main	26816	100-year	14900.00	455.70	3.24	6382.20	1224.97	0.18
FlatCreek	Main	28396	100-year	14900.00	459.12	8.35	1916.33	735.66	0.48
FlatCreek	Main	28499	100-year	14900.00	459.91	7.00	2202.97	647.33	0.35
FlatCreek	Main	28592 Robinson Rd.		Bridge					
FlatCreek	Main	28675	100-year	14900.00	462.17	4.86	4633.09	1545.12	0.24
FlatCreek	Main	28798	100-year	14900.00	462.34	5.95	4438.53	1061.97	0.32
FlatCreek	Main	29459	100-year	15050.00	463.94	4.87	5478.94	1222.21	0.23
FlatCreek	Main	29839.0*	100-year	15050.00	464.46	5.23	5646.44	1141.53	0.25
FlatCreek	Main	30219	100-year	15050.00	465.06	5.38	5366.83	890.41	0.25
FlatCreek	Main	30285	100-year	15050.00	465.13	6.33	4949.80	1155.05	0.32
FlatCreek	Main	30314 Old Robinson Rd.		Bridge					
FlatCreek	Main	30332	100-year	15050.00	466.20	5.47	5231.30	1164.91	0.27
FlatCreek	Main	30375	100-year	15050.00	466.21	5.95	4937.16	1122.05	0.28
FlatCreek	Main	30744.0*	100-year	15050.00	466.62	5.36	4094.52	982.63	0.26
FlatCreek	Main	31113	100-year	15050.00	466.62	9.52	2333.52	367.11	0.47
FlatCreek	Main	31815	100-year	15050.00	469.27	10.42	2036.03	555.76	0.48
FlatCreek	Main	31898	100-year	15050.00	469.95	9.58	2066.33	506.77	0.48
FlatCreek	Main	31910 Private LWC		Culvert					
FlatCreek	Main	31918	100-year	15050.00	470.18	10.00	1900.52	466.71	0.54
FlatCreek	Main	31996	100-year	15050.00	470.55	12.32	1644.78	388.47	0.63
FlatCreek	Main	32907	100-year	15050.00	474.47	4.08	4308.31	811.92	0.20
FlatCreek	Main	34933	100-year	12350.00	477.67	10.38	2041.00	465.74	0.48
FlatCreek	Main	35522	100-year	12350.00	480.19	5.15	2796.03	591.24	0.27
FlatCreek	Main	35987	100-year	12350.00	481.02	3.89	3692.19	859.07	0.23
FlatCreek	Main	36086	100-year	12350.00	481.15	4.13	3398.89	910.24	0.25
FlatCreek	Main	36846	100-year	12350.00	482.63	6.39	2406.72	434.75	0.36
FlatCreek	Main	38472	100-year	12350.00	488.25	7.28	1910.07	523.23	0.45
FlatCreek	Main	39704	100-year	12350.00	491.94	5.63	4406.35	2118.30	0.29
FlatCreek	Main	40054	100-year	12350.00	492.42	8.60	1601.59	683.44	0.51
FlatCreek	Main	40838	100-year	12350.00	495.22	4.22	5047.42	2370.89	0.24
FlatCreek	Main	40893	100-year	12350.00	495.26	4.73	4360.99	2340.25	0.29
FlatCreek	Main	40992	100-year	12350.00	495.50	4.56	4787.54	2332.58	0.28
FlatCreek	Main	41407	100-year	12350.00	496.13	4.82	5007.19	2240.02	0.25
FlatCreek	Main	41436	100-year	12350.00	496.17	4.47	4393.93	2029.58	0.26
FlatCreek	Main	41465 Greig Dr.		Mult Open					
FlatCreek	Main	41480	100-year	12350.00	498.42	2.20	8429.77	2699.73	0.12
FlatCreek	Main	41527	100-year	12350.00	498.43	2.34	8364.56	2634.76	0.14
FlatCreek	Main	41712	100-year	12350.00	498.51	3.13	5438.30	1837.17	0.19
FlatCreek	Main	42765	100-year	12350.00	500.06	7.74	1847.64	356.20	0.46
NorthFlatCreek	Main	321	100-year	4730.00	502.23	2.93	1976.15	353.90	0.16
NorthFlatCreek	Main	1036	100-year	4730.00	503.00	4.48	1055.07	138.87	0.29
NorthFlatCreek	Main	2664	100-year	4730.00	509.09	5.53	859.50	124.14	0.35
NorthFlatCreek	Main	4387	100-year	3570.00	514.41	2.81	1409.32	470.29	0.19
NorthFlatCreek	Main	5341	100-year	3570.00	515.77	5.46	653.50	152.37	0.40
NorthFlatCreek	Main	5529	100-year	3570.00	515.91	6.27	569.54	126.74	0.32
NorthFlatCreek	Main	5838 IH 35		Culvert					
NorthFlatCreek	Main	5989	100-year	3570.00	518.69	5.48	651.93	132.38	0.26
NorthFlatCreek	Main	6200	100-year	3570.00	519.63	5.68	628.34	120.72	0.44
NorthFlatCreek	Main	7613	100-year	3570.00	525.34	3.31	1524.59	313.16	0.19
NorthFlatCreek	Main	8635	100-year	3460.00	528.59	6.95	585.67	128.22	0.44
NorthFlatCreek	Main	9753	100-year	3460.00	535.12	4.35	931.83	325.72	0.29
NorthFlatCreek	Main	10207	100-year	3460.00	536.96	4.64	943.04	447.11	0.32
NorthFlatCreek	Main	10845	100-year	3460.00	539.76	5.06	983.68	368.17	0.31
NorthFlatCreek	Main	12090	100-year	3460.00	544.06	3.96	1143.92	461.98	0.26

HEC-RAS Plan: Flat_Ck_01_2017 Profile: 100-year (Continued)

River	Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft/s)	(sq ft)	(ft)	
NorthFlatCreek	Main	12530	100-year	3460.00	545.88	8.18	637.05	302.17	0.52
NorthFlatCreek	Main	12787	100-year	3460.00	548.04	4.16	904.68	321.16	0.30
NorthFlatCreek	Main	12882 Bagby Ave.		Bridge					
NorthFlatCreek	Main	13028	100-year	3460.00	550.24	4.67	741.56	319.29	0.33
NorthFlatCreek	Main	13196	100-year	3460.00	551.23	6.32	547.32	108.51	0.50
NorthFlatCreek	Main	13503	100-year	3460.00	552.86	3.78	959.71	138.21	0.22
NorthFlatCreek	Main	13623 Texas Central		Bridge					
NorthFlatCreek	Main	13746	100-year	3460.00	554.67	2.83	1411.71	511.84	0.17
NorthFlatCreek	Main	13887	100-year	3460.00	554.73	3.10	1270.69	332.76	0.20
NorthFlatCreek	Main	15088	100-year	3230.00	556.12	7.01	461.07	122.39	0.64
NorthFlatCreek	Main	15743	100-year	3230.00	560.16	5.82	560.50	124.29	0.45
NorthFlatCreek	Main	15913	100-year	3230.00	561.00	6.09	552.87	127.39	0.46
NorthFlatCreek	Main	17209	100-year	3230.00	567.95	5.30	774.45	221.44	0.35
NorthFlatCreek	Main	17416	100-year	3230.00	569.03	6.74	478.99	222.27	0.44
NorthFlatCreek	Main	17479	100-year	3230.00	568.70	13.27	243.47	273.94	0.64
NorthFlatCreek	Main	17514 RR Crossing		Bridge					
NorthFlatCreek	Main	17528	100-year	3230.00	578.69	1.15	7066.86	1603.32	0.04
NorthFlatCreek	Main	17671	100-year	3230.00	578.70	0.57	10042.40	1694.42	0.03
NorthFlatCreek	Main	18406	100-year	5250.00	578.72	0.87	10168.63	1982.99	0.04
NorthFlatCreek	Main	19195	100-year	5250.00	578.81	2.03	4216.66	1164.22	0.11
NorthFlatCreek	Main	19693	100-year	5250.00	579.19	2.45	3297.96	993.18	0.15
NorthFlatCreek	Main	20352.0*	100-year	5250.00	580.30	5.27	1473.32	592.67	0.35
NorthFlatCreek	Main	21011	100-year	5250.00	583.82	4.93	1482.56	453.67	0.31
NorthFlatCreek	Main	21187	100-year	5250.00	584.40	10.26	506.26	758.63	0.60
NorthFlatCreek	Main	21239 Imperial Dr.		Mult Open					
NorthFlatCreek	Main	21282	100-year	5250.00	586.40	2.38	3842.39	1114.98	0.14
NorthFlatCreek	Main	21393	100-year	5250.00	586.42	2.71	2300.41	486.10	0.17
NorthFlatCreek	Main	21948	100-year	5250.00	587.49	3.84	1807.83	508.08	0.26
NorthFlatCreek	Main	22408	100-year	1750.00	588.68	2.00	1385.02	624.84	0.14
NorthFlatCreek	Main	22595	100-year	1750.00	588.89	3.91	499.52	588.37	0.28
NorthFlatCreek	Main	22669	100-year	1750.00	589.15	4.83	409.50	591.22	0.33
NorthFlatCreek	Main	22709 RR Crossing		Bridge					
NorthFlatCreek	Main	22753	100-year	1750.00	589.97	3.39	516.84	455.05	0.26
NorthFlatCreek	Main	22804	100-year	1750.00	590.17	3.85	497.96	150.54	0.32
NorthFlatCreek	Main	22990	100-year	1750.00	591.06	3.13	647.80	301.66	0.24
SFT Trib1	SFT 08-09	814	100-year	1310.00	583.05	6.08	298.18	334.17	0.72
SFT Trib1	SFT 08-09	1218	100-year	1310.00	587.45	2.58	493.27	328.71	0.29
SFT Trib1	SFT 08-09	1293	100-year	1310.00	588.38	11.04	118.64	134.66	1.00
SFT Trib1	SFT 08-09	1315 RR Crossing		Culvert					
SFT Trib1	SFT 08-09	1334	100-year	1310.00	591.82	1.81	802.27	667.45	0.12
SFT Trib1	SFT 08-09	1372	100-year	1310.00	591.86	1.33	913.05	510.18	0.11
SFT Trib1	SFT 08-09	1696	100-year	1310.00	592.12	1.89	595.15	456.52	0.21
SFT Trib1	SFT 08-09	2365.50*	100-year	760.00	596.59	5.59	158.14	218.37	0.76
SFT Trib1	SFT 08-09	3035	100-year	760.00	603.25	2.71	352.43	315.88	0.27
SFT Trib1	SFT 08-09	3141	100-year	760.00	603.66	3.41	222.72	138.77	0.30
SFT Trib1	SFT 08-09	3170 RR Crossing		Culvert					
SFT Trib1	SFT 08-09	3216	100-year	760.00	606.83	2.19	348.02	501.19	0.15
SFT Trib1	SFT 08-09	3300	100-year	760.00	606.86	2.34	382.95	310.60	0.20
SFT Trib1	SFT 08-09	3490	100-year	760.00	606.83	5.21	174.03	121.98	0.49
SFT Trib1	SFT 08-09	3543	100-year	760.00	606.76	7.57	100.44	94.06	0.64
SFT Trib1	SFT 08-09	3586 Mars Dr.		Culvert					
SFT Trib1	SFT 08-09	3625	100-year	760.00	610.40	1.65	698.35	439.40	0.12
SFT Trib1	SFT 08-09	3824	100-year	760.00	610.43	2.65	525.37	324.05	0.22
SFT Trib1	SFT 08-09	4001.67*	100-year	250.00	610.53	2.69	116.56	118.21	0.31
SFT Trib1	SFT 08-09	4179.33*	100-year	250.00	610.99	6.02	41.53	37.51	1.01
SFT Trib1	SFT 08-09	4357	100-year	250.00	613.10	3.67	73.71	100.69	0.58
SFT Trib1	SFT 08-09	4680.33*	100-year	250.00	616.67	5.21	47.94	57.82	1.01
SFT Trib1	SFT 08-09	5003.67*	100-year	250.00	620.88	3.89	66.04	79.52	0.69
SFT Trib1	SFT 08-09	5327	100-year	250.00	624.71	4.04	79.92	226.51	0.83
SFT Trib2	SFT 10-11	378	100-year	2210.00	599.18	1.30	2520.26	568.99	0.07
SFT Trib2	SFT 10-11	809	100-year	2210.00	599.28	2.38	1803.74	544.36	0.13
SFT Trib2	SFT 10-11	840	100-year	2210.00	599.31	1.53	1568.30	526.64	0.10
SFT Trib2	SFT 10-11	877 Panther Way		Culvert					
SFT Trib2	SFT 10-11	921	100-year	2210.00	600.69	4.13	867.59	381.31	0.29
SFT Trib2	SFT 10-11	975	100-year	2210.00	600.73	4.58	518.14	169.28	0.33
SFT Trib2	SFT 10-11	1506	100-year	2210.00	604.92	8.09	273.33	73.18	0.72
SFT Trib2	SFT 10-11	2010	100-year	1460.00	608.66	3.56	498.76	243.00	0.32
SFT Trib2	SFT 10-11	2755	100-year	1460.00	614.37	9.56	152.75	54.35	1.01
SFT Trib2	SFT 10-11	3015	100-year	1460.00	618.39	7.09	209.31	73.38	0.64
SFT Trib2	SFT 10-11	3223	100-year	1460.00	620.11	11.86	123.12	37.81	0.96
SFT Trib2	SFT 10-11	3289 Hewitt Dr.		Culvert					
SFT Trib2	SFT 10-11	3330	100-year	1460.00	626.86	2.68	738.80	684.58	0.17
SFT Trib2	SFT 10-11	3466	100-year	1460.00	626.90	3.89	489.41	426.83	0.29
SFT Trib2	SFT 10-11	3995	100-year	1460.00	629.45	6.57	315.99	302.85	0.63
SFT Trib2	SFT 10-11	4875	100-year	1460.00	638.76	7.11	328.38	364.79	0.68
SFT Trib2	SFT 10-11	5681	100-year	1460.00	649.01	7.95	272.40	218.84	0.72
SFT Trib2	SFT 10-11	6077	100-year	1460.00	655.15	7.54	467.09	357.97	0.58
SFT Trib2	SFT 10-11	6100 Lindenwood Ln.		Culvert					
SFT Trib2	SFT 10-11	6162	100-year	1460.00	657.24	8.14	414.29	329.53	0.65
SFT Trib2	SFT 10-11	6376	100-year	1460.00	658.73	3.67	628.95	348.01	0.28
SFT Trib2	SFT 10-11	6590	100-year	1460.00	660.10	7.13	291.26	276.81	0.84
SFT Trib3	SFT 07	476	100-year	2420.00	618.21	7.90	364.08	219.64	0.58
SFT Trib3	SFT 07	601	100-year	2420.00	619.46	3.09	1439.75	886.04	0.19
SFT Trib3	SFT 07	668 Hewitt Dr.		Culvert					
SFT Trib3	SFT 07	747	100-year	2420.00	621.33	1.48	2772.26	1013.05	0.10
SFT Trib3	SFT 07	949	100-year	2420.00	621.26	4.35	824.28	393.72	0.31
SFT Trib3	SFT 07	1914	100-year	2420.00	629.60	7.57	344.09	221.64	0.73

HEC-RAS Plan: Flat_Ck_01_2017 Profile: 100-year (Continued)

River	Reach	River Sta	Profile	Q Total	W.S. Elev	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft/s)	(sq ft)	(ft)	
SFT Trib3	SFT 07	2438	100-year	2420.00	636.54	6.39	424.51	227.26	0.46
SFT Trib3	SFT 07	2710	100-year	2420.00	638.52	5.86	665.02	308.02	0.40
SouthFlatCreek	SFT 02-03	651	100-year	9270.00	504.30	4.88	2350.51	728.76	0.28
SouthFlatCreek	SFT 02-03	2326	100-year	9270.00	510.17	5.89	1596.85	252.11	0.36
SouthFlatCreek	SFT 02-03	4188	100-year	8470.00	518.66	7.76	1740.57	572.24	0.41
SouthFlatCreek	SFT 02-03	4752	100-year	8470.00	520.95	5.96	2489.13	1448.75	0.34
SouthFlatCreek	SFT 02-03	4796	100-year	8470.00	521.40	3.41	4439.02	1207.43	0.16
SouthFlatCreek	SFT 02-03	4998 IH 35		Culvert					
SouthFlatCreek	SFT 02-03	5206	100-year	8470.00	522.18	4.71	2478.31	647.45	0.25
SouthFlatCreek	SFT 02-03	5245	100-year	8470.00	521.82	9.21	919.65	110.19	0.54
SouthFlatCreek	SFT 02-03	5790	100-year	8470.00	526.68	6.02	1414.53	242.76	0.36
SouthFlatCreek	SFT 02-03	7685	100-year	7830.00	535.64	6.53	1308.65	201.42	0.35
SouthFlatCreek	SFT 02-03	9471	100-year	7830.00	545.11	7.09	1285.48	315.64	0.42
SouthFlatCreek	SFT 02-03	9871	100-year	7830.00	547.67	7.01	1210.59	362.81	0.40
SouthFlatCreek	SFT 02-03	9980 Bagby Ave.		Bridge					
SouthFlatCreek	SFT 02-03	10129	100-year	7830.00	550.21	4.97	1864.22	450.85	0.26
SouthFlatCreek	SFT 02-03	10381	100-year	7830.00	550.91	5.87	1496.72	352.10	0.34
SouthFlatCreek	SFT 02-03	11765	100-year	7830.00	556.75	5.90	1582.39	494.40	0.34
SouthFlatCreek	SFT 02-03	11932	100-year	7830.00	557.50	4.69	1927.21	434.49	0.27
SouthFlatCreek	SFT 02-03	12013	100-year	7830.00	557.70	5.68	1561.58	361.04	0.35
SouthFlatCreek	SFT 02-03	12104 Gateway Blvd.		Culvert					
SouthFlatCreek	SFT 02-03	12188	100-year	7830.00	560.84	4.29	2409.84	575.28	0.23
SouthFlatCreek	SFT 02-03	12245	100-year	7830.00	560.84	4.84	2150.32	560.85	0.24
SouthFlatCreek	SFT 02-03	12355	100-year	7830.00	560.87	5.94	1662.16	420.33	0.32
SouthFlatCreek	SFT 02-03	13896	100-year	6580.00	564.37	9.78	672.97	90.19	0.63
SouthFlatCreek	SFT 02-03	15007	100-year	6580.00	572.49	10.53	726.44	145.65	0.69
SouthFlatCreek	SFT 04	15911	100-year	7550.00	579.72	9.08	900.02	448.27	0.61
SouthFlatCreek	SFT 04	16248	100-year	6710.00	581.98	5.19	2299.62	804.00	0.33
SouthFlatCreek	SFT 04	16386 RR Crossing		Bridge					
SouthFlatCreek	SFT 04	16457	100-year	6710.00	599.13	0.74	16453.56	1889.28	0.03
SouthFlatCreek	SFT 04	16695	100-year	6710.00	599.14	0.66	16296.74	1603.80	0.03
SouthFlatCreek	SFT 04	17183	100-year	6710.00	599.15	0.39	16385.21	1709.92	0.02
SouthFlatCreek	SFT 04	17329	100-year	6710.00	599.15	0.40	15707.41	1661.36	0.02
SouthFlatCreek	SFT 04	17363 Panther Run Dr.		Culvert					
SouthFlatCreek	SFT 04	17404	100-year	6710.00	599.14	0.73	11112.67	1598.02	0.03
SouthFlatCreek	SFT 04	17634	100-year	6710.00	599.15	0.86	9686.36	1432.77	0.04
SouthFlatCreek	SFT 05	18084	100-year	5630.00	599.19	1.00	5741.46	1100.02	0.05
SouthFlatCreek	SFT 05	18426	100-year	5630.00	599.23	2.09	3652.51	850.24	0.13
SouthFlatCreek	SFT 05	18952	100-year	5630.00	599.76	4.12	2034.28	460.52	0.28
SouthFlatCreek	SFT 05	19025	100-year	5630.00	599.98	2.97	2394.03	489.71	0.19
SouthFlatCreek	SFT 05	19206	100-year	5630.00	600.29	3.89	1968.59	456.45	0.24
SouthFlatCreek	SFT 05	19372	100-year	5630.00	600.77	4.08	2084.91	630.51	0.27
SouthFlatCreek	SFT 05	19449	100-year	5630.00	600.98	2.81	2621.38	820.33	0.18
SouthFlatCreek	SFT 05	19482 Old Hewitt Rd.		Culvert					
SouthFlatCreek	SFT 05	19513	100-year	5630.00	601.59	2.37	2808.52	818.33	0.16
SouthFlatCreek	SFT 05	19577	100-year	5630.00	601.62	2.86	2179.82	734.88	0.21
SouthFlatCreek	SFT 05	20136	100-year	5630.00	603.53	7.80	924.02	556.95	0.72
SouthFlatCreek	SFT 05	20269	100-year	4390.00	604.84	5.67	1173.58	545.25	0.38
SouthFlatCreek	SFT 05	20945	100-year	4390.00	608.43	9.35	523.90	840.58	0.62
SouthFlatCreek	SFT 05	21013	100-year	4390.00	610.19	2.78	2262.24	1103.29	0.18
SouthFlatCreek	SFT 05	21048 Mars Dr.		Culvert					
SouthFlatCreek	SFT 05	21073	100-year	4390.00	610.49	2.89	2062.14	975.58	0.22
SouthFlatCreek	SFT 05	21133	100-year	4390.00	610.52	9.60	600.59	265.67	0.73
SouthFlatCreek	SFT 05	21566	100-year	4390.00	615.71	6.00	1088.01	439.46	0.37
SouthFlatCreek	SFT 06	21992	100-year	2020.00	618.37	6.06	460.84	226.39	0.42
SouthFlatCreek	SFT 06	22286	100-year	2020.00	619.96	9.26	321.27	271.75	0.63
SouthFlatCreek	SFT 06	22412	100-year	2020.00	621.23	3.94	795.73	369.24	0.25
SouthFlatCreek	SFT 06	22440 La Village Ave.		Culvert					
SouthFlatCreek	SFT 06	22474	100-year	2020.00	621.55	4.16	665.07	197.63	0.25
SouthFlatCreek	SFT 06	22546	100-year	2020.00	621.28	8.11	284.81	87.91	0.58
SouthFlatCreek	SFT 06	22594	100-year	2020.00	622.34	4.96	911.04	807.37	0.35
SouthFlatCreek	SFT 06	22707 Hewitt Dr.		Culvert					
SouthFlatCreek	SFT 06	22755	100-year	2020.00	624.06	3.15	1234.73	885.91	0.21
SouthFlatCreek	SFT 06	22787	100-year	2020.00	624.05	4.23	897.16	597.56	0.33
SouthFlatCreek	SFT 06	22941	100-year	2020.00	625.16	7.35	440.44	879.93	0.79
SouthFlatCreek	SFT 06	23903	100-year	2020.00	631.26	8.88	375.58	237.68	0.67

Appendix D – Problem Areas

Exhibit D-1 FCR-001 Woodcock Drive & 12th Street BCA

Exhibit D-2 FCR-002 Robinson Drive & Old Robinson Road BCA

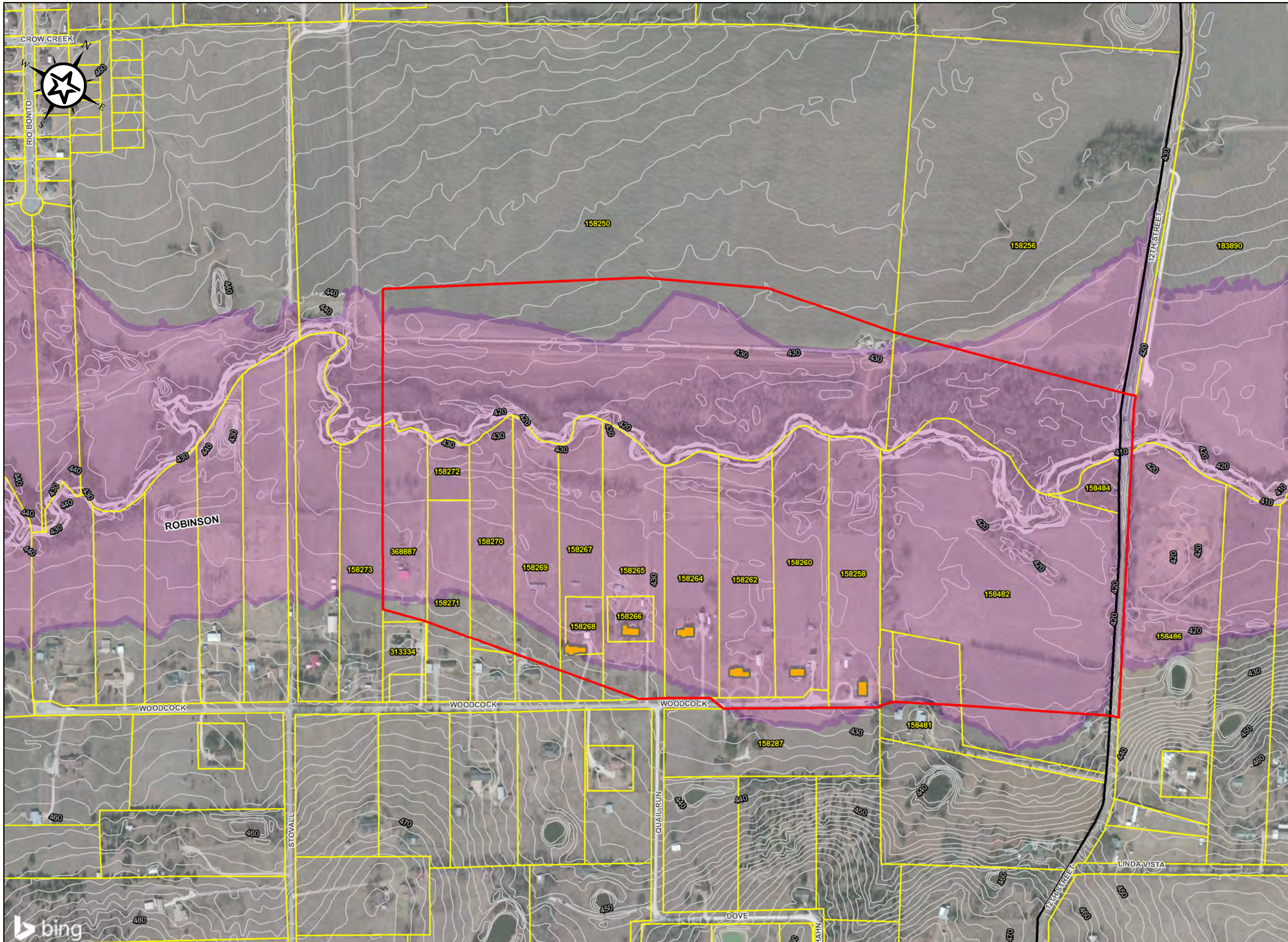
Exhibit D-3 FCR-003 Panther Way & Old Hewitt Road BCA

Exhibit D-4 FCR-004 Hewitt Elementary and Applewood / Lindenwood BCA

Exhibit D-5 FCR-005 Chapel Road Detention BCA

Exhibit D-6 Inundated Roadways

(This Page Intentionally Left Blank)



Legend

- BCA > 1
- BCA Analysis
- Problem Area Boundary
- Building
- City Limit
- Parcel
- 2011-1% Floodplain
- 2 ft Contour

DATA SOURCE :

FLOODPLAIN : HDR
CONTOURS : TNRIS 2011

0 125 250 500
Scale (Feet)

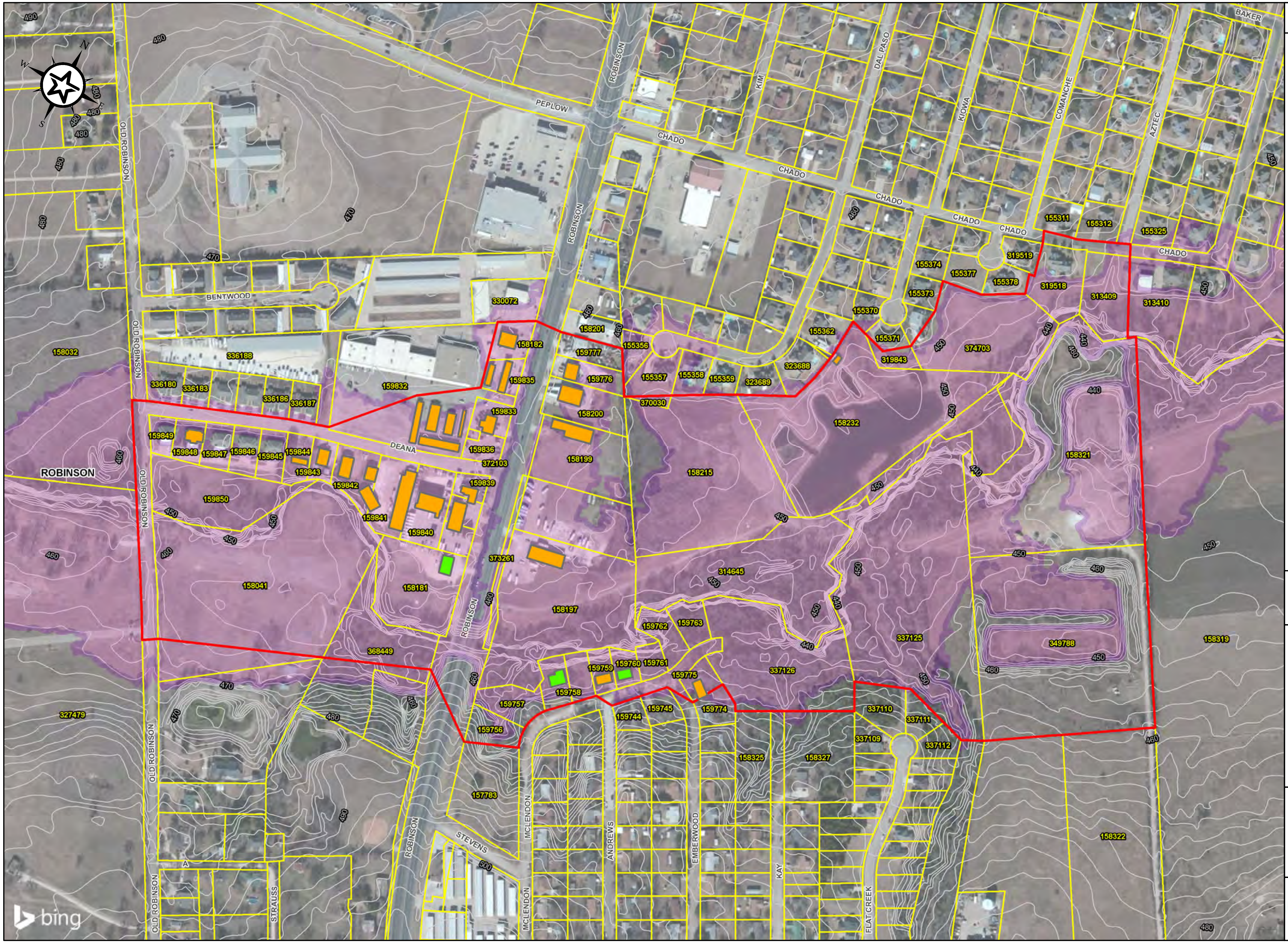
Flat Creek
Flood Protection Plan

Exhibit D-1 Problem Area
FCR-001
Woodcock Dr &
12th St BCA

Texas Water Development Board

Walker Partners

HDR



Legend

- BCA > 1
- BCA Analysis
- Problem Area Boundary
- Building
- City Limit
- Parcel
- 2011-1% Floodplain
- 2 ft Contour

DATA SOURCE :

FLOODPLAIN : HDR
CONTOURS : TNRIS 2011

0 100 200 400
Scale (Feet)

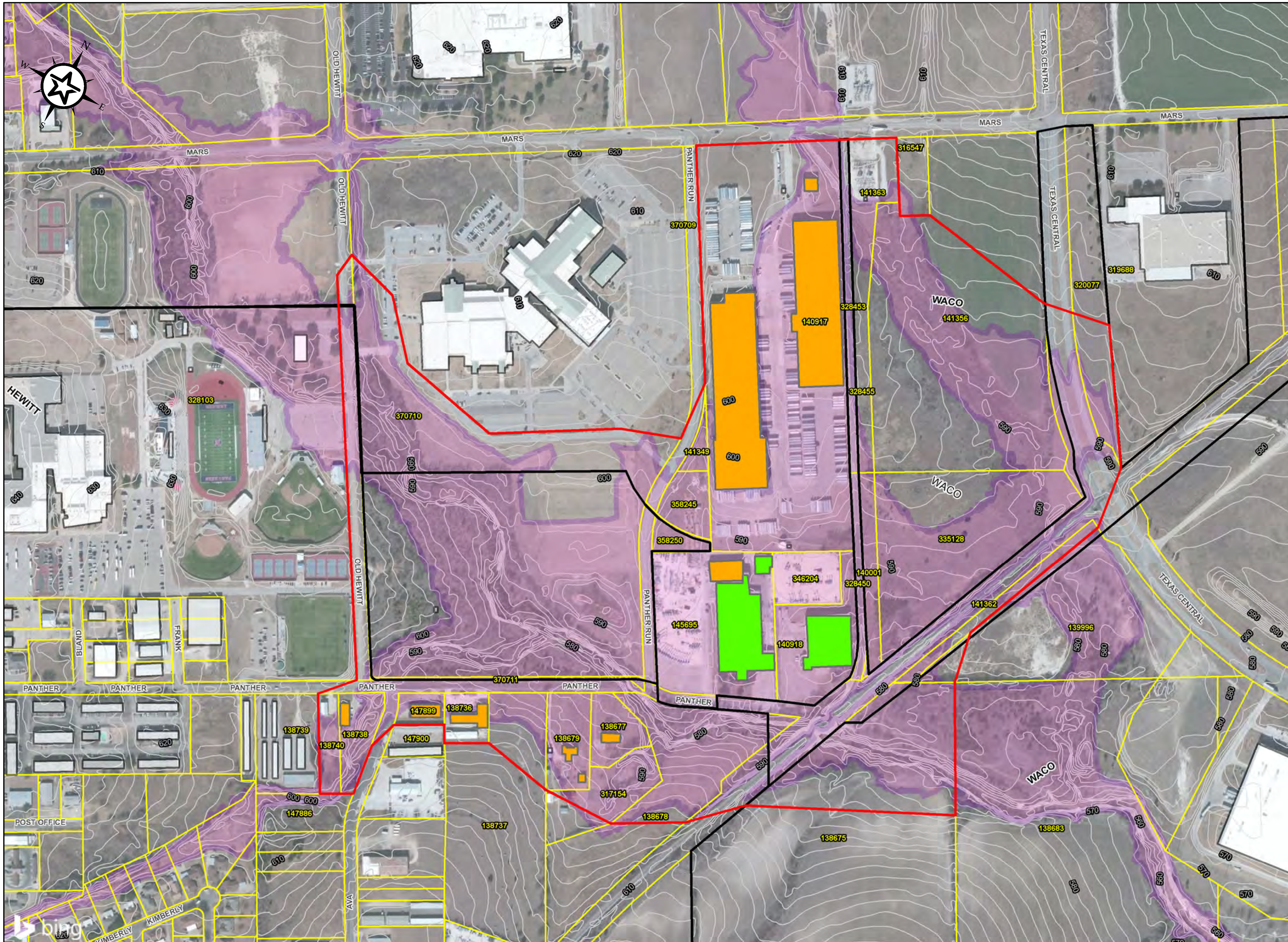
Flat Creek Flood Protection Plan

Exhibit D-2 Problem Area FCR-002 Robinson Dr & Old Robinson Rd BCA

Texas Water Development Board

Walker Partners

HDR



Legend

- BCA > 1
- BCA Analysis
- Problem Area Boundary
- Building
- City Limit
- Parcel
- 2011-1% Floodplain
- 2 ft Contour

DATA SOURCE :

FLOODPLAIN : HDR
CONTOURS : TNRIS 2011

0 155 310 620
Scale (Feet)

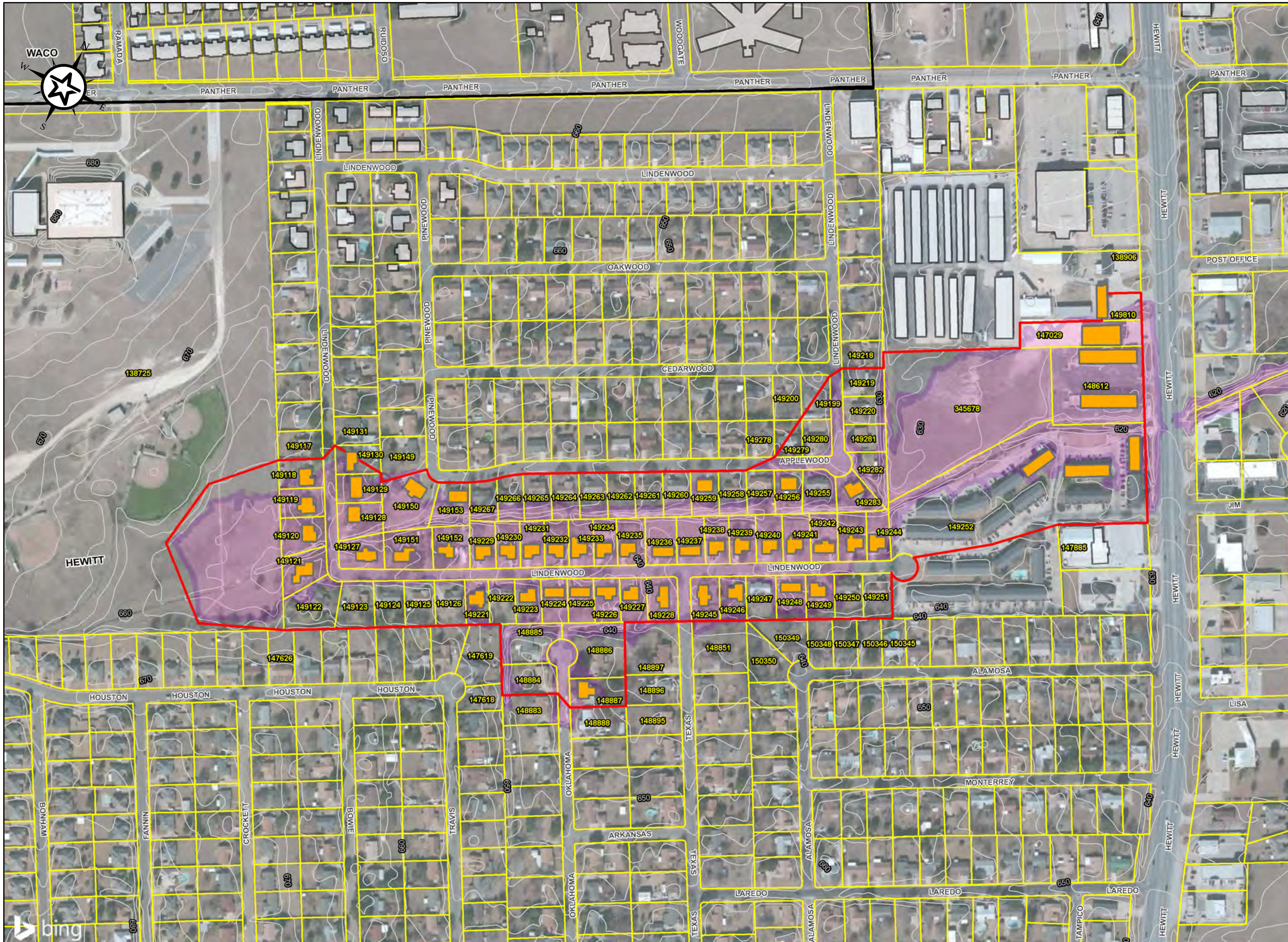
Flat Creek Flood Protection Plan

Exhibit D-3 Problem Area FCR-003 Panther Way & Old Hewitt Rd BCA

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend

- BCA > 1
- BCA Analysis
- Problem Area Boundary
- Building
- City Limit
- Parcel
- 2011-1% Floodplain
- 2 ft Contour

DATA SOURCE :

FLOODPLAIN : HDR
CONTOURS : TNRIS 2011

0 75 150 300
Scale (Feet)

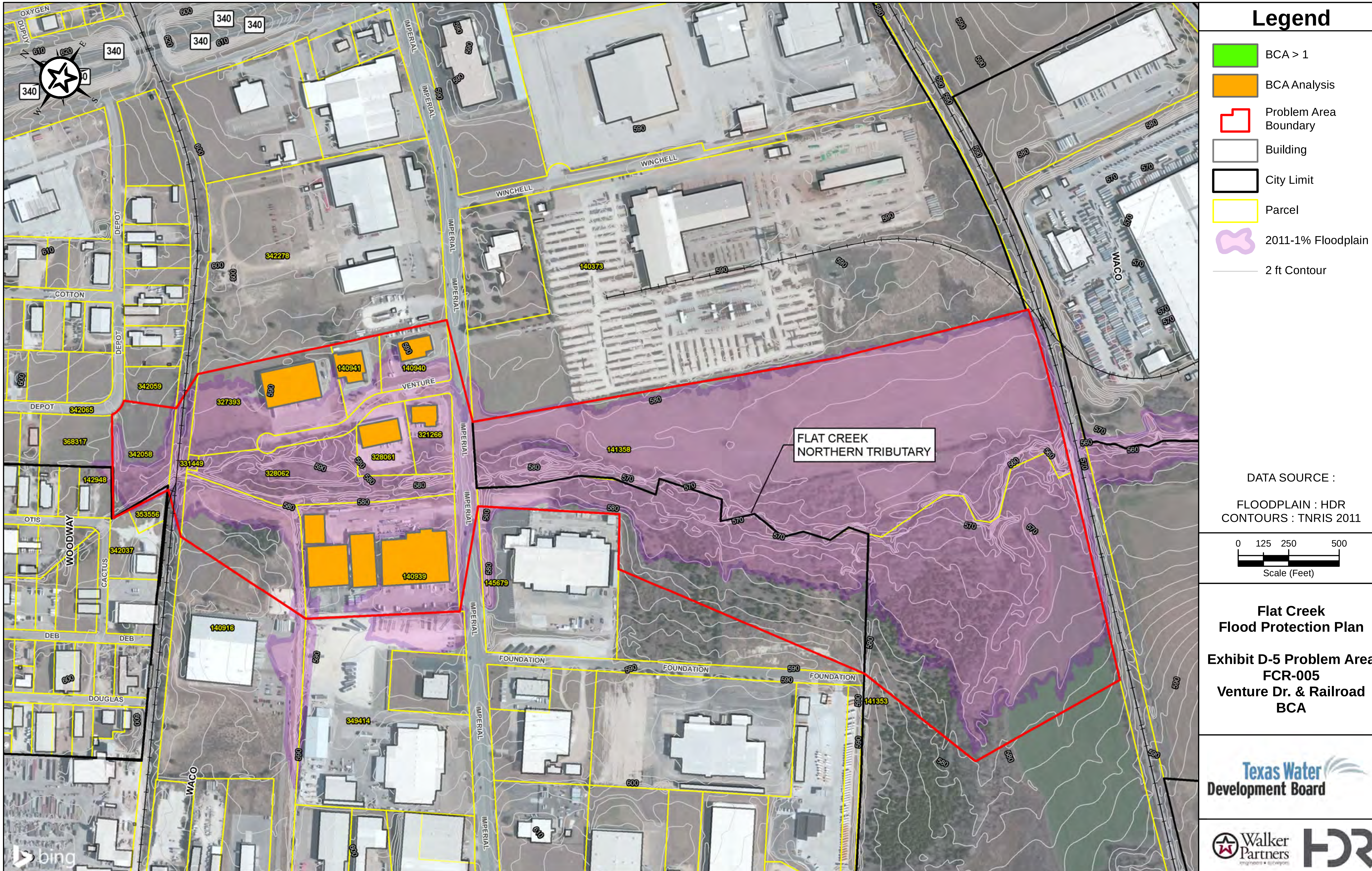
Flat Creek Flood Protection Plan

Exhibit D-4 Problem Area FCR-004 Elementary & Applewood / Lindenwood BCA

Texas Water Development Board

Walker Partners engineers • surveyors

HDR



Legend
BCA > 1
BCA Analysis
Problem Area Boundary
Building
City Limit
Parcel
2011-1% Floodplain
2 ft Contour
DATA SOURCE :
FLOODPLAIN : HDR
CONTOURS : TNRIS 2011
0 125 250 500
Scale (Feet)
Flat Creek
Flood Protection Plan
Exhibit D-5 Problem Area
FCR-005
Venture Dr. & Railroad
BCA
Texas Water Development Board
Walker Partners
HDR
FLAT CREEK
NORTHERN TRIBUTARY
IMPERIAL
WINCHELL
VENTURE
DEPOT
COTTON
OTIS
WOODWAY
CACTUS
DEB
DOUGLAS
WACO
FOUNDATION
OXYGEN
DUPUY
340
140373
342278
140941
140940
327393
342059
342065
368317
342058
331449
142948
321266
328061
328062
141358
353556
342037
140939
145679
140916
349414
141353

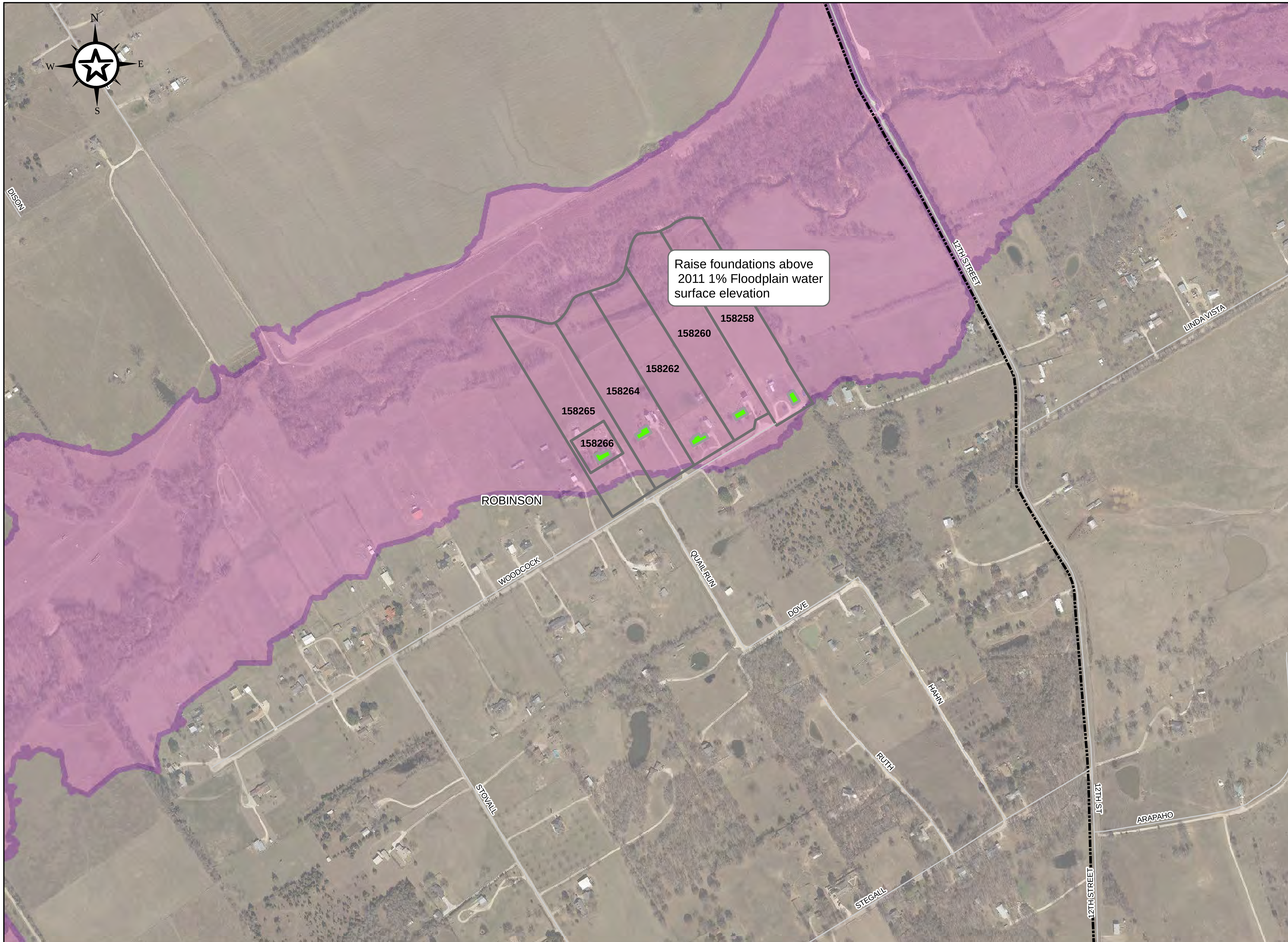
EXHIBIT D-6: INUNDATED ROADWAYS

REACH	CROSSING	ROAD ELEV	PASSING STORM FREQUENCY	100-yr Overtopping Flood Depth
Main	3rd St.	391.94	100-YR	-1.15
Main	University Parks	406.60	5-YR	1.64
Main	12th St.	423.40	5-YR	2.85
Main	Robinson Rd.	460.98	10-YR	1.19
Main	Old Robinon Rd.	463.36	2-YR	2.84
Main	Greig Rd.	495.54	2-YR	2.93
North Trib.	IH 35	520.05	100-YR	-5.87
North Trib.	Bagby Rd.	552.50	500-YR	-3.62
North Trib.	Texas Central Pkwy	555.81	500-YR	-1.23
North Trib.	Imperial Drive	584.10	2-YR	2.30
South Trib.	IH 35	518.04	5-YR	3.65
South Trib.	Bagby Rd.	552.07	100-YR	-2.51
South Trib.	Gateway Blvd.	558.61	5-YR	0.67
South Trib.	Panther Way	587.18	none	11.96
South Trib.	Old Hewitt Dr.	598.98	none	2.61
South Trib.	Mars Dr.	609.26	5-YR	1.23
South Trib.	Hewitt Dr.	622.00	none	2.06
SFT Trib 1	Mars Dr.	609.11	10-YR	1.29
SFT Trib 2	Panther Way	598.29	none	2.40
SFT Trib 2	Hewitt Dr.	626.35	10-YR	0.51
SFT Trib 2	Lindenwood	654.94	none	2.3
SFT Trib 3	N. Hewitt Dr.	620.34	2-YR	0.99
			Average =	**1.32**

Appendix E – Mitigation Solutions

Exhibit E-1A	**FCR-001 Woodcock Drive & 12th Street Conceptual Solution**
Exhibit E-1B	**FCR-001 One-Page Summary Form**
Exhibit E-2A	**FCR-002 Robinson Drive & Old Robinson Road Conceptual Solution**
Exhibit E-2B	**FCR-002 One-Page Summary Form**
Exhibit E-3A	**FCR-003 Panther Way & Old Hewitt Road Conceptual Solution**
Exhibit E-3B	**FCR-003 One-Page Summary Form**
Exhibit E-4A	**FCR-004 Hewitt Elementary Applewood / Lindenwood Conceptual Solution**
Exhibit E-4B	**FCR-004 One-Page Summary Form**
Exhibit E-5	**FCR-005 Venture Drive and Railroad Conceptual Solution**

(This Page Intentionally Left Blank)



Legend

- Affected Properties
- 2011 - 1% Floodplain
- City Limits

0 125 250 500
Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit E-1A
FCR001: Woodcock Drive & 12th Street Conceptual Solution

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

Exhibit E-1B

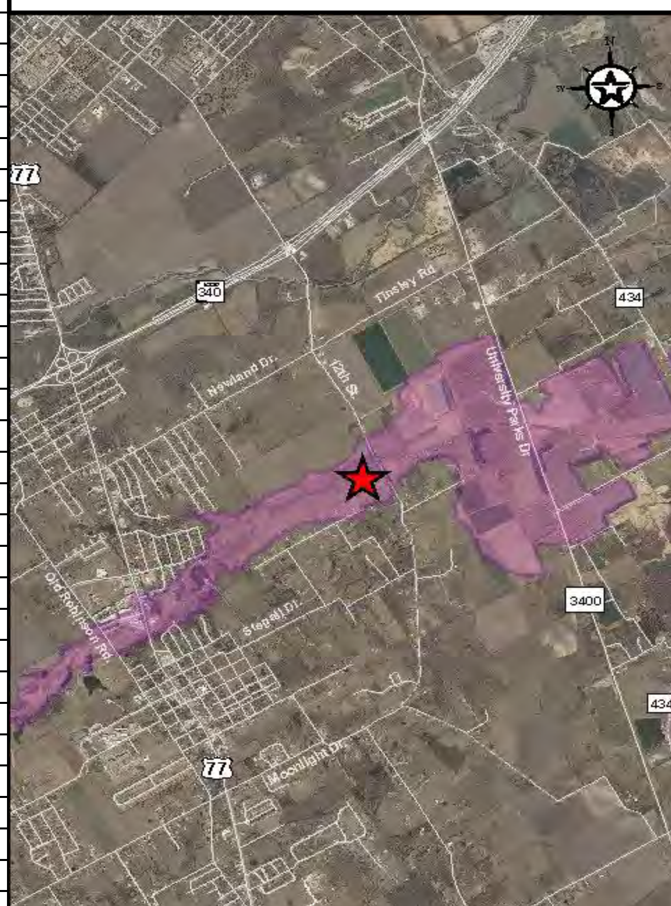
Project Number:	Flooding Source:
FCR001	Flat Creek Main

Recommended Improvements			Location (Nearest Street Intersection)	
☑ Buyout	☐ Channel Improvements	☐ Other	From:	Woodcock Dr
☐ Detention	☐ Structure Improvements		To:	Woodcock Dr

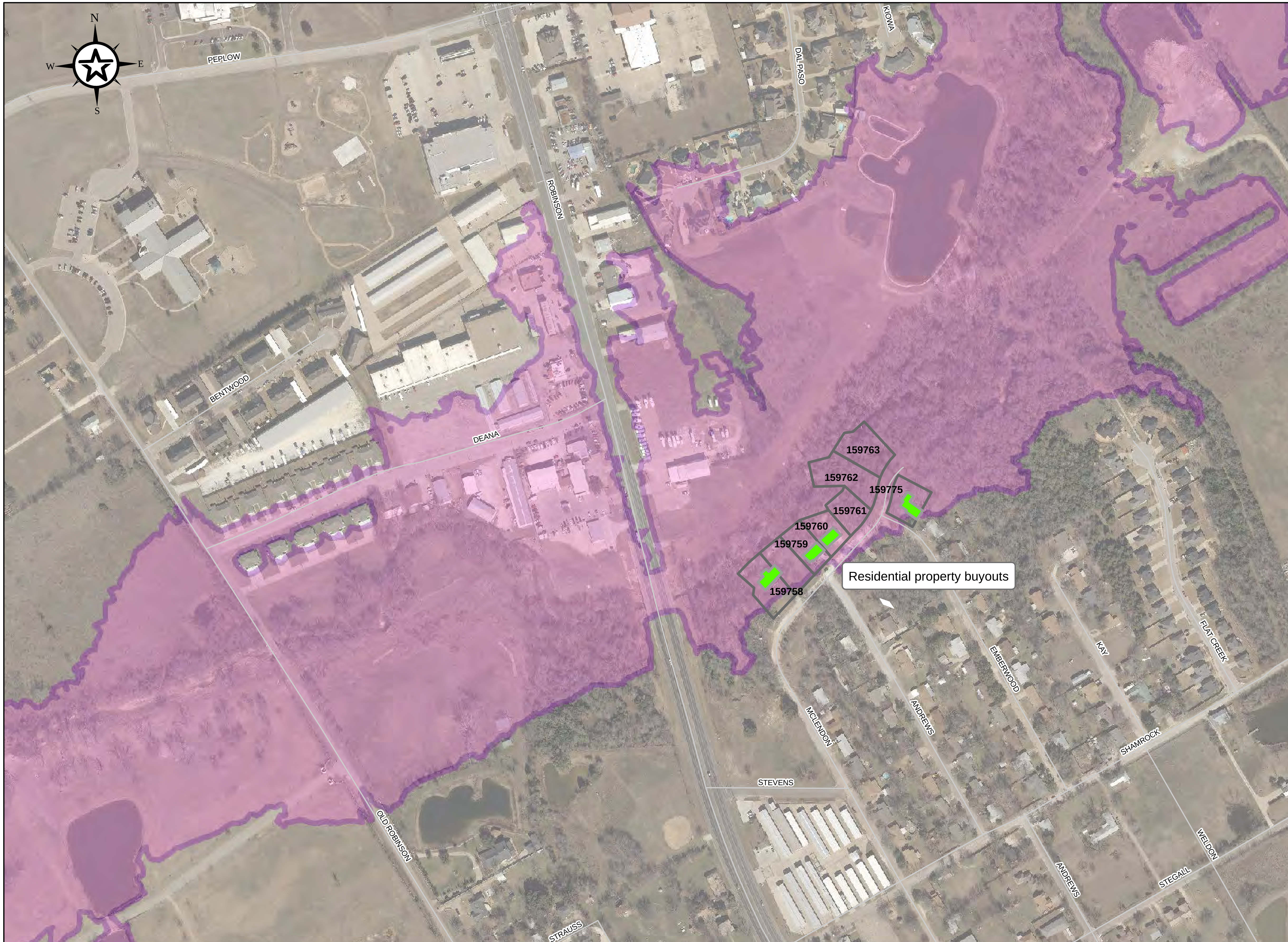
Description	Est. Qty.	Unit	Unit Price	Total
Property Buyout Items				
Prop. ID #158258 - 1400 Woodcock Drive	2815	SF	$25.00	$70,375.00
Prop. ID #158260 - 1311 Woodcock Drive	2604	SF	$25.00	$65,100.00
Prop. ID #158262 - 1309 Woodcock Drive	3616	SF	$25.00	$90,400.00
Prop. ID #158264 - 1305 Woodcock Drive	3331	SF	$25.00	$83,275.00
Prop. ID #158266 - 1213 Woodcock Drive	3331	SF	$25.00	$83,275.00
Construction Subtotal				$392,425.00
Contingency (20%)				-
Engineering and Surverying (15%)				-
Easement/ROW Acquisition				-
Foundation Raising Subtotal				**$392,425.00**
Total Estimated Project Cost				**$392,425.00**

Project Description

This project includes the raising of residential home foundations in Robinson along Woodcock Drive. Five structures will need to be raised to have finished floors above the 1% floodplain water surface elevation.



C.I.P. Rank:	**By:** JAC	**Date:** 4/6/17



Legend

Buyout Properties

2011 - 1% Floodplain

0 75 150 300

Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit E-2A
FCR002: Robinson Drive & Old Robinson Road Conceptual Solution

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

Exhibit E-2B

Project Number:	Flooding Source:
FCR002	Flat Creek Main

Recommended Improvements			Location (Nearest Street Intersection)	
☑ Buyout	☐ Channel Improvements	☐ Other	From:	Emberwood Drive
☐ Detention	☐ Structure Improvements		To:	US Hwy 77/Robinson Drive

Texas Water Development Board

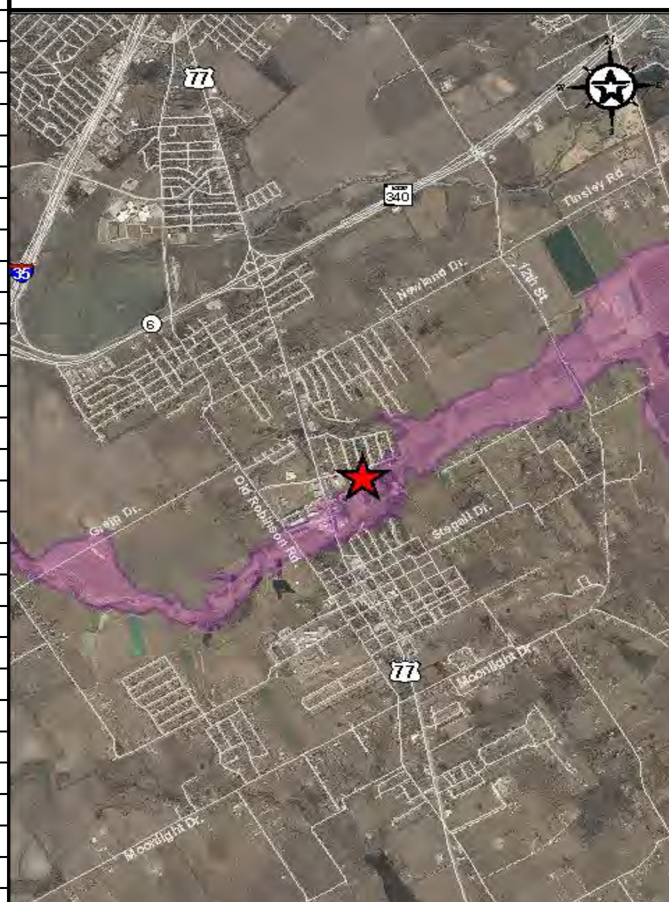
Walker Partners engineers • surveyors

HDR

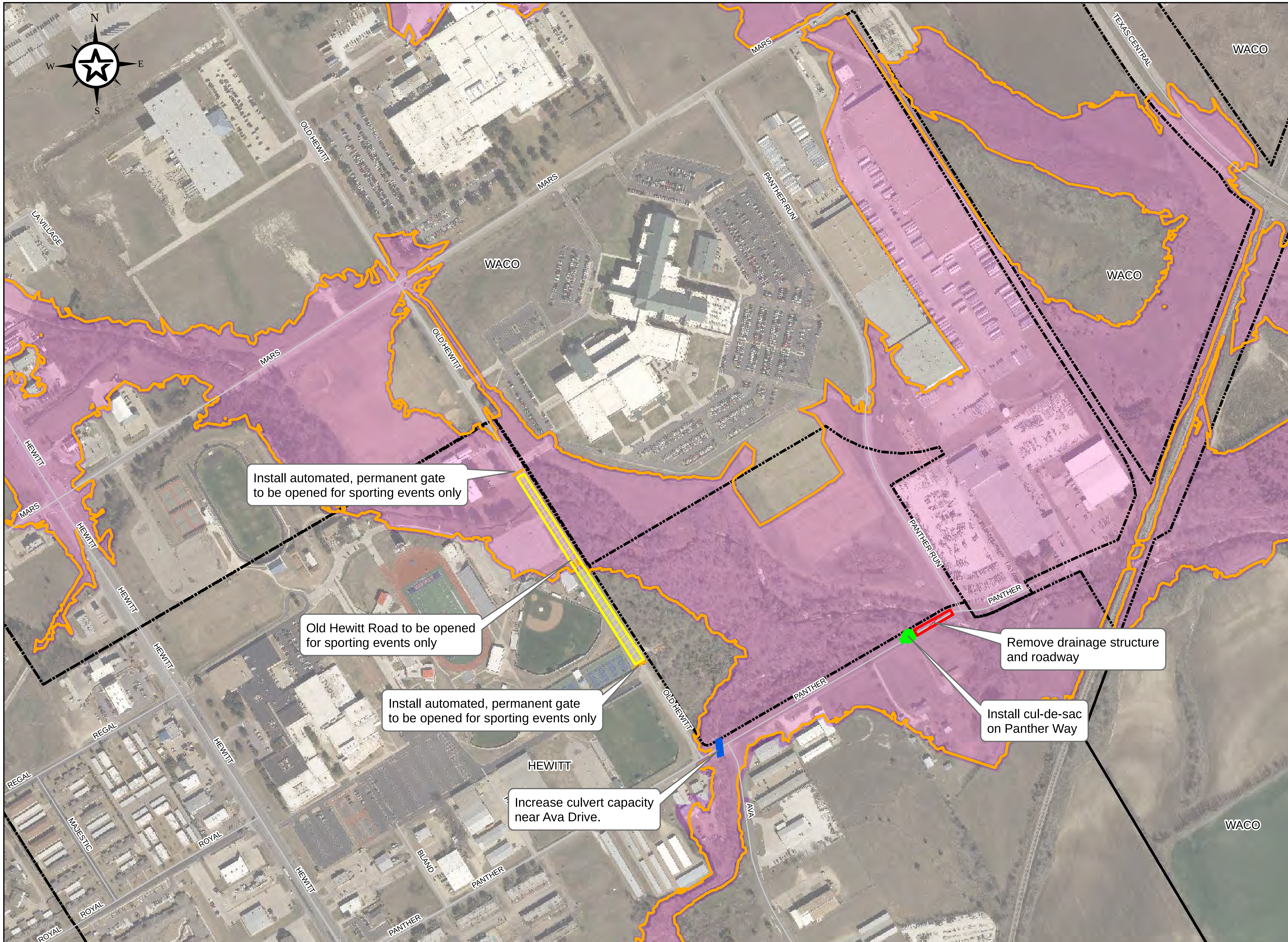
Description	Est. Qty.	Unit	Unit Price	Total
Property Buyout Items				
Prop. ID #159758 - 116 N. McLendon Drive	1.5	LS	$51,350.00	$77,025.00
Prop. ID #159759 - 118 N. McLendon Drive	1.5	LS	$62,920.00	$94,380.00
Prop. ID #159760 - 120 N. McLendon Drive	1.5	LS	$91,200.00	$136,800.00
Prop. ID #159761 - N. McLendon Drive (vacant)	1.5	LS	$4,304.00	$6,456.00
Prop. ID #159762 - N. McLendon Drive (vacant)	1.5	LS	$5,102.00	$7,653.00
Prop. ID #159763 - N. McLendon Drive (vacant)	1.5	LS	$5,642.00	$8,463.00
Prop. ID #159775 - 121 N. Emberwood Drive	1.5	LS	$116,930.00	$175,395.00
Buyout Subtotal				$506,172.00
Contingency (20%)				-
Engineering and Surverying (15%)				-
Easement/ROW Acquisition				-
Total Buyout Subtotal				**$506,172.00**
Total Estimated Project Cost				**$506,172.00**

Project Description

This project includes the buyout of seven residential properties in Robinson along McLendon Drive and Emberwood Drive. Four of the seven properties have inhabitable structures. The cost associated with the buyout of each property includes the appraisal and closing costs, demolition and disposal of the structure including hazardous materials (e.g. asbestos, lead paint), restoration of the lot to open space, and any difference between appraised and fair market value of the house.



C.I.P. Rank:		By: JAC	Date: 4/6/17



Legend

- 2011 - 1% Floodplain
- 2011 - 1% Floodplain With Project FCR003
- City Limits

0 100 200 400
Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit E-3A
FCR003: Panther Way & Old Hewitt Road Conceptual Solution

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

Exhibit E-3B

Project Number:	Flooding Source:
FCR003	South Flat Creek

Recommended Improvements		
☐ Buyout	☐ Channel Improvements	☑ Other
☐ Detention	☑ Structure Improvements	

Location (Nearest Street Intersection)	
From:	Old Hewitt Road
To:	Panther Way

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

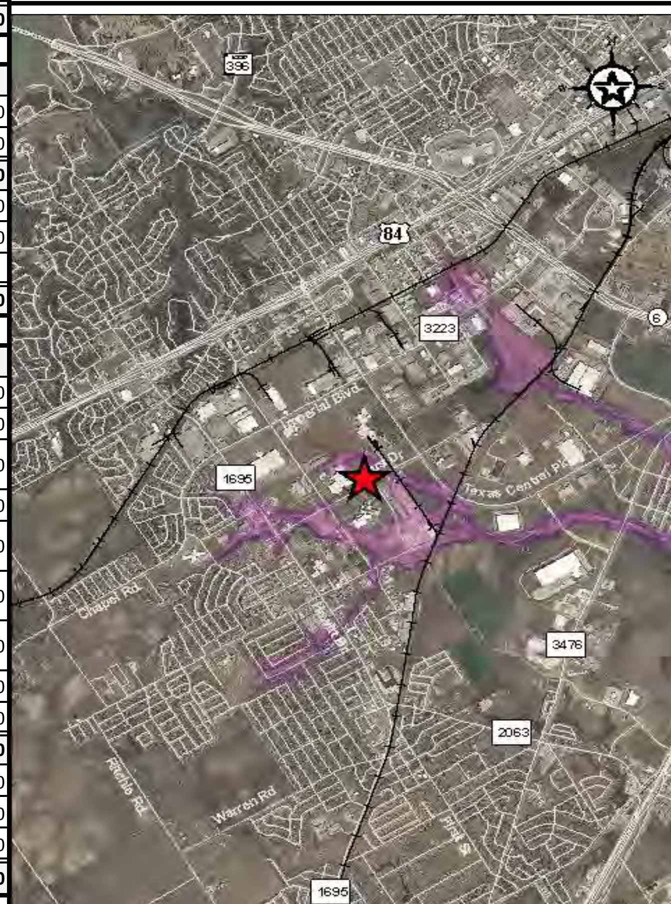
Description	Est. Qty.	Unit	Unit Price	Total
FCR003.1: Panther Way Cul-de-Sac Items				
Mobil., Barricade & Project Incidentals (15%)	1	LS	$12,000.00	$12,000.00
Stormwater Pollution Prevention Plan	1	LS	$750.00	$750.00
Stormwater Pollution Prevention Plan Implementation	1	LS	$3,000.00	$3,000.00
Remove Existing Roadway	780	SY	$7.00	$5,460.00
Remove Concrete Headwall	2	EA	$7,000.00	$14,000.00
Remove 3-10'x8' culverts	40	LF	$410.00	$16,400.00
Channel Stabilization	400	SY	$12.00	$4,800.00
6" Lime Stabilization of Existing Sub-base Material	245	SY	$10.00	$2,450.00
Hydrated Lime	4	TN	$320.00	$1,280.00
6" Cement Treated Base	245	SY	$25.00	$6,125.00
1.5" H.M.A.C. (Crushed 'D')	21	TN'	$170.00	$3,570.00
Metal Beam Guard Fence	400	LF	$40.00	$16,000.00
Type 3 Barricade	2	EA	$1,200.00	$2,400.00
Broadcast Seeding	540	SY	$2.50	$1,350.00
Curlex Blanket (Green)	540	SY	$4.00	$2,160.00
Construction Subtotal				**$91,745.00**
Contingency (20%)				$18,300.00
Engineering and Surveying (15%)				$13,800.00
Easement/ROW Acquisition ($0.35 per square foot)				-
Cul-de-Sac Subtotal				**$123,845.00**
FCR003.2: Old Hewitt Road Closure Items				
Mobil., Barricade & Project Incidentals (15%)	1	LS	$3,800.00	$3,800.00
Automated Permanent Gate	2	EA	$25,000.00	$50,000.00
Construction Subtotal				**$53,800.00**
Contingency (20%)				$10,800.00
Engineering and Surveying (15%)				$8,100.00
Easement/ROW Acquisition ($0.35 per square foot)				-
Road Closure Subtotal				**$72,700.00**
FCR003.3: Panther Way Culvert Improvement Items				
Mobil., Barricade & Project Incidentals (15%)	1	LS	$54,300.00	$54,300.00
Stormwater Pollution Prevention Plan	1	LS	$750.00	$750.00
Stormwater Pollution Prevention Plan Implementation	1	LS	$3,000.00	$3,000.00
Remove 72" Metal Culvert	57	LF	$110.00	$6,270.00
3-10'x7' R.C.B.C (Class III) Including Excavation & Backfill	166	CY	$1,550.00	$257,300.00
Reinforced Concrete Headwall for 3-10'x7' R.C.B.C.	2	EA	$30,000.00	$60,000.00
Concrete Channel Lining - 4" Thick with 4" Gravel Cushion Reinforced with 6" x 6" / #10 W.W.F.	423	SY	$65.00	$27,495.00
6" Cement Treated Base	178	SY	$25.00	$4,450.00
1.5" H.M.A.C. (Crushed 'D')	15	TN	$170.00	$2,550.00
Construction Subtotal				**$416,115.00**
Contingency (20%)				$83,200.00
Engineering and Surverying (15%)				$62,400.00
Easement/ROW Acquisition ($0.35 per square foot)				$1,925.00
Culvert Improvements Subtotal				**$563,640.00**
Total Estimated Project Cost				**$760,185.00**

Project Description

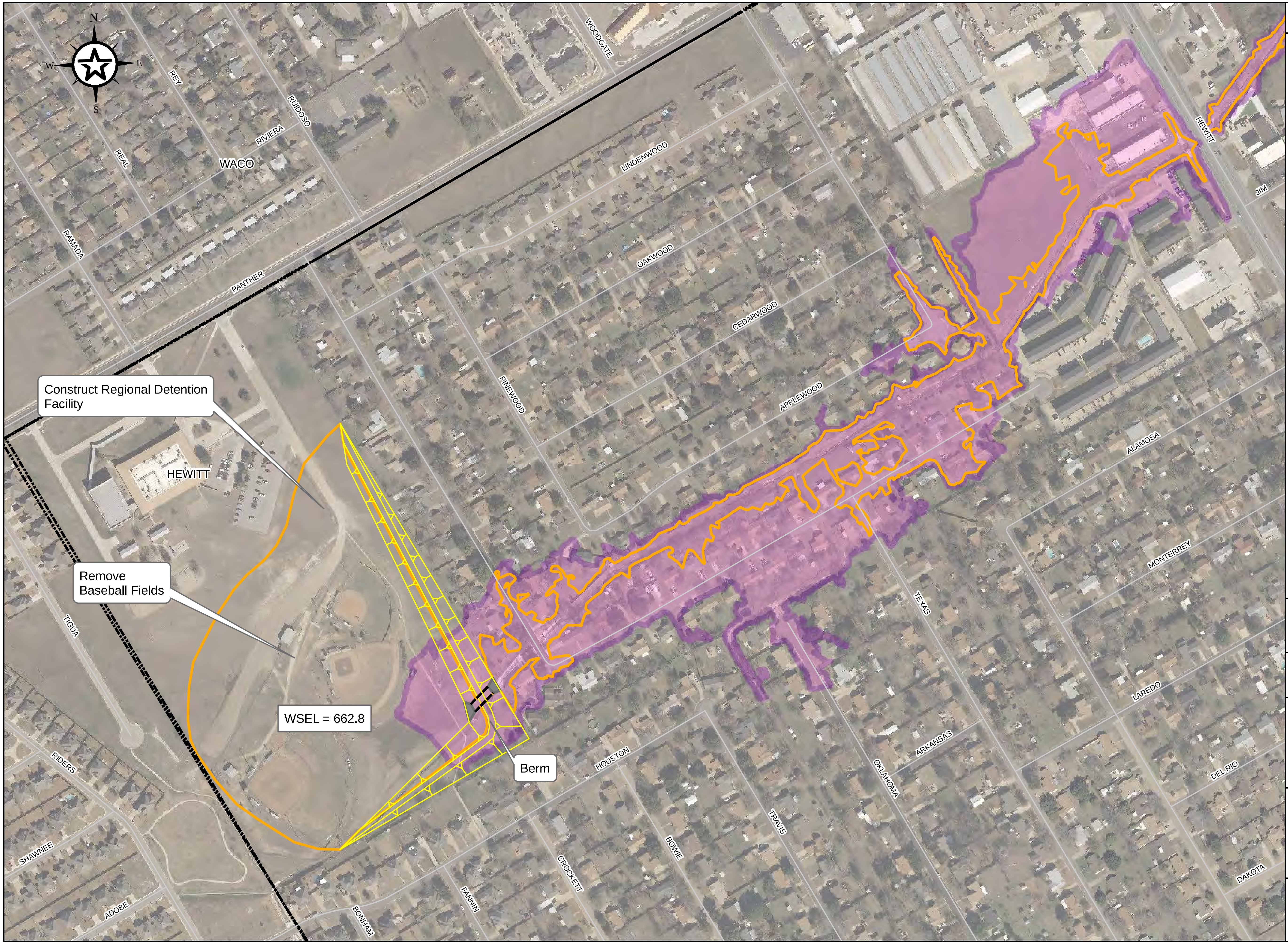
This project contains improvements in three areas. The first is at the intersection of Panther Way and Panther Run Road. Improvements in this location will include installation of a cul-de-sac on Panther Way and removal of the creek crossing at the corresponding intersection. This will remove a crossing that floods in low flow events and reduce the amount of vehicles navigating through the flood-prone area by eliminating the traffic loop.

The second area of improvements is along Old Hewitt Road in between Mars Drive and Panther Way. An automated, permanent gate will be installed in two locations on Old Hewitt Drive to eliminate an additional flood-prone crossing to traffic. The gates will only be open during large sporting events and by default will be down at all other times. Both gates will be positioned to avoid adverse impacts to the existing traffic patterns at Midway High School and Middle School.

The final area of improvements will be at the Panther Way channel crossing near Ava Drive. Improvements will include removal of the existing drainage structure and addition of 3-10'x7' box culverts. Addition of the box culverts will decrease the water surface elevation over the road and improve safety at the crossing.



C.I.P. Rank:		By: JAC	Date: 4/6/17



Legend

2011 - 1% Floodplain

2011 - 1% Floodplan With Project FCR004

City Limits

0 75 150 300

Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit E-4A
FCR004: Hewitt Elementary & Applewood/Lindenwood Conceptual Solution

Texas Water Development Board

Walker Partners engineers + surveyors

HDR

Exhibit E-4B

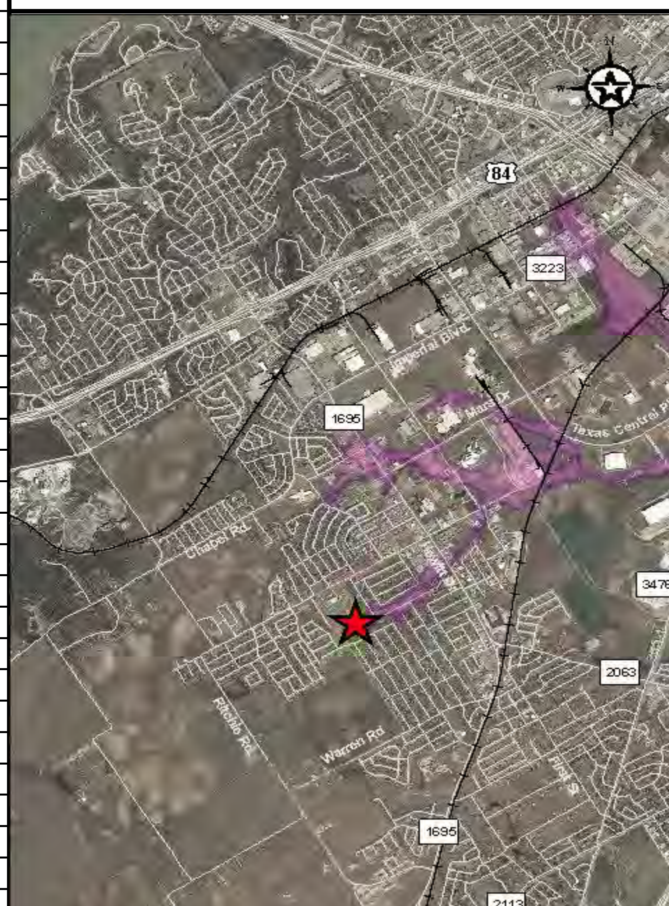
Project Number:	Flooding Source:
FCR004	South Flat Creek Tributary 2

Recommended Improvements			Location (Nearest Street Intersection)	
☐ Buyout	☐ Channel Improvements	☐ Other	From:	Panther Way
☑ Detention	☐ Structure Improvements		To:	Lindenwood Lane

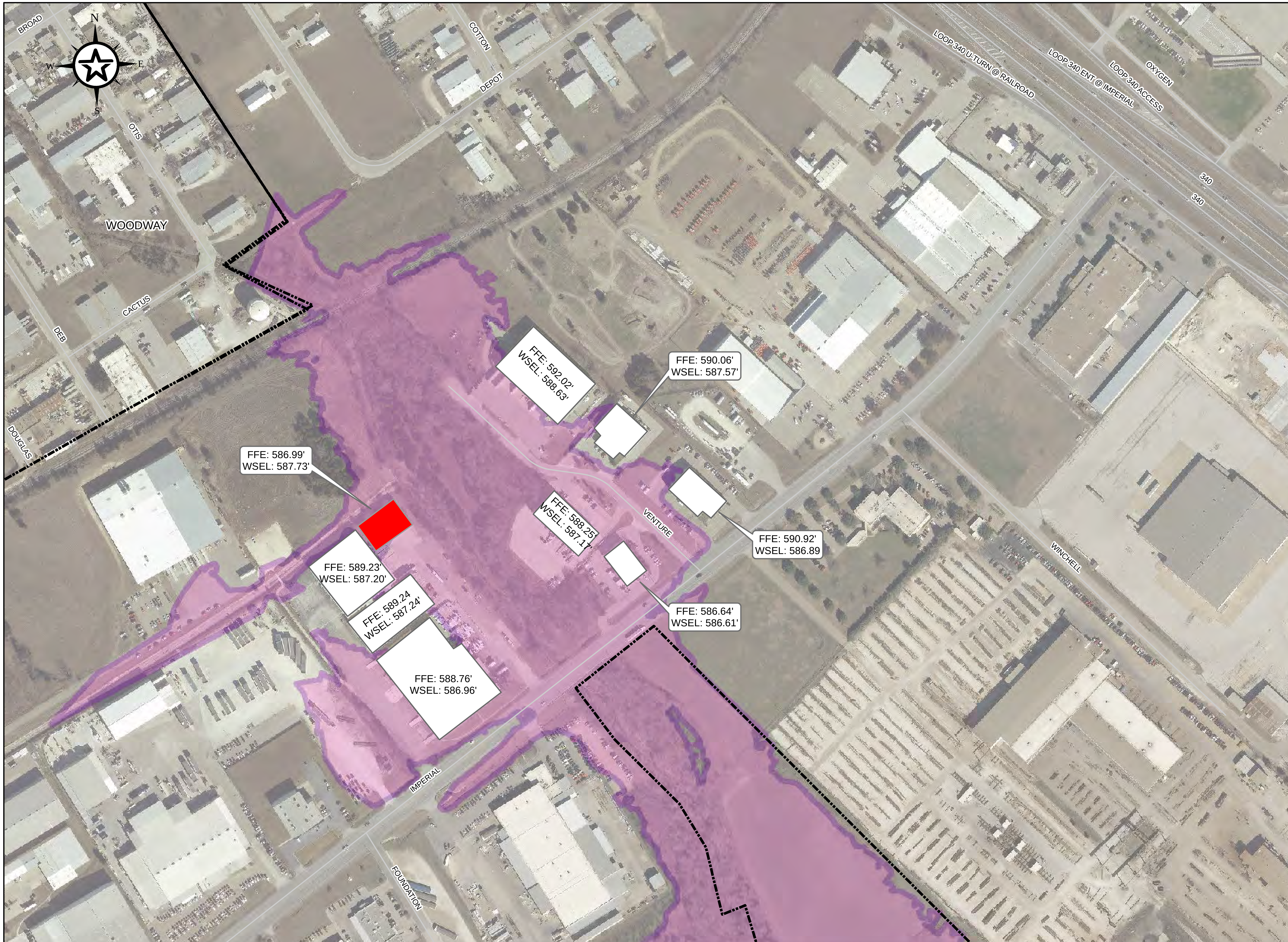
Description	Est. Qty.	Unit	Unit Price	Total
Regional Detention Facility Items				
Mobil., Barricade & Project Incidentals (15%)	1	LS	$443,800.00	$443,800.00
Stormwater Pollution Prevention Plan	1	LS	$750.00	$750.00
Stormwater Pollution Prevention Plan Implementation	1	LS	$3,000.00	$3,000.00
Remove Existing Baseball Fields	1	LS	$50,000.00	$50,000.00
Pond Grading and Excavation	150,000	CY	$15.00	$2,250,000.00
Density Controlled Embankment	20,000	CY	$5.00	$100,000.00
Outlet Structure	1	LS	$250,000.00	$250,000.00
Concrete Channel Lining - 4" Thick with 4" Gravel Cushion Reinforced with 6" x 6" / #10 W.W.F.	550	SY	$65.00	$35,750.00
Broadcast Seeding	91500	SY	$2.50	$228,750.00
Curlex Blanket (Green)	10000	SY	$4.00	$40,000.00
Reconstruct Baseball Fields (Including Lighting)	1	LS	TBD	TBD
Construction Subtotal				**$3,402,050.00**
Contingency (20%)				$680,400.00
Engineering and Surveying (15%)				$510,300.00
Easement Acquisition (450' Width x 3000' Length x $0.35 per square foot)				$472,500.00
Detention Facility Subtotal				**$5,065,250.00**
Total Estimated Project Cost				**$5,065,250.00**
C.I.P. Rank:				

Project Description

This project includes construction of a regional detention facility on South Flat Creek Tributary 2 to reduce flows through the downstream subdivision and at Hewitt Drive. The detention facility location is behind Hewitt Elementary near Houston Drive, and Lindenwood Lane. Construction of the facility would require removal of the existing baseball fields that currently occupy the land just south of the elementary school. Further study would be required to determine if the baseball fields could be reconstructed after the completion of the detention facility.



By: JAC **Date:** 4/6/17



Legend

2011 - 1% Floodplain

City Limits

FFE: Finished Floor Elevation

WSEL: 1% Flood Water Surface Elevation

0 75 150 300

Scale (Feet)

Flat Creek Flood Protection Plan

Exhibit E-5A
FCR005: Venture Drive & Railroad Conceptual Solution

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

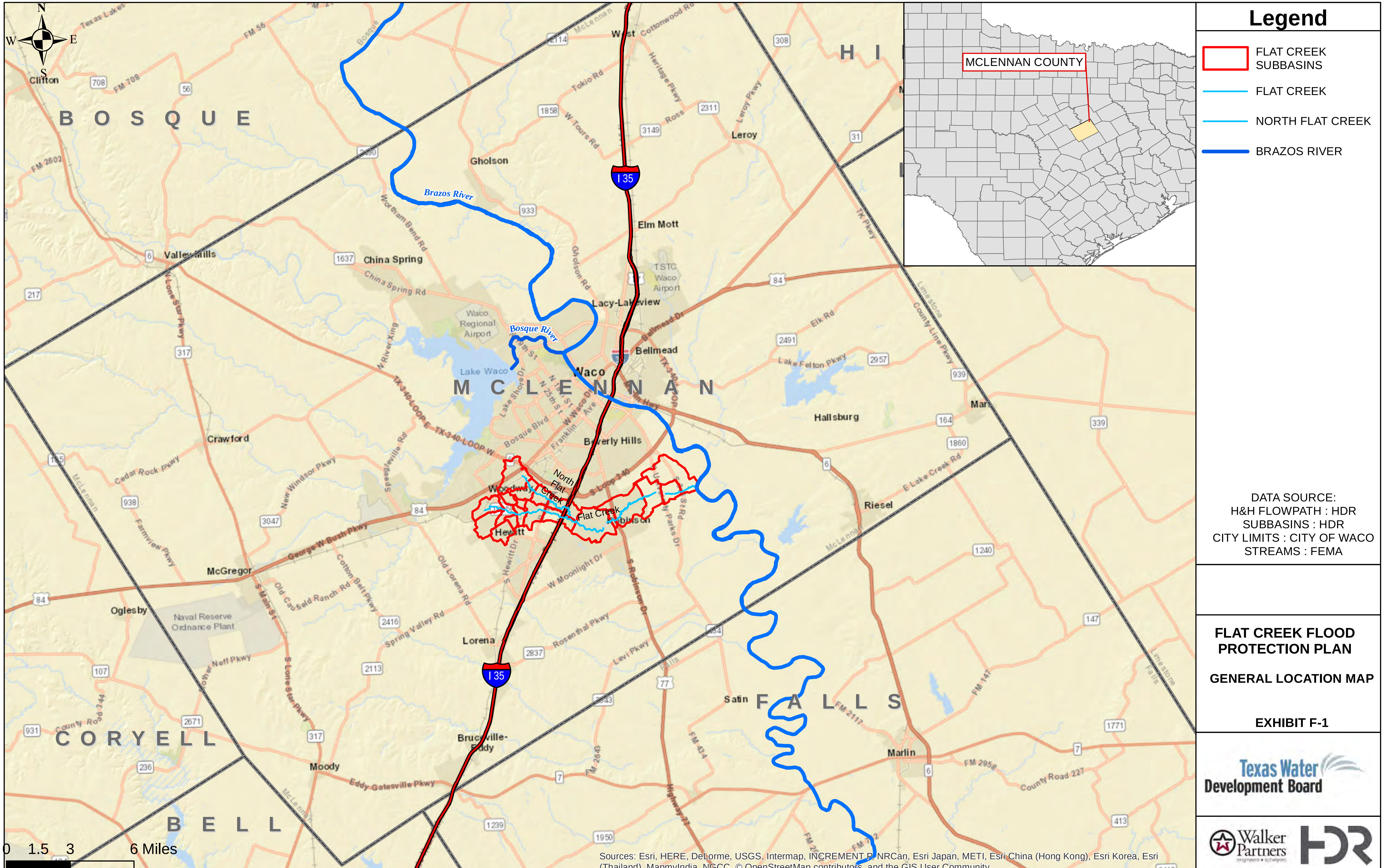
Appendix F – Environmental

Exhibit F-1 **General Location Map**

Exhibit F-2 **Preliminary Waters of the U.S.**

Exhibit F-3 **Preliminary Cultural Resources Map**

(This Page Intentionally Left Blank)


Legend
FLAT CREEK SUBBASINS
FLAT CREEK
NORTH FLAT CREEK
BRAZOS RIVER
MCLENNAN COUNTY
DATA SOURCE:
H&H FLOWPATH : HDR
SUBBASINS : HDR
CITY LIMITS : CITY OF WACO
STREAMS : FEMA
FLAT CREEK FLOOD PROTECTION PLAN
GENERAL LOCATION MAP
EXHIBIT F-1
Texas Water Development Board
Walker Partners
HDR
0 1.5 3 6 Miles
N
S
E
W
B O S Q U E
M C L E N N A N
C O R Y E L L
B E L L
F A L L S
Brazos River
Bosque River
Lake Waco
Waco
Bellmead
Lacy-Lakeview
Beverly Hills
Woodway
Hewitt
Robinson
North Flat Creek
Flat Creek
China Spring
Gholson
Elm Mott
West
Leroy
Valley Mills
Crawford
McGregor
Oglesby
Naval Reserve Ordnance Plant
Lorena
Bruceville-Eddy
Moody
Hallsburg
Riesel
Satin
Marlin
Clifton
Waco Regional Airport
TSTC Waco Airport
I 35
Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Legend

POTENTIAL WATERS OF THE U.S.

- STREAMS
- PROBLEM
- CITY LIMITS

CITY LIMITS : TxDOT 2013

0 0.25 0.5 1
Miles

FLAT CREEK FLOOD PROTECTION PLAN

PRELIMINARY WATERS OF THE U.S.

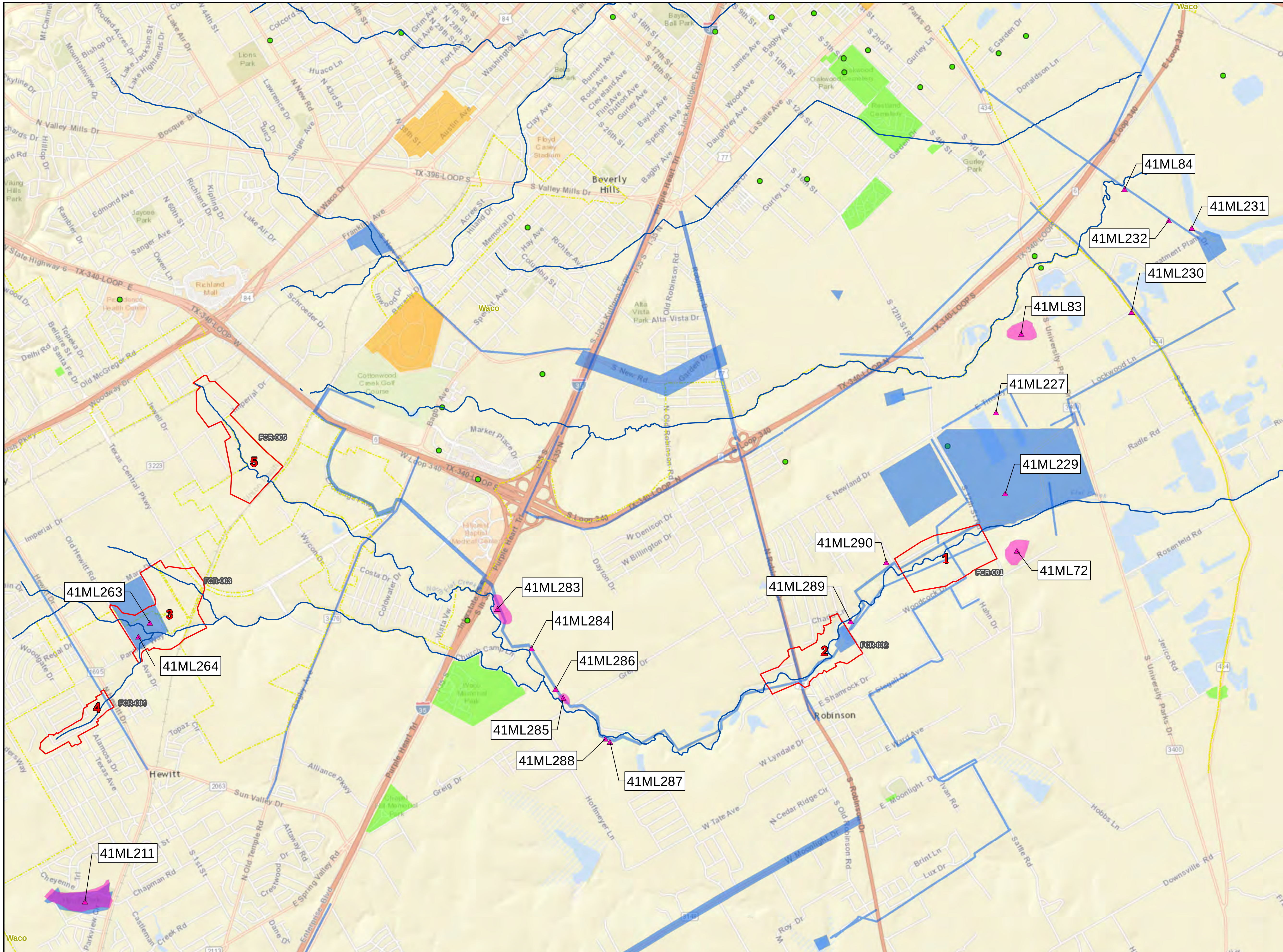
EXHIBIT F-2

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

FILE: O:\247993_037_WALKER_PRTNRS_WACO_STRM_MP_PH1_PH2\MAP_DOCS\FIGURES\WACOSWMP_FLATCREEK_WOTUS_11X17.MXD



Legend

PROBLEM AREA
PREVIOUSLY RECORDED ARCHAEOLOGICAL SITE
PREVIOUSLY RECORDED ARCHAEOLOGICAL SITE BOUNDARY
PREVIOUSLY-SURVEYED AREA (LINEAR)
PREVIOUSLY-SURVEYED AREA
HISTORICAL FEATURE
CEMETARY
HISTORICAL DISTRICT
CITY LIMITS

CITY LIMITS : TxDOT 2013

0 0.25 0.5 1
Miles

FLAT CREEK FLOOD PROTECTION PLAN

PRELIMINARY CULTURAL RESOURCES MAP

EXHIBIT F-3

Texas Water Development Board

Walker Partners engineers • surveyors

HDR

FILE: O:\1247993_037_WALKER_PRTNRS_WACO_STRM_MP_PH1_PH2\MAP_DOCS\FIGURES\CULTURAL\WACOSWMP_FLATCREEK_CULTURALAERIALRESULTS_11X17.MXD

Appendix G – Digital Data on DVD

Draft Report.pdf

Draft Report.doc

Appendices

HEC-HMS Model

HEC-RAS Model

(This Page Intentionally Left Blank)