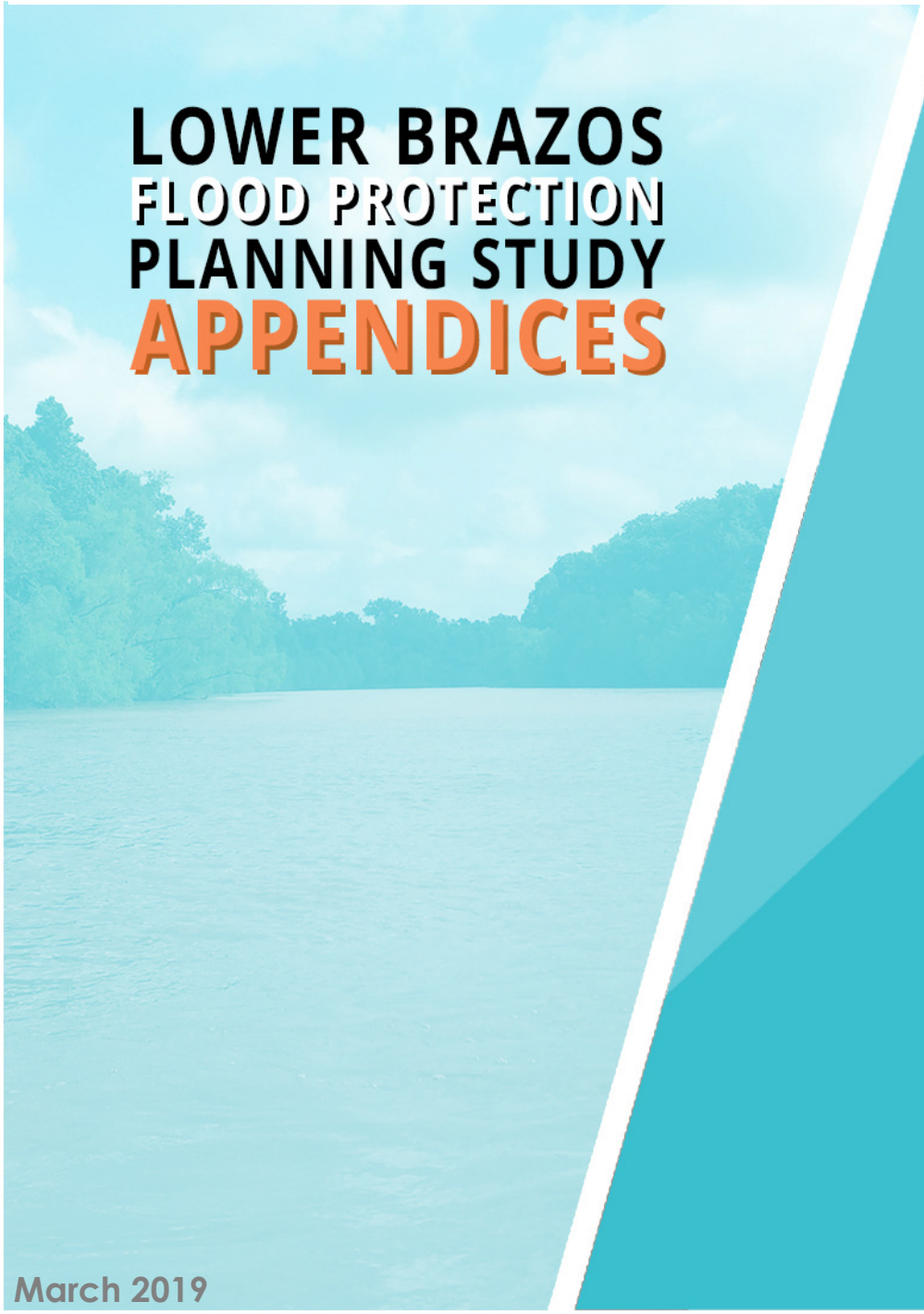
Appendix E:
Hydraulic Analysis



March 2019

Appendix E – Hydraulic Results

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Design Storm Water Surface Elevations

Model vs FIS 1% ACE Water Surface Elevations

Appendix E – Hydraulic Analysis

E.1.0 Introduction

The Lower Brazos River was modeled using Hydrologic Engineering Center River Analysis System (HEC-RAS) version 5.0.3 to produce water surface elevations for historical storms and the design storms from the hydrologic analysis. The HEC-RAS model consisted of a one-dimensional unsteady analysis of the Lower Brazos region. The model extended from the northern edge of Waller County (at the Grimes County Line) down to the Gulf of Mexico. In addition to the Brazos River, other river systems in Fort Bend and Brazoria Counties were included to account for the overflow conditions that exist within the Brazos River basin. The calibration storms consisted of the June – July 2007, the May – June 2016 and the August – September 2017 events. The model was tested against an event of high releases in October 2018 from the upstream reservoirs and appropriate parameters were adjusted so the model calibrated to the low event. Design storms analyzed were the 10%, 2%, 1%, and 0.2% ACE events. All water surface elevations shown in this report are referenced to the NAVD 88 vertical datum.

E.2.0 Geometric Data

E.2.1 Preliminary 2D Hydraulic Model

To aid in developing the one-dimensional (1D) geometric layout, a one/two-dimensional (1D/2D) unsteady hydraulic models were built in HEC-RAS to observe flow patterns and overflow conditions. The models upstream and downstream of Fort Bend County to simulate dynamic flow conditions in the Brazos River floodplain and to determine areas where overflow occurred in the model. This analysis was considered high-level and was only created to help facilitate the development of the 1D unsteady hydraulic model. HEC-GeoRAS in ArcGIS was used to build the 1D/2D model. Once the layout was set in HEC-GeoRAS, the geometry was imported into HEC-RAS. 1D cross sections were drawn from bank to bank of the Brazos River and lateral structures were drawn along the edges of the cross sections to connect the 1D and 2D areas. 2D areas were drawn outside of the 0.2% ACE floodplain of the Brazos River to ensure overflow was accounted for in all areas. Flows from the hydrologic model were applied to the cross sections to simulate the hydraulic conditions of the Brazos River and its floodplain.

Based on the results from the 1D/2D hydraulic model, overflow areas were identified upstream and downstream of Fort Bend County. At Mill Creek, flow from the Brazos River causes Mill Creek to backwater towards Bellville, TX. In Brazoria County, the overflow interaction with Oyster Creek was identified as a major influence on the Brazos River, in which much of the flow from the Brazos River transfers into the Oyster Creek floodplain. These observations aided in developing the 1D unsteady hydraulic model. The 1D model development is discussed in the following sections.

E.2.2 Cross-Section Geometry

Cross section data were developed using ArcGIS software, specifically the HEC-GeoRAS toolbar in ArcMap to create cross section profiles. HEC-GeoRAS is a tool in ArcMap where a user can create hydraulic features that are used in HEC-RAS with the ability to import the created data

directly into HEC-RAS. The hydraulic model incorporated newly built cross section data along with previously created cross section data from older hydraulic models. In addition to the Brazos River, cross sections in overflow river reaches were created to simulate the interaction between both the Brazos River and the overflow river reaches. Since the hydraulic modeling consisted of a 1D unsteady analysis, Hydraulic Table (HTab) parameters were established to determine the stage and hydraulic parameter relationships for each cross section. Detailed discussions of the cross-section data for each river reach is discussed below.

E.2.2.1 Brazos River – Waller, Washington, and Austin Counties

Information from the Waller County digital flood insurance rate map (DFIRM) such as base flood elevations (BFEs) and lettered cross sections (XSs) was used to help create cross sections within ArcMap. The data from Waller County originated from the Flood Insurance Study (FIS) completed in February 2009. The FIS only included portions of the Brazos River which included the stretch from US 290 to SH 159 and FM 1458 to the Waller County line. Cross section alignment followed the BFEs and lettered XSs as guides, while maintaining perpendicularity to the stream centerline and contours. Cross sections were spaced at an average interval of 0.75 miles, with minimum and maximum spacing of 30 feet and approximately 3 miles, respectively. Ineffective areas were added at structures and in overbank areas where no conveyance was assumed based on the terrain data and mapping. Levees were used on the downstream end of the Brazos River in Waller County to block overflow east of Bessies Creek. The geometric layout for the Brazos River in Waller County is shown in Figure E-1.

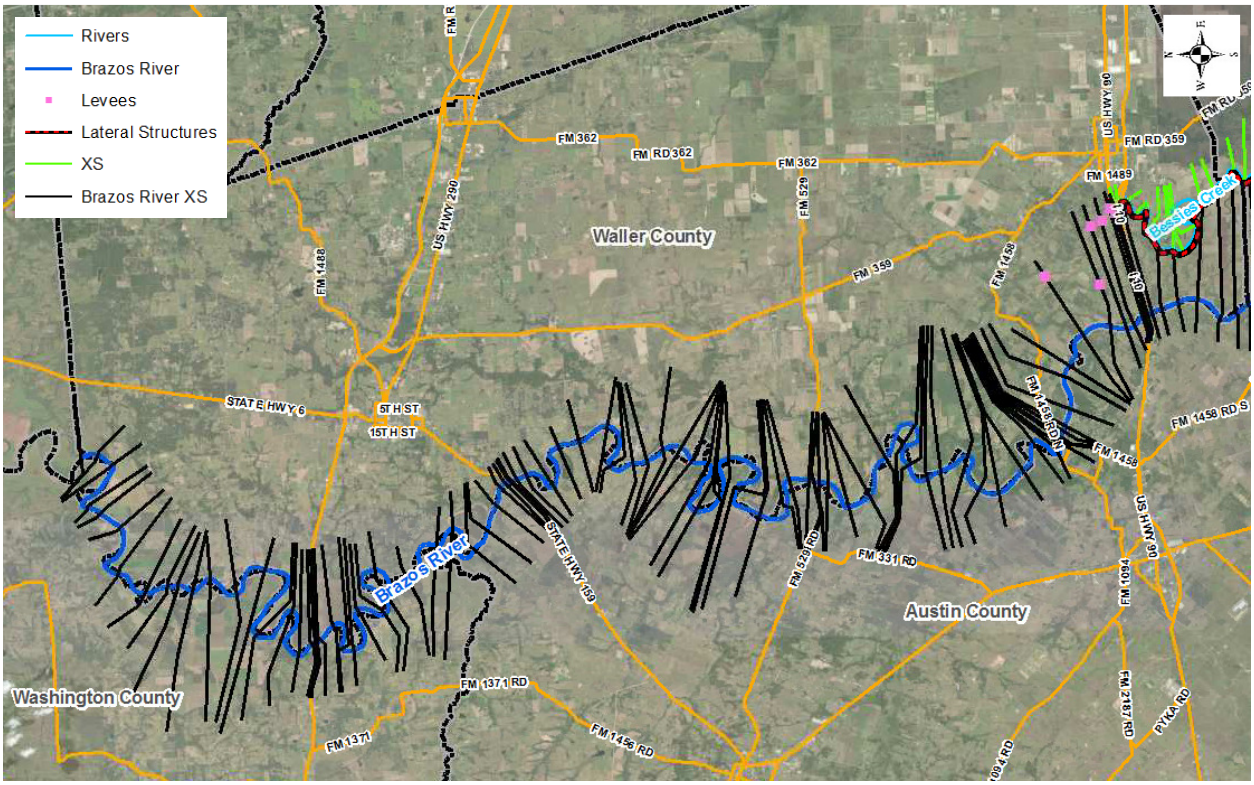

Figure E-1: Brazos River – Waller County Geometric Layout

E.2.2.2 Brazos River – Fort Bend County

In Fort Bend County, the Brazos River was studied in 2009 by LJA Engineering & Surveying, Inc. and resulted in the creation of an effective hydraulic model of the river within the county. This hydraulic model was used to create cross sections within Fort Bend County that were modified when necessary. Some of the original cross sections from the model were realigned, truncated or extended to integrate additional hydraulic elements such as the overflow river reaches and storage areas. Additional cross sections were added in the model to provide more detail in needed areas. Cross sections were spaced at an average interval of 0.85 miles with minimum and maximum spacing of 12 feet and approximately 3 miles, respectively. The Brazos River was also split into two reaches at the confluence with Ditch H to simulate backwater from the Brazos River into Ditch H with cross sections close to the modeled junction. Ineffective areas were added at structures and in overbank areas where no conveyance was assumed based on the terrain data and mapping. Levees were used to model the levee districts in Fort Bend County which prevent flooding from the Brazos River into the neighborhoods. Blocked obstructions were used to model low-lying areas that are not flooded by the river, such as neighborhoods with ring levees and areas beyond high points. The geometric layout for the Brazos River in Fort Bend County is shown below in Figure E-2.

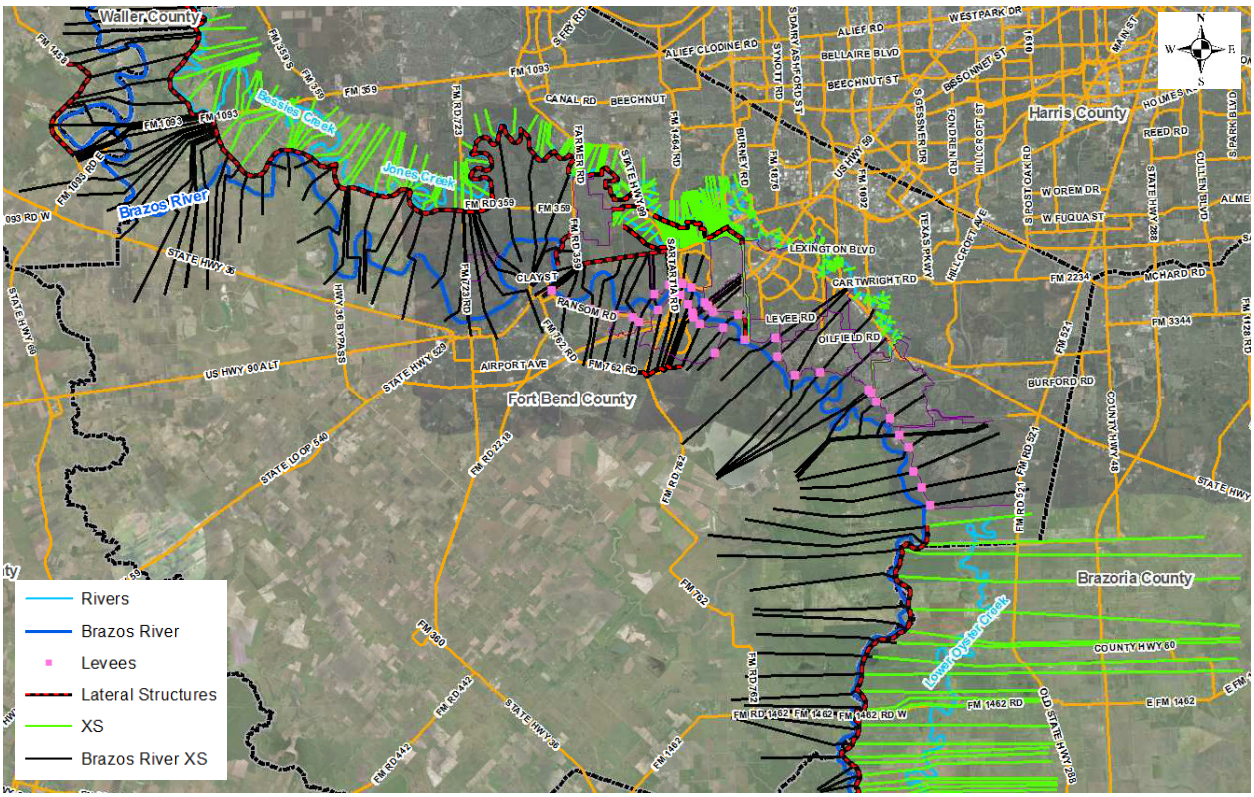

Figure E-2: Brazos River – Fort Bend Geometric Layout

E.2.2.3 Brazos River – Brazoria County

Like Waller, Washington, and Austin Counties, preliminary DFIRM data of Brazoria County was used to help create cross sections utilizing BFEs and lettered XS's. The last FIS study of Brazoria County was updated in September 1999 but was not used since no digital data were available from this study. Cross section alignment followed the BFEs and lettered XS's as guides while maintaining perpendicularity to the stream centerline and contours and were extended beyond the 0.2% ACE floodplain. Cross sections were drawn to a high point on the left overbank of the Brazos River. Lateral structures were drawn along the high point to model overflow from the Brazos River to Lower Oyster Creek. Cross sections were spaced at an average interval of 0.58 miles with minimum and maximum spacing of 83 feet and approximately 2 miles, respectively. Ineffective areas were added at structures and in overbank areas where no conveyance was assumed. Blocked obstructions were used to model low-lying areas that are not flooded by the river, such as neighborhoods with ring levees and areas beyond high points. The geometric layout for the Brazos River in Brazoria County is shown below in Figure E-3.

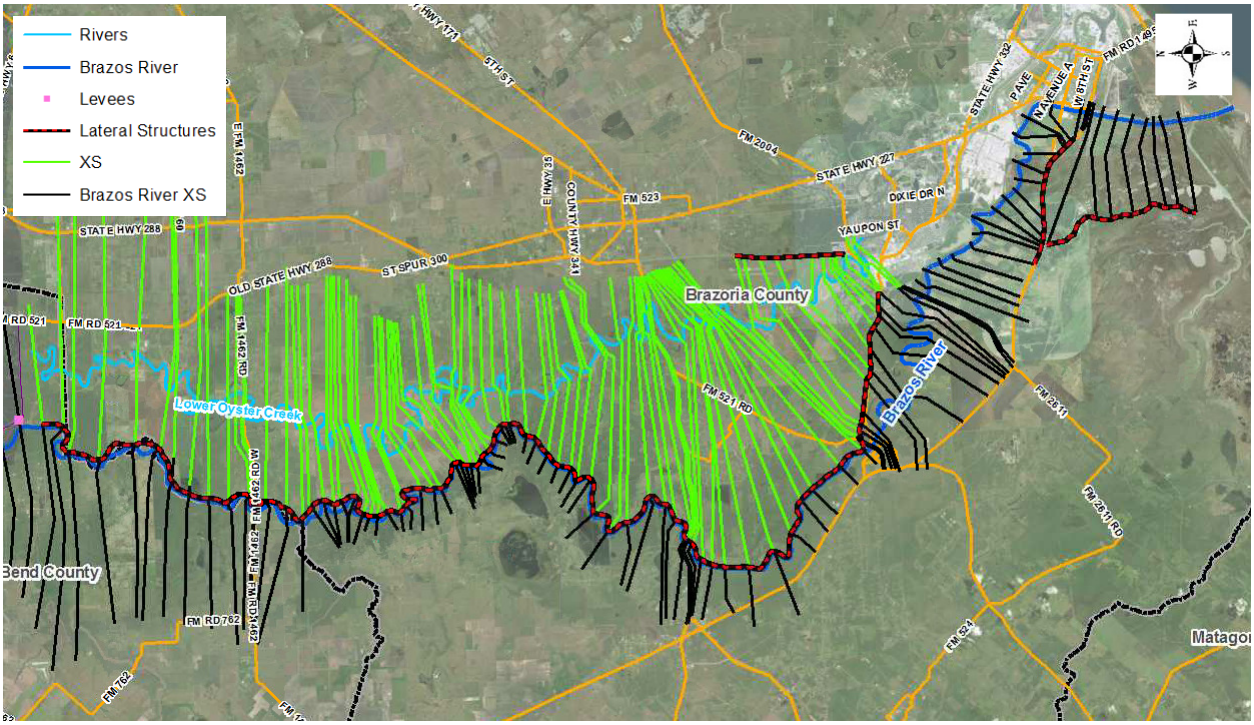

Figure E-3: Brazos River – Brazoria County Geometric Layout

E.2.2.4 Bessies Creek

Bessies Creek is located in the left overbank of the Brazos River in Fort Bend County and is modeled beginning just downstream of IH-10. Cross sections for both Bessies Creek and the Brazos River were drawn to high points and connected to each other by lateral structures to simulate the overflow conditions of the Brazos River into Bessies Creek. Some of the cross sections along Bessies Creek were drawn to the ends of the Brazos River cross sections to maintain the alignment across both reaches. Cross sections were drawn perpendicular to the stream centerline and contours. Spacing of cross sections averaged a length of 0.76 miles with minimum and maximum spacing of 56 feet and approximately 2 miles, respectively. Ineffective areas were added in overbank areas where no conveyance was assumed based on the terrain data and mapping. The geometric layout for Bessies Creek with the Brazos River cross sections shown in green is shown below in Figure E-4.

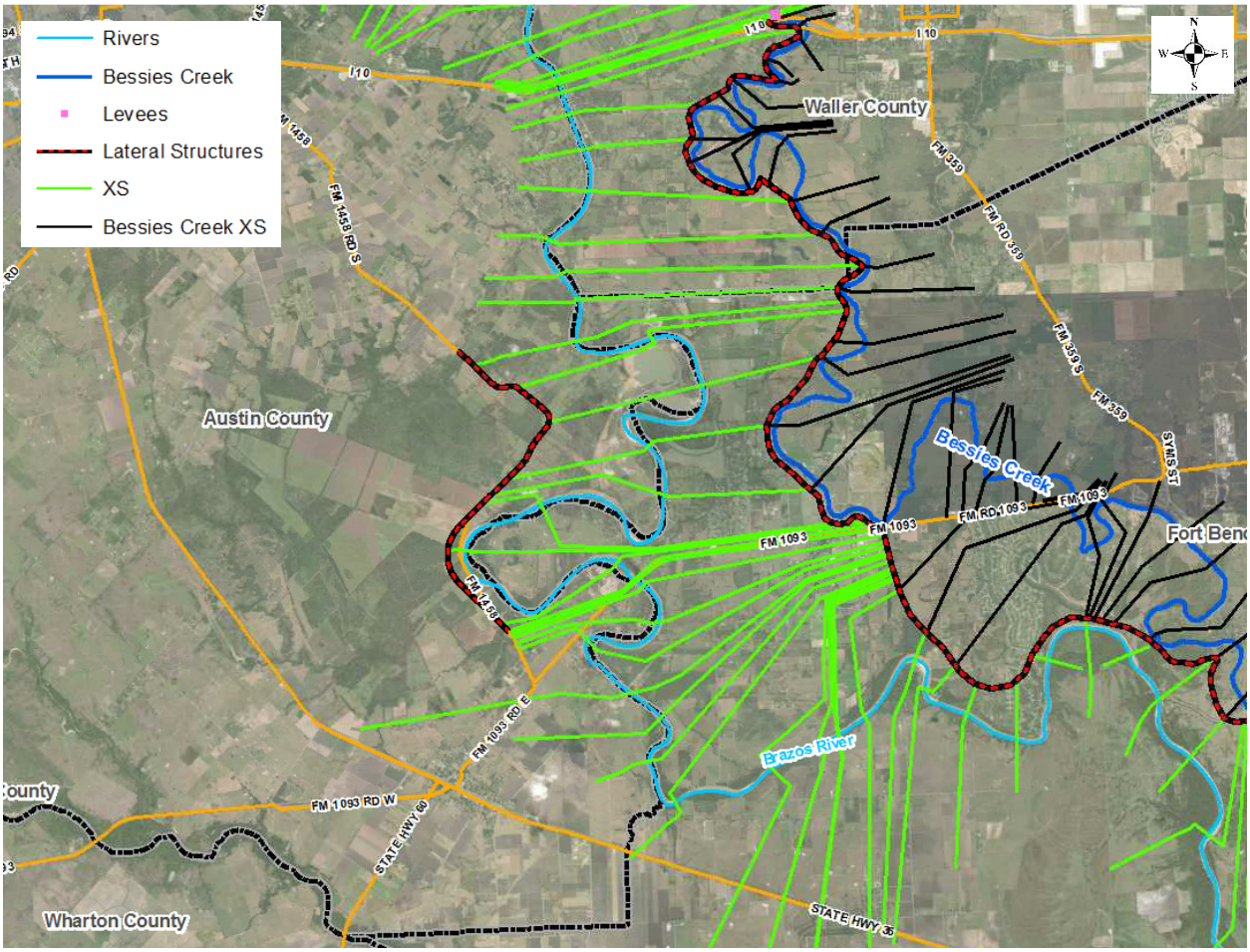

Figure E-4: Bessies Creek Geometric Layout

E.2.2.5 Jones Creek

Jones Creek is located near the Brazos River in Fort Bend County and is impacted by overflow from Bessies Creek and the Brazos River. Like Bessies Creek, cross sections were drawn to a high point for both the Brazos River and Jones Creek and connected to each other by lateral structures to simulate overflow conditions of the Brazos River and Jones Creek. Some of the cross sections

along Jones Creek were drawn to the ends of the Brazos River cross sections to maintain the alignment across both reaches. Cross sections were drawn perpendicular to the stream centerline and contours and were extended beyond the 0.2% ACE floodplain. Cross sections were spaced at an average interval of 0.76 miles with minimum and maximum spacing of 165 feet and approximately 1.5 miles, respectively. The geometric layout for Jones Creek is shown below in Figure E-5.

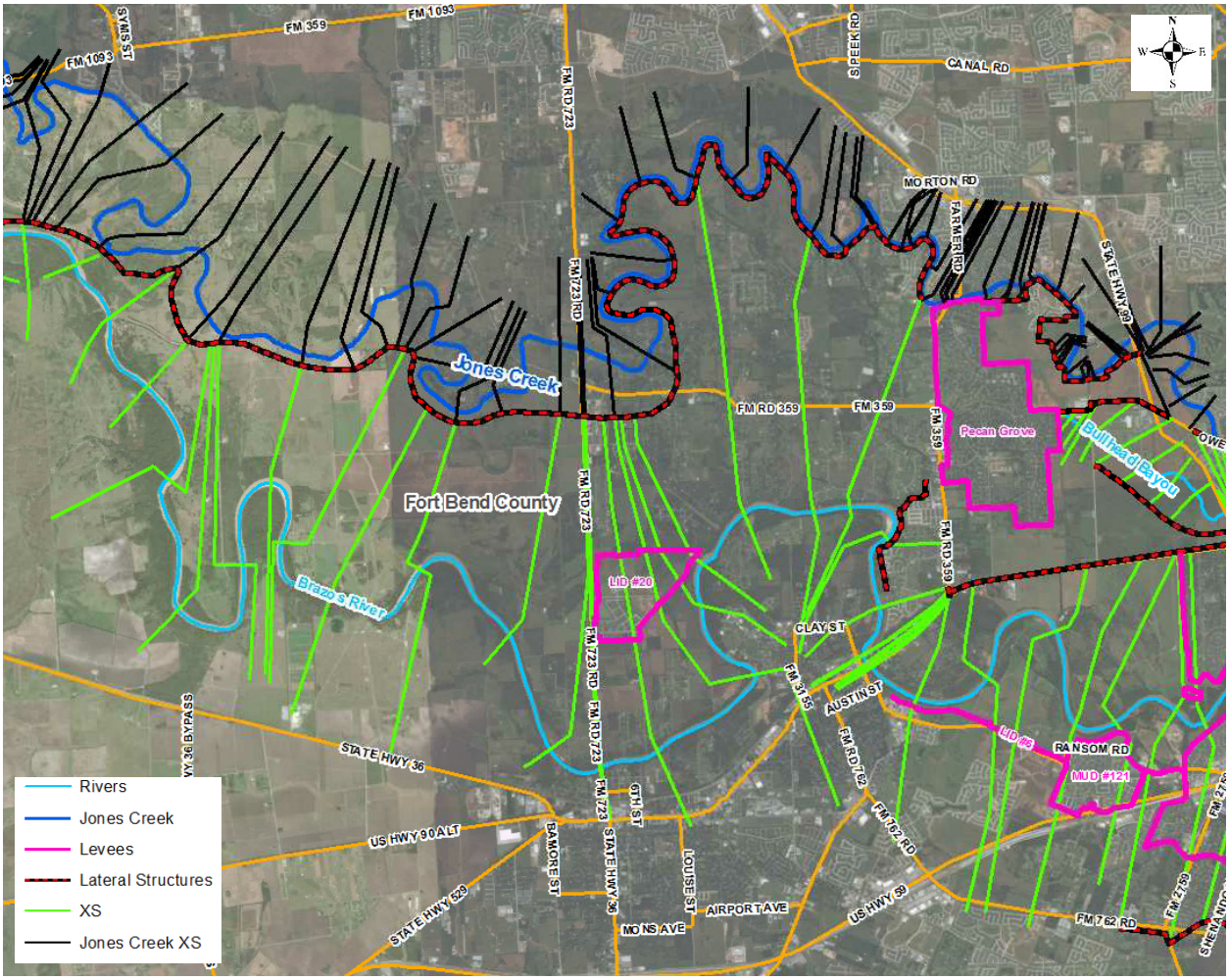

Figure E-5: Jones Creek Geometric Layout

E.2.2.6 Upper Oyster Creek

Cross sections of Upper Oyster Creek were derived from the hydraulic model provided by Freese and Nichols, Inc. (FNI). The FNI hydraulic model consisted of 1D and 2D hydraulic elements with overflow simulated in the 2D areas. Cross sections from FNI were used for Upper Oyster Creek but were extended into the overflow areas previously covered by the 2D areas to maintain the 1D analysis. Cross sections for both Upper Oyster Creek and Bullhead Bayou were extended to high points and connected by lateral structures to simulate overflow conditions between the two reaches. Upper Oyster Creek downstream of Stadium Drive was directly imported from the FNI model; only the downstream portion was modified by truncating part of the reach. Cross section spacing averaged a distance of approximately 600 feet with minimum of 1 foot and maximum

spacing of 3,800 feet. Ineffective areas were added at structures and in overbank areas where no conveyance was assumed based on the terrain data and mapping. The geometric layout for Upper Oyster Creek is shown below in Figure E-6.

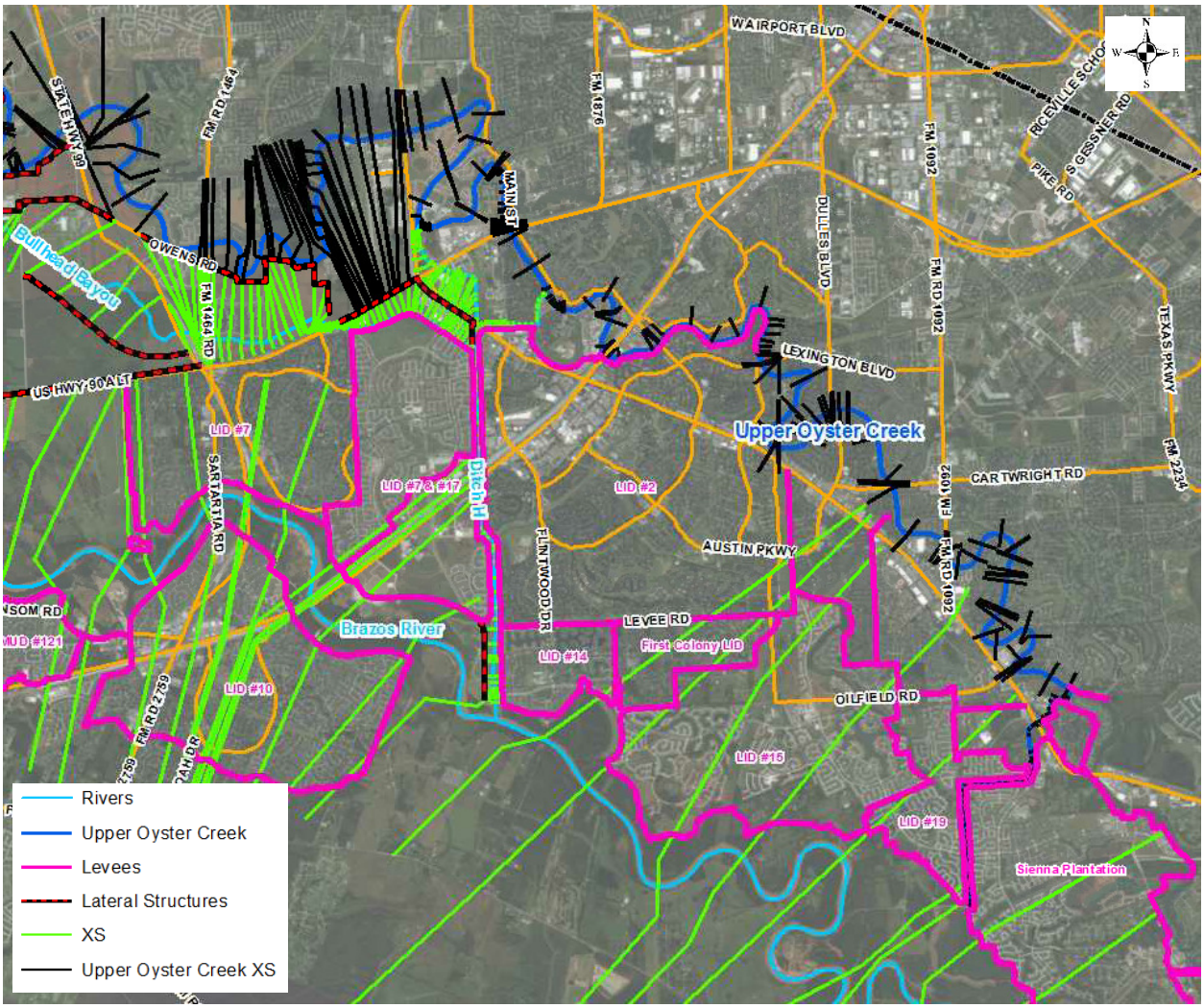

Figure E-6: Upper Oyster Creek Geometric Layout

E.2.2.7 Ditch H

Cross sections of Ditch H were imported from the FNI hydraulic model and modified to maintain consistency with the Lower Brazos River hydraulic model from this analysis. Like Upper Oyster Creek, cross sections were extended into overflow areas that were previously covered by 2D areas to maintain the 1D analysis. Cross sections adjacent to the 2D areas were extended to Highway 6 which was considered a high point in the overbank. Cross section spacing averaged a distance of approximately 250 feet with minimum and maximum spacing of 2 feet and approximately 875 feet, respectively. Ditch H splits the Brazos River in the HEC-RAS model into two reaches and models backwater from the Brazos River into Ditch H. Ineffective areas were added at structures and in overbank areas where no conveyance was assumed based on the terrain data and mapping. The geometric layout for Ditch H is shown below in Figure E-7.

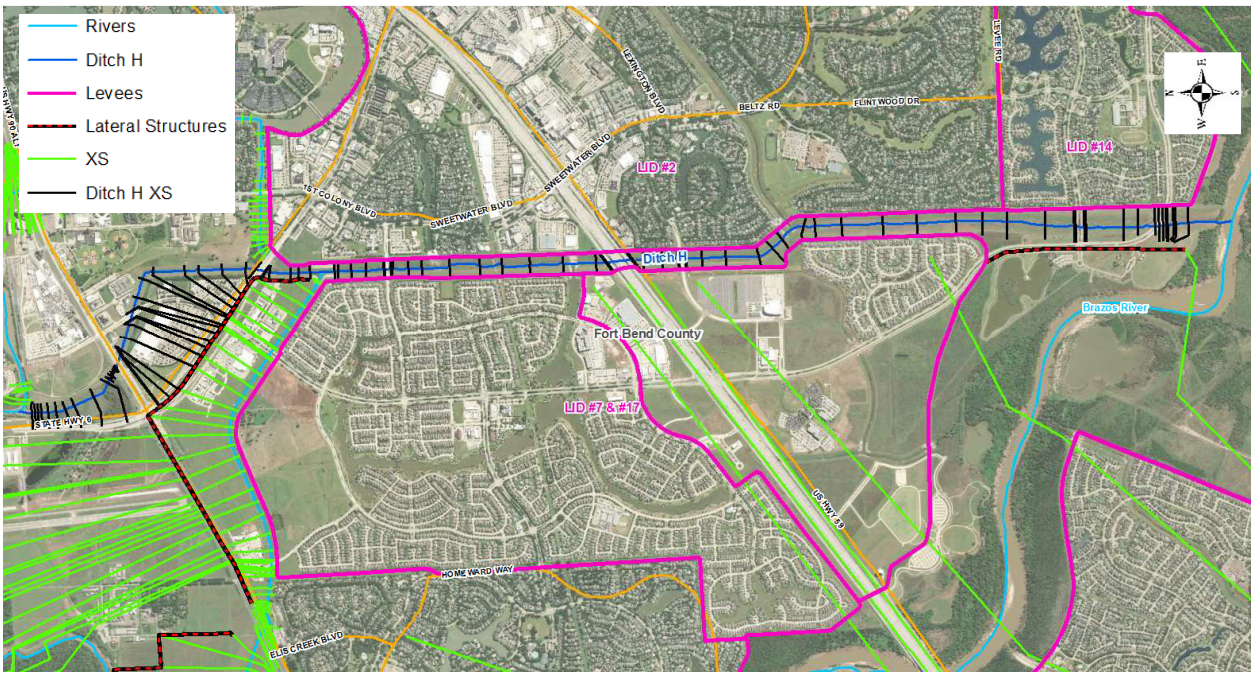

Figure E-7: Ditch H Geometric Layout

E.2.2.8 Bullhead Bayou

Cross sections of Bullhead Bayou were imported from the FNI hydraulic model with new cross sections added to extend the reach upstream of SH 99. Like Upper Oyster Creek and Ditch H, cross sections were extended into overflow areas that were previously covered by 2D areas to maintain the 1D analysis. Cross sections adjacent to the 2D areas were extended in the Chelsea Harbour area to simulate overflow conditions between Upper Oyster Creek, US 90A and SH 6. Extended cross sections were drawn to SH 99 which acted as a high point between Ditch H and Bullhead Bayou. Lateral structures were drawn along SH 99 to simulate the overflow conditions between Ditch H and Bullhead Bayou. Cross section spacing averaged a distance of approximately 300 feet with minimum and maximum spacing of 1 foot and approximately 3100 feet, respectively. Ineffective areas were added at structures and in overbank areas where no conveyance was assumed based on the terrain data Mapping. Blocked obstructions are used in the Chelsea Harbour area to block flow from entering the area. The geometric layout for Bullhead Bayou is shown below in Figure E-8.

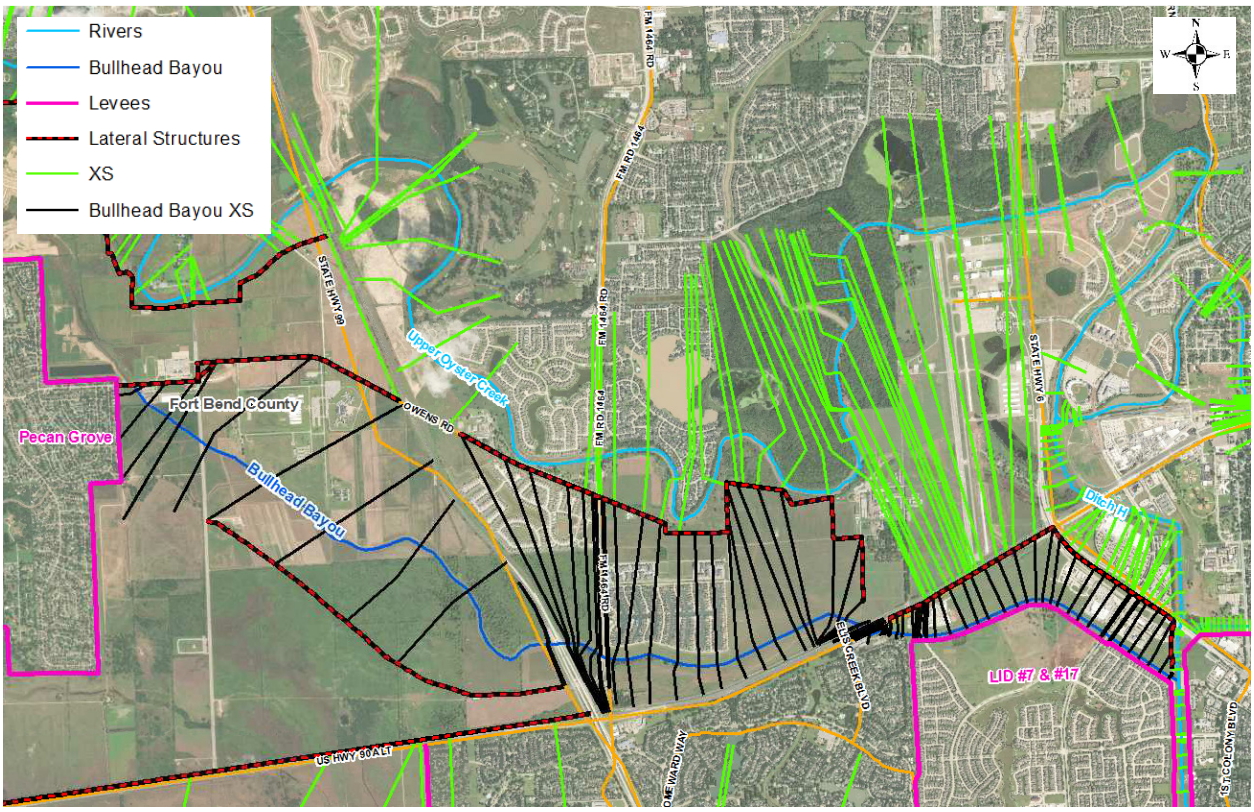

Figure E-8: Bullhead Bayou Geometric Layout

E.2.2.9 Lower Oyster Creek

Preliminary DFIRM data of Brazoria County was used to help create cross sections utilizing BFEs and lettered XSs on Lower Oyster Creek. Cross section alignment followed the BFEs and lettered XSs as guides while maintaining perpendicularity to the stream centerline and contours and were extended beyond the 0.2% ACE floodplain. Cross sections were drawn to the Brazos River cross sections and were connected by lateral structures to model overflow from the Brazos River to Lower Oyster Creek. Cross sections were spaced at an average interval of 0.58 miles with minimum and maximum spacing of 83 feet and approximately 2 miles, respectively. Ineffective areas were added at structures and in overbank areas where no conveyance was assumed based on the terrain data and mapping. Blocked obstructions were used to model low-lying areas that are not flooded by the river, such as neighborhoods with ring levees and areas beyond high points. The geometric layout for Lower Oyster Creek is shown below in Figure E-9.

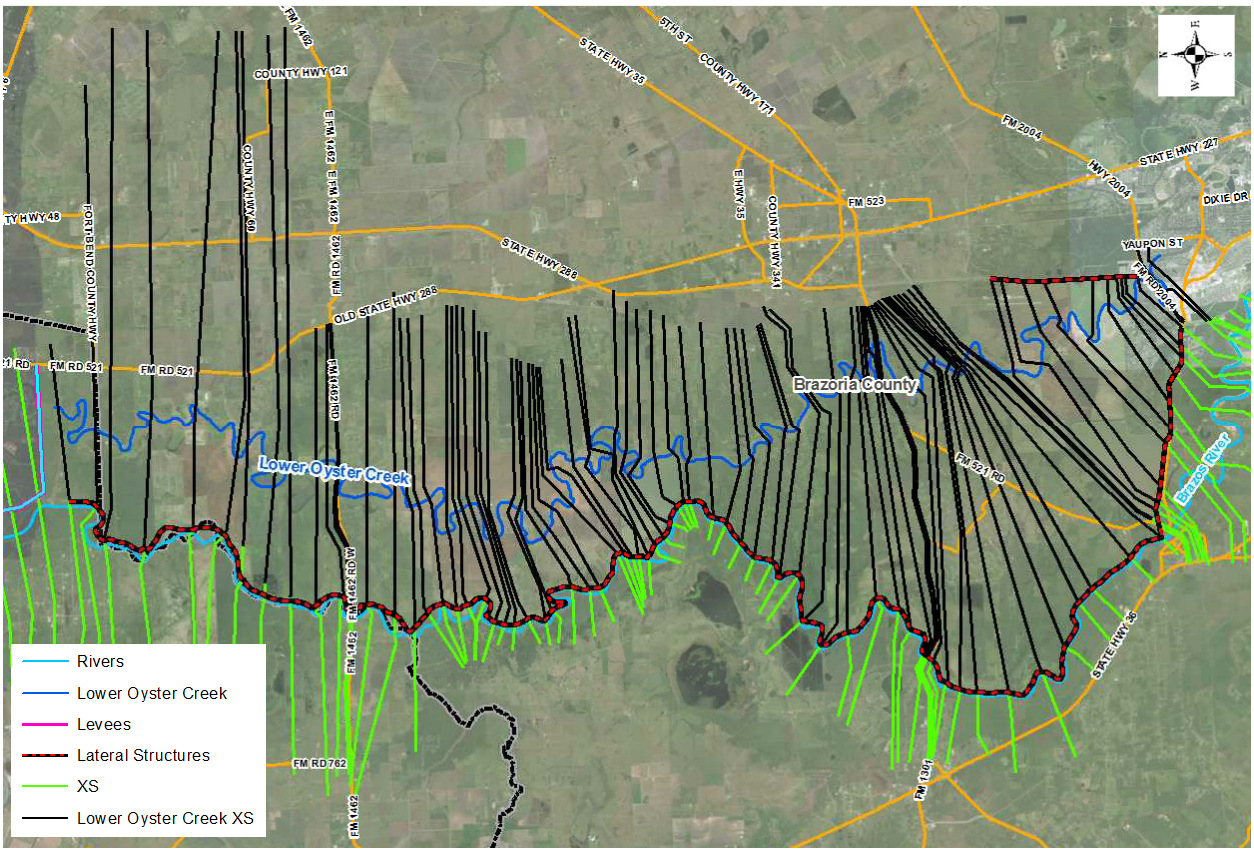

Figure E-9: Lower Oyster Creek Geometric Layout

E.2.3 Manning's N Values

Roughness values for each cross section were either imported from provided shapefile data using the HEC-GeoRAS tool or incorporated from previous hydraulic modeling efforts. AECOM, Inc. (formerly URS Corporation) provided detailed Manning's N values upstream and downstream of Fort Bend County which included overbank and channel roughness values. While the provided shapefile was sufficient in determining the Manning's N values for cross sections in these areas, too many N values were assigned to cross sections. HEC-RAS only allows up to 20 Manning's N values per cross section. In some instances, almost 120 different N values were assigned to one cross section. To resolve this issue, the shapefile for the Manning's N values was simplified by examining aerial imagery and assigning an N value based on land use. The HEC-GeoRAS process was then rerun to extract the Manning's N values for the cross sections upstream and downstream of Fort Bend County.

For Fort Bend County, Manning's N values were derived from previous analyses including the FNI models and the effective FEMA hydraulic model of the Brazos River. Wherever cross sections were extended, the Manning's N value of the original end segment of the overbank was adopted. Manning's N values for added cross sections were inferred from the closest upstream or downstream cross section of the effective model. Manning's N values for river reaches such as Bessies and Jones Creeks were assigned values based on typical channel and overbank areas. A table of n-value ranges used in the hydraulic model is shown below in Table E-1.

Table E-1: Manning's N Values

Region			Manning's N Values	
Description	U/S XS	D/S XS	Channel	Overbank
Waller County Line to Hempstead USGS Gage	1158482	1062059	0.042	0.06 - 0.09
Hempstead USGS Gage to San Felipe USGS Gage	1062059	811091	0.042	0.06 - 0.09
San Felipe USGS Gage to Richmond USGS Gage	811091	504102	0.033 - 0.08	0.023 - 0.12
Richmond USGS Gage to Rosharon USGS Gage	504102	305615.2	0.033 - 0.044	0.038 - 0.12
Rosharon USGS Gage to Gulf of Mexico	305615.2	9604	0.03 - 0.055	0.02 - 0.15

E.2.4 Bridges

A total of 20 bridges were modeled on the Brazos River and were either surveyed, determined from plan sets provided by TxDOT, imported from previous hydraulic models or inferred based on aerial imagery. Several bridges were input using combinations of these methods. Halff surveyed bridges located in Waller and Brazoria Counties. Bridges located in Fort Bend county were imported from the effective HEC-RAS model with updated river stationing to match the Lower Brazos River hydraulic model. Bridges located in the Fort Bend overflow areas were imported from the hydraulic models provided by FNI. Bridge structures in Lower Oyster Creek were inferred based on aerial imagery with bridge deck data determined from the 3D Analyst toolset in ArcMap. Since a 1D unsteady analysis was conducted, HTab parameters were established for each bridge to determine the stage and hydraulic parameter relationships. A list of the bridges located along the Brazos River in the detailed hydraulic study area and their method of determination is shown below in Table E-2.

Table E-2: Brazos River Bridge Determination Methods

Bridge	US XS	DS XS	County	Method
US 290	1062340	1062059	Waller	Survey, Bridge Plans
TX 159	987325	987017	Waller	Survey, Bridge Plans
FM 529	884491	884356	Waller	Survey, Inference
FM 1458	811391	811091	Waller	Survey
Railroad Bridge at I-10	782360	782282	Waller	Survey
I-10	782184	781951	Waller	Survey
FM 1093	696865	696595	Fort Bend	From Ft. Bend Co. Model
FM 1489	657122	657028	Fort Bend	From Ft. Bend Co. Model
FM 723	548194	548083	Fort Bend	From Ft. Bend Co. Model
ATSF Railroad	505081	504995	Fort Bend	From Ft. Bend Co. Model
SH 90A Southbound	504515	504430	Fort Bend	From Ft. Bend Co. Model
SH 90A Northbound	504199	504102	Fort Bend	From Ft. Bend Co. Model
SH 99	466380	466239	Fort Bend	From Ft. Bend Co. Model

Bridge	US XS	DS XS	County	Method
SH 59	459163	458977	Fort Bend	From Ft. Bend Co. Model
ATSF Railroad	384737	384516	Fort Bend	From Ft. Bend Co. Model
FM 1462	305772	305615	Brazoria	Survey, Bridge Plans
SH 35	179155	178790	Brazoria	Survey, Bridge Plans
FM 521	130048	129599	Brazoria	Survey, Bridge Plans
FM 2004	82907.9	82530.3	Brazoria	Survey, Bridge Plans
TX 36	26001	25641	Brazoria	Survey, Bridge Plans

E.2.5 Storage Areas

Several key areas in the Lower Brazos region were identified where water could pond and attenuate flow. These areas were modeled as storage areas in HEC-RAS with storage-volume curves extracted from the provided terrain. To allow flow to enter in these areas, lateral structures were drawn along the edges of the storage areas and the ends of cross sections. Summaries of the modeled storage areas are discussed below.

E.2.5.1 Mill Creek

Mill Creek is located just south of Bellville, TX and outfalls into the Brazos River. Discharges from the Mill Creek basin were determined from the hydrologic analysis and added into the hydraulic model on the Brazos River. Since discharges were applied from Mill Creek to the Brazos River, additional runoff volume was added into the Brazos River system that couldn't backwater into Mill Creek. To simulate the backwater from the Brazos River into Mill Creek, a storage area was drawn connecting to the right overbank of the Brazos River. During high flow events, water backs into the storage area and recedes as the Brazos River drains downstream. The storage area simulates backwater storage from the Brazos River by allowing volume to enter the Mill Creek area. The geometric layout of the Mill Creek overflow area is shown below in Figure E-10.

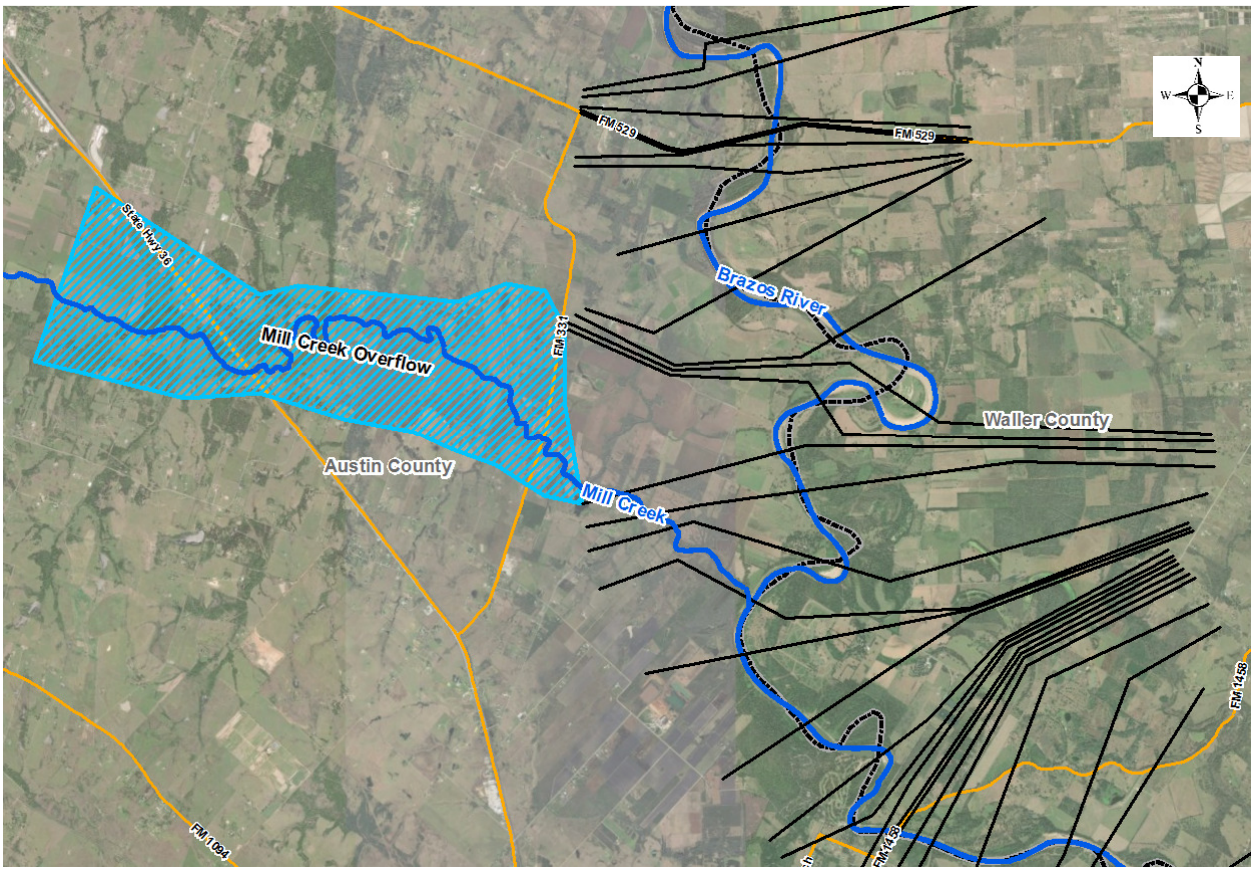

Figure E-10: Mill Creek Overflow Area

E.2.5.2 Frydek Bottom

Frydek Bottom is approximately 14.3 square miles of low-lying area located east of FM 1458 downstream of IH-10 and upstream of FM 1093. Flow from the Brazos River overtops and flows through roadway drainage structures along FM 1458. Once the Brazos River recedes, flow leaves Frydek Bottom via Allens Creek and returns to the Brazos River. Flow enters from the upstream end of the area and exits on the downstream end of the area. When flow enters from the Brazos River into Frydek Bottom, water is stored within the area for days and is released back into the Brazos River. Frydek Bottom is modeled as two storage areas to simulate the overflow in the area. These two areas were connected with a storage area connection and were separated to analyze the flow entering upstream and leaving downstream. The storage area connection is similar to a lateral structure where flow transfer occurs between storage areas and is determined from ground terrain. A lateral structure was placed in the right overbank of the Brazos River to allow flow to enter and leave Frydek Bottom. The geometric layout for Frydek Bottom is shown below in Figure E-11.

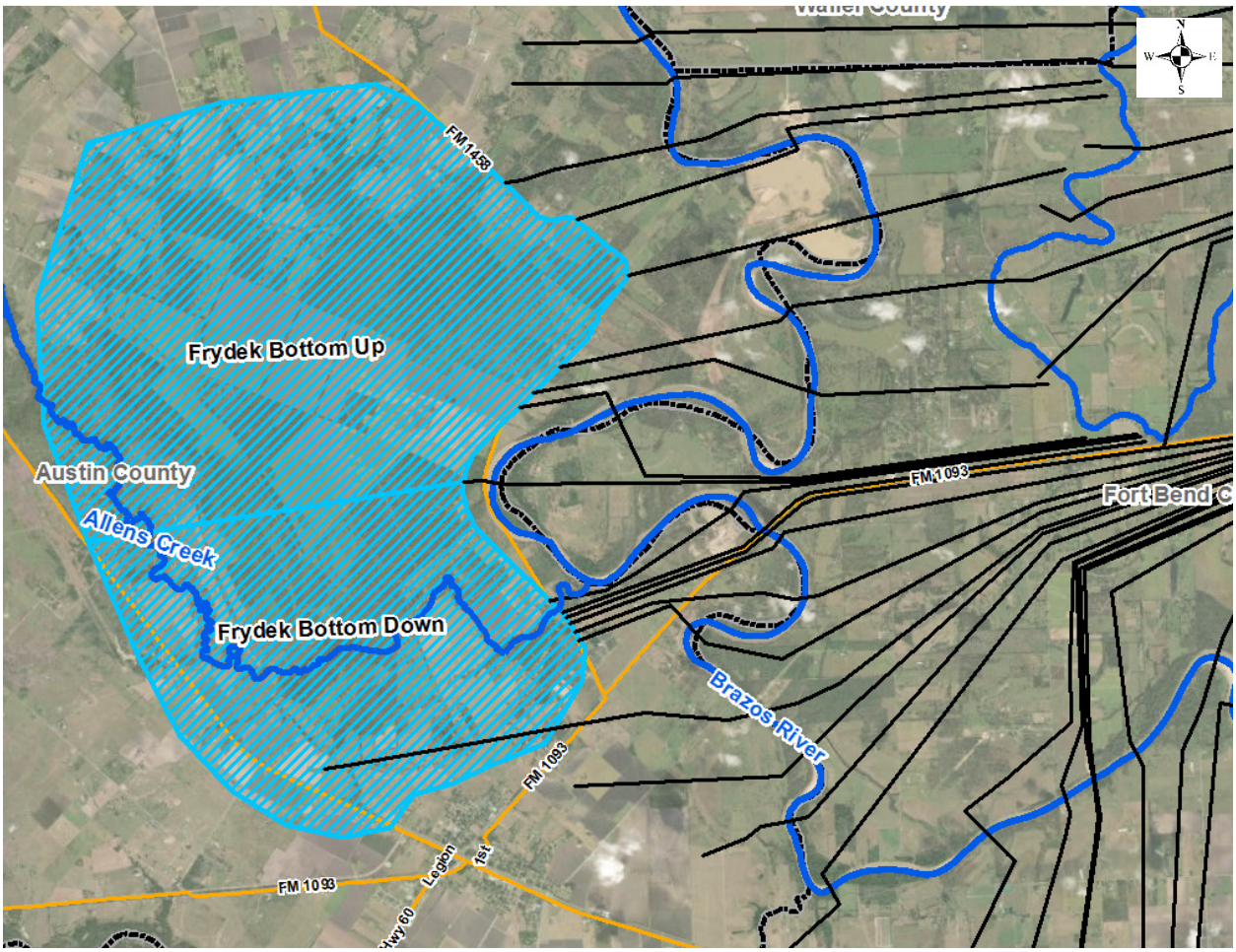

Figure E-11: Frydek Bottom Geometric Layout

E.2.5.3 US 90A/Pecan Grove Area

The area located between Pecan Grove, US 90A and Bullhead Bayou contains complex drainage patterns that are influenced by both the Brazos River and Bullhead Bayou. The overflow area was modeled as two storage areas and connected by a storage area connection at Harlem Road. The storage areas are divided into two because the area located west of Harlem Road is influenced by the Brazos River while the area to the east of Harlem Road is influenced by Bullhead Bayou. During high flow events, these areas interact with one another as water overtops Harlem Road. Additionally, water flow eastwards through the storage areas from the Brazos River towards Bullhead Bayou. The geometric layout for US90A/Pecan Grove area is shown below in Figure E-12.

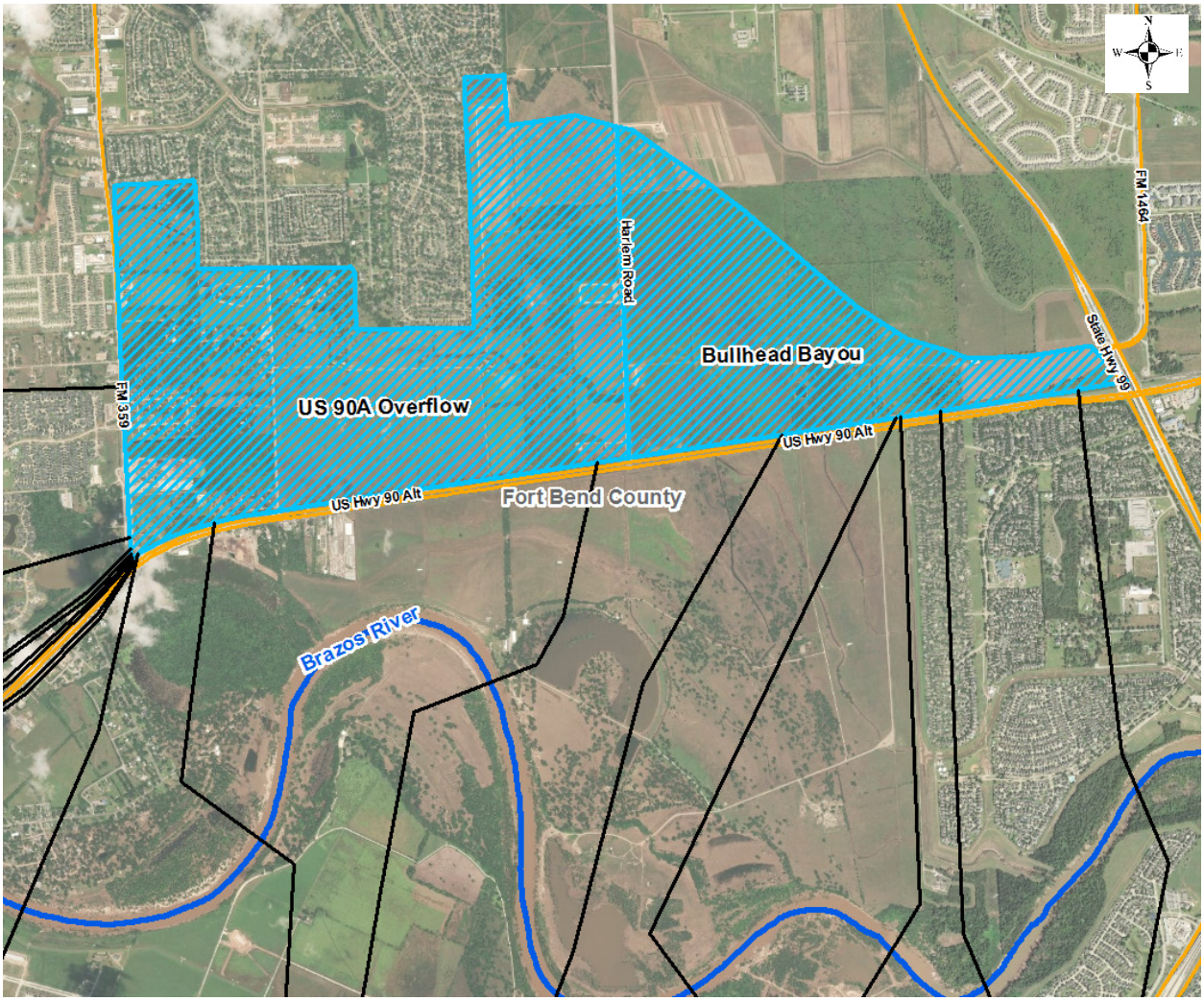

Figure E-12: US 90A/Pecan Grove Area Geometric Layout

E.2.5.4 Oyster Creek Overbank

In Oyster Creek, a large overbank area is located to the right of the creek between Harvest Corner Drive and SH 99. The area is bounded by Pecan Grove, Plantation Road, Owens Road and Oyster Creek itself. During high flow events, Oyster Creek flows outs of its banks and fills in the area up to the boundaries specified. The overbank area was modeled as a storage area to hold water from Oyster Creek which releases water once the creek recedes. In addition to Oyster Creek inundating the storage area, lateral structures were drawn along Plantation Road and Owens Road to allow overflow from the overbank area to spill into Bullhead Bayou. The geometric layout for the Oyster Creek Overbank is shown below in Figure E-13.

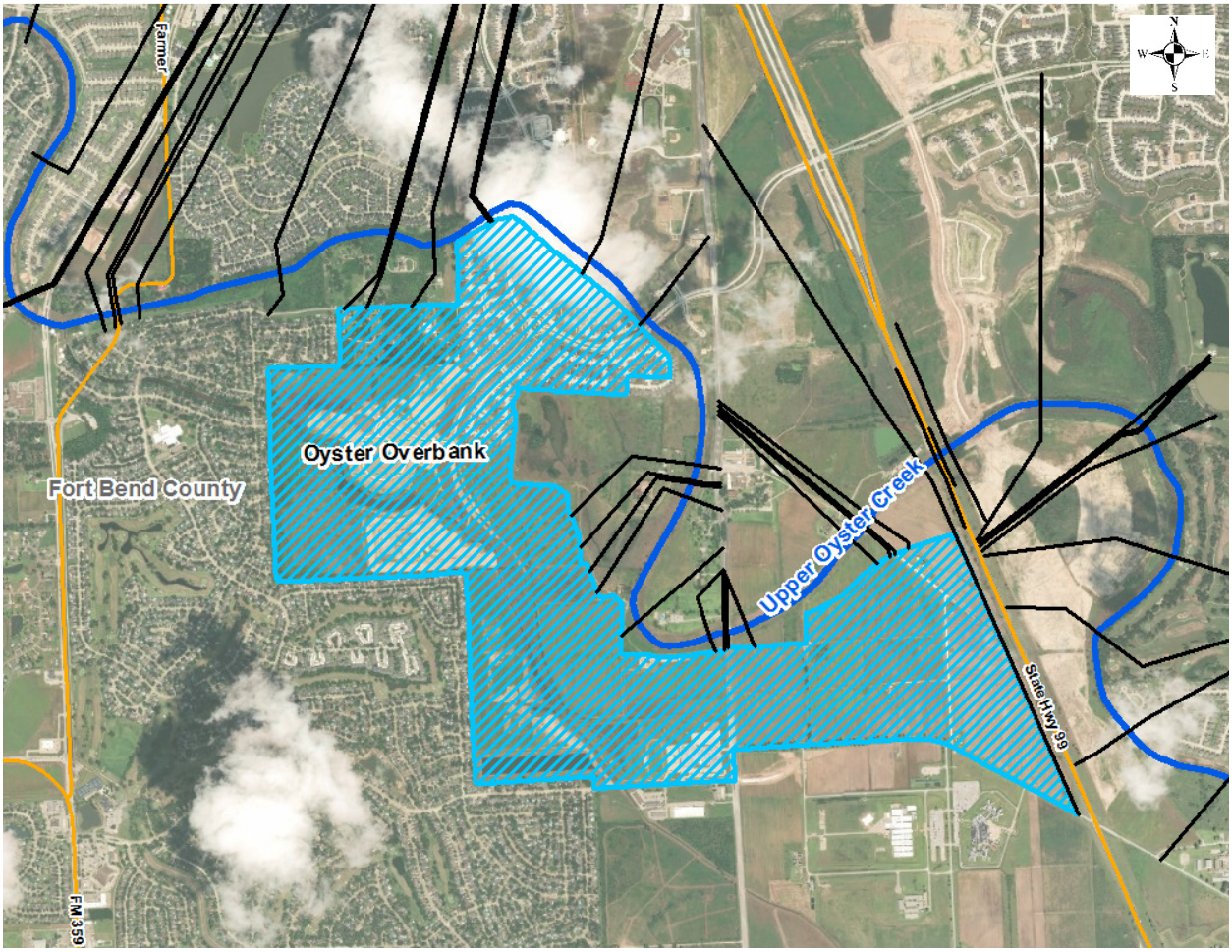

Figure E-13: Oyster Creek Overbank Geometric Layout

E.2.6 Lateral Structures

Lateral structures were used in the model to allow flow transfer between storage areas and river reaches. Lateral structure centerlines were drawn along high ridges in ArcMap using HEC-GeoRAS and coincide with the cross section end points. Lateral structures were broken at various lengths and did not exceed 3 miles in length because longer lateral structures can produce more errors in the model. Once the centerlines were drawn, terrain data were extracted and imported into HEC-RAS with the centerlines georeferenced. When extracting data from the terrain, several low points were identified in many lateral structures where no hydraulic connectivity was expected. These points were raised to prevent flow from leaving the systems where it would not occur. Weir coefficients were assigned to lateral structures with a value of 1 or less since the terrain along the lateral structure was either at ground level or slightly elevated. Weir coefficients were adjusted to ensure a level water surface elevation between connected areas.

E.3.0. Unsteady Flow Data

To model the historical storm events and design storms, discharge data were used to model the hydraulic conditions of the Brazos River region for each simulation. Discharge data were derived from the hydrologic calculations from the hydrologic model (see Appendix D) and were used to model discharges from drainage areas into the Brazos River and Bessies Creek. Hydrologic conditions of the other tributaries were not considered for this analysis and only included discharge hydrographs to maintain stability within the reaches. Data entered into the unsteady flow editor were added as boundary conditions under three different categories: upstream, internal and downstream boundaries. These categories are discussed below in detail, and a table of the locations of the boundary conditions is shown in Table E-3.

Table E-3: Unsteady Flow Boundary Conditions

River	Reach	XS	Boundary Condition	Description	Category
Bessie&Oyster	US_H_Ext	416367	Flow Hydrograph	Upstream boundary of Bessies Creek.	Upstream
Bessie&Oyster	US_H_Ext	368514	Uniform Lateral Inflow	Inflow from Bessies Creek drainage area.	Internal
Bessie&Oyster	DS_BLD	77492 IS	Rules	Gate operations near Creekbend Dr.	Internal
Bessie&Oyster	DS_BLD	58344 IS	Elev Controlled Gates	Gate operations near Lexington Blvd.	Internal
Bessie&Oyster	DS_BLD	65	Stage Hydrograph	Controlling downstream condition.	Downstream
Brazos River	1	1158482	Flow Hydrograph	Upstream limit of Brazos River.	Upstream
Brazos River	1	1155776	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	1	1062971	Lateral Inflow Hydr.	Inflow from New Year Creek.	Internal
Brazos River	1	1062340	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	1	1000049	Lateral Inflow Hydr.	Inflow from Brazos River drainage area.	Internal
Brazos River	1	996420	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	1	955101	Lateral Inflow Hydr.	Inflow from Brazos River drainage area.	Internal
Brazos River	1	951013	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	1	829065	Lateral Inflow Hydr.	Inflow from Mill Creek.	Internal

River	Reach	XS	Boundary Condition	Description	Category
Brazos River	1	823798	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	1	810118	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	1	788820	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	1	713598	Lateral Inflow Hydr.	Inflow from Brazos River drainage area.	Internal
Brazos River	1	698638	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	1	613273	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	1	500713	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	2	378642	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	2	308583.5	Lateral Inflow Hydr.	Inflow from Big Creek.	Internal
Brazos River	2	302875.8	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	2	291502.8	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	2	177914.6	Lateral Inflow Hydr.	Inflow from Brazos River drainage area.	Internal
Brazos River	2	174103.5	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	2	126833.8	Uniform Lateral Inflow	Inflow from Brazos River drainage area.	Internal
Brazos River	2	58376 LS	T.S. Gate Openings	Culvert at Jones Creek on TX 36.	Internal
Brazos River	2	9604	Normal Depth	Downstream boundary condition of the Brazos River.	Downstream
BrooksLakeDiv	BLD	393 IS	Rules	Gate operations near SH 6	Internal
BrooksLakeDiv	BLD	34	Normal Depth	Downstream boundary condition of Brooks Lake.	Downstream
Bullhead Bayou	Bullhead Bayou	29629	Flow Hydrograph	Upstream boundary of Bullhead Bayou.	Upstream
Ditch H	US_BHB	25704	Lateral Inflow Hydr.	Constant flow for model stability.	Internal

River	Reach	XS	Boundary Condition	Description	Category
Lower Oyster	1	335764	Flow Hydrograph	Upstream boundary of Lower Oyster.	Upstream
Lower Oyster	1	144043.9	Lateral Inflow Hydr.	Constant flow for model stability.	Internal
Lower Oyster	1	1481.803	Normal Depth	Downstream boundary of Lower Oyster.	Downstream

E.3.1 Upstream Boundary Conditions

The upstream boundary condition of the Lower Brazos model consists of a flow hydrograph calculated from the hydrologic model. The flow hydrograph is applied at the Grimes/Waller County line and includes the contributing basin for the Lower Brazos River north of the upstream boundary. Approximately 43,600 square miles of drainage area contributes to the upstream cross section at the county line. The upstream boundary condition for Bessies Creek consists of the discharge from the contributing subbasin upstream. Other upstream boundary conditions consist of a constant flow rate to maintain model stability. Discharges for all the historical storms and design storms were used for this boundary condition.

E.3.2 Internal Boundary Conditions

Internal boundary conditions consisted of lateral inflow hydrographs, uniform lateral inflow hydrographs, time series gate openings and gate rules. These internal boundary conditions modeled drainage basins, incoming tributaries and gate structures. Lateral hydrographs are flow boundaries that are set at a specified cross section within a river reach and are typically used to model inflow from incoming river systems. The hydrograph is applied at a single location downstream of the specified cross section in the flow data. Uniform lateral inflow hydrographs are applied to a range of cross sections within a river reach and usually model an internal drainage area. The inflow is distributed uniformly across the range of cross sections specified.

For lateral structures and inline structures with gates, time series gate openings and gate rules were used. Time series gate openings are an internal boundary where a gate opening is assigned to every time step during the simulation. The time series gate boundary located on the Brazos River at SH 36 was a culvert structure modeled as fully open. For the hydraulic analysis, the gates were modeled as fully open throughout the entire simulation. Gate rules allows the user to develop specific rules for controlling the gate structures. These boundary conditions were taken from the previous FNI models to be used in the new hydraulic model layout. There are three gate structures in the model: one along Brooks Lake Diversion near SH 6 and two on Upper Oyster Creek near Oyster Creek Drive and Lexington Blvd.

E.3.3 Downstream Boundary Conditions

The downstream boundary condition consisted of applying a normal depth to the last cross section on the Lower Brazos River. This cross section was located just upstream of the Gulf of Mexico. The normal depth boundary uses the Manning's equation to estimate a stage for each computed flow. This method required a friction slope (slope of the energy grade line) for the reach. The friction slope was estimated by measuring the bed slope of the channel. Normal depth boundary conditions were also used as downstream boundary conditions for other tributaries except for the Bessies Creek and Oyster Creek river reach. A stage hydrograph was used for the Bessies Creek and Oyster Creek river reach to reduce volume lost from the system since the reach did not connect back into the Brazos River. Tidal influence was not used as a boundary condition as the Rosharon gauge did not reflect tidal impacts for the calibration events. Tidal influence may need to be considered for any remapping effort of the effective floodplain in Brazoria County.

E.4.0 Model Calibration and Comparison

To improve the accuracy and precision of the model, certain calibration parameters were set and compared to historical storms that were simulated in the model. The calibration process utilized the flow roughness factors option in the unsteady flow analysis to match the model results with the observed data at the USGS gauges. A table of USGS gauges analyzed with historical storms is provided below in Table E-4. The flow roughness factors option allows the modeler to apply a factor to the Manning's N values of a specified range of cross sections based on changes in flow. Roughness factors can be raised or lowered to match the observed data in the model. These factors were used in the Brazos River to account for changes in the vegetated state of the river and for areas of scour and sediment deposition not reflected in the terrain data.

Table E-4: USGS Gauge Locations

USGS Gauge	Adjacent Structure	XS	County	Historical Storms
Brazos Rv nr Hempstead, TX	US 290	1062059	Waller	2007, 2016, 2017
Brazos Rv at San Felipe, TX	FM 1458	811091	Waller	2016, 2017
Brazos Rv at Richmond, TX	US 90A	504102	Fort Bend	2007, 2016, 2017
Brazos Rv nr Rosharon, TX	FM 1462	305615.2	Brazoria	2007, 2016, 2017

Ranges of roughness factors were applied along sections of the Brazos River and were set between USGS gauges. Additional sets of roughness factors were applied when the reach was separated by junctions. To calibrate to the observed data, the range of roughness factors were adjusted downstream of the USGS gauge to match the gauge data. This process was completed for each USGS gauge along the Brazos River starting from upstream to downstream. In addition to USGS gauges, additional high-water marks were used during some of the historical storms to allow for supplementary calibration. This calibration process was used for all three historical storms analyzed and aided in modeling the hydraulic conditions for the design storms. Stage hydrographs were given preference over flow hydrographs at the USGS gauges for calibration. Detailed discussions of the calibration of the historic storm events for each USGS gauge is shown below.

E.4.1 June - July 2007 Calibration

The June-July 2007 storm event was a long low-flow event that occurred along the Brazos River. The storm event's time frame extends from June 17, 2007 to July 28, 2007 and consisted of several peaks. This historical storm was utilized to help form the flow (less than 80,000 cfs) roughness factors along the Brazos River. Calibrating to the observed data for the 2007 event was difficult, as calibration usually involves matching to one peak in the hydrograph as opposed to multiple peaks. As a result, the modeled hydrographs did not match the observed data but followed the relative trend of the observed hydrographs. A table of the roughness factors used for the 2007 event is shown below in Table E-5.

Table E-5: 2007 Calibration Roughness Factors

Flow (cfs)	Factors for Range of Cross Sections							
	1158482 to 811091	811091 to 696595	696595 to 657028	657028 to 548083	548083 to 504102	504102 to 447908	443035 to 305615.2	305615.2 to 12687
10,000	0.9	0.86	1	1	0.7	1.2	0.9	1
20,000	0.9	0.86	1	1	0.7	1.2	0.9	1
30,000	0.9	0.86	1	1	0.7	1.2	0.9	1
40,000	0.9	0.86	1	1	0.7	1.2	0.9	1
50,000	0.9	0.86	1	1	0.7	1.2	0.9	1
60,000	0.9	0.9	1	1	0.7	1.2	0.9	1
70,000	0.9	0.9	1	1	0.7	1.2	1	1.2
80,000	0.9	0.9	1.1	1.1	0.8	1.2	1	1.4
90,000	0.9	1.1	1.1	1.1	0.8	1.2	1	1.4
100,000	0.9	1.1	1.1	1.2	0.8	1.2	1.1	1.4
110,000	1	1.1	1.4	1.3	0.9	1.2	1.1	1.4
120,000	1	1.1	1.6	1.3	1	1.2	1.1	1.4
130,000	1.15	1.1	1.6	1.3	1	1.2	1.3	1.4
140,000	1.15	1.4	1.6	1.3	1	1.2	1.3	1.4
150,000	1.15	1.5	1.6	1.3	1	1.2	1.3	1.4
160,000	1.15	1.5	1.6	1.3	1	1.2	1.3	1.4
170,000	1.15	1.5	1.6	1.3	1	1.2	1.3	1.4

As shown in Table E-5, the roughness factors for the 2007 event tend to be less than 1 for the low flows except in the area between US 90A and Ditch H (XS 504102 to 447908). These coefficients increase as the flows increase, effectively reducing the flow in the hydraulic model and raising the water surface elevation. Comparisons of the observed and modeled data for the USGS gauges are discussed below.

E.4.1.1 Hempstead

The first set of roughness factors from cross sections 1158482 to 811091 was used to calibrate to the Hempstead USGS gauge. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-14.

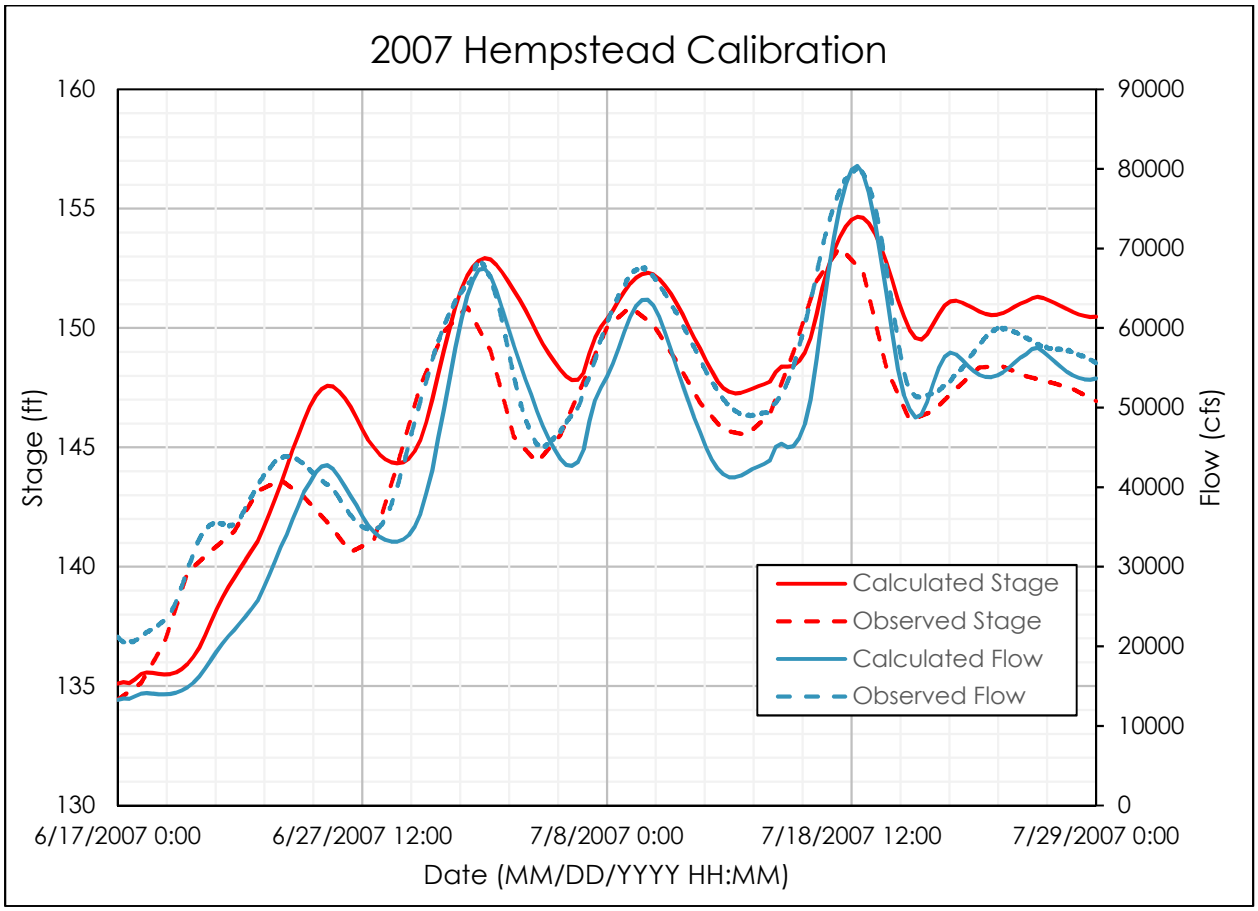

Figure E-14: 2007 Hempstead Stage and Discharge Calibration

The results showed that the stage and discharge comparisons between the calculated and observed data followed the overall trend of the hydrographs. Both calculated stage and discharge lagged behind the first observed peak but matched the later peaks. The calculated stage was generally higher than the observed stage while the calculated discharge was generally lower than the observed discharge. The calculated peak stage during this event was 154.66 feet and occurred 18 hours after the peak observed stage of 153.38 feet. The calculated peak discharge during this event was 80,400 cfs and occurred 30 minutes after the peak observed discharge of 80,100 cfs.

A complication to calibrating to this historical storm event was trying to match several peaks over the course of the event. Calibrating to several peaks was difficult since the roughness factors calibrated well to either the front-end or tail-end of one peak. This problem compounds when several peaks are observed in the model, making the calculations less precise. Overall, the calculated stage and discharge hydrographs followed the trend of the storm event but did not produce precise results.

E.4.1.2 Richmond

Since the San Felipe USGS gauge was implemented in 2013, the gauge was not analyzed for the 2007 historical storm event. As a result, the sets of roughness factors between cross sections 811091 and 447908 influenced the calibration at the Richmond USGS gauge. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-15.

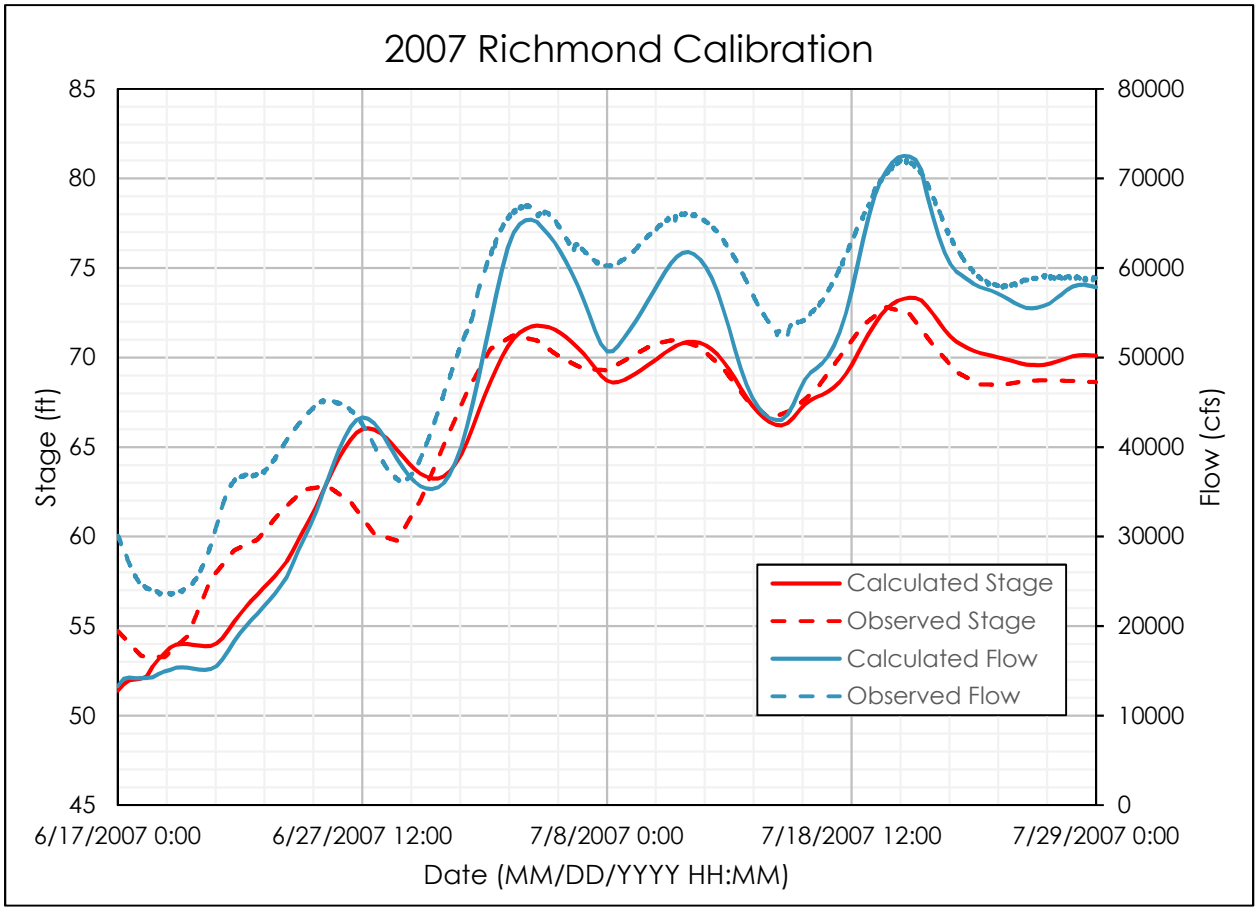

Figure E-15: 2007 Richmond Stage and Discharge Calibration

The results showed that the stage and discharge comparisons between the calculated and observed data at the Richmond USGS gauge are more precise in that the calculated results tracked better with the observed data compared to the Hempstead USGS gauge. While the first peak of both the calculated stage and discharge lagged behind the observed data, the later peaks in the model aligned well with the observed data. Like the Hempstead USGS gauge, the calculated results were late on the first peak but match the timing of the observed results by the

second peak. The calculated stage hydrograph was more closely aligned to the observed results compared to the Hempstead USGS gauge. The calculated discharge hydrograph matched closely with the observed peaks though diverged on the rising and falling limbs during the entire storm event. The calculated peak stage during this event was 73.34 feet and occurred 1 day after the peak observed stage of 72.82 feet. The calculated peak discharge during this event was 72,500 cfs and occurred approximately 4 hours after the peak observed discharge of 72,100 cfs.

E.4.1.3 Rosharon

The roughness factors between cross sections 443035 and 12687 influenced the calibration of the Rosharon USGS gauge. Since the discharge was spread across both the Brazos River and Oyster Creek, the calculated discharge from both reaches were added together and compared to the observed results. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-16.

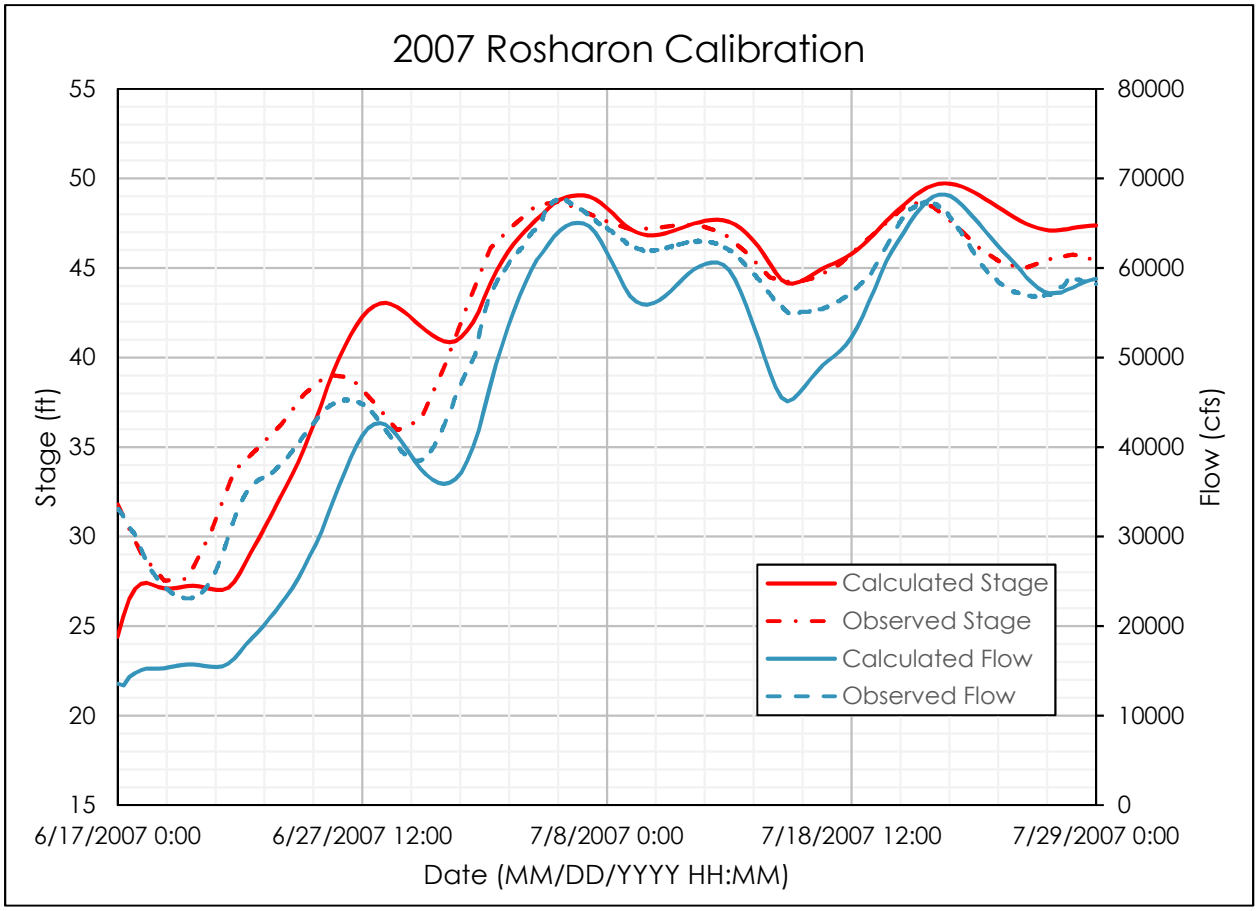

Figure E-16: 2007 Rosharon Stage and Discharge Calibration

The results showed that the stage and discharge comparisons followed the similar trend of the upstream USGS gauges where the first calculated peak was late while the subsequent peaks matched the timing of the observed data. The calculated stage hydrograph matched well with the observed data after the first peak but diverged after the last peak near the end of the simulation. Like the upstream USGS gauges, the calculated discharge hydrograph was lower when compared to the observed data. The calculated peak stage during this event was 49.73 feet while the peak observed stage was 48.71 feet. The calculated peak discharge during this event was 69,500 cfs while the peak observed discharge was 67,800 cfs.

E.4.1.4 Summary

Overall, the results of the 2007 calibration became more accurate as the simulation approached the second peak of the storm event and traveled downstream. The calculated stage hydrographs at the USGS gauges produced on average higher water surface elevations compared to the observed data while the calculated discharge hydrographs produced lower discharges compared to the observed data. As stated earlier, calibrating to several peaks in the hydraulic model was difficult due to the roughness factors favoring either the front-end or tail-end of one peak and compounding the issue as the simulation progresses. Since the surveyed channel sections from the terrain were conducted in 2015, changes in terrain could have also presented difficulties in calibrating to the 2007 event. Over the years, the Brazos River has changed its banks due to erosion and sediment deposition as well as its vegetated state resulting in different hydraulic conditions in the river. The changing dynamics of the river pose challenges to calibrating to prior storm events.

E.4.2 May – June 2016 Calibration

The May – June 2016 storm event was a rainfall event that occurred within the Lower Brazos River basin that produced widespread flooding throughout the entire study region. Many structures were flooded, and records were set at the USGS gauges along the Brazos River. The heaviest of the rainfall occurred in Washington County and around the Brenham area with a record 24-hour rainfall gauge reading of over 16 inches. The large amount of rainfall resulted in very high flows entering Waller County, and additional rainfall in the downstream basins resulted in large-scale impacts for Fort Bend and Brazoria Counties. The event was modeled from May 26, 2016 to June 6, 2016 with high-water lasting for several days in many areas. The model was calibrated to each USGS gauge except for the Rosharon gauge which conflicted with a high-water mark determined by the City of Lake Jackson at FM 1462. The peak elevation at the Rosharon gauge for the Brazos River during this event was approximately 52.50 feet while the Lake Jackson high-water mark was approximately 50.5 feet. A compromised elevation was set by calibrating between these readings at approximately 51.5 feet. A table of roughness factors used for the 2016 event is shown below in Table E-6.

Table E-6: 2016 Calibration Roughness Factors

Discharge (cfs)	Factors for Range of Cross Sections					
	1158482 to 1062059	1062059 to 811091	811091 to 504102	504102 to 447908	443035 to 305615.2	305615.2 to 12687
10,000	0.8	0.8	0.8	1	1	0.7
20,000	0.8	0.8	0.8	1	1	0.7
30,000	0.8	0.8	0.8	1	1	0.7
40,000	0.8	0.8	1.05	1.35	1.35	1
50,000	0.8	0.9	1.3	1.35	1.35	1.7
60,000	0.8	1	1.3	1.35	1.35	1.8
70,000	0.8	1	1.3	1.35	1.35	1.8
80,000	0.8	1.3	1.3	1.4	1.4	1.8
90,000	0.8	1.3	1.35	1.4	1.4	1.8
100,000	0.8	1.3	1.35	1.45	1.45	1.8
110,000	0.8	1.2	1.4	1.45	1.45	1.8
120,000	0.8	1.2	1.45	1.5	1.5	1.8
130,000	0.8	1.2	1.55	1.5	1.5	1.8
140,000	1	1.3	1.55	1.5	1.5	1.8
150,000	1	1.3	1.55	1.5	1.5	1.8
160,000	1	1.3	1.55	1.5	1.5	1.8
170,000	1	1.3	1.55	1.5	1.5	1.8

Based on Table E-6, the roughness factors for the 2016 event tended to be less than 1 for the low flows within the area between the Grimes/Waller County line and the Hempstead USGS gauge. Roughness factors for higher flows downstream were greater than 1 along the Brazos River. These coefficients increase as the discharges increase, effectively reducing the discharge in the hydraulic model and raising the water surface elevation. Comparisons of the observed and modeled data for the USGS gauges are discussed below.

E.4.2.1 Hempstead

The first set of roughness factors from cross sections 1158482 to 811091 was used to calibrate to the Hempstead USGS gauge. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-17.

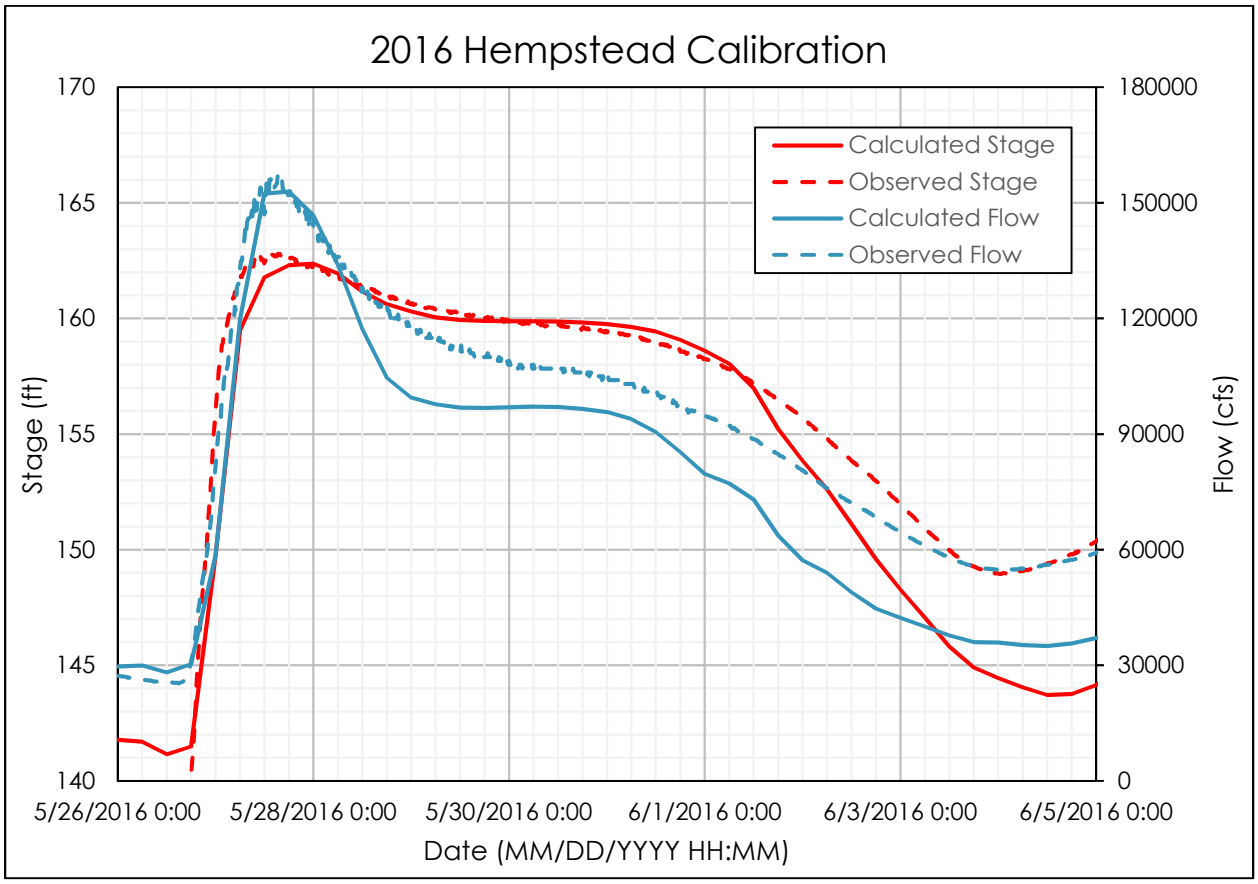

Figure E-17: 2016 Hempstead Stage and Discharge Calibration

The results showed that the calculated stage hydrograph matched the observed data throughout most of the storm event but eventually diverged on the tail end of the hydrograph. The calculated discharge hydrograph matched the observed peak discharge but dropped below the observed data on the receding limb of the hydrograph. Both the calculated stage and discharge hydrographs started higher than the observed data but do not affect the overall calibration of the storm event. The calculated peak stage during this event was 162.37 feet and occurred approximately 9 hours after the peak observed stage of 162.79 feet. The calculated peak discharge during this event was 152,900 cfs and occurred approximately 4 hours before the observed peak discharge of 157,000 cfs.

E.4.2.2 San Felipe

The roughness factors between cross sections 811091 and 504102 influenced the calibration of the San Felipe USGS gauge. Since the gauge was implemented in 2013, the gauge was added to the calibration analysis for the 2016 storm event. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-18.

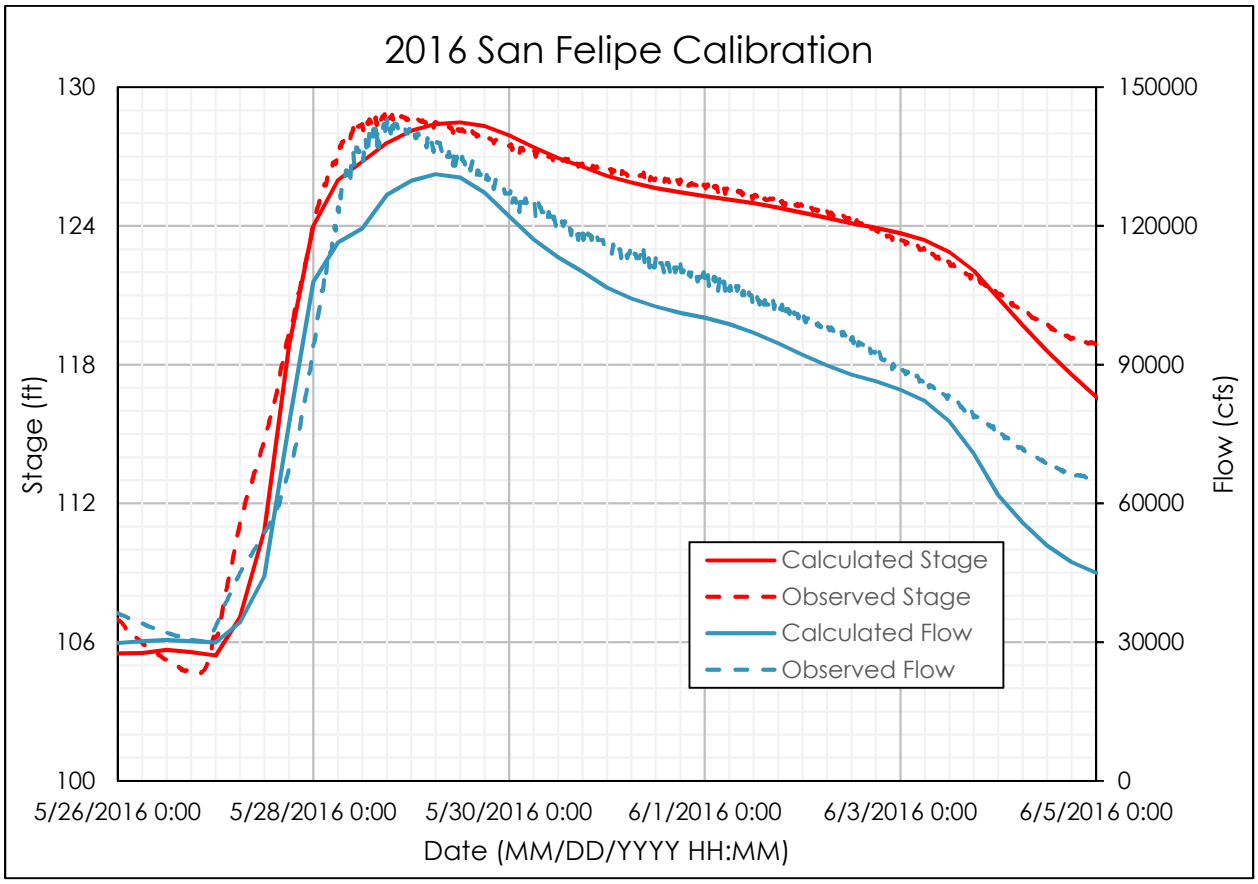

Figure E-18: 2016 San Felipe Stage and Discharge Calibration

The results showed that the calculated stage hydrograph was late compared to the observed peak but tracks closely to the observed data for both the rising and receding limb of the observed stage hydrograph. The calculated discharge hydrograph followed a similar trend where the peak was late but tracks along the rising and receding limbs of the observed discharge hydrograph. The calculated peak stage during this event was 128.48 feet and occurred 18 hours after the observed peak stage of 128.85 feet. The calculated peak discharge during this event was 131,200 cfs and occurred 12 hours after the peak observed discharge of 143,000 cfs.

E.4.2.3 Richmond

The roughness factors between cross sections 504102 and 477908 influenced the calibration at the Richmond USGS gauge. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-19.

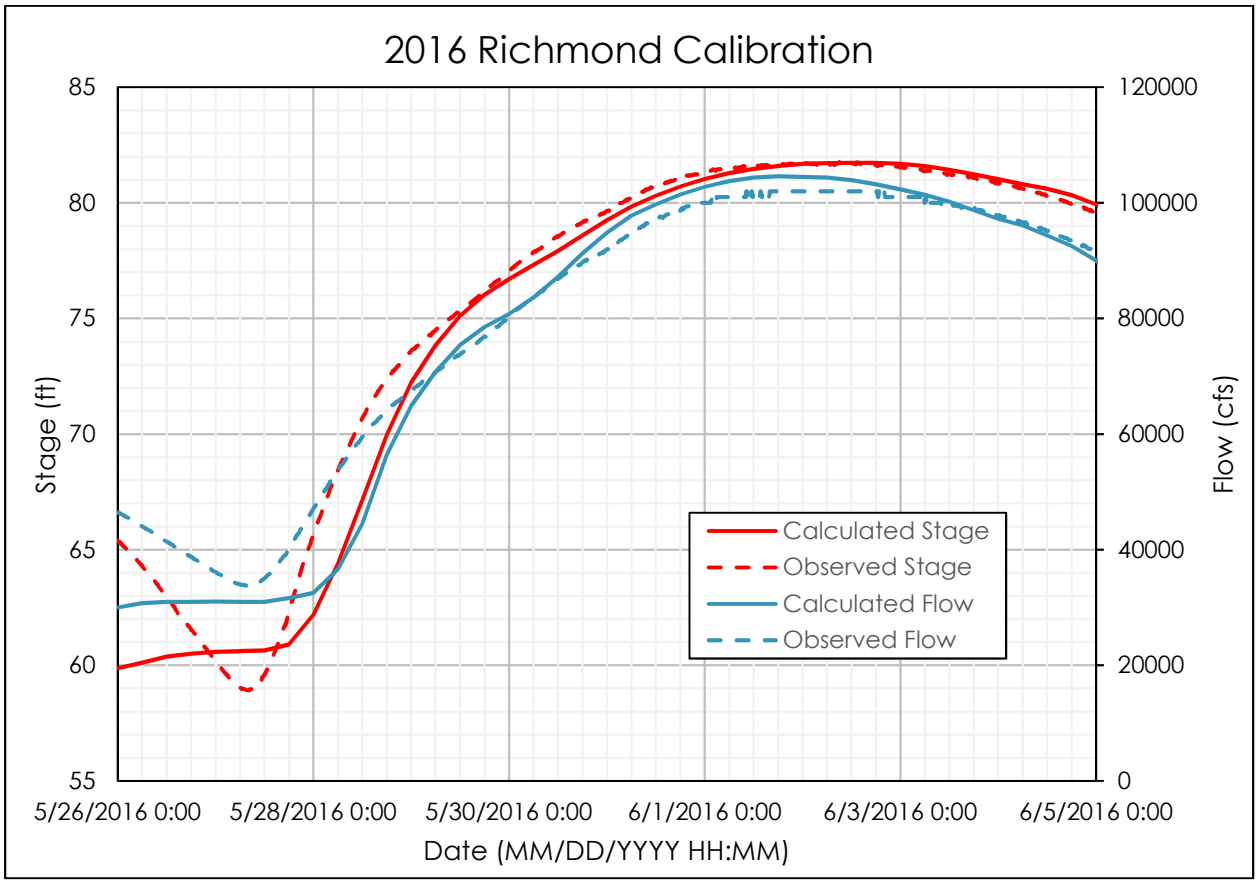

Figure E-19: 2016 Richmond Stage and Discharge Calibration

The results showed that the calculated stage hydrograph did not match the observed data on the front-end of the hydrograph but eventually converged towards the peak and receding limb of the observed stage data. This pattern is also seen with the discharge hydrograph in which the calculated discharge did not compare well with the front-end of the observed discharge hydrograph but eventually matched the observed data as the simulation elapsed. The calculated peak stage during this event was 81.73 feet and occurred 3 hours after the peak observed stage of 81.76 feet. The calculated peak discharge during this event was 104,600 cfs and occurred approximately 8 hours after the peak observed discharge of 102,000 cfs.

E.4.2.4 Rosharon

The roughness factors between cross sections 443035 and 12687 influenced the calibration of the Rosharon USGS gauge. Since the discharge was spread across both the Brazos River and Oyster Creek, the calculated discharge from both reaches were added together and compared to the observed results. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-20.

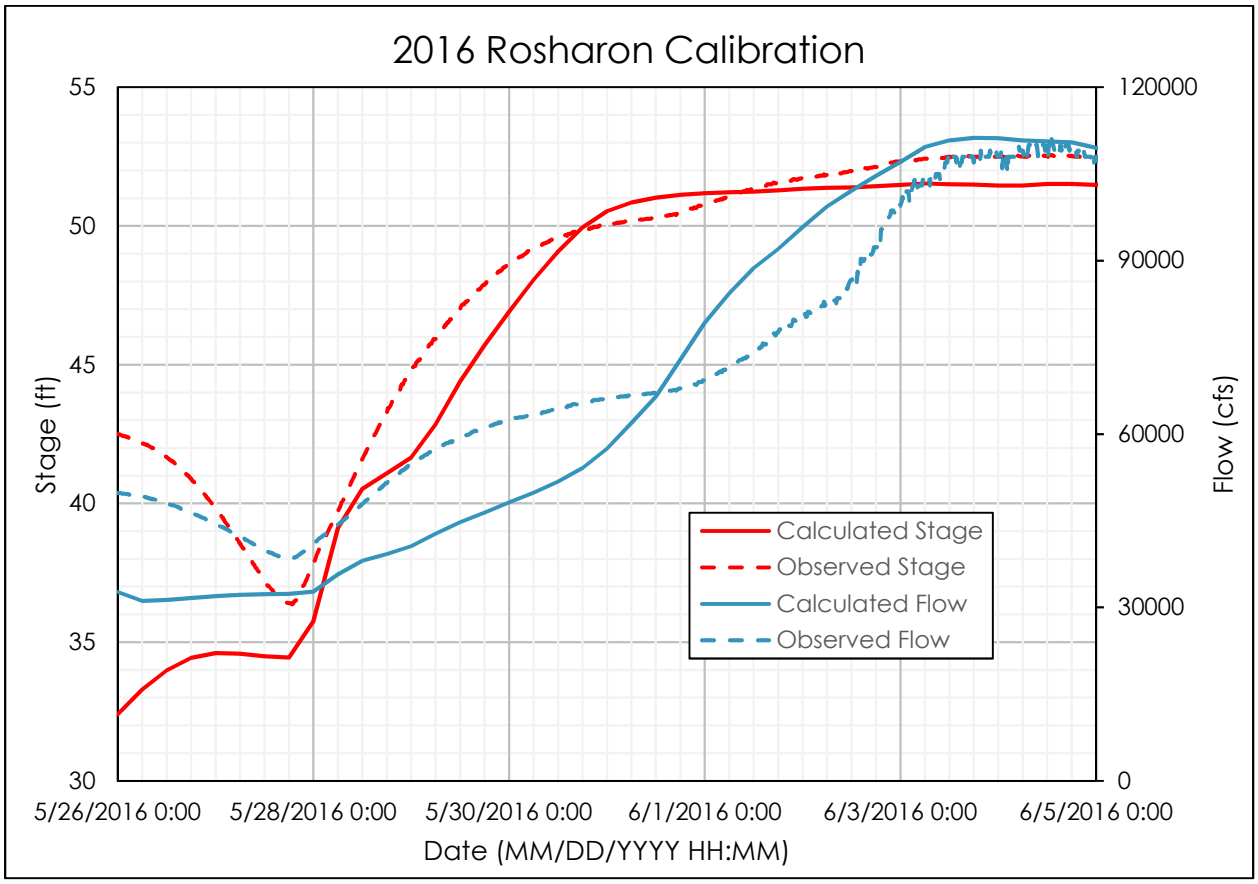

Figure E-20: 2016 Rosharon Stage and Discharge Calibration

The results showed that the calculated stage hydrograph matched the general trend of the observed data but did not match the actual values accurately. The same was true for the calculated discharge hydrograph. The calculated peak stage during this event was 51.53 feet and occurred approximately 1.3 days before the peak observed stage of 52.56 feet. The calculated peak discharge during this event was 111,200 cfs and occurred approximately 13 hours before the peak observed discharge of 112,000 cfs. While the difference between the calculated and observed peak stage was more than 1 foot, a high-water mark (HWM) was taken during the 2016 event by the City of Lake Jackson showing a water surface elevation of approximately 50.5 feet. As a compromise, the model was calibrated to an elevation between the peak USGS gauge reading and the HWM from Lake Jackson, resulting in a "target" water surface elevation of approximately 51.5 feet.

E.4.2.5 Summary

Overall, the calculated and observed data matched adequately for the Hempstead, San Felipe and Richmond USGS gauges. Calculated data from the Rosharon gauge followed the general trend of the observed data but did not match the results accurately. Calculated data was better calibrated to the observed data when compared to the 2007 storm event since the 2016 storm event was a higher flow event with only one peak to calibrate. Timing of the peaks were also closely aligned, with most peaks occurring less than half a day apart when comparing the calculated and observed results.

E.4.3 Hurricane Harvey Calibration

Hurricane Harvey, also known as the 2017 storm event, created large-scale impacts in Southeast Texas affecting the Lower Brazos region. Widespread flooding and damage of structures occurred throughout the area. Within the Brazos River Basin, Hurricane Harvey resulted in up to 30 inches of rain within Fort Bend County. Since the storm was concentrated in Fort Bend County, there was less significant impact to Waller County when compared to the 2016 storm event. Multiple high-water observations were provided by Fort Bend County during the Harvey event, and the data was utilized to further calibrate the hydraulic model. The calibration process was completed for each gauge and high-water observation from upstream to downstream within the model. A table of roughness factors used for the Harvey event is shown below in Table E-7.

Table E-7: Hurricane Harvey Calibration Roughness Factors

Discharge (cfs)	Factors for Range of Cross Sections							
	1158482 to 811091	811091 to 696595	696595 to 657028	657028 to 548083	548083 to 504102	504102 to 447908	443035 to 305615.2	305615.2 to 12687
10,000	0.9	0.86	1	1	0.7	1.2	0.9	1
20,000	0.9	0.86	1	1	0.7	1.2	0.9	1
30,000	0.9	0.86	1	1	0.7	1.2	0.9	1
40,000	0.9	0.86	1	1	0.7	1.2	0.9	1
50,000	0.9	0.86	1	1	0.7	1.2	0.9	1
60,000	0.9	0.9	1	1	0.7	1.2	0.9	1
70,000	0.9	0.9	1	1	0.7	1.2	1	1.2
80,000	0.9	0.9	1.1	1.1	0.8	1.2	1	1.4
90,000	0.9	1.1	1.1	1.1	0.8	1.2	1	1.4
100,000	0.9	1.1	1.1	1.2	0.8	1.2	1.1	1.4
110,000	1	1.1	1.4	1.3	0.9	1.2	1.1	1.4
120,000	1	1.1	1.6	1.3	1	1.2	1.1	1.4
130,000	1.15	1.1	1.6	1.3	1	1.2	1.3	1.4
140,000	1.15	1.4	1.6	1.3	1	1.2	1.3	1.4
150,000	1.15	1.5	1.6	1.3	1	1.2	1.3	1.4
160,000	1.15	1.5	1.6	1.3	1	1.2	1.3	1.4
170,000	1.15	1.5	1.6	1.3	1	1.2	1.3	1.4

Based on Table E-7, the roughness factors for Hurricane Harvey tend be less 1 for the low flows, with some exceptions in the Fort Bend County area. These coefficients increase as the flows increase, effectively reducing the flow in the hydraulic model and raising the water surface elevation. Comparisons of the observed and modeled data for the USGS gauges as well as measured high-water marks are discussed below.

E.4.3.1 Hempstead

The first set of roughness factors from cross sections 1158482 to 811091 were used to calibrate to the Hempstead USGS gauge. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-21.

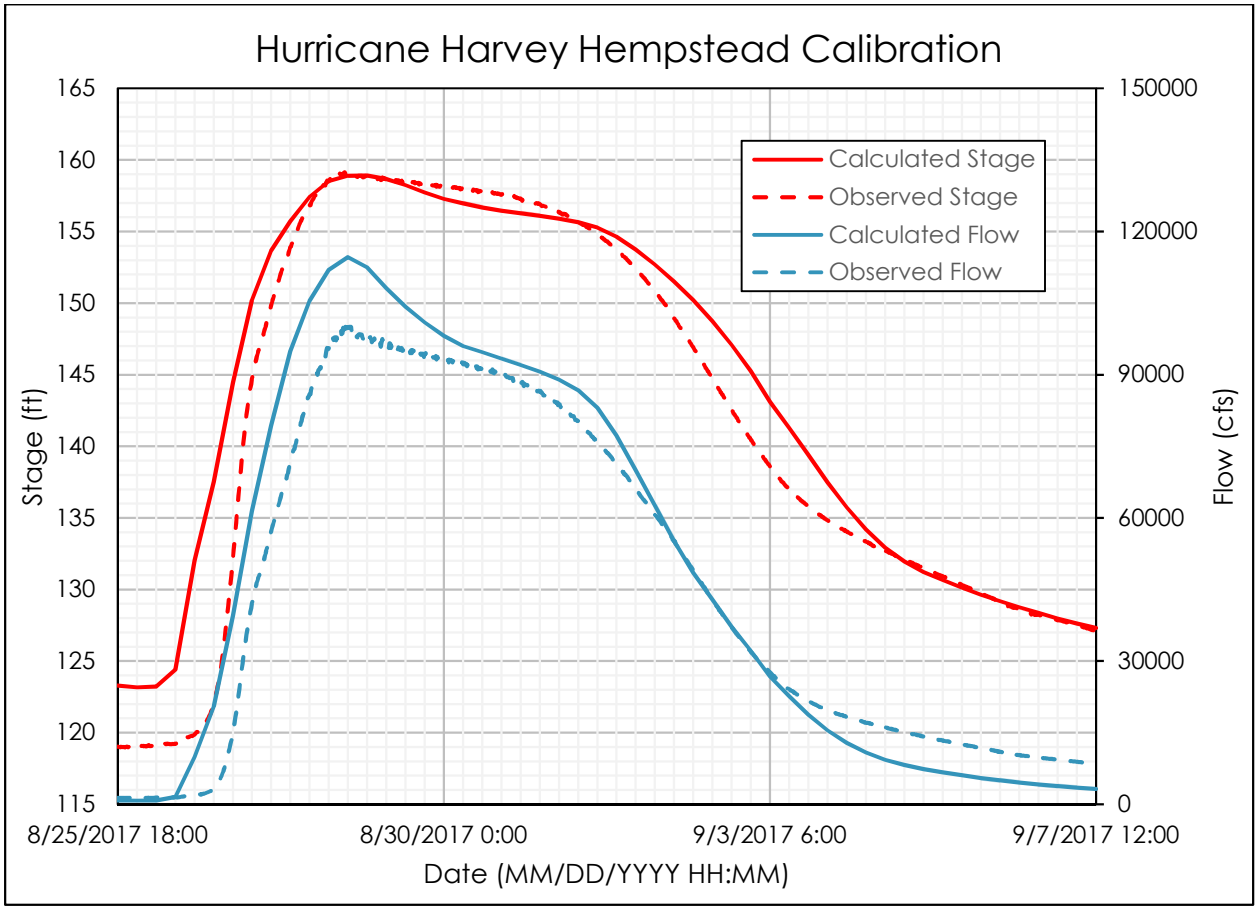

Figure E-21: Hurricane Harvey Hempstead Stage and Discharge Calibration

The results showed that the calculated stage hydrograph matched the observed data well, with results close at the peak though diverging slightly from the rising and receding limbs of the observed stage hydrograph. The calculated discharge hydrograph tracks the observed data as well but produced higher discharge rates on the rising limb and peak and lower discharge rates on the receding limb. The calculated peak stage during this event was 158.91 feet and occurred approximately 7 hours after the peak observed stage of 159.14 feet. The calculated peak discharge during this event was 114,630 cfs and occurred 1 hour after the peak observed discharge of 101,000 cfs.

E.4.3.2 San Felipe

The roughness factors between cross sections 811091 and 696595 were used to calibrate to the San Felipe USGS gauge. Since the gauge was implemented in 2013, the gauge was added to the calibration analysis for the 2017 storm event. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-22.

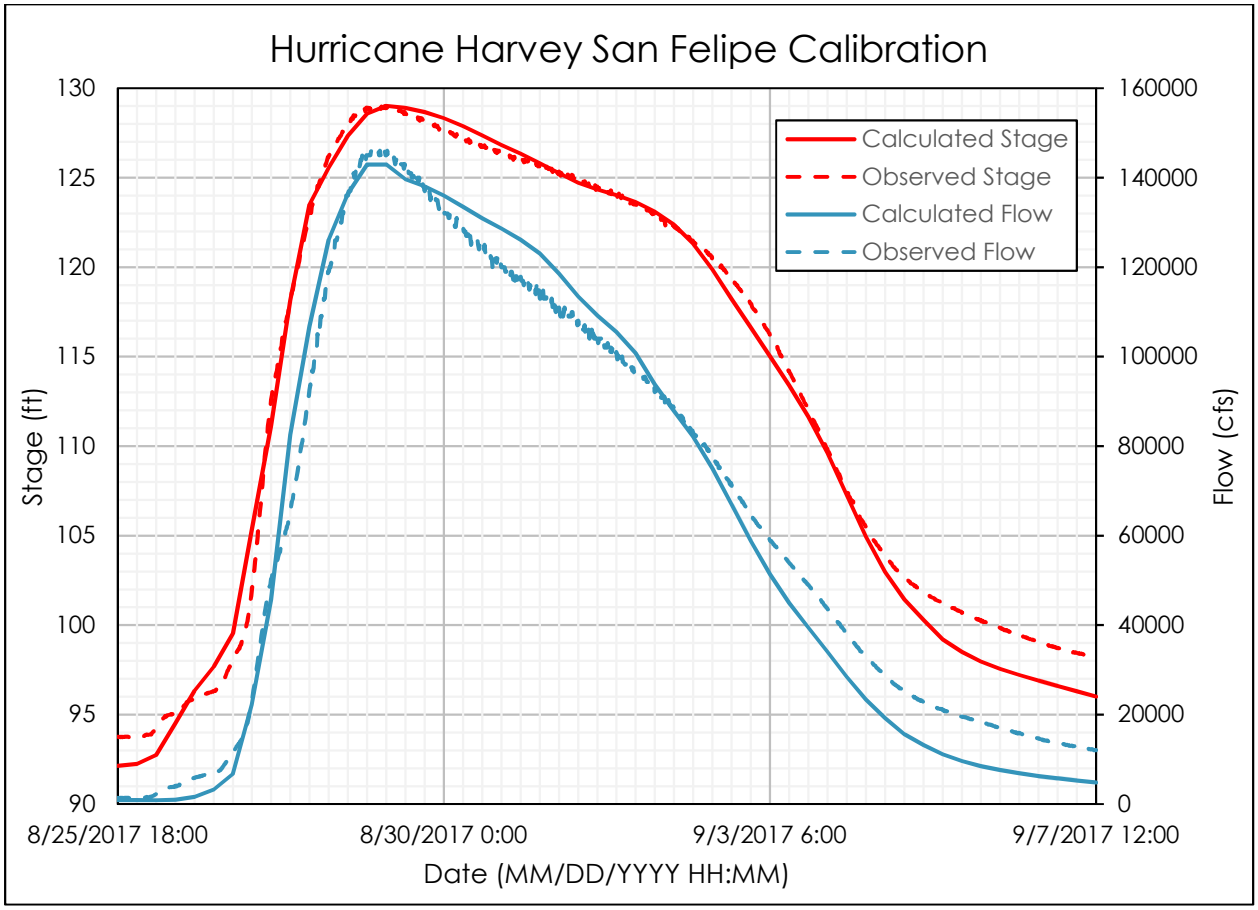

Figure E-22: Hurricane Harvey San Felipe Stage and Discharge Calibration

The results showed that the calculated stage hydrograph matched very closely to the observed stage hydrograph and diverged only at the front-end and tail-end. The calculated peak stage during this event was 129.00 feet and occurred approximately 5 hours after the peak observed stage of 129.00 feet. The calculated peak discharge during this event was 142,900 cfs and occurred approximately 3 hours after the peak observed discharge of 146,000 cfs.

E.4.3.3 Richmond

The roughness factors between cross sections 548083 and 477908 were used to calibrate to the Richmond USGS gauge. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-23.

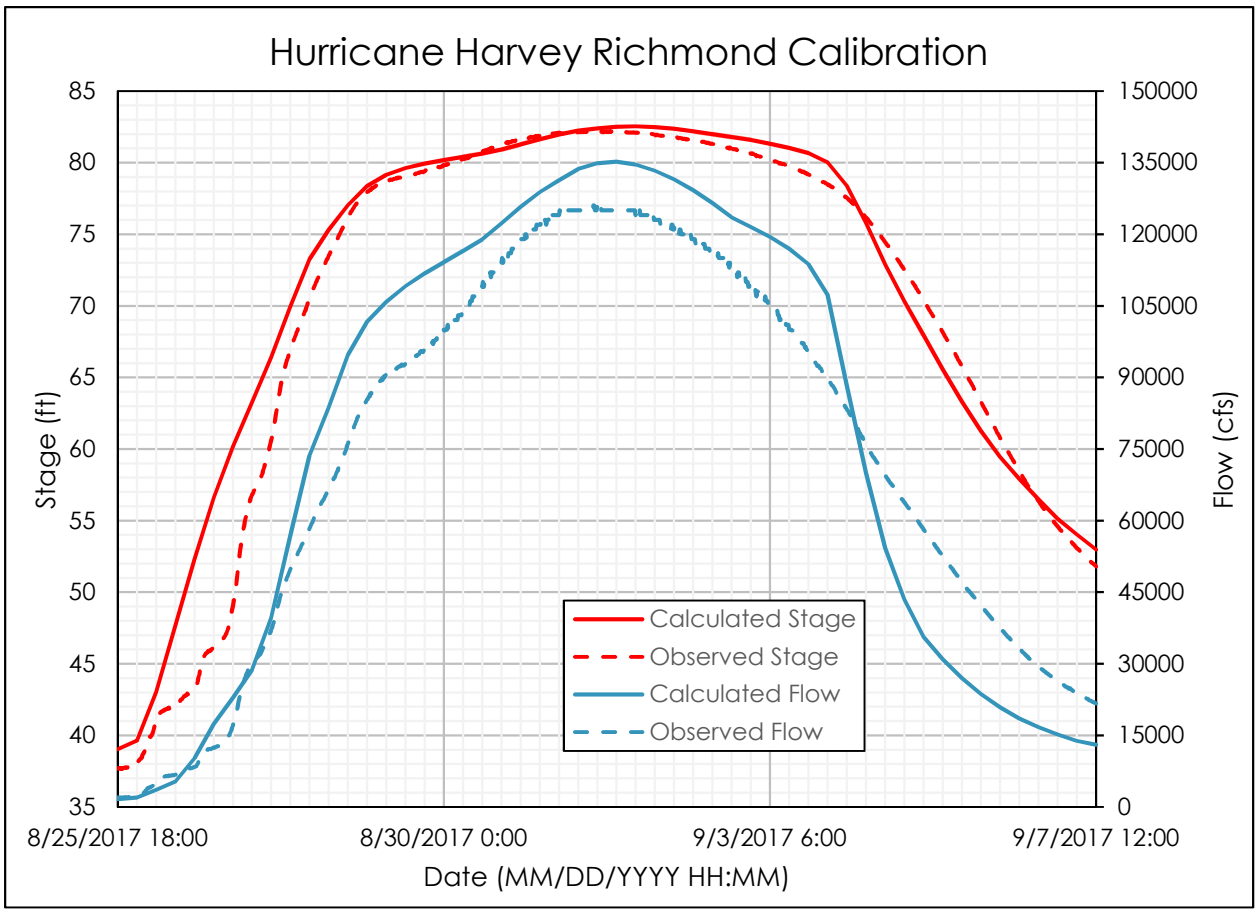

Figure E-23: Hurricane Harvey Richmond Stage and Discharge Calibration

The results showed that the calculated stage hydrograph closely followed the observed stage hydrograph with results matching near the peak and the receding limb. The calculated discharge hydrograph showed discharges that were higher than the observed values through most of the storm event but lower values on the tail end. The calculated peak stage during this event was 82.57 feet and occurred approximately 12 hours after the peak observed stage of 82.21 feet. The calculated peak discharge during this event was 135,300 cfs and occurred approximately 7 hours after the peak observed discharge of 126,000.

E.4.3.4 Rosharon

The roughness factors between cross sections 443035 and 12687 were used to calibrate to the Rosharon USGS gauge. Since the discharge was spread across both the Brazos River and Oyster Creek, the calculated discharge from both reaches were added together and compared to the observed results. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-24.

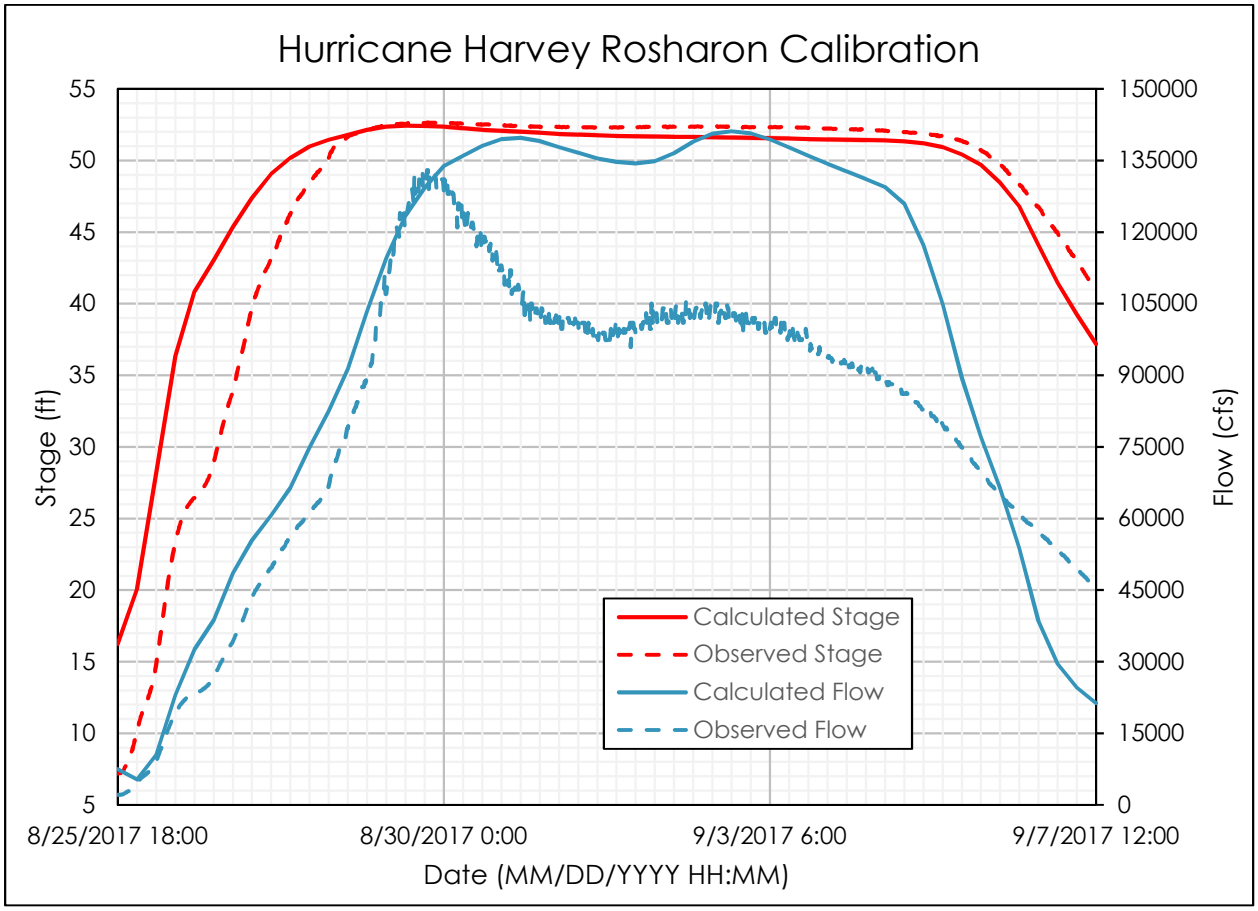

Figure E-24: Hurricane Harvey Rosharon Stage and Discharge Calibration

The results showed that the calculated stage hydrograph on the rising limb was higher when compared to the observed stage hydrograph but eventually flatlined and nearly matched the peak and receding limb. The calculated discharge hydrograph tracks well on the rising limb but eventually diverged and stayed at a high flow rate while the observed discharge hydrograph receded to a lower discharge rate. The divergence may be attributed to the lack of calibration (i.e., flow roughness factors) in Lower Oyster Creek which reduced the discharge. Also, there might be possible errors in the flow measurement at the Rosharon gauge since the water surface remained constant for nearly a week but dropped over 30,000 cfs in discharge during that period. The calculated peak stage during this event was 52.42 feet and occurred approximately 3.5 hours before the peak observed stage of 52.65. The calculated peak discharge during this event was 141,120 cfs and occurred approximately 4 days after the peak observed discharge of 142,000 cfs.

E.4.3.5 Fort Bend High-Water Marks

In addition to the calibration points at the USGS gauges, several high-water marks were recorded during the Hurricane Harvey event by the Fort Bend County Drainage District (FBCDD). Roughness factors were broken up into additional ranges to calibrate to the given high-water marks. A total of four high-water marks were determined during the Hurricane Harvey event and were used to adjust the roughness factors for optimal calibration of the model to the storm event. These high-water marks were located at FM 1093, FM 1489, FM 723 and SH 59. A table of comparisons between the calculated and observed water surface elevations at these locations is shown below in Table E-8.

Table E-8: Hurricane Harvey Fort Bend High-Water Marks

Location	Water Surface Elevation (ft)		Time of Peak	
	Observed	Calculated	Observed	Calculated
FM 1093	111.71	111.31	8/30/2017 14:45	8/31/2017 12:00
FM 1489	107.40	106.85	8/30/2017 11:00	8/31/2017 18:00
FM 723	91.95	91.00	8/31/2017 13:15	9/1/2017 6:00
SH 59	75.56	76.06	8/31/2017 16:15	9/1/2017 12:00

The results showed that most of the calculated water surface elevations were below the observed elevations except for at SH 59. The water surface elevations overall deviate by less than 1 foot, with differences ranging from 0.4 feet to 0.95 feet. Also, the calculated time of peak occurred later in the simulation compared to the observed results with several peak times differing by almost a day. While these high-water marks provided important information for calibration, the USGS gauges were the focus for the calibration process and took precedence over the high-water marks.

E.4.3.6 Summary

Overall, the peak stages for the Hurricane Harvey event matched very closely to the observed values at the USGS gauges. The calculated stage hydrographs also closely aligned with the observed stage hydrographs, tracking along both the rising and receding limbs. While the discharge hydrographs did not track as well as the stage hydrographs, the calculated discharge hydrographs followed the trend of observed stage hydrographs at the USGS gauges. The

calibration method consisted of matching model elevations to observed stage hydrographs, and thus the final outcome was more favorable for the stage hydrographs than the discharge hydrographs.

E.4.4 October 2018 Calibration

The October 2018 storm event was a two-week long storm event with the Brazos River under low-flow conditions. To validate the low flow roughness factors, this storm event was calibrated in addition to the June – July 2007 event. The storm event's time frame extends from October 10, 2018 to October 25, 2018 and consisted of a single peak. No hydrologic calculations were conducted for this event with only the observed discharge from the USGS Hempstead gage applied at the upstream end of the model to be used in the calibration effort. As a result, the model results did not match accurately with the observed data but followed the relative trend of the hydrographs. A table of the roughness factors used for the 2018 event is shown below in Table E-9.

Table E-9: 2018 Calibration Roughness Factors

Discharge (cfs)	Factors for Range of Cross Sections							
	1158482 to 811091	811091 to 696595	696595 to 657028	657028 to 548083	548083 to 504102	504102 to 447908	443035 to 305615.2	305615.2 to 12687
10,000	0.15	0.83	0.9	0.9	0.75	0.88	0.95	0.8
20,000	0.7	0.85	0.9	0.9	0.75	0.88	0.95	0.8
30,000	0.7	0.85	0.9	0.9	0.75	0.88	0.95	0.75
40,000	0.7	0.85	1	1	0.875	0.88	1	0.75
50,000	0.7	0.85	1	1	1	0.88	1	0.7
60,000	0.75	0.9	1	1	1	0.9	1	0.7
70,000	0.95	1.1	1.15	1.15	1	1.275	1.175	1.5
80,000	1.1	1.1	1.2	1.2	1.05	1.3	1.2	1.6
90,000	1.1	1.225	1.225	1.225	1.075	1.3	1.2	1.6
100,000	1.1	1.225	1.225	1.275	1.075	1.325	1.275	1.6
110,000	1.1	1.25	1.4	1.35	1.15	1.325	1.275	1.6
120,000	1.1	1.275	1.525	1.375	1.225	1.35	1.3	1.6
130,000	1.175	1.325	1.575	1.425	1.275	1.35	1.4	1.6
140,000	1.225	1.475	1.575	1.425	1.275	1.35	1.4	1.6
150,000	1.225	1.525	1.575	1.425	1.275	1.35	1.4	1.6
160,000	1.225	1.525	1.575	1.425	1.275	1.35	1.4	1.6
170,000	1.225	1.525	1.575	1.425	1.275	1.35	1.4	1.6

Based on Table E-9, the roughness factors for the 2007 event tend to be less than 1 for the low flows. These coefficients increase as the flows increase, effectively reducing the flow in the hydraulic model and raising the water surface elevation. Comparisons of the observed and modeled data for the USGS gauges are discussed below.

E.4.4.1 Hempstead

The first set of roughness factors from cross sections 1158482 to 811091 was used to calibrate to the Hempstead USGS gauge. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-25.

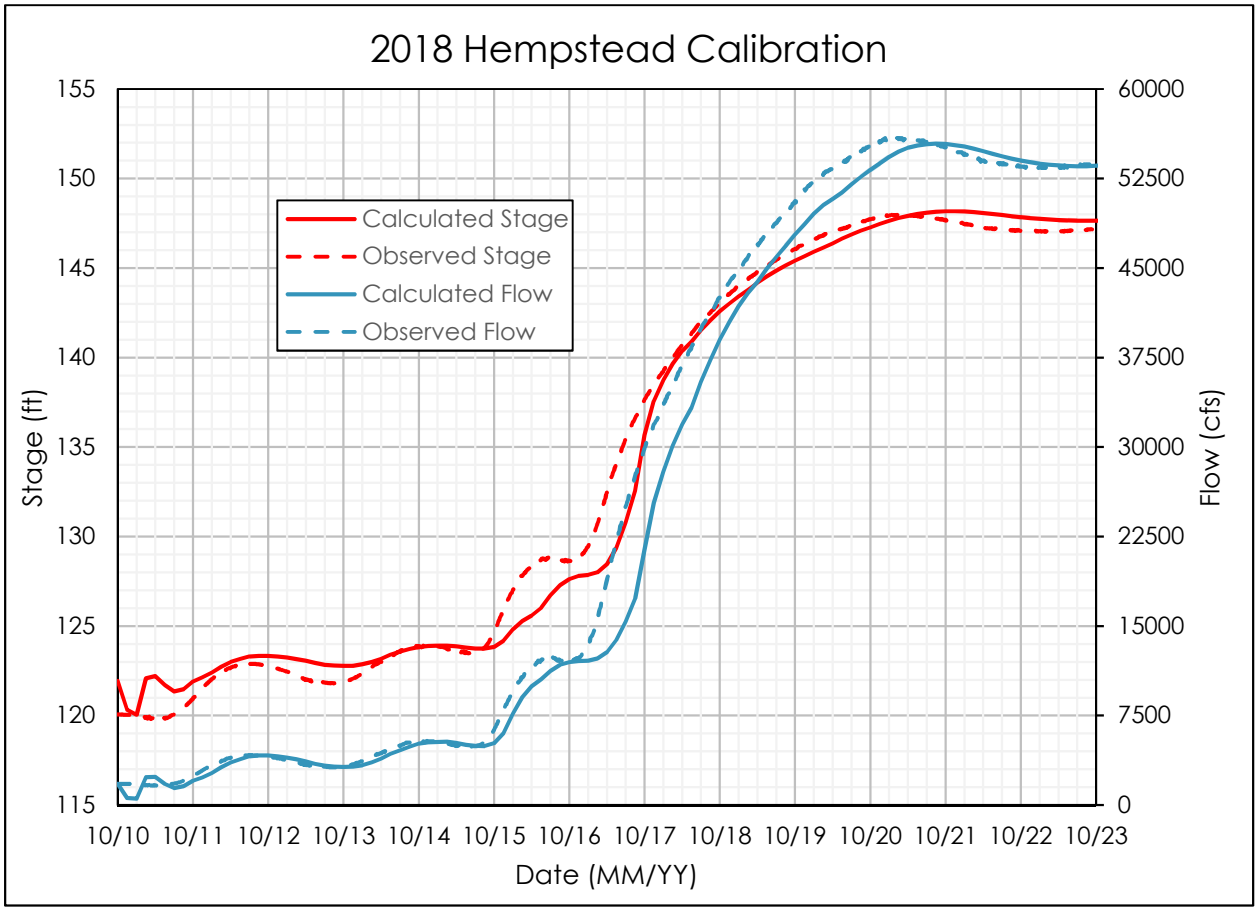

Figure E-25: 2018 Hempstead Stage and Discharge Calibration

The results showed that the stage and discharge comparisons between the calculated and observed data followed the overall trend of the hydrographs. Both calculated stage and discharge lag behind the observed data once the flows go higher than 5,000 cfs. The reason for lag could be the observed hydrograph from the Hempstead gage is applied to the upstream end of the hydraulic model which is nearly 18 miles upstream of the gage. The calculated peak stage during this event was 148.17 feet and occurred approximately 19 hours after the peak observed stage of 147.97 feet. The calculated peak discharge during this event was 55,400 cfs and occurred approximately 16 hours after the peak observed discharge of 55,900 cfs.

E.4.4.2 San Felipe

The roughness factors between cross sections 811091 and 504102 influenced the calibration of the San Felipe USGS gauge. Since the gauge was implemented in 2013, the gauge was added to the calibration analysis for the 2018 storm event. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-26.

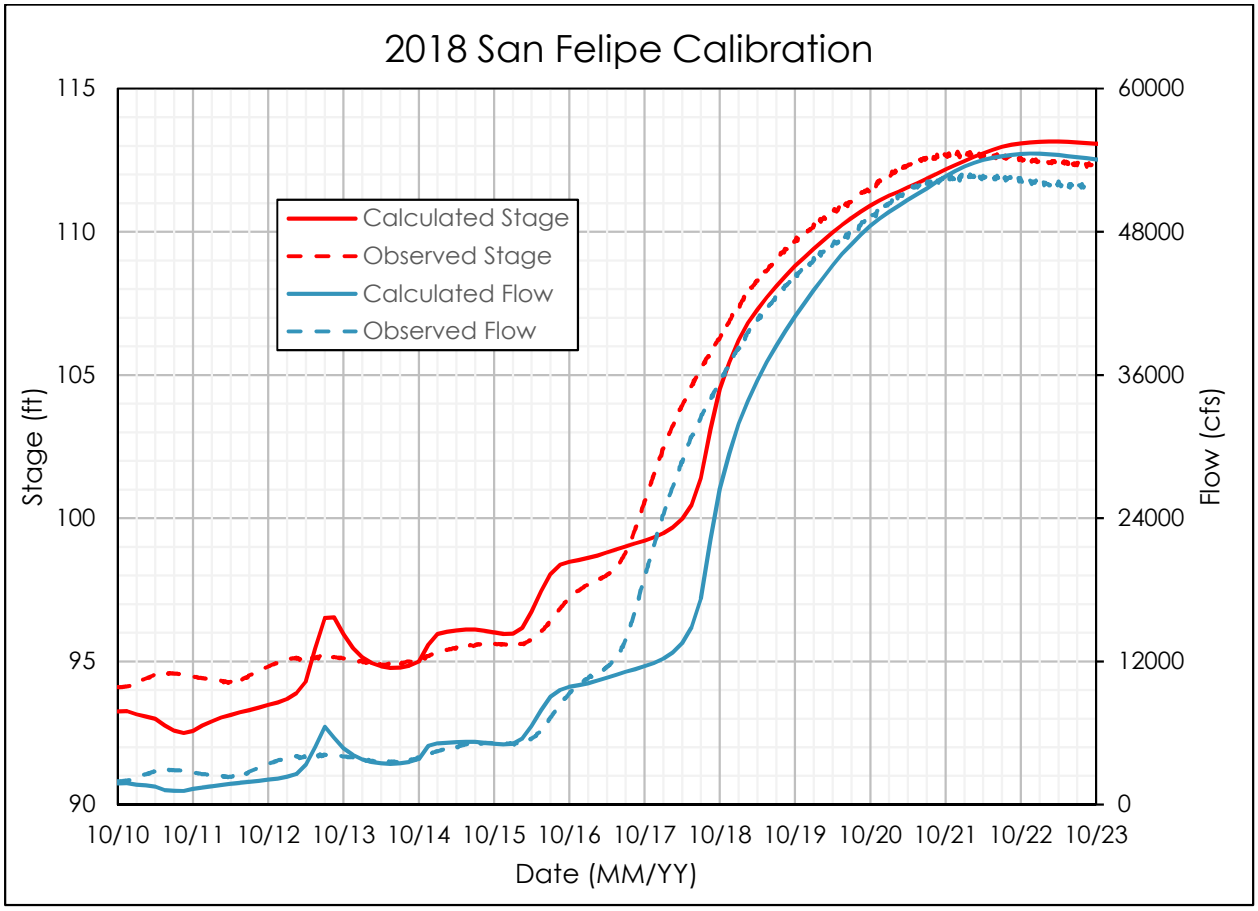

Figure E-26: San Felipe Stage and Discharge Calibration

The results showed that the calculated stage and discharge hydrographs were late compared to the observed hydrographs. At nearly 10,000 cfs, the calculated stage and discharge data level out and respond later than the observed data on the rising limb. The calculated peaks are also shown to be above the observed data. The calculated peak stage during this event was 113.15 feet and occurred approximately 1 day after the observed peak stage of 112.82 feet. The calculated peak discharge during this event was 54,500 cfs and occurred approximately 22 hours after the peak observed discharge of 52,900 cfs.

E.4.4.3 Richmond

The roughness factors between cross sections 548083 and 477908 were used to calibrate to the Richmond USGS gauge. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-27.

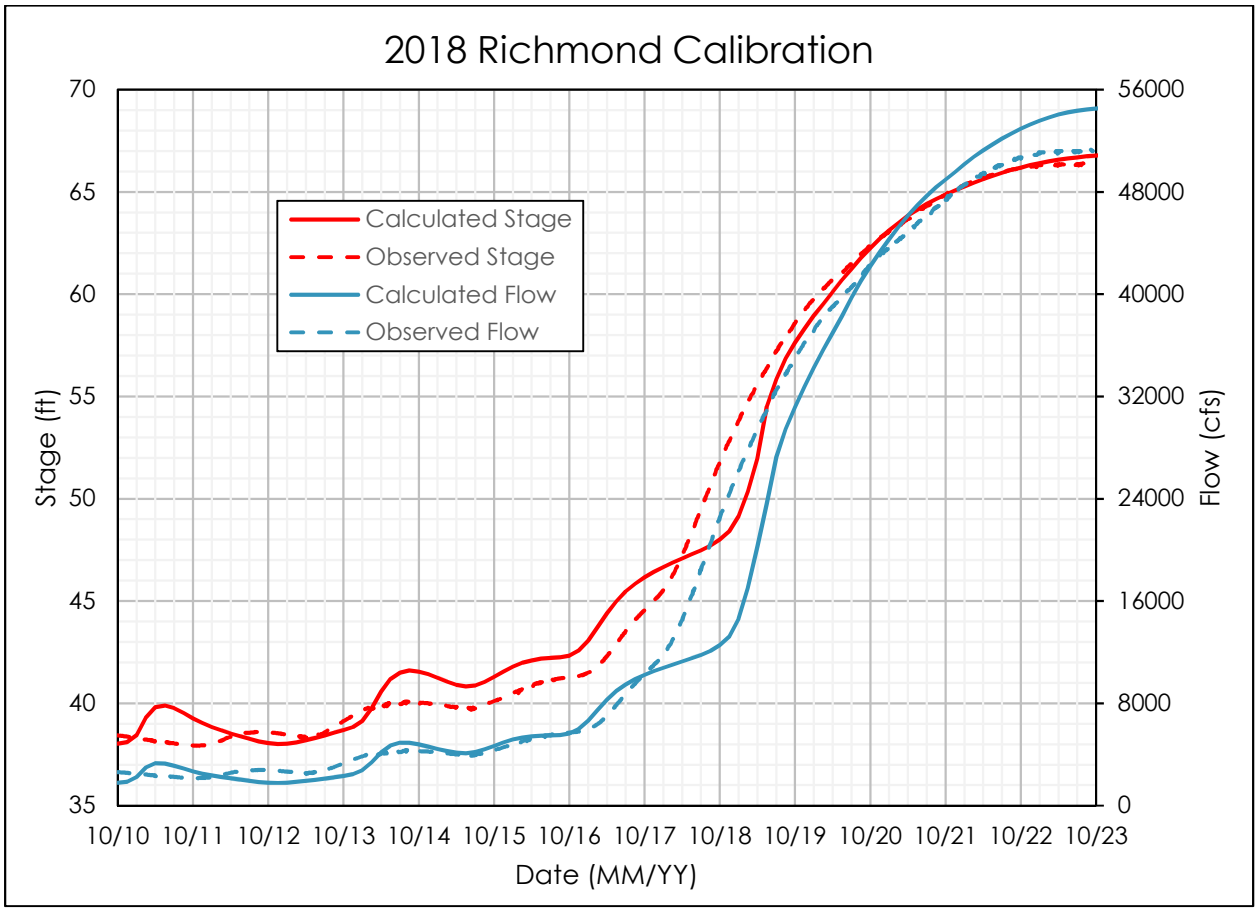

Figure E-27: 2018 Richmond Stage and Discharge Calibration

Like the San Felipe gage comparison, the calculated results stagnate at approximately 10,000 cfs and lagged the observed results for both stage and discharge. The calculated stage hydrograph matches well with flows below 10,000 cfs while stagnating between 10,000 and 13,000 cfs and rising fast above 13,000 cfs. The calculated peak discharge matches closely with the observed data while the calculated peak stage rises above the observed data. The calculated peak stage during this event was 66.81 feet and occurred approximately 19 hours after the peak observed stage of 66.41 feet. The calculated peak discharge during this event was 54,400 cfs and occurred approximately 10 hours after the peak observed discharge of 51,300 cfs.

E.4.4.4 Rosharon

The roughness factors between cross sections 443035 and 12687 were used to calibrate to the Rosharon USGS gauge. Since the discharge was spread across both the Brazos River and Oyster Creek, the calculated discharge from both reaches were added together and compared to the observed results. Several iterations were simulated to determine the best fit to the observed data. A graph of comparisons between the observed and modeled data is shown below in Figure E-28.

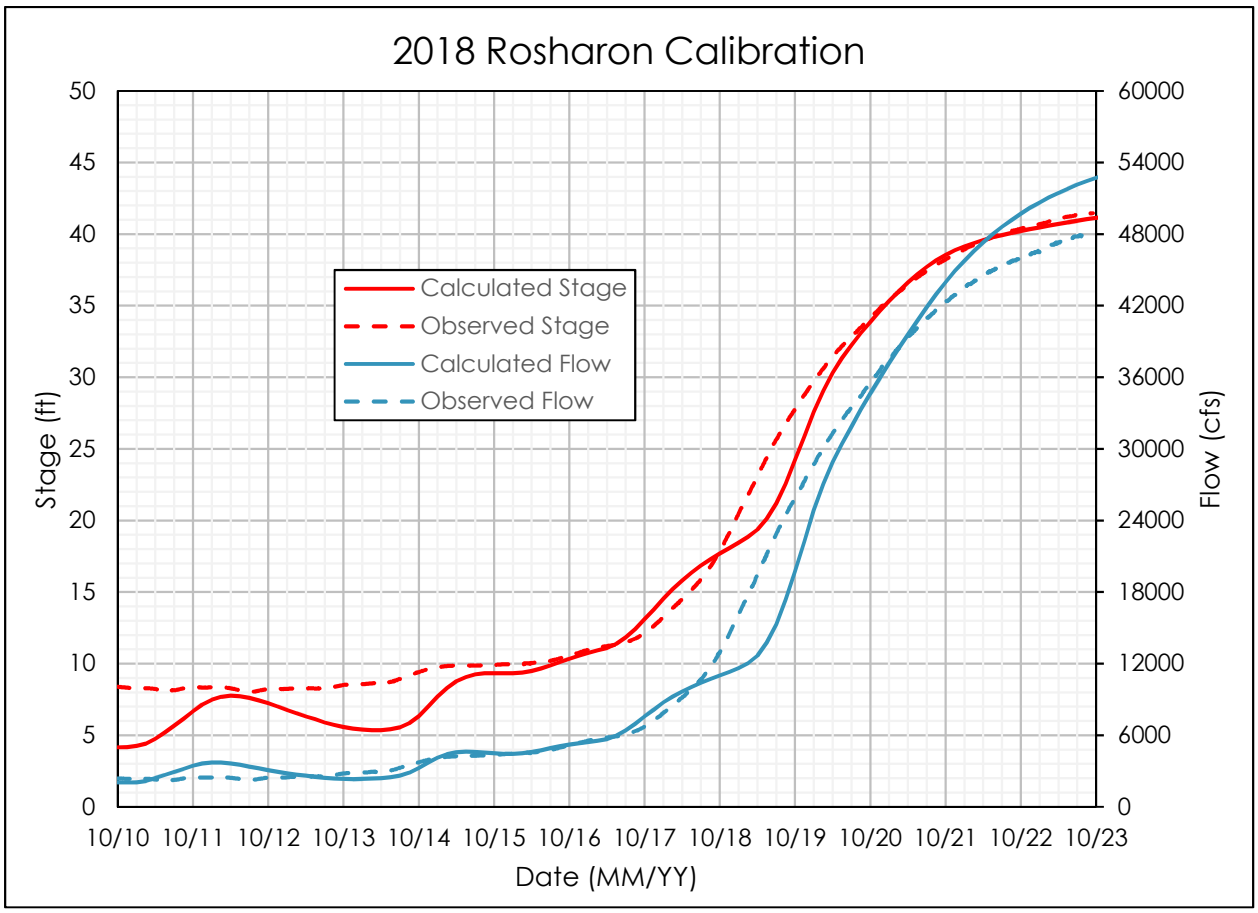

Figure E-28: 2018 Rosharon Stage and Discharge Calibration

The results showed that the stage and discharge comparisons followed the similar trend of the upstream USGS gauges with the slight stagnation in the calculated data. Overall, the stage hydrograph matches well once flows become higher and the discharges peak above the observed discharges. The higher discharges could be a combination of the flows from both the Brazos River and Oyster Creek overestimating the amount of flow through the system during this event. The calculated peak stage during this event was 41.45 feet while the peak observed stage was 41.49 feet. The calculated peak discharge during this event was 53,000 cfs while the peak observed discharge was 48,100 cfs.

E.4.4.5 Summary

Since no hydrologic calculations were conducted for the 2018 storm event, it was more difficult to calibrate to the observed data without the intermediate subbasin flows in the Lower Brazos region. The 2018 event provided more assurance of the low flow roughness factors for the design storm events in addition to the 2007 event. While the calculated results stagnated on the rising limb portion of the storm at all the USGS gages, the calculated hydrographs followed the trend of the observed hydrographs

E.4.5 Final Calibration Factors

After the hydraulic models were calibrated to each of the four historical storms by adjusting the roughness factors, the four sets of factors were averaged in the given ranges to be used for the design storm hydraulic analyses. For flows below 60,000 cfs, all four calibration storm flow roughness factors were averaged. For flows above 60,000 cfs, only the 2016 and Harvey event flow roughness factors were averaged. These parameters were averaged for each discharge and within the cross sections specified. The roughness factors were averaged to give an overall condition of the Brazos River since the river changes over time due to gain/loss of vegetation, scour and sediment deposition. These averaged roughness factors were used for all the design storm events. A table of the averaged roughness coefficients is shown below in Table E-10.

Table E-10: Averaged Roughness Factors

Discharge (cfs)	Average Roughness Factors for Range of Cross Sections							
	1158482 to 811091	811091 to 696595	696595 to 657028	657028 to 548083	548083 to 504102	504102 to 447908	443035 to 305615.2	305615.2 to 12687
10,000	0.85	0.83	0.9	0.9	0.75	1.1	0.95	0.85
20,000	0.85	0.83	0.9	0.9	0.75	1.1	0.95	0.85
30,000	0.85	0.83	0.9	0.9	0.75	1.1	0.95	0.85
40,000	0.85	0.955	1.025	1.025	0.875	1.275	1.125	1
50,000	0.9	1.08	1.15	1.15	1	1.275	1.125	1.35
60,000	0.95	1.1	1.15	1.15	1	1.275	1.125	1.4
70,000	0.95	1.1	1.15	1.15	1	1.275	1.175	1.5
80,000	1.1	1.1	1.2	1.2	1.05	1.3	1.2	1.6
90,000	1.1	1.225	1.225	1.225	1.075	1.3	1.2	1.6
100,000	1.1	1.225	1.225	1.275	1.075	1.325	1.275	1.6
110,000	1.1	1.25	1.4	1.35	1.15	1.325	1.275	1.6
120,000	1.1	1.275	1.525	1.375	1.225	1.35	1.3	1.6
130,000	1.175	1.325	1.575	1.425	1.275	1.35	1.4	1.6
140,000	1.225	1.475	1.575	1.425	1.275	1.35	1.4	1.6
150,000	1.225	1.525	1.575	1.425	1.275	1.35	1.4	1.6
160,000	1.225	1.525	1.575	1.425	1.275	1.35	1.4	1.6
170,000	1.225	1.525	1.575	1.425	1.275	1.35	1.4	1.6

The different roughness factors for each historic storm demonstrate that the response from the river changes over time depending on the vegetation condition of the Brazos River. Averaging of these coefficients produced a model that generalized the differences between the historical storm events in the Brazos River. The calibration process produced results which assured the hydraulic model responded well to the observed data and that greater accuracy would be achieved during the design storm analysis.

E.4.6 Calibration Summary

As stated earlier, the goal of the model calibration was to validate the hydraulic model and provide more accurate results for the design storm events. The 2007, 2016, Harvey and 2018 events were chosen to simulate low (2007, 2018) and high (2016 and Harvey) flow conditions and also to them being relatively recent to represent the existing conditions of the Lower Brazos River. Since vegetative conditions, scour and soil depositions change the hydraulic nature of the Brazos River over time, roughness factors calculated for each historical event were determined to be the best method to calibrate the model. Averaging the roughness factors from the historical storms provided an overall existing representation of the Lower Brazos River in the hydraulic model to be used for the design storm events.

E.5.0 Design Storms

Once the roughness factors from all three historical storm events were averaged, design storms were modeled for the 10%, 2%, 1%, and 0.2% ACE events. Discharge hydrographs of each design storm event were derived from the HEC-HMS model discussed in Appendix D. Each of these design storms were mapped using the RAS Mapper tool with comparisons made to the current effective FIS for the 1% ACE event. Comparisons were made for all design storms of the stage and discharge at the USGS gauge locations from previous analyses along the Brazos River. The goal of the comparisons was to evaluate the changes from previous studies and to determine whether the hydraulic model of the Brazos River was sufficient in determining impacts. USGS gauges were used as key points for the results comparisons, and current effective FIS comparisons were made for each county in the study area. The design storm water surface elevations tables are located within the supporting information at the end of the Appendix. The inundation mapping for the 1% ACE event is shown in Exhibit E-1. The inundation mapping for the 0.2% ACE event is shown in Exhibit E-2. Inundation mapping for the 1% ACE and 0.2 % ACE is shown in Exhibit E-3. The 1% ACE velocity mapping is shown in Exhibit E-4.

E.5.1 Results Comparisons

E.5.1.1 Hempstead

The Hempstead USGS gauge is located just downstream of US 290 along the border between Waller County and Washington County and has a contributing drainage area of approximately 43,880 square miles. Comparisons were made between the 2009 Waller County FIS, the gauge frequency storm analysis (as discussed in Appendix D) and the design storm analysis for all storm events. A comparison of results is shown below in Table E-11.

Table E-11: Hempstead Discharge and Elevation Comparisons

Return Period	Discharge (cfs)			Water Surface Elevation (feet NAVD 88)		
	2009 Waller Co. FIS	Gauge Freq. Storm Analysis	HEC-RAS Design Storm Analysis	2009 Waller Co. FIS	HEC-RAS Design Storm Analysis	USGS Rating Curve*
10% ACE	110,000	97,000	98,000	163.00	158.62	160.04
2% ACE	182,473	140,000	142,000	167.80	162.05	162.65
1% ACE	206,962	157,000	161,000	169.20	162.92	163.24
0.2% ACE	260,000	195,000	227,000	171.70	165.66	-**

**Water surface elevations are derived from the Hempstead USGS Rating Curve (Version 15) using the Design Storm Analysis discharges*
***Design Storm Discharge not found within USGS rating curve*

The results showed that the peak discharges form the design storm analysis closely aligned with those of the gauge frequency storm analysis, except for the 0.2% ACE storm event, which differed by over 30,000 cfs. Compared to the 2009 Waller County FIS, the design storm analysis showed a decrease in water surface elevations at Hempstead for all storm events. The maximum difference between the FIS and design storm analysis water surface elevations was 6.28 feet for the 1% ACE event. The decrease in water surface elevations could be attributed to new terrain as well as the averaged calibration parameters affecting the hydraulic modeling. Also, the design storm analysis produced significantly lower discharges than the FIS in Waller County, which resulted in lower water surface elevations. The 1% ACE floodplain with the overflow areas near the Hempstead USGS gauge is shown below in Figure E-29.

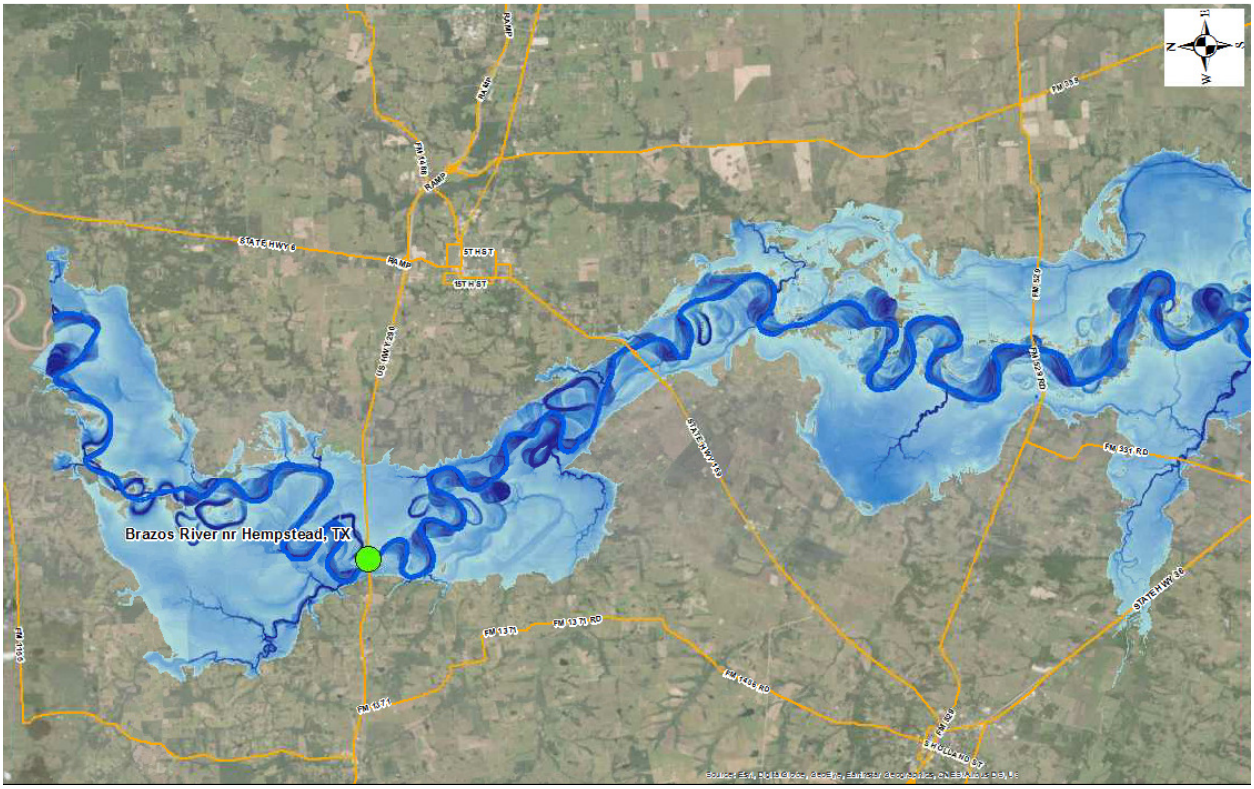

Figure E-29: 1% ACE Floodplain near Hempstead USGS Gauge

E.5.1.2 San Felipe

The San Felipe USGS gauge is a relatively new gauge that is located downstream of FM 1458 in Waller County and has a contributing drainage area of 44,670 square miles. Comparisons were only made between the 2010 Austin County FIS and the design storm analysis. Results are compared below in Table E-12.

Table E-12: San Felipe Discharge and Elevation Comparisons

Return Period	Discharge (cfs)	Water Surface Elevation (feet NAVD 88)		
	HEC-RAS Design Storm Analysis	2010 Austin Co. FIS	HEC-RAS Design Storm Analysis	USGS Rating Curve*
10% ACE	94,000	120.20	123.57	122.89
2% ACE	136,000	123.40	127.96	127.99
1% ACE	157,000	127.20	129.84	130.03
0.2% ACE	225,000	129.50	132.71	-**

**Water surface elevations are derived from the San Felipe USGS Rating Curve (Version 2.1) using the Design Storm Analysis discharges*
***Design Storm Discharge not found within USGS rating curve*

The results show that the design storm analysis had higher elevations when compared to the 2010 Austin County FIS. The higher elevations are attributed to the averaged roughness factor in the hydraulic model which were multiplied by a factor greater than one for the high flow events. While the water surface elevations were shown to be higher at this gauge, the results were deemed more accurate due to the calibration process. The 1% ACE floodplain with the overflow areas near the San Felipe USGS gauge is shown below in Figure E-30.

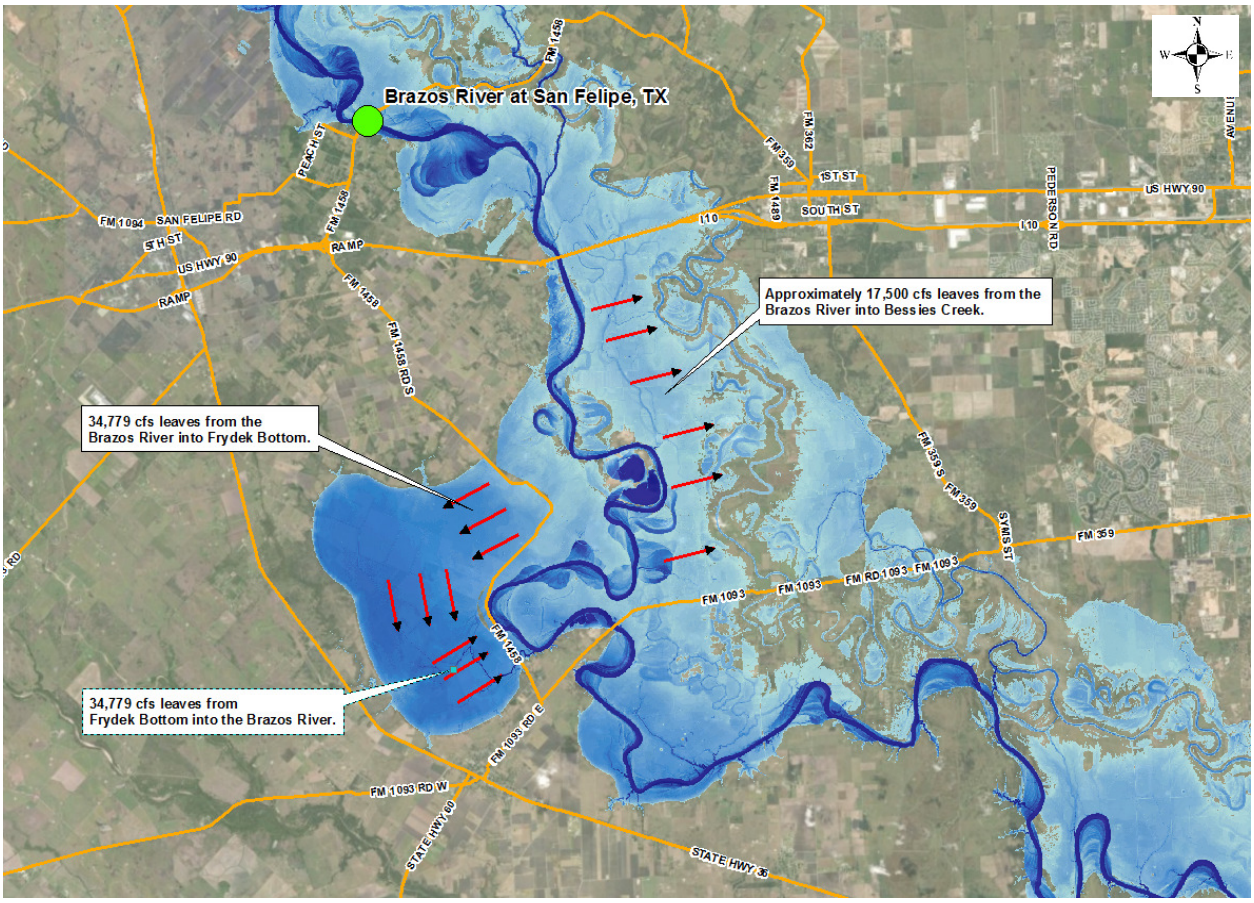

Figure E-30: 1% ACE Floodplain near San Felipe Gauge

E.5.1.3 Richmond

The Richmond USGS gauge is located downstream of US 90A in Fort Bend County and has a contributing drainage area of 45,107 square miles. Comparisons were made with the 2014 Fort Bend County FIS, the gauge frequency storm analysis (as discussed in Appendix D) and the design storm analysis. Results are compared below in Table E-13.

Table E-13: Richmond Discharge and Elevation Comparisons

Return Period	Discharge (cfs)			Water Surface Elevation (feet NAVD 88)		
	2014 Fort Bend Co. FIS	Gauge Freq. Storm Analysis	HEC-RAS Design Storm Analysis	2014 Fort Bend Co. FIS	HEC-RAS Design Storm Analysis	USGS Rating Curve*
10% ACE	103,000	88,000	86,000	76.70	77.04	76.84
2% ACE	147,000	117,000	123,000	81.30	82.76	81.14
1% ACE	164,000	127,000	139,000	82.80	84.43	82.65
0.2% ACE	202,000	148,000	183,000	85.20	87.70	-**

**Water surface elevations are derived from the Richmond USGS Rating Curve (Version 18) using the Design Storm Analysis discharges*
***Design Storm Discharge not found within USGS rating curve*

The results showed that the design storm analysis closely aligned with the gauge frequency storm analysis for the 1% ACE and more frequent events. Comparisons to the water surface elevations showed increases in the design storm events. These increases in water surface elevations were attributed to both the updated hydrology and the calibrated roughness factors. Average roughness factors were greater than one for higher flows causing water surface elevations to rise. While these changes created higher water surface elevations, these results were deemed more accurate because the model was calibrated to historical high-flow events.

The design storm analysis primarily focused on peak discharges. In addition to the peak discharges, a comparison was made between the volumes of the 1% ACE event design storm and historic events. Figure E-27 shows the 1% ACE event design storm hydrograph at Richmond compared to several historic events. As shown in Figure E-31, the design storm volume was comparable to several historic events.

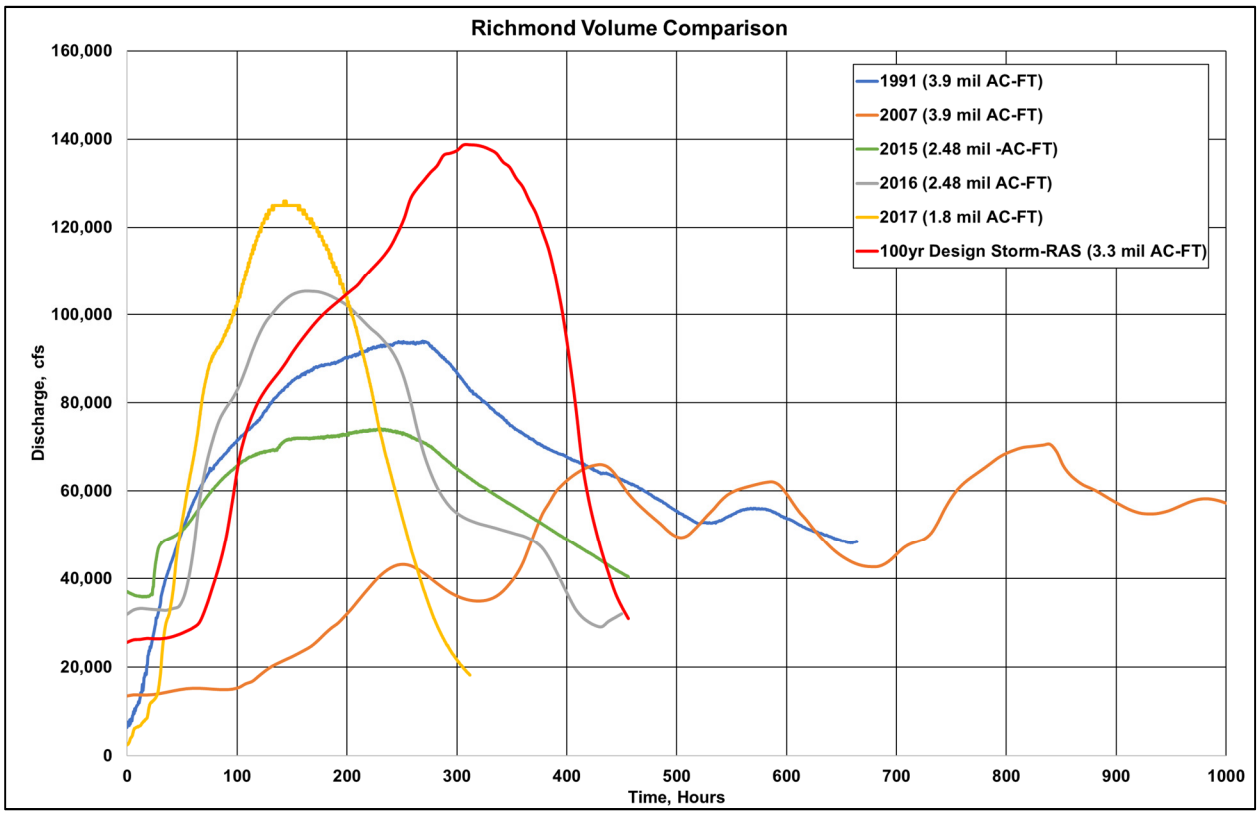

Figure E-31: Richmond Volume Comparisons

The 1% ACE floodplain with the overflow areas near the Richmond USGS gauge is shown below in Figure E-32.

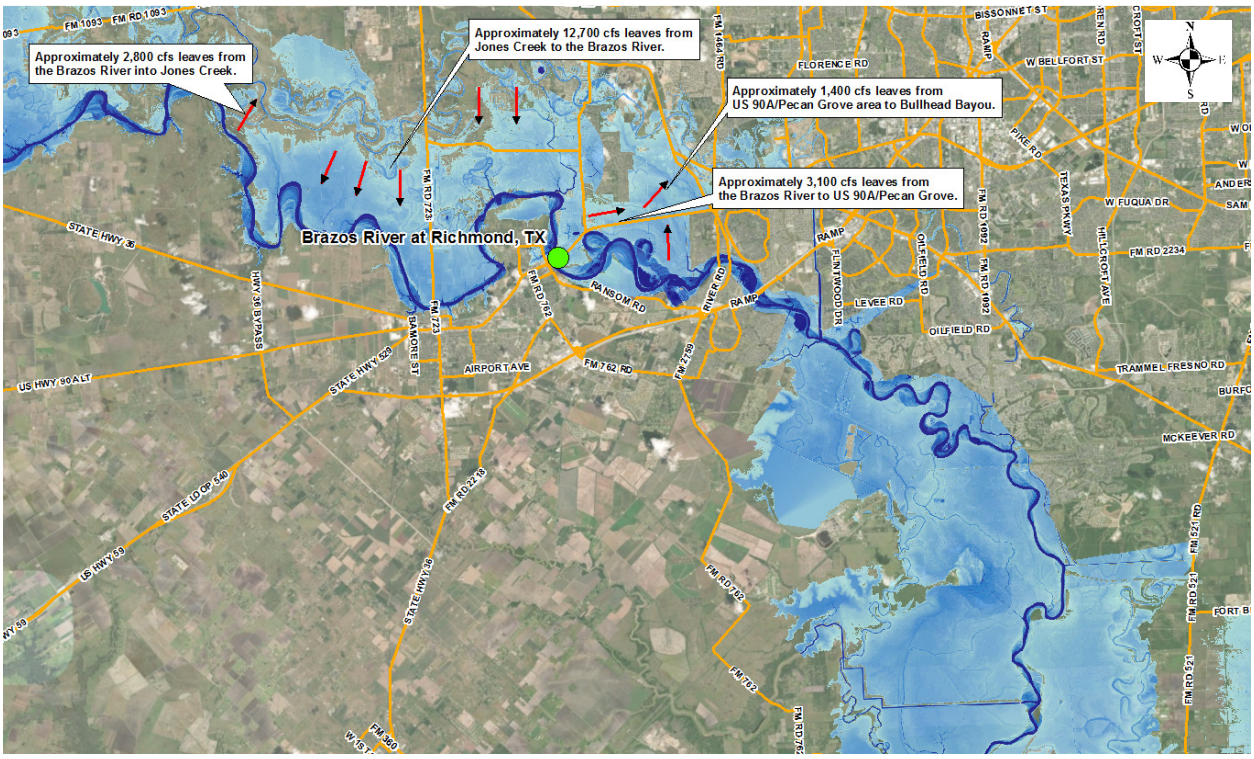

Figure E-32: 1% ACE Floodplain near Richmond USGS Gauge

E.5.1.4 Rosharon

The Rosharon USGS gauge is located downstream of FM 1462 in Brazoria County and has a contributing drainage area of 45,339 square miles. The Brazos River in this area overflows into Oyster Creek resulting in a very wide floodplain. Discharge is measured across the floodplain for both the Brazos River and Oyster Creek for the USGS gauge. As a result, discharge hydrographs from the hydraulic model for both the Brazos River and Oyster Creek were combined to compare to the gauge data. Comparisons were made between the 2014 Fort Bend County FIS and the design storm analysis from this study. Results are compared in Table E-14.

Table E-14: Rosharon Discharge and Elevation Comparisons

Return Period	Discharge (cfs)		Water Surface Elevation (feet NAVD 88)		
	2014 Fort Bend Co. FIS	HEC-RAS Design Storm Analysis	2014 Fort Bend Co. FIS	HEC-RAS Design Storm Analysis	USGS Rating Curve*
10% ACE	103,000	86,000	51.00	50.73	51.98
2% ACE	145,000	126,000	51.50	51.17	52.59
1% ACE	162,000	145,000	51.50	51.29	-**
0.2% ACE	200,000	202,000	51.80	51.62	-**

**Water surface elevations are derived from the Rosharon USGS Rating Curve (Version 16) using the Design Storm Analysis discharges*
***Design Storm Discharge not found within USGS rating curve*

The results showed that the discharges at Rosharon are lower in this study than in the Fort Bend County FIS for all storm events except the 0.2% ACE event. Water surface elevations were comparable to one another in both analyses for all the storm events. The water surface elevations of the different storm events did not differ significantly because much of the discharge upstream in the Brazos River overflowed into Oyster Creek. This overflow widened the floodplain and therefore required a substantial amount of discharge to increase the water surface elevations. The 1% ACE floodplain with the overflow areas near the Rosharon USGS gauge is shown below in Figure E-33.

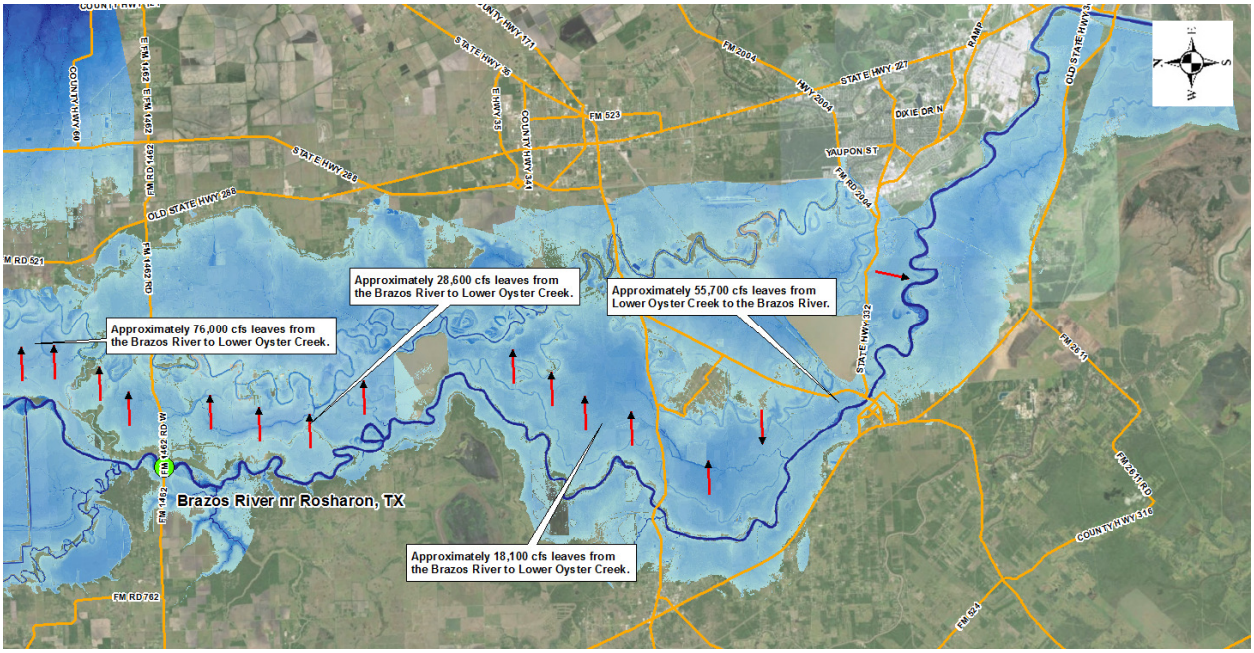

Figure E-33: 1% ACE Floodplain near Rosharon USGS Gauge

E.5.2 Rating Curve Comparisons

Rating curves are stage-discharge relationships where a specific area within a river system produced a water surface elevation for a given discharge value. The USGS created a set of rating curves that are utilized to determine the discharge based on the measured stage of the river. When a high-water event occurred, the USGS measures the discharge using field measurement techniques to assert whether the current rating needs to be adjusted. Rating curves were produced for each USGS gauge along the Brazos River by the USGS and compared to the rating curves produced by the hydraulic model developed as part of this current study. To account for a wide range of discharges, rating curves from the 0.2% ACE event in the hydraulic model were used to compare with the USGS gauges. Rating curve discussions for each USGS gauge within the study are shown below.

E.5.2.1 Hempstead

The Hempstead gauge located at US 290 in Waller County was compared to the rating curve at cross section 1062059 in the hydraulic model. The USGS rating curve from the Hempstead gauge is Curve#15 and was created in 2018. Stage-discharge data from both rating curves were used to interpolate data points for every 10,000 cfs. The graph of the comparisons between the USGS gauge and the hydraulic model is shown below in Figure E-34.

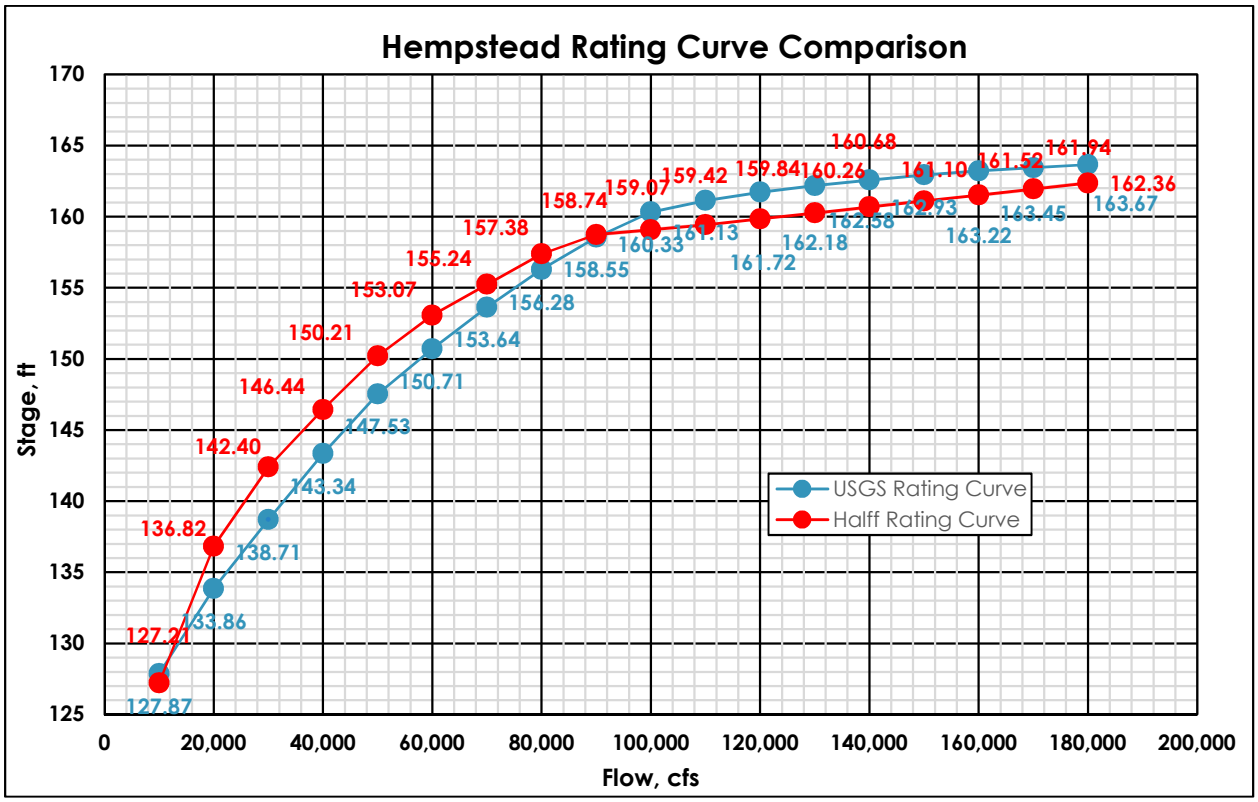

Figure E-34: Hempstead Rating Curve Comparison

The results showed that the rating curve calculated from the hydraulic model followed closely to the USGS gauge rating curve for the high flows (greater than 100,000 cfs). The rating curve for the hydraulic model trends above the USGS rating curve for the lower flows (less than 100,000 cfs) with a maximum difference of approximately 4 feet occurring at a discharge of 30,000 cfs.

E.5.2.2 San Felipe

The San Felipe gauge located at FM 1458 in Waller County was compared to the rating curve at cross section 811091 in the hydraulic model. The USGS rating curve from the San Felipe gauge is Curve#2 and was created in 2018. Stage-discharge data from both rating curves were used to interpolate data points for every 10,000 cfs. The graph of the comparisons between the USGS gauge and the hydraulic model is shown below in Figure E-35.

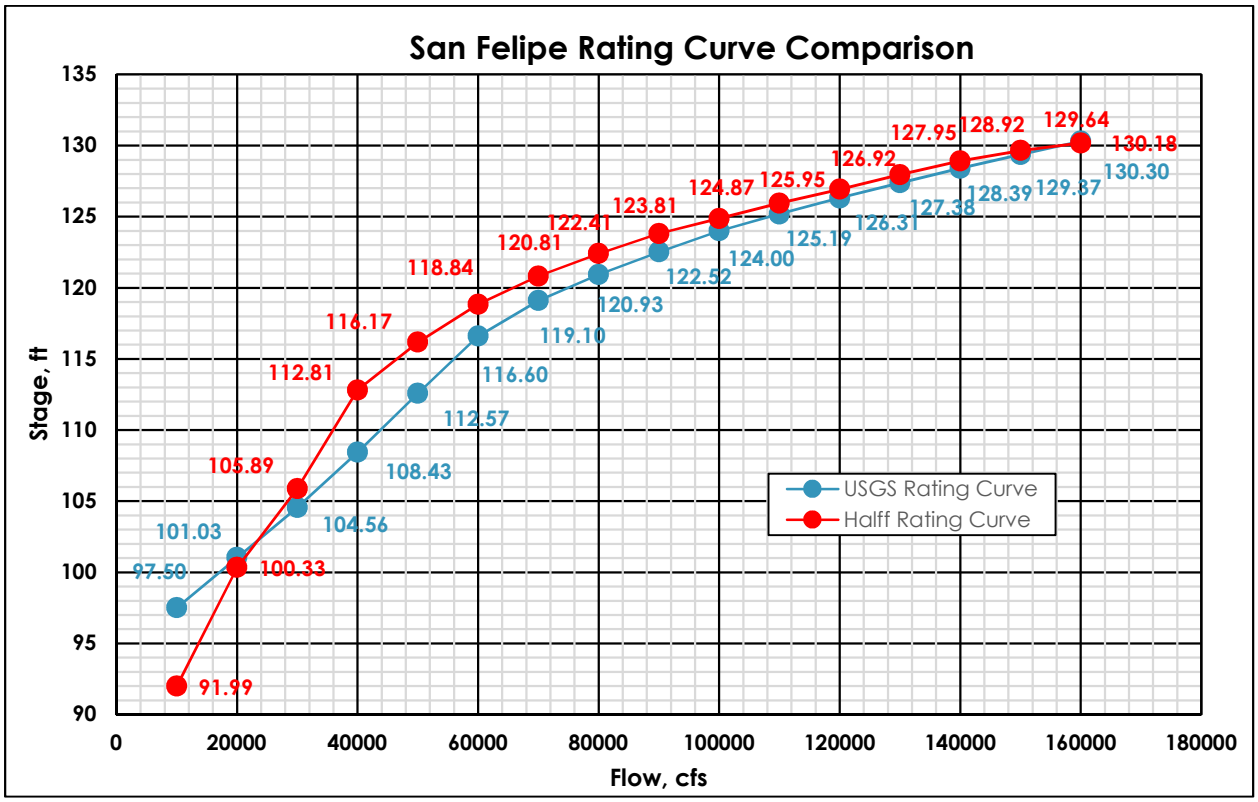

Figure E-35: San Felipe Rating Curve Comparison

The results showed that the rating curve calculated from the hydraulic model followed closely to the USGS gauge rating curve during the higher flow events. The rating curve for the hydraulic model showed more change in water surface elevation for the low flows compared to the USGS rating curve. At higher flows, the hydraulic model rating curve more closely matched the USGS rating curve.

E.5.2.3 Richmond

For the Richmond gauge, several rating curves have been produced by the USGS over the last decade to measure flow and stage conditions in the Brazos River. The most recent version of the Richmond rating curve is Curve 18 and has been used since 2016. Rating curves were adjusted to account for the changes in the Brazos River such as erosion and soil deposits and were updated when needed by the USGS.

Comparisons were made between the current and previous USGS rating curves (versions 17 and 18), the rating curve from the effective HEC-RAS model and the rating curve developed from the design storm analysis as part of this study. These comparisons were used to validate the model created for this analysis and to the differences in readings at the Richmond gauge. A graph of the comparisons is shown below in Figure E-36.

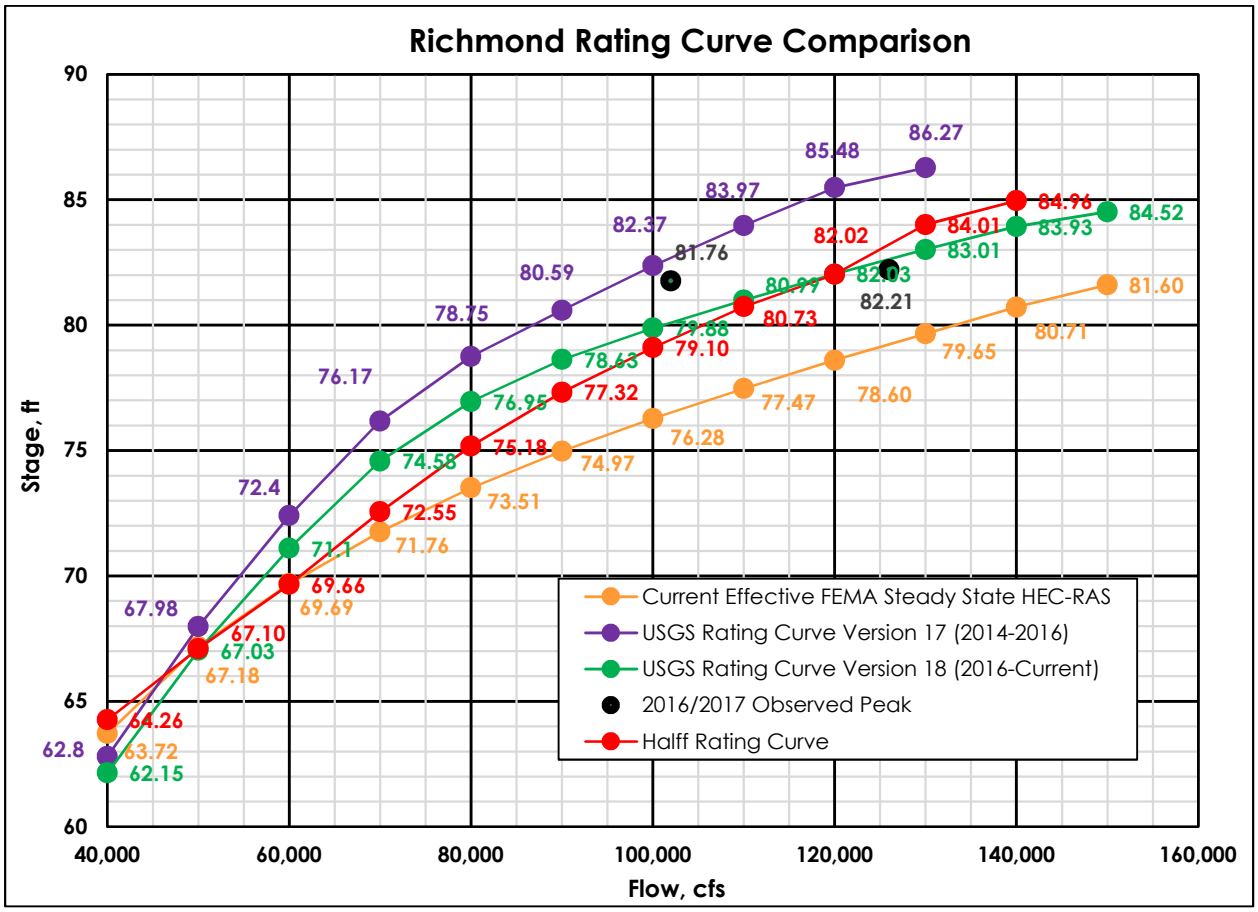

Figure E-36: Richmond Rating Curve Comparison

The results showed that the hydraulic model for the analysis closely followed the most recent version of the USGS rating curve for the Richmond gauge. The effective FEMA HEC-RAS rating curve was considerably lower than the USGS curves, differing by over three feet on some flow ordinates. The comparisons of the rating curves validated that the hydraulic model closely aligned with the current condition of the Brazos River based on the most recent USGS rating curve. The difference between the observed high-water marks for 2016 and 2017 showed how the Brazos River can change over time in which the water surface elevations between the two points were similar but have a much greater difference in flow. Vegetation changes in the Brazos River are a contributing factor in the rating curve changes for the USGS gage in which the hydraulic conditions of the river system change

E.5.2.4 Rosharon

As stated earlier, the Rosharon gauge is located at FM 1462 in Brazoria County. Unlike the previous rating curves, the rating curve from the hydraulic model for Rosharon was developed by adding the discharge hydrographs from both the Brazos River and Oyster Creek at cross sections 305615.2 and 256465.5, respectively. These combined flows were compared with the water surface elevations at cross section 305615.2 on the Brazos River to create a combined flow rating curve to compare to the USGS rating curve. The USGS rating curve from the Hempstead gauge is Curve#15

and was created in 2018. The USGS rating curve uses and index-velocity method rather than the traditional stage-discharge rating curve method used in this study. For this reason, the difference in the two curves is greater than the comparisons shown previously. The graph of the comparisons between the USGS gauge and the hydraulic model is shown below in Figure E-37.

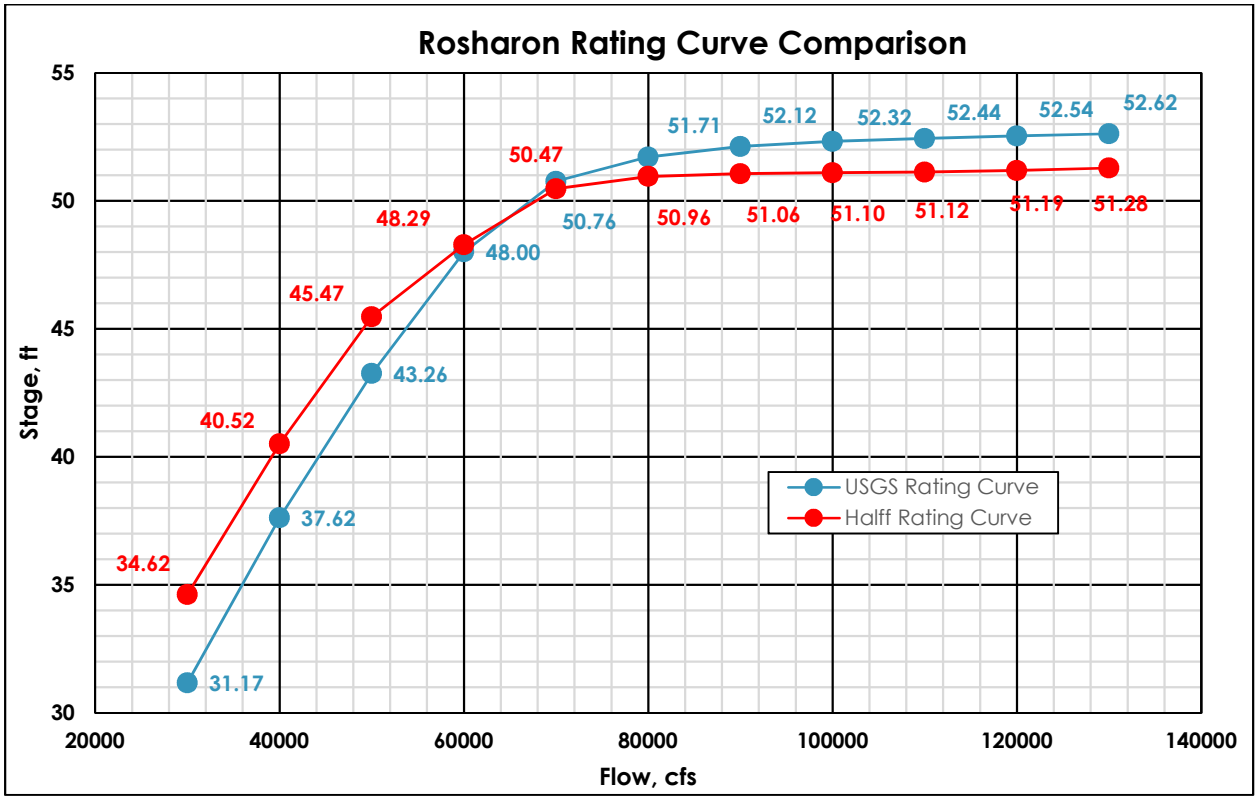

Figure E-37: Rosharon Rating Curve Comparison

The results showed that the hydraulic model rating curve was much higher compared to the USGS rating curve for the low flows. Beyond 70,000 cfs, the water surface elevations plateaued and rose very little even with significantly higher flows due to the overflow conditions between the Brazos River and Oyster Creek.

E.5.3 Rosharon Key Elevations

In Brazoria County, overflow occurred between the Brazos River and Oyster Creek creating a very wide floodplain during the 1% ACE event. Critical areas within Brazoria County become inundated once the overflow into Oyster Creek occurs. Since stage and discharge data of the Brazos River was limited within the area to just the USGS Rosharon Gauge near FM 1462, the stage from the gauge was utilized to determine inundation in key areas in Brazoria County. The goal of this analysis was to predict when certain areas within the County will be subject to flooding based on the Rosharon gauge readings.

Using the hydraulic model, water surface elevations at the Rosharon gauge location were used to determine the expected maximum depths within key areas. Water surface elevations from the Rosharon gauge were taken from the design storm analysis and included the 50%, 20%, and 4%

ACE events as well. These depths were taken at a calculation point within the key area that produced the maximum depth from the terrain. As a result, this table does not represent the overall depth in the key area as some areas will be higher or lower than the calculation point used for this analysis. A table of the key area depths is shown below in Table E-15.

Table E-15: Rosharon Key Elevations Results

Key Area	Maximum Ponding Depth based on Rosharon Elevations						
	41.09	50.03	50.73	51.01	51.17	51.29	51.62
Lochridge	0.95	1.61	3.78	5.06	5.94	6.61	8.21
CR25 & Brazos River Rd	0	0.71	1.12	1.29	1.39	1.48	1.78
TDJC Prisons	0	0	1.53	2.72	3.58	4.24	5.87
Holiday Lakes, TX	0.41	4.82	5.95	7.02	7.66	8.21	9.56
Columbia Lakes	2.24	4.83	4.97	5.19	5.39	5.61	6.56
West Columbia, TX	0	1.70	1.95	2.25	2.49	2.73	3.76
Bar X Ranch	0	3.35	4.30	5.07	5.41	5.41	6.67
Lake Jackson Farms	2.21	6.00	6.94	7.93	8.53	9.08	10.18
Brazoria, TX	0	0	0	0.88	1.57	2.18	3.53
Jones Creek, TX	0	1.61	2.99	5.59	6.18	6.51	7.28

The results showed that some key areas become severely inundated by the Brazos River and Oyster Creek while others did not. For example, if the Rosharon gauge is expected to reach 50.73 feet, Columbia Lakes could expect to have a maximum ponding depth of 4.97 feet.

E.5.4 Richmond Key Elevations

The Levee Improvement Districts (LIDs) located in Fort Bend County rely on outfalls to release runoff from the internal drainage area behind the levees. During storm events, the Brazos River rises and potentially affects the tailwater on the outfalls for the LIDs. 1% ACE water surface elevations were extracted from the water surface elevation grid of the hydraulic model at each of the LID outfall locations to identify the impacts to the outfalls. These water surface elevations were based on a 1% ACE water surface elevation of 84.45 feet at the Richmond USGS gauge. A table of 1% ACE water surface elevations of the LID outfalls is shown below in Table E-16.

Table E-16: Richmond Key Elevations Results

Location	Water Surface Elevation based on Richmond Elevations 84.43' (NAVD 88) /57.41' (Gauge)
LID #20 Outfall	91.80
Pecan Grove Outfall	87.55
MUD 121 Outfall	81.52
LID #7 New Territory Outfall	81.06
LID #10 Outfall	78.59
LID #11 Outfall 1	76.99
LID #11 Outfall 2	75.64
LID #2 Outfall 2	74.79
LID #17 Outfall	74.75
LID #2 Outfall 1	74.67
LID #14 Avalon Outfall	74.60
LID #2 First Colony Outfall	74.60
LID #15 Outfall	69.75
LID #19 Outfall	66.90
Sienna Plantation North Outfall	64.61
Sienna Plantation Outfall 1	61.28
Sienna Plantation Outfall 2	58.93

E.5.5 Current Effective FIS Comparison

Comparisons of the design storm analysis of the Brazos River were made to the surrounding county Flood Insurance Study (FIS) to show how the floodplain has changed when compared to FEMA's results. Some of these counties with FIS's have studied the Brazos River using approximate methods resulting in Zone A special flood hazard areas (SFHAs) as discussed in Appendix A. Detailed studies of the Brazos River were mapped as Zone AE which gives base flood elevations (BFEs). 1% ACE water surface elevation profiles from the FIS of Waller, Fort Bend and Brazoria Counties were compared to that of the model developed for this study. Comparisons of the model and FIS water surface elevations are located within the supporting information at the end of the Appendix. Comparisons of Brazoria, Fort Bend and Waller Counties are shown below in Figures E-38, E-39 and E-40, respectively.

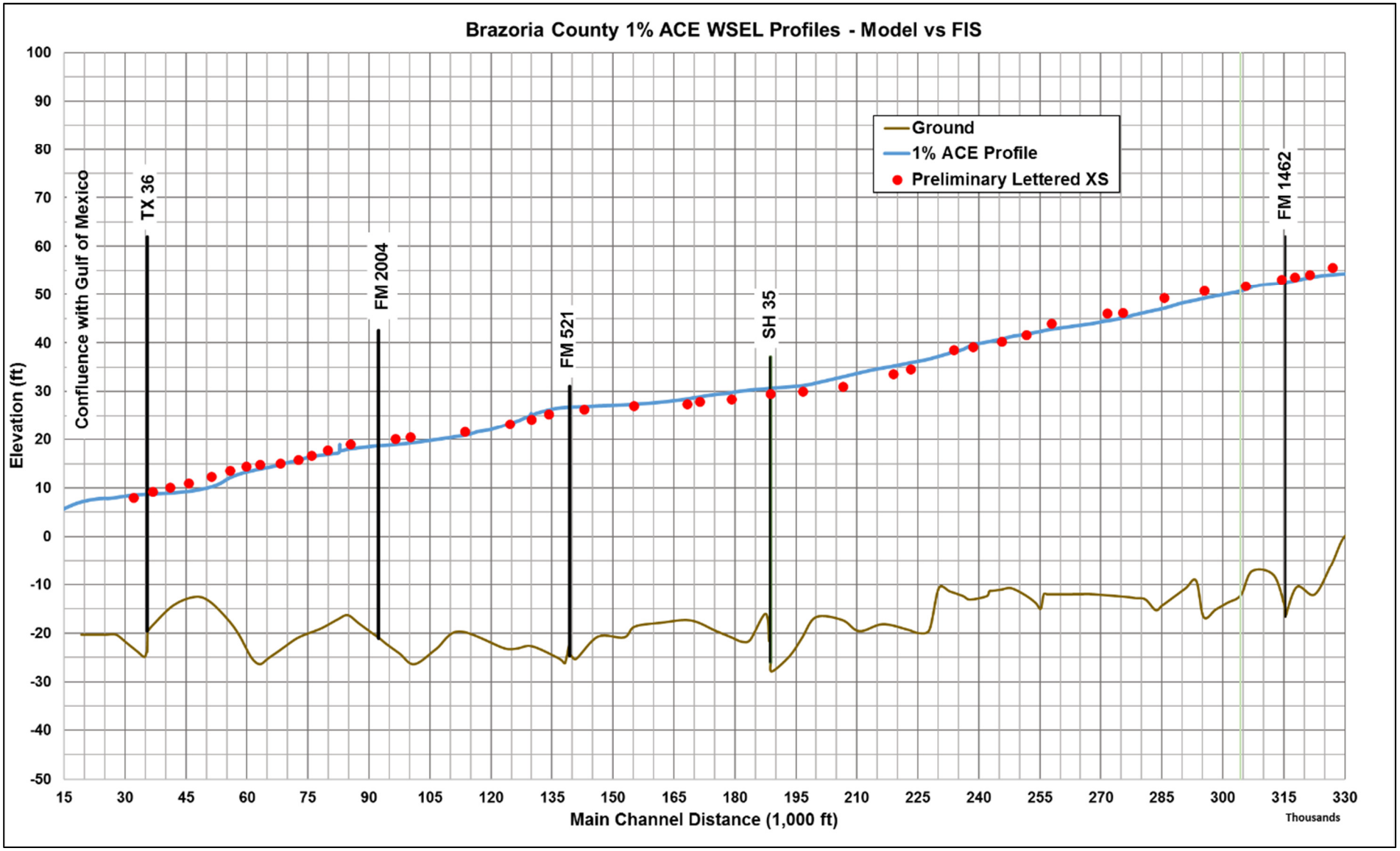

Figure E-38: Brazoria County - Model vs FIS Comparison

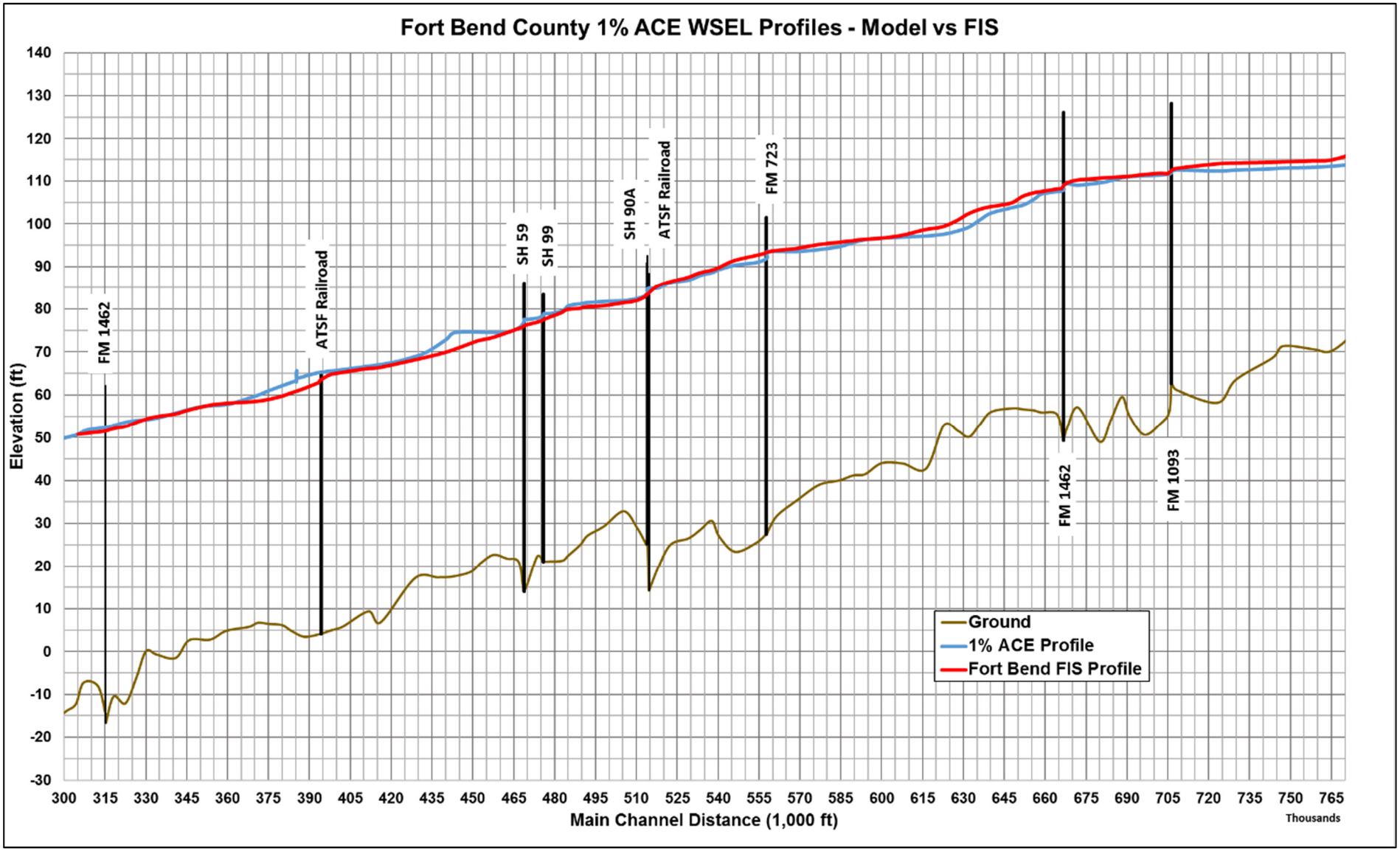

Figure E-39: Fort Bend County - Model vs FIS Comparisons

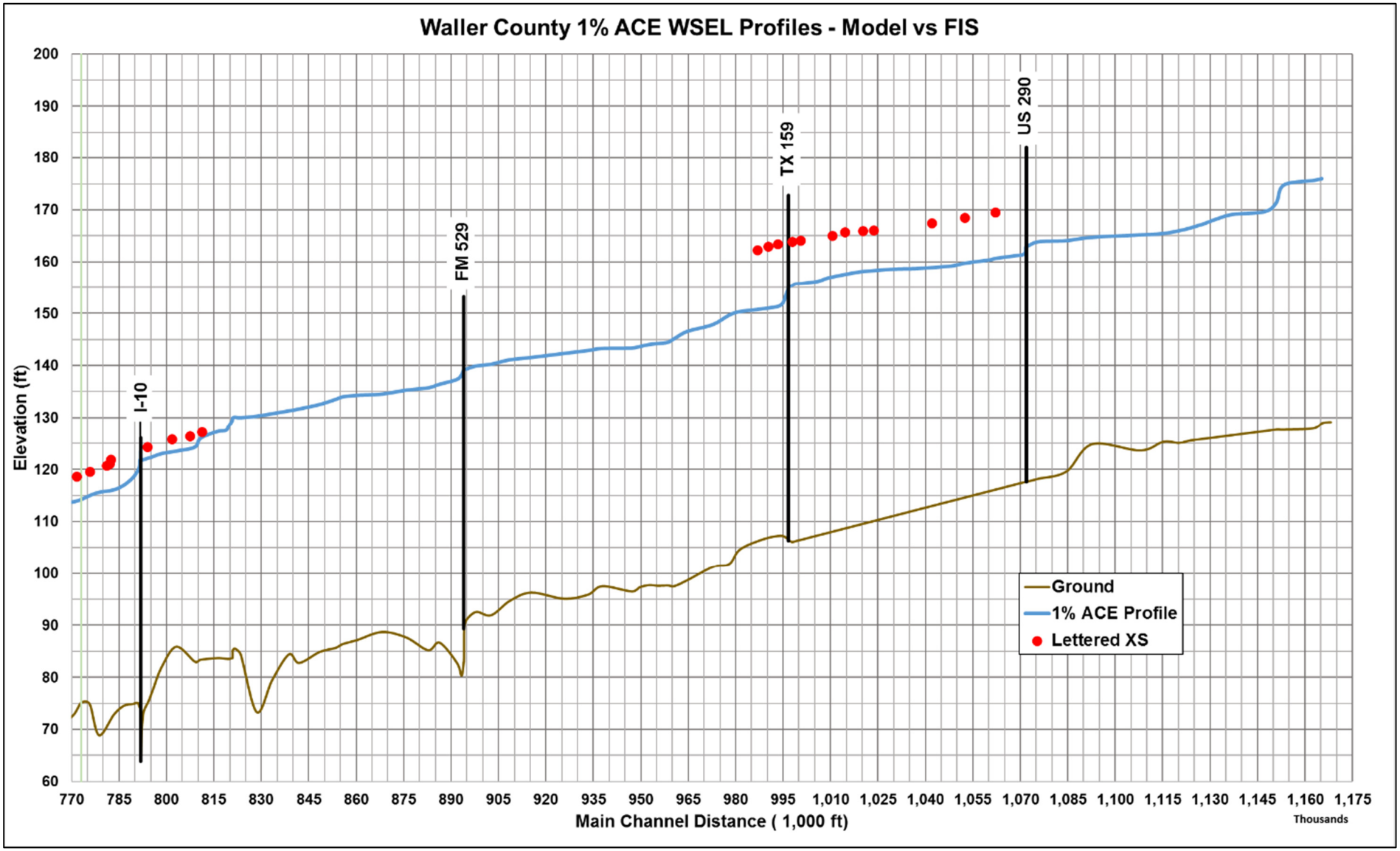

Figure E-40: Waller County - Model vs FIS Comparisons

Based on Figures E-38, E-39 and E-40, the 1% ACE profiles from the hydraulics analysis varied considerably from the FIS water surface elevations in some areas. The results were considered more accurate due to more calibration events, newer terrain and the incorporation of unsteady hydraulic modeling. Comparisons of the 1% ACE event and the FEMA mapping is shown in Exhibit E-5.

E.6.0 Hydraulics Analysis Conclusions

To model the hydraulic conditions of the Brazos River, a 1D unsteady HEC-RAS model was developed from the Waller/Grimes County Line to the Gulf of Mexico. The 1D hydraulic model incorporated bridge structures, levees and overflow areas that were identified within the study area. To produce more accurate results of the design storms, three historical storms were used to calibrate the model to match the observed water surface elevations at USGS gauges and various HWMs for the 2007, 2016 and 2017 events. Flow roughness factors were used to adjust the model to match the observed data of each calibration storm. These factors were then averaged once a final set of factors were determined from each calibration storm to be used for the design storm analysis. Design storms for the 10%, 2%, 1% and 0.2% ACE events were calculated from the Brazos River hydraulic model.

Based on unsteady hydraulics analysis, the Brazos River and its tributaries comprise a complex system of flow transfers that were not considered as part of previous modeling efforts of the Brazos River. These areas of interaction included transferring flow to other river systems or storing volume to be released back into the Brazos River. High-flow events of greater than 60,000 cfs can trigger these overflows and created a vast network of impacted streams and areas. Other factors such as vegetative cover, changing banks and flowline elevations directly impacted how the river system responded to flows through the Brazos River as well as the impacted streams. Flow roughness factors were used to adjust for these changes and will likely need to be addressed in later analyses since the Brazos River changes over time. The calibration process helped create more accurate and updated results for the design storms using the flow roughness factors and provides vital information on the current conditions of the Brazos River and its tributaries.

Appendix E: Hydraulic Analysis

Exhibits

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-1
Lower 1% ACE Inundation Mapping

Index

- USGS Gauge
- Lateral Weir
- Levee
- Limit of Study
- Brazos River
- 1 % ACE Mapping Limits
- Basin Limits
- County Line

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Miles

1 inch = 4 miles

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2 of 4

3 of 4

4 of 4

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Gauge No. 08111500

Mill Ck nr Bellville, TX
Gauge No. 08111700

Brazos Rv at San Felipe, TX
Gauge No. 08111850

Brazos Rv at Richmond, TX
Gauge No. 08114000

Brazos Rv nr Rosharon, TX
Gauge No. 08116650

Brazos River

Brazos River Tidal

Limit of Study

Pecan Grove LID
LID 20
LID 07
LID 10
LID 17
LID 02
LID 11
LID 15
LID 14
LID 19
MUD 121
First Colony
Sienna Plantation
Sienna Plantation LID

Burleson
Brazos
Grimes
Walker
San Jacinto
Washington
Austin
Waller
Fort Bend
Harris
Montgomery
Liberty
Chambers
Galveston
Brazoria
Wharton
Jackson
Matagorda

Lake Conroe
Lake Houston
Yegua Creek
Navasota River
San Jacinto River
Oyster Creek
Colorado River
Matagorda Bay
Gulf of Mexico

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-1
Lower 1% ACE Inundation Mapping

- USGS Gauge
- Cross Section
- Lateral Weir
- Levee
- Limit of Study
- Brazos River
- 10ft Contour
- 50ft Contour
- 1 % ACE Mapping Limits
- Basin Limits
- County Line

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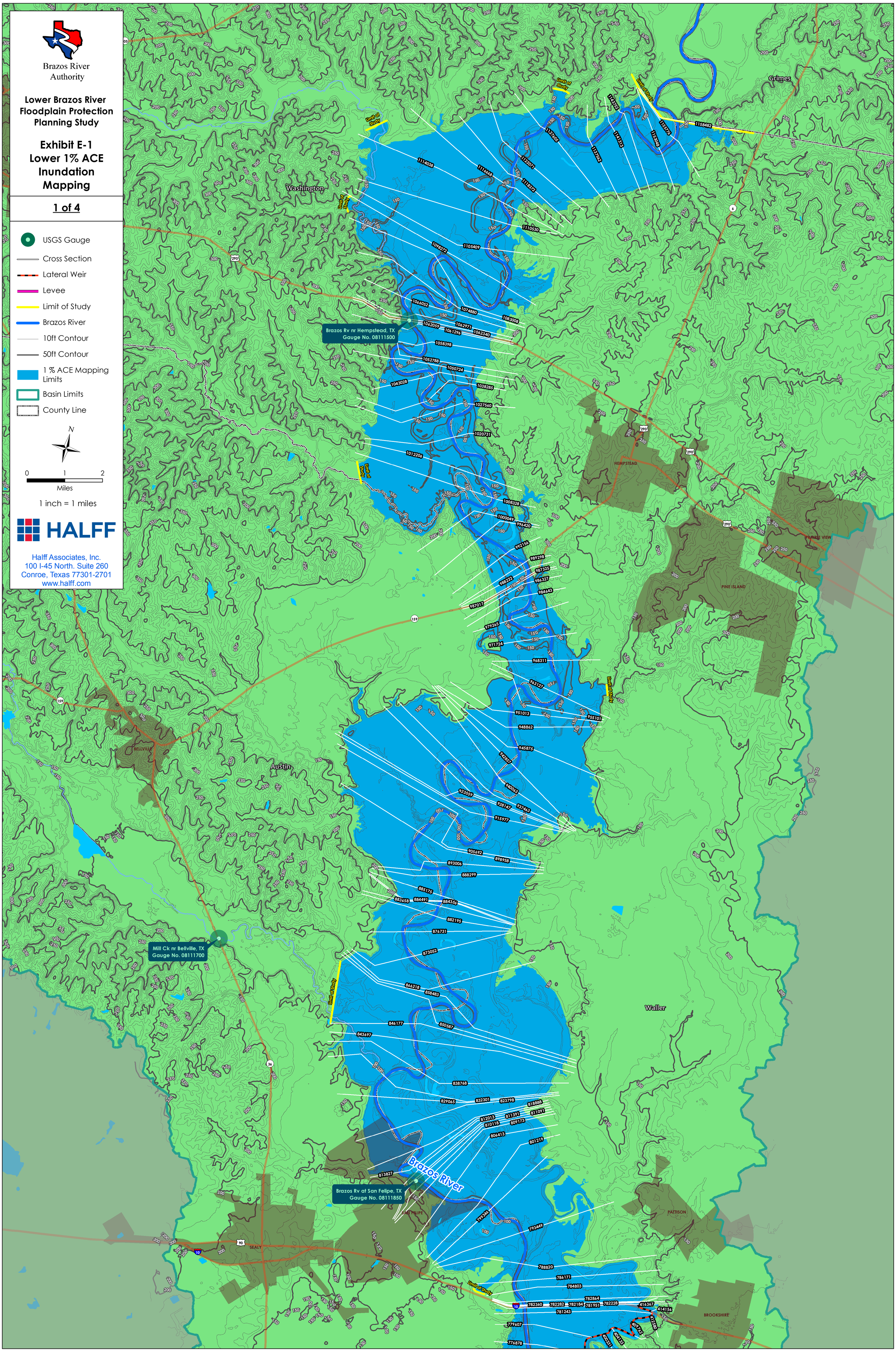

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-1
Lower 1% ACE Inundation Mapping

2 of 4

- USGS Gauge
- Cross Section
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- Levee
- Limit of Study
- Brazos River
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1 inch = 1 miles

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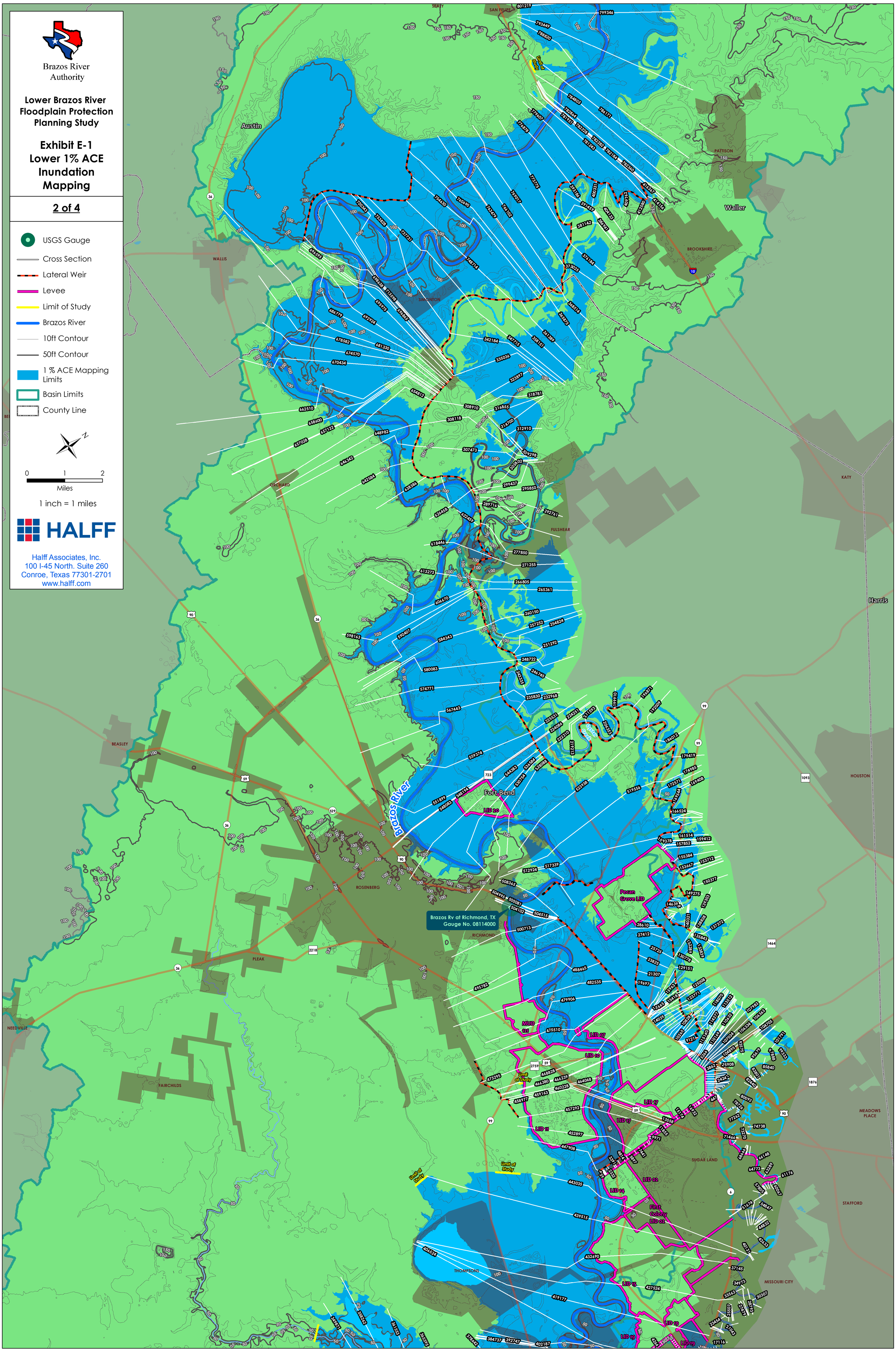

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-1
Lower 1% ACE Inundation Mapping

- USGS Gauge
- Cross Section
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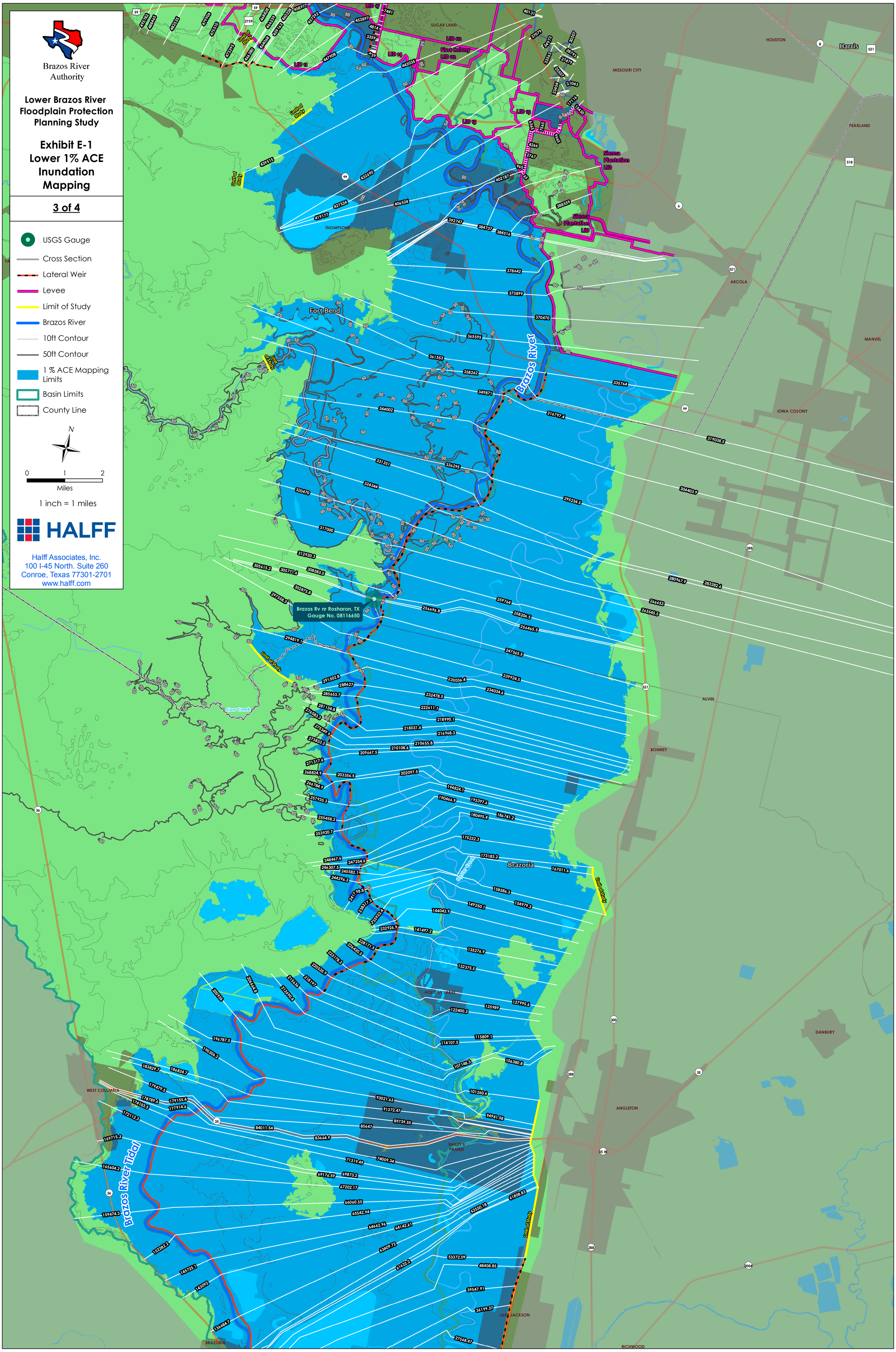

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-1
Lower 1% ACE Inundation Mapping

4 of 4

- Cross Section
- Lateral Weir
- Levee
- Limit of Study
- Brazos River
- 10ft Contour
- 50ft Contour
- 1 % ACE Mapping Limits
- Basin Limits
- County Line

N

0 1 2
Miles

1 inch = 1 miles

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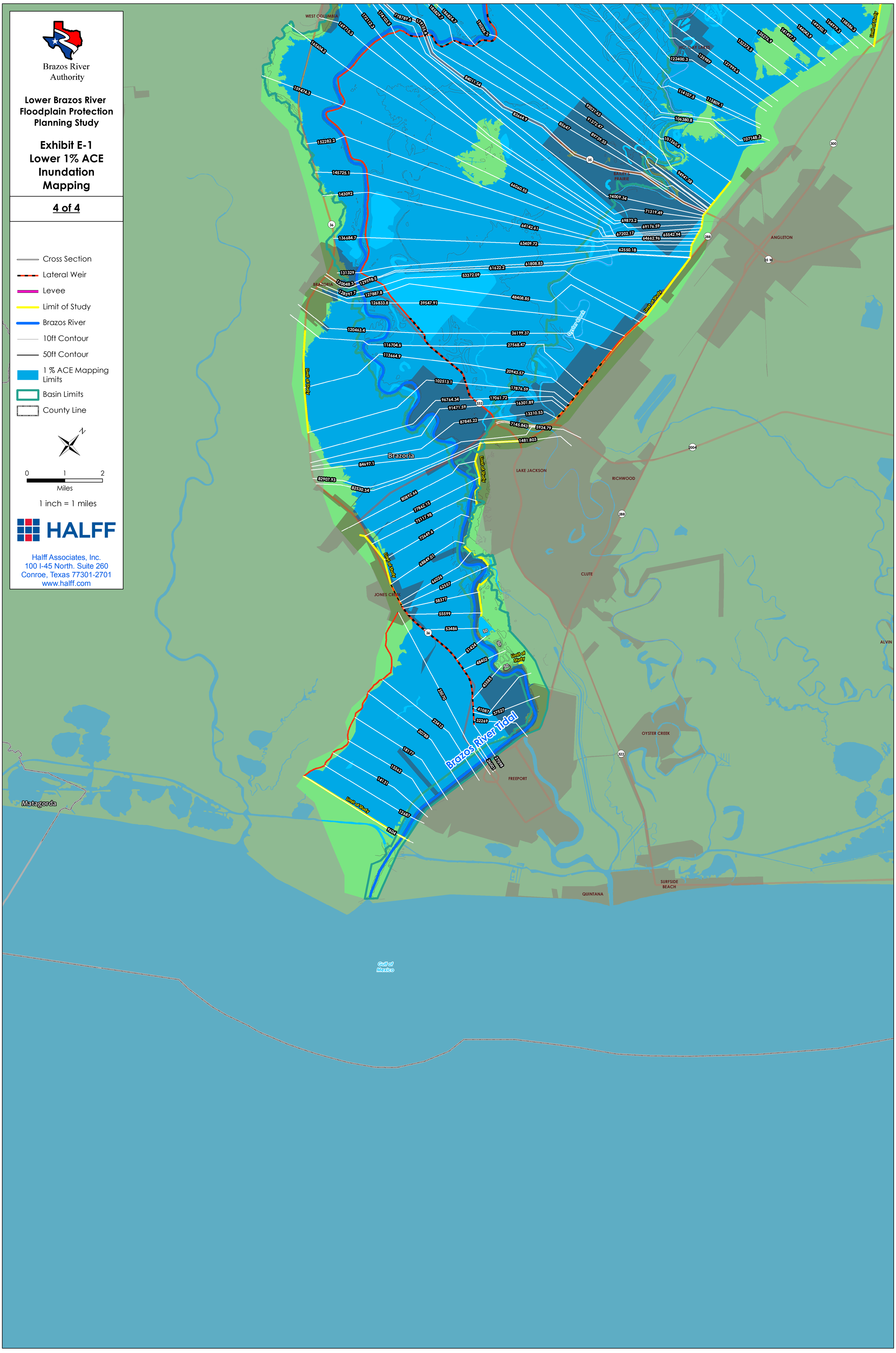

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-2
Lower 0.2% ACE Inundation Mapping

Index

- Lateral Weir
- Levee
- Basin Limits
- Limit of Study
- Brazos River
- County Line
- 0.2% ACE Mapping Limits
- USGS Gauge

N

0 4 8
Miles

1 inch = 4 miles

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1 of 4

2 of 4

3 of 4

4 of 4

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Gauge No. 08111500

Mill Ck nr Bellville, TX
Gauge No. 08111700

Brazos Rv at San Felipe, TX
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Brazos Rv at Richmond, TX
Gauge No. 08114000

Brazos Rv nr Rosharon, TX
Gauge No. 08116650

Brazos River

Brazos River Tidal

Limit of Study

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LID 20
LID 07
LID 10
LID 17
LID 02
MUD 121
First Colony
LID 11
LID 15
LID 14
Sienna Plantation LID
LID 19

Burleson
Brazos
Grimes
Walker
San Jacinto
Washington
Montgomery
Liberty
Austin
Waller
Harris
Fort Bend
Wharton
Chambers
Galveston
Brazoria
Jackson
Matagorda

Lake Conroe
Lake Houston
Yegua Creek
Navasota River
San Jacinto River
Oyster Creek
Colorado River
Matagorda Bay
Gulf of Mexico

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-2
Lower 0.2% ACE Inundation Mapping

1 of 4

- Lateral Weir
- Basin Limits
- Limit of Study
- Brazos River
- County Line
- 50ft Contour
- 10ft Contour
- 0.2% ACE Mapping Limits
- USGS Gauge
- Cross Section

N

0 1 2
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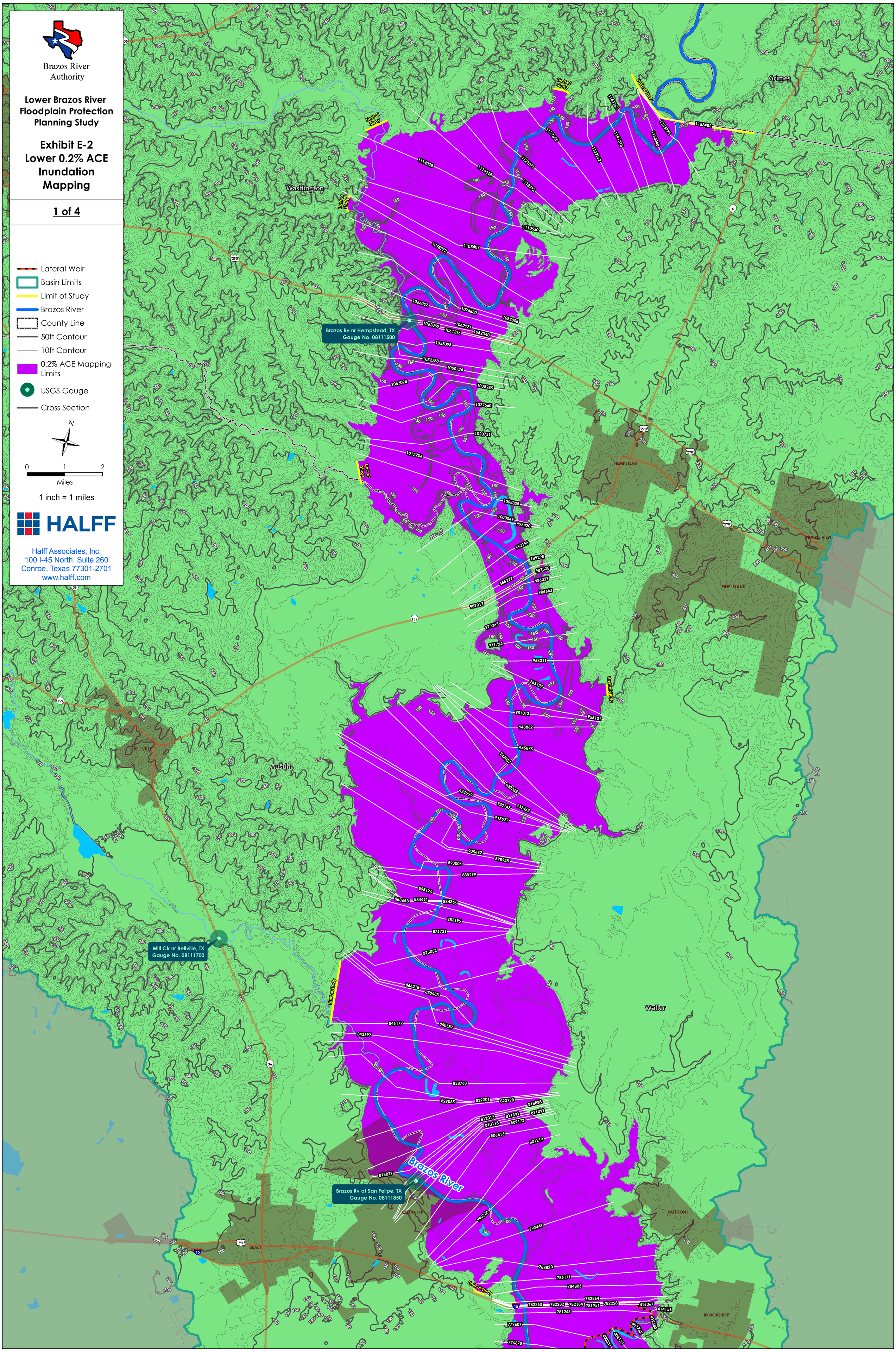

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-2
Lower 0.2% ACE Inundation Mapping

2 of 4

- Lateral Weir
- Levee
- Basin Limits
- Limit of Study
- Brazos River
- County Line
- 50ft Contour
- 10ft Contour
- 0.2% ACE Mapping Limits
- USGS Gauge
- Cross Section

0 1 2
Miles

1 inch = 1 miles

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Brazos Rv at Richmond, TX
Gauge No. 08114000

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-2
Lower 0.2% ACE Inundation Mapping

3 of 4

- Lateral Weir
- Levee
- Basin Limits
- Limit of Study
- Brazos River
- County Line
- 50ft Contour
- 10ft Contour
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- Cross Section

N

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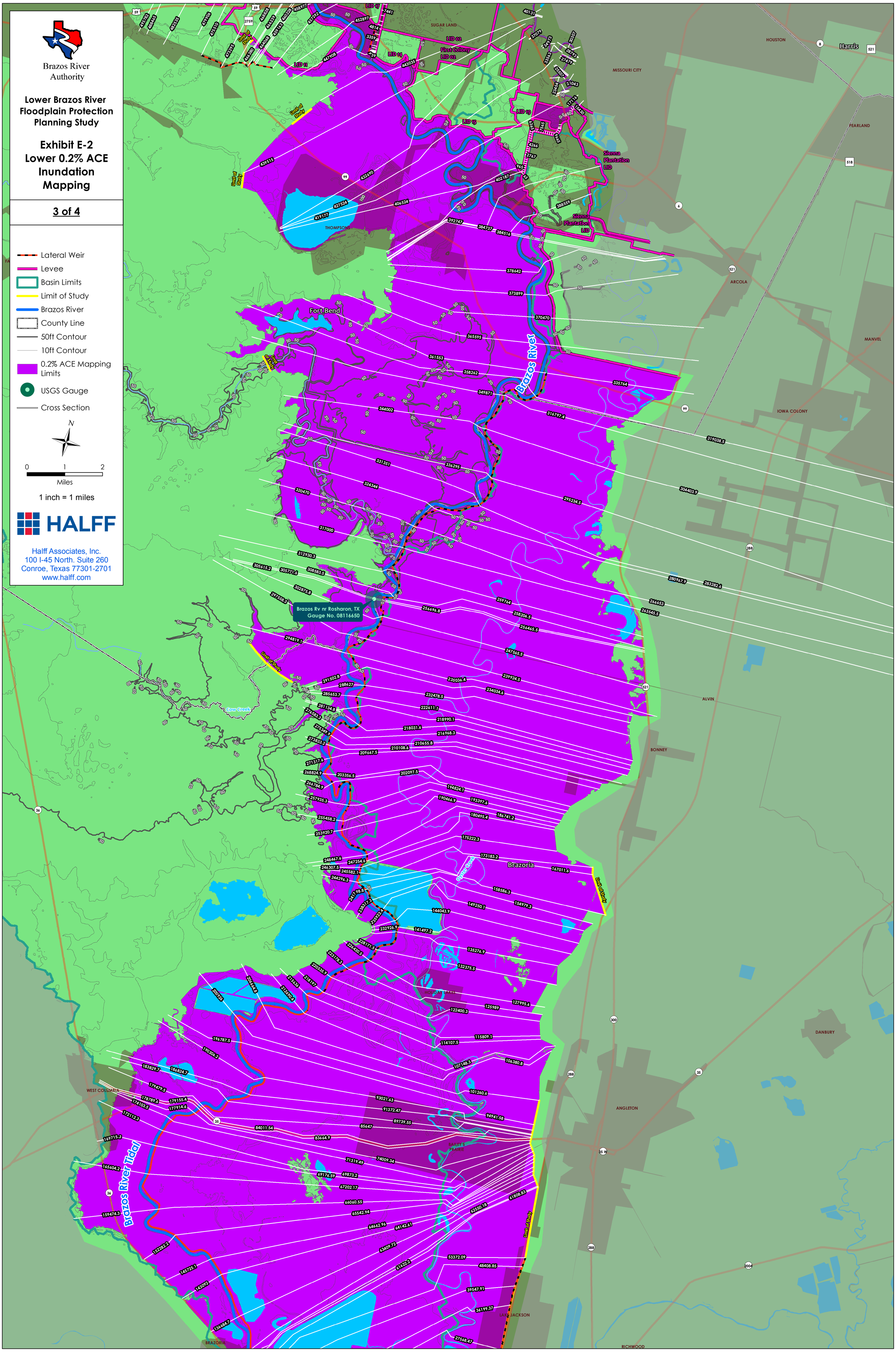

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-2
Lower 0.2% ACE Inundation Mapping

4 of 4

- Lateral Weir
- Basin Limits
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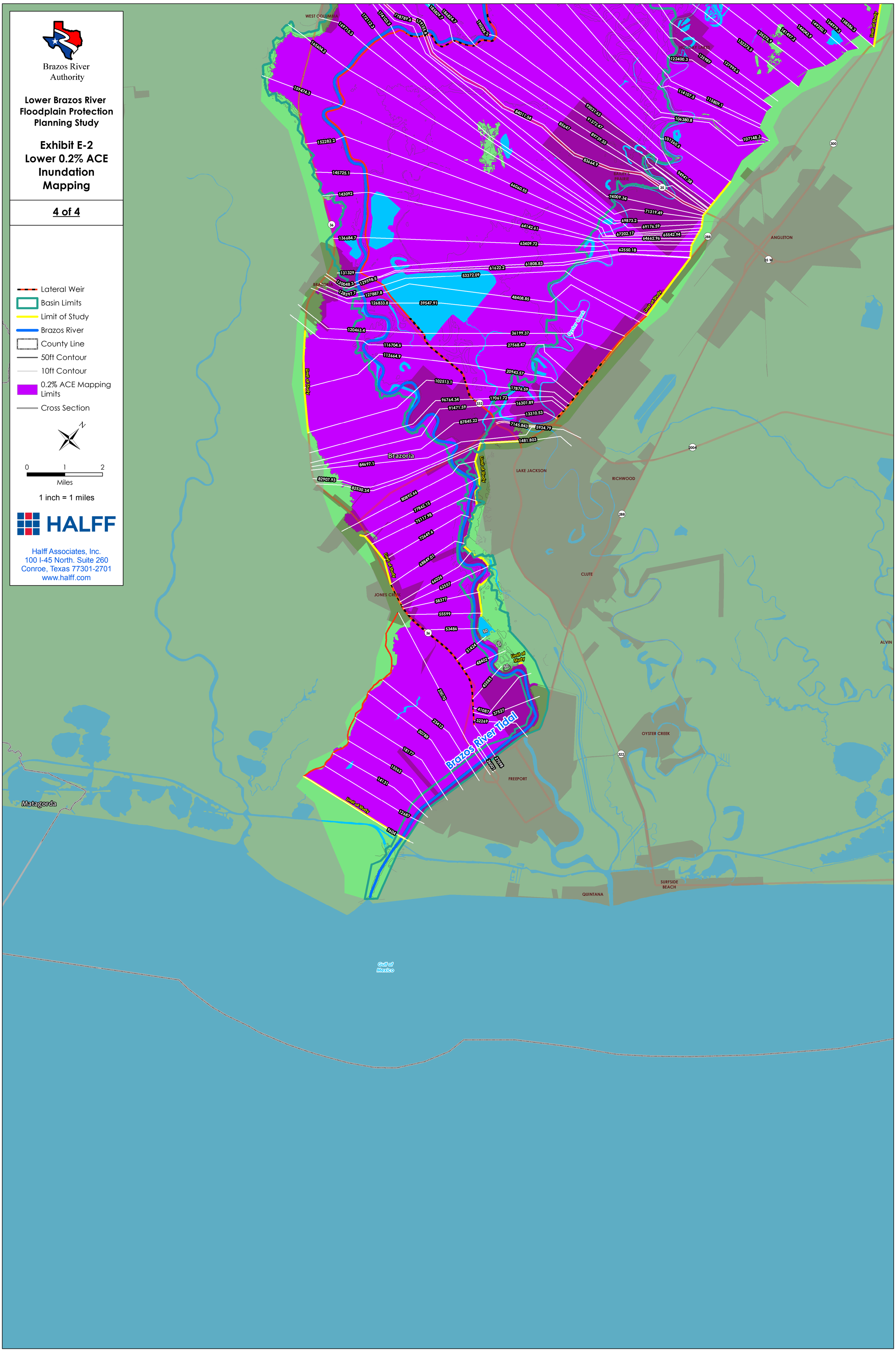

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-3
Lower Inundation 1% vs 0.2% ACE Mapping

Index

- USGS Gauge
- Lateral Weir
- Levee
- Limit of Study
- Brazos River
- 1% ACE Mapping Limits
- 0.2% ACE Mapping Limits
- Basin Limits
- County Line

N

0 4 8
Miles

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Brazos Rv nr Rosharon, TX
Gauge No. 08116650

Brazos River Tidal

Pecan Grove LID

Sienna Plantation LID

Limit of Study

Brazos River

Navasota River

Yegua Creek

Lake Conroe

San Jacinto River

Lake Houston

Oyster Creek

Colorado River

Matagorda Bay

Gulf of Mexico

Burleson
Brazos
Grimes
Walker
San Jacinto
Washington
Austin
Waller
Harris
Fort Bend
Wharton
Jackson
Matagorda
Brazoria
Galveston
Chambers
Liberty
Montgomery

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-3
Lower Inundation 1% vs 0.2% ACE Mapping

1 of 4

- USGS Gauge
- Cross Section
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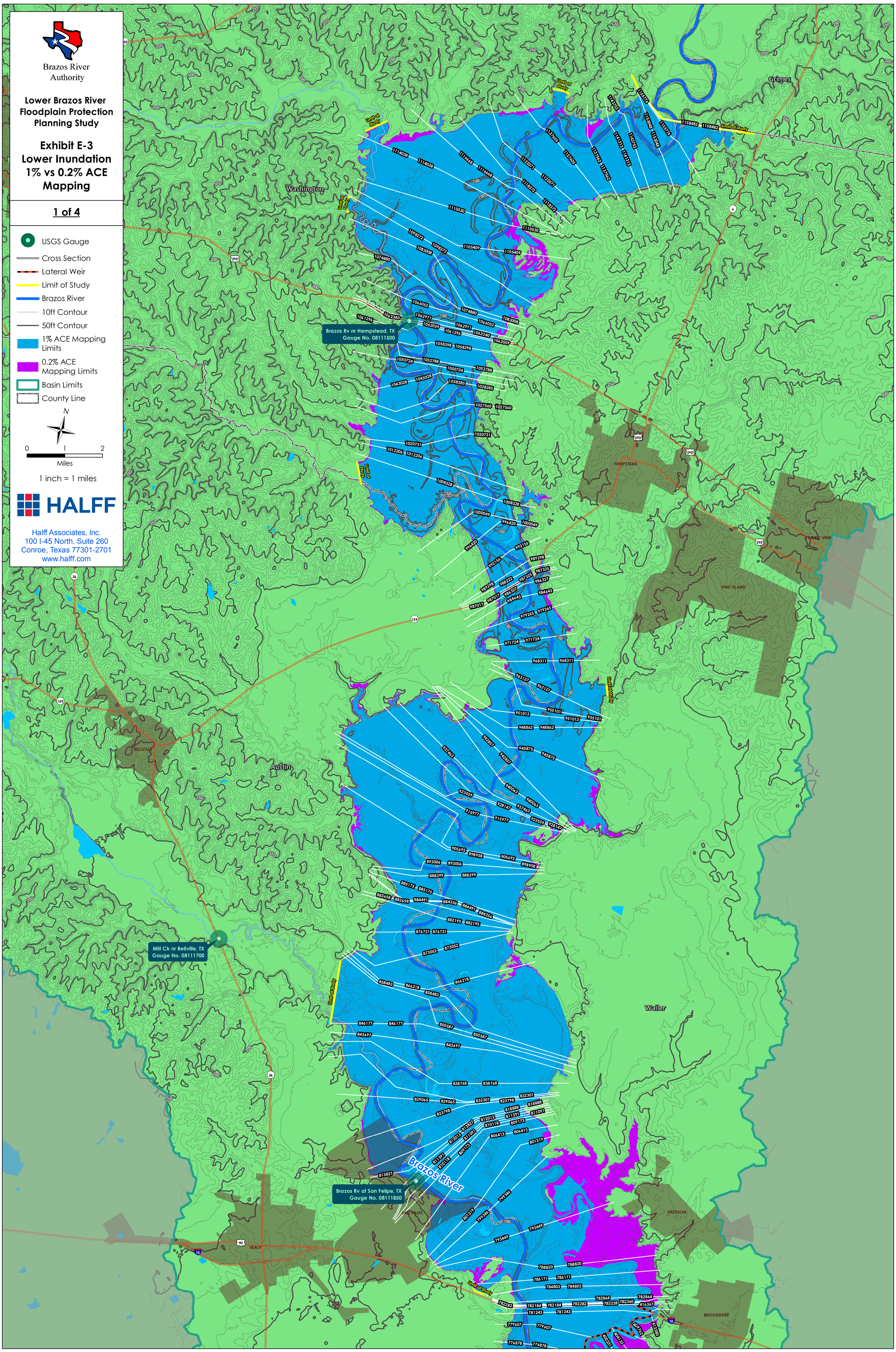

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-3
Lower Inundation 1% vs 0.2% ACE Mapping

2 of 4

- USGS Gauge
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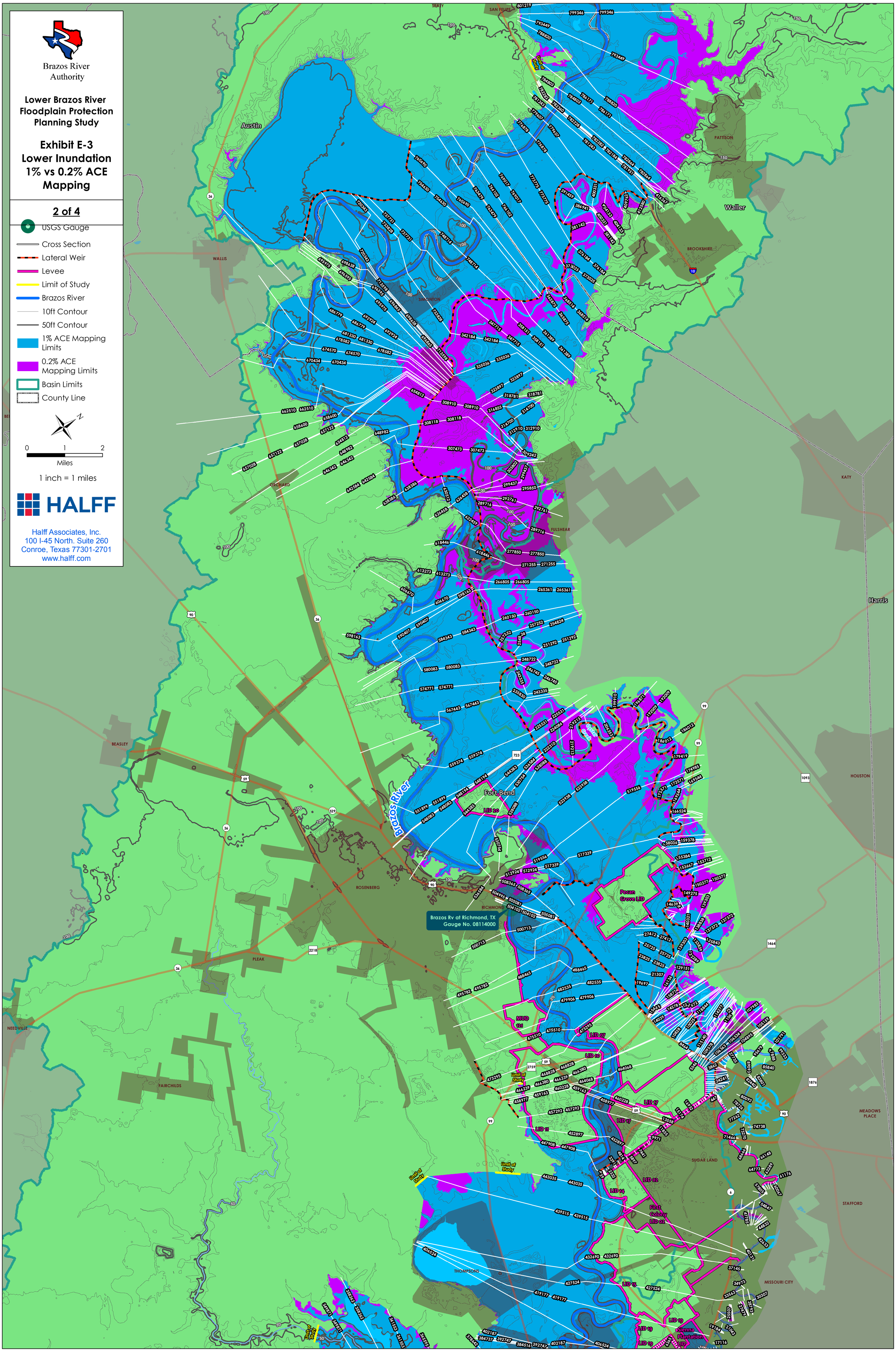

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-3
Lower Inundation 1% vs 0.2% ACE Mapping

3 of 4

- USGS Gauge
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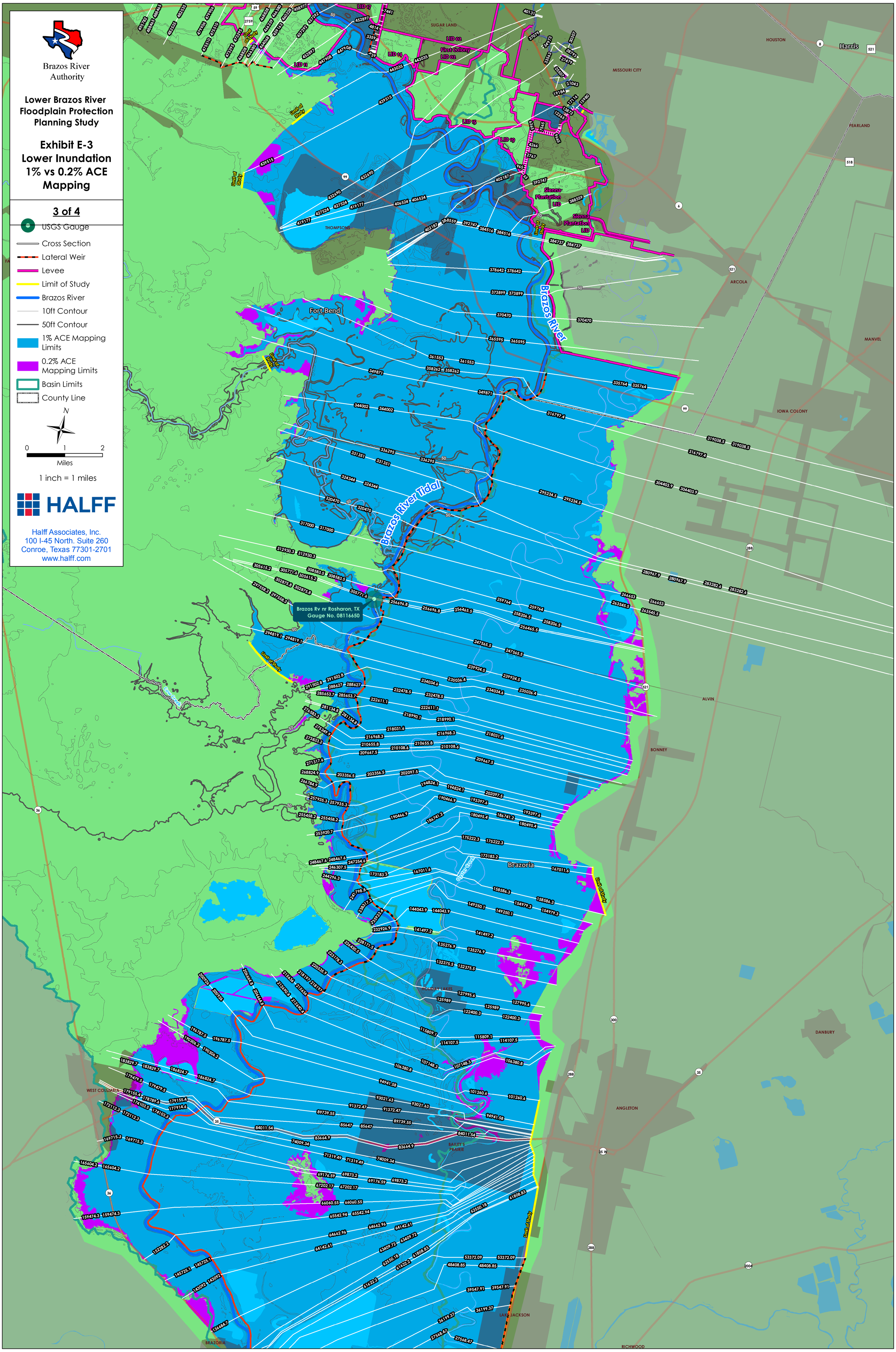

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-3
Lower Inundation 1% vs 0.2% ACE Mapping

4 of 4

- Cross Section
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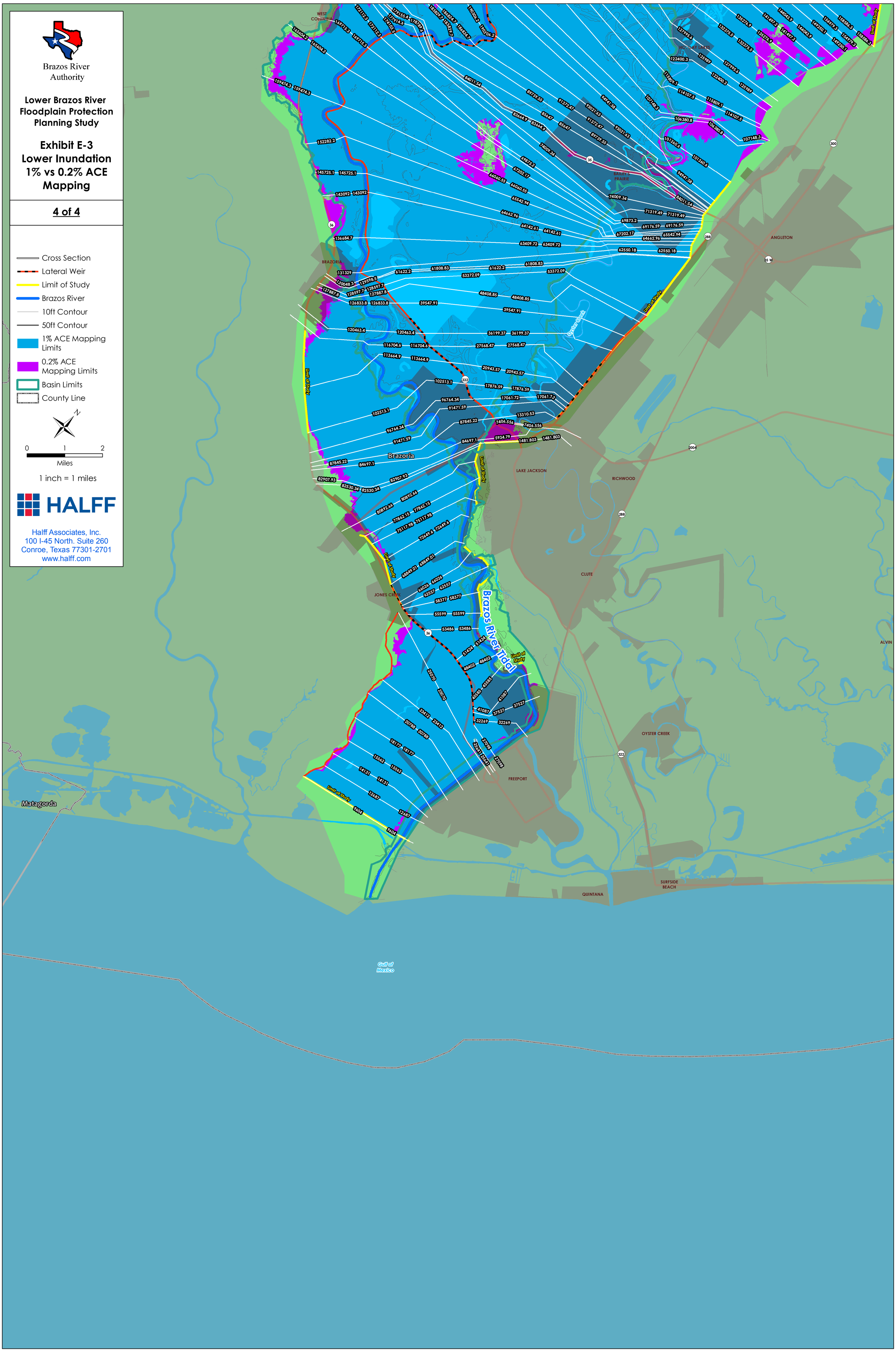

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-4
Velocity Grids Map

Index

- USGS Gauge
- Lateral Weir
- Levee
- Limit of Study
- Brazos River
- Basin Limits
- County Line

100YR Velocity (FPS)

- 0 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10.5

N

0 4 8
Miles

1 inch = 4 miles

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Brazos Rv nr Rosharon, TX
Gauge No. 08116650

Brazos River

Brazos River Tidal

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LID 14
LID 19
MUD 121
First Colony
Sienna Plantation LID

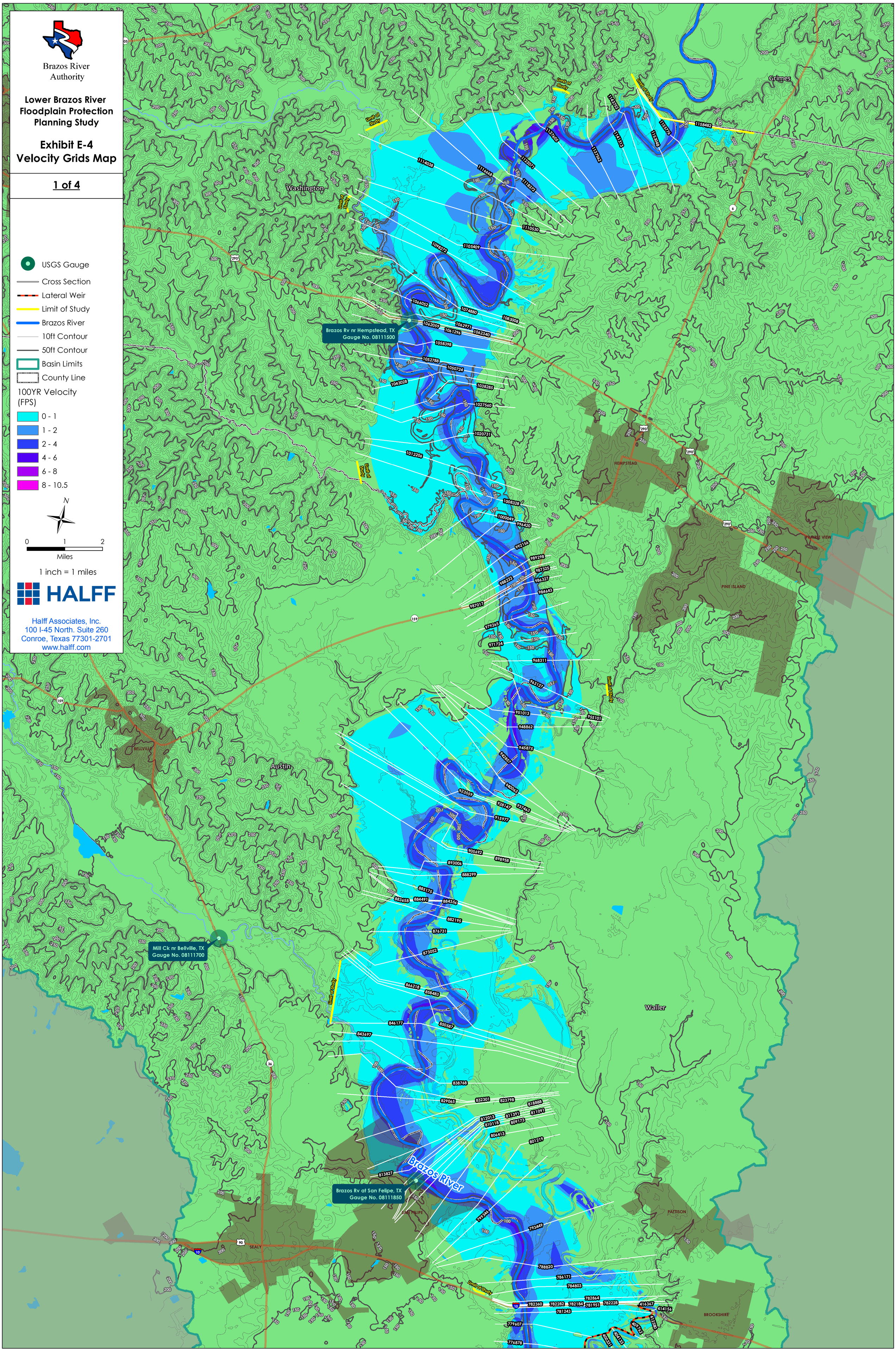
Burleson
Brazos
Grimes
Washington
Walker
San Jacinto
Montgomery
Liberty
Austin
Waller
Harris
Fort Bend
Wharton
Chambers
Galveston
Brazoria
Jackson
Matagorda

Lake Conroe
Lake Houston
Yegua Creek
Navasota River
San Jacinto River
Oyster Creek
Colorado River
Matagorda Bay
Gulf of Mexico

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-4
Velocity Grids Map



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Lower Brazos River Floodplain Protection Planning Study

Exhibit E-4
Velocity Grids Map

2 of 4

- USGS Gauge
- Cross Section
- Lateral Weir
- Levee
- Limit of Study
- Brazos River
- 10ft Contour
- 50ft Contour
- Basin Limits
- County Line

100YR Velocity (FPS)

- 0 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10.5

N

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Miles

1 inch = 1 miles

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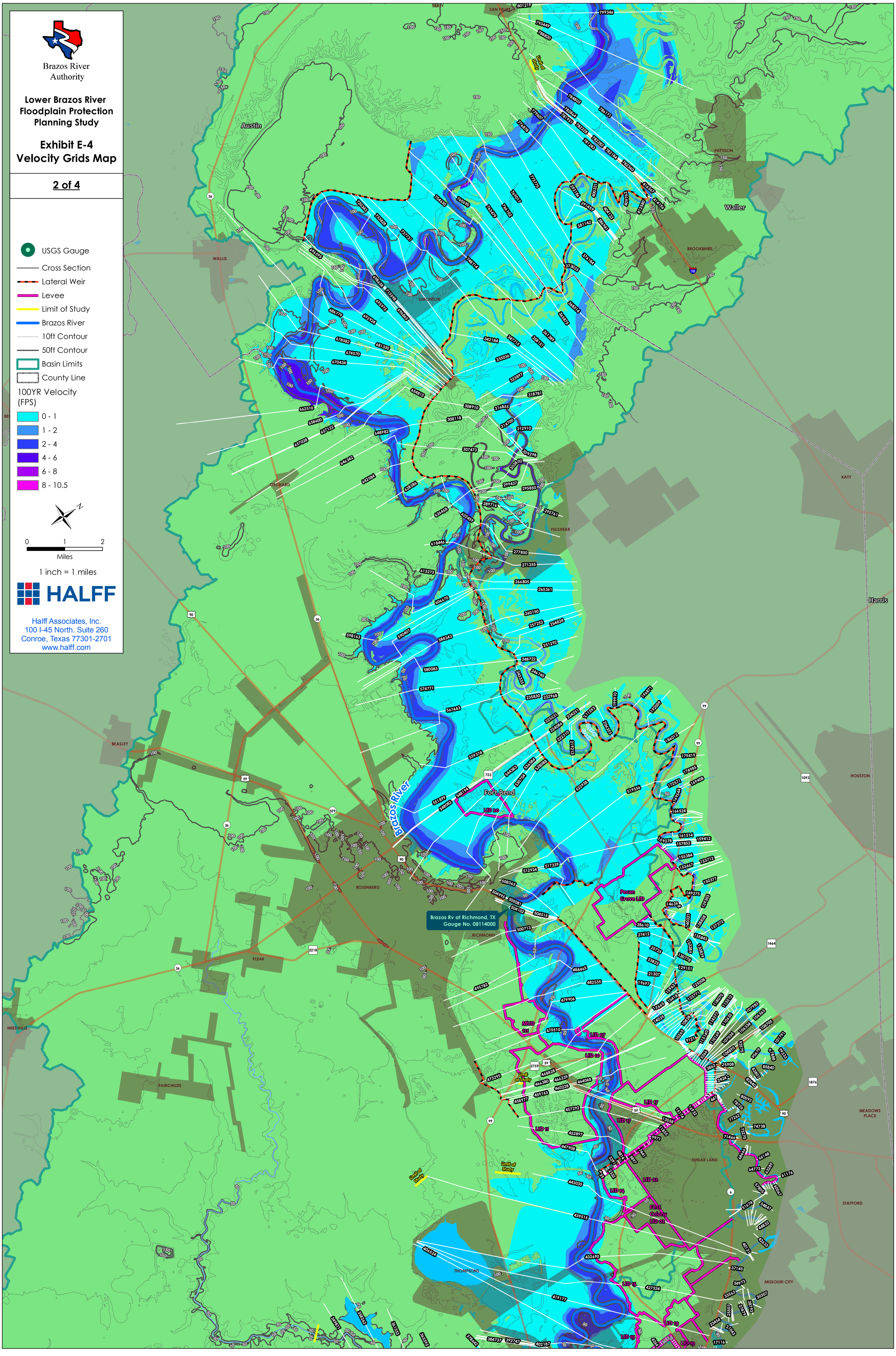

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-4
Velocity Grids Map

3 of 4

- USGS Gauge
- Cross Section
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- Levee
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Brazos Rv nr Rosharon, TX
Gauge No. 08116650

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-4
Velocity Grids Map

4 of 4

- Cross Section
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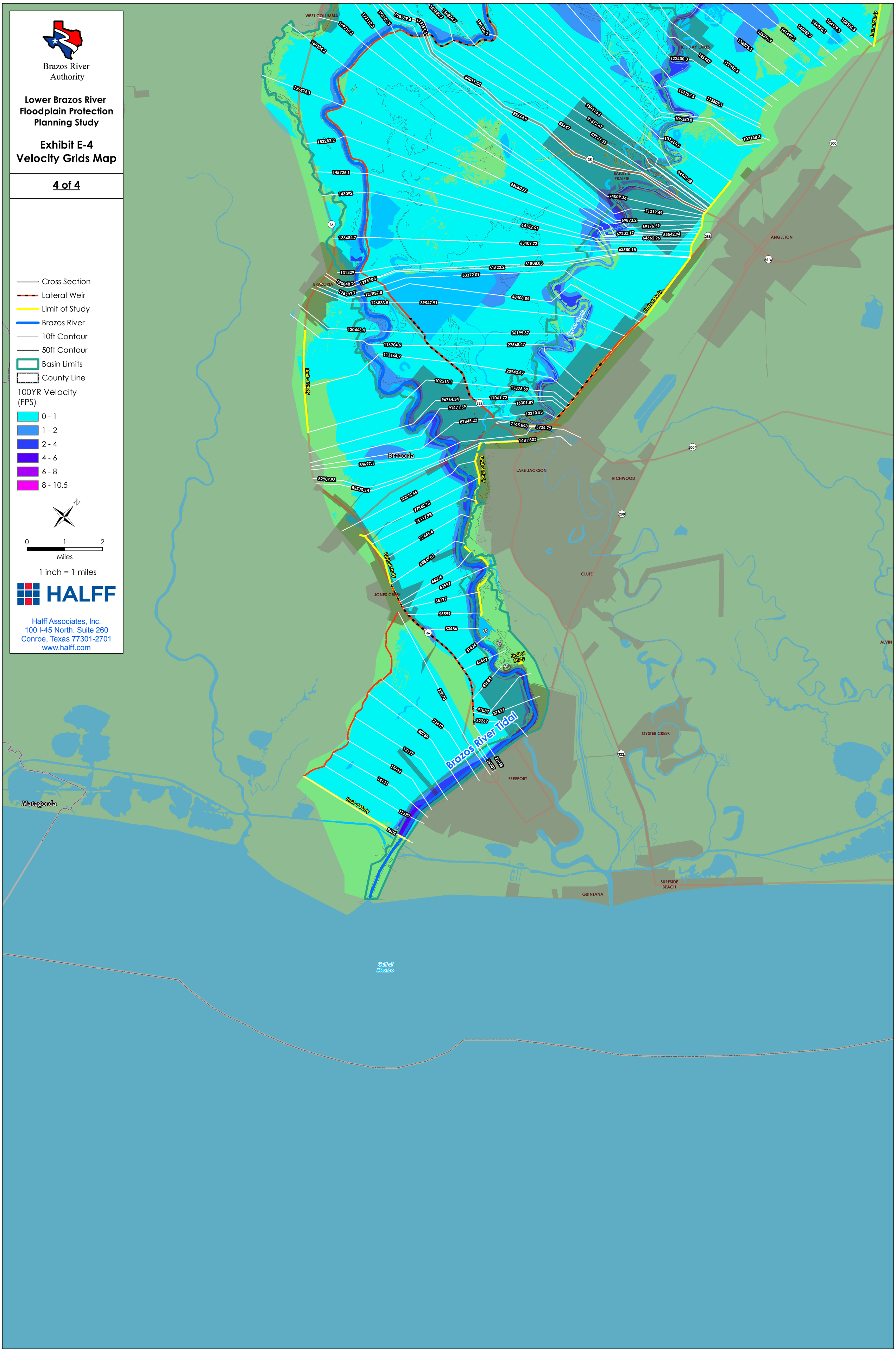

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-5
Lower 1% ACE Inundation Mapping vs FEMA Floodplain

Index

- USGS Gauge
- Lateral Weir
- Levee
- Limit of Study
- Brazos River
- 1 % ACE Mapping Limits
- Basin Limits
- County Line

FEMA Flood Zones

- 0.2 PCT ANNUAL CHANCE
- A
- AE
- AE, FLOODWAY

N

0 4 8
Miles

1 inch = 4 miles

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1 of 4

2 of 4

3 of 4

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Brazos River Tidal

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Washington
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Walker
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Montgomery
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Harris
Fort Bend
Wharton
Jackson
Matagorda
Brazoria
Galveston
Chambers

Lake Conroe
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Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-5
Lower 1% ACE Inundation Mapping vs FEMA Floodplain

1 of 4

- USGS Gauge
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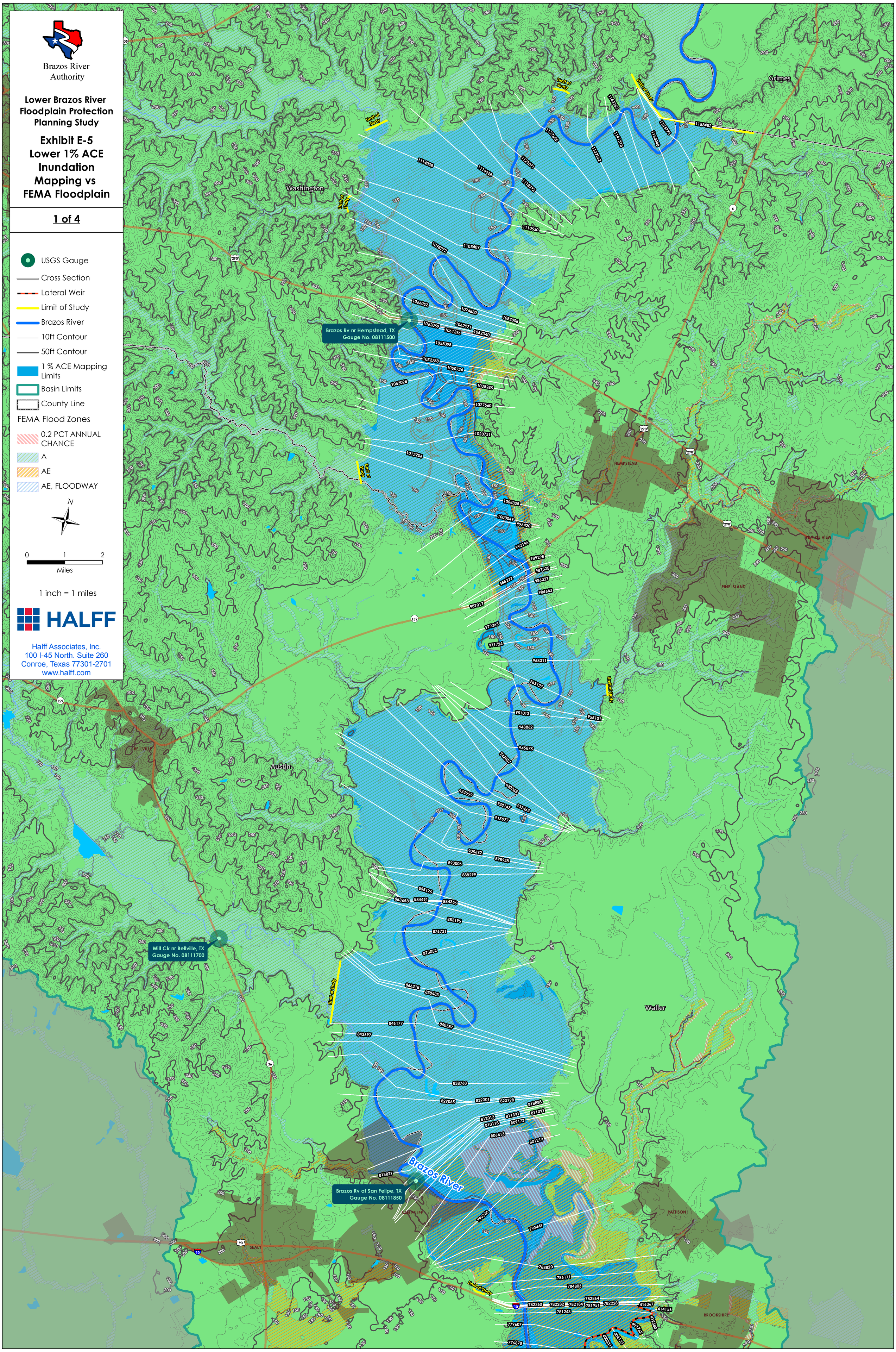

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-5
Lower 1% ACE Inundation Mapping vs FEMA Floodplain

2 of 4

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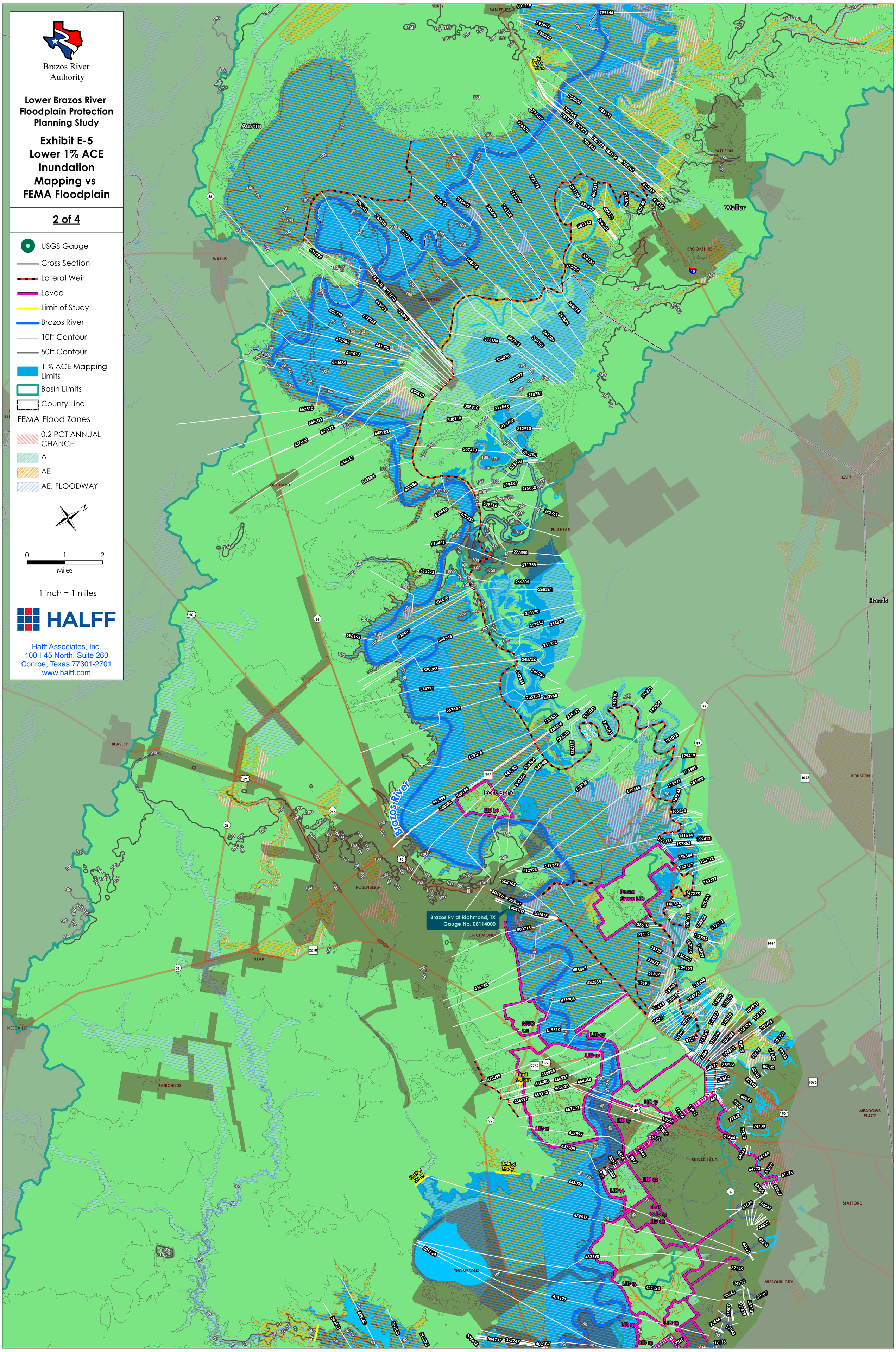

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-5
Lower 1% ACE Inundation Mapping vs FEMA Floodplain

3 of 4

- USGS Gauge
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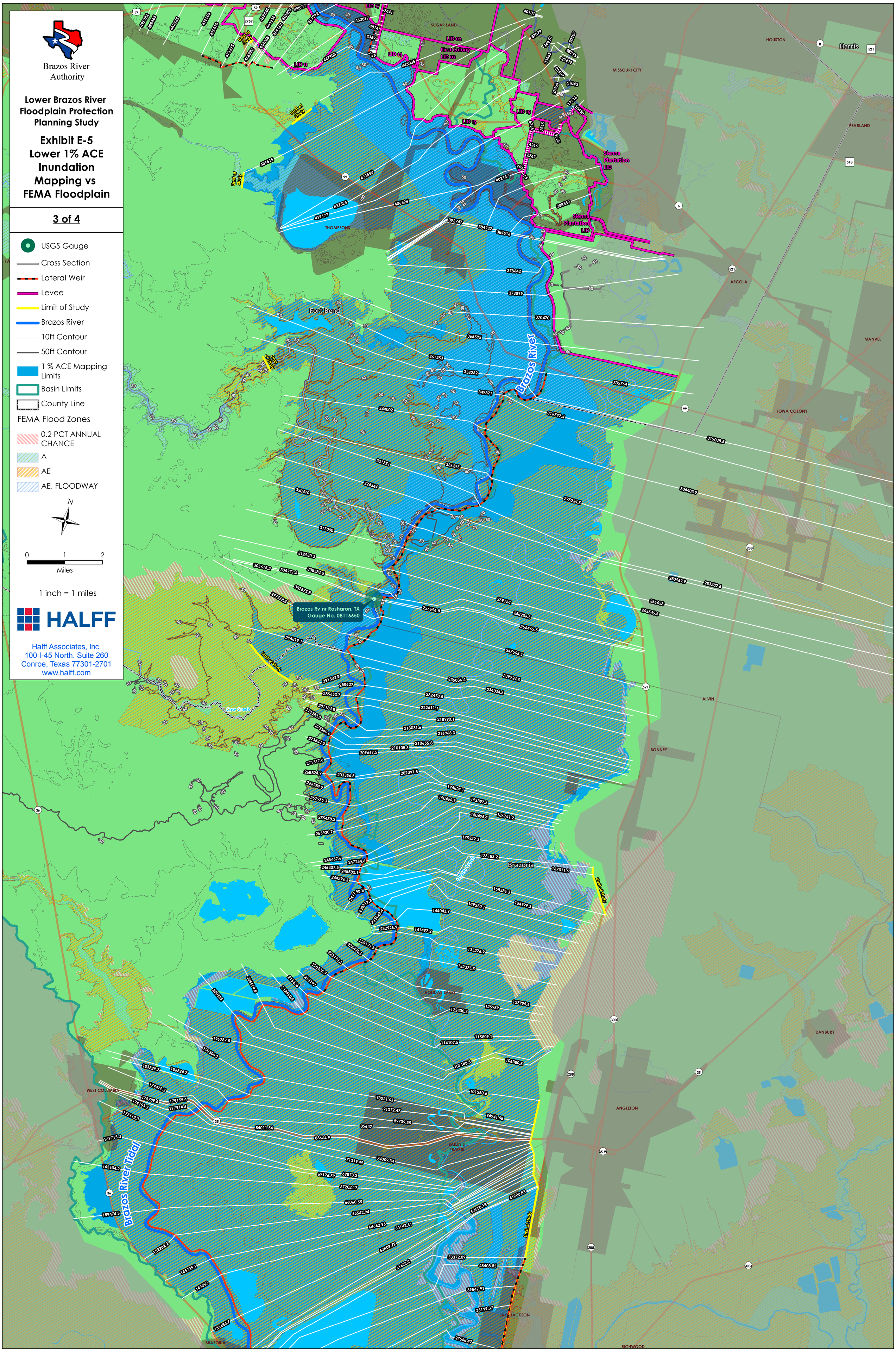

Brazos River Authority

Lower Brazos River Floodplain Protection Planning Study

Exhibit E-5
Lower 1% ACE Inundation Mapping vs FEMA Floodplain

4 of 4

- Cross Section
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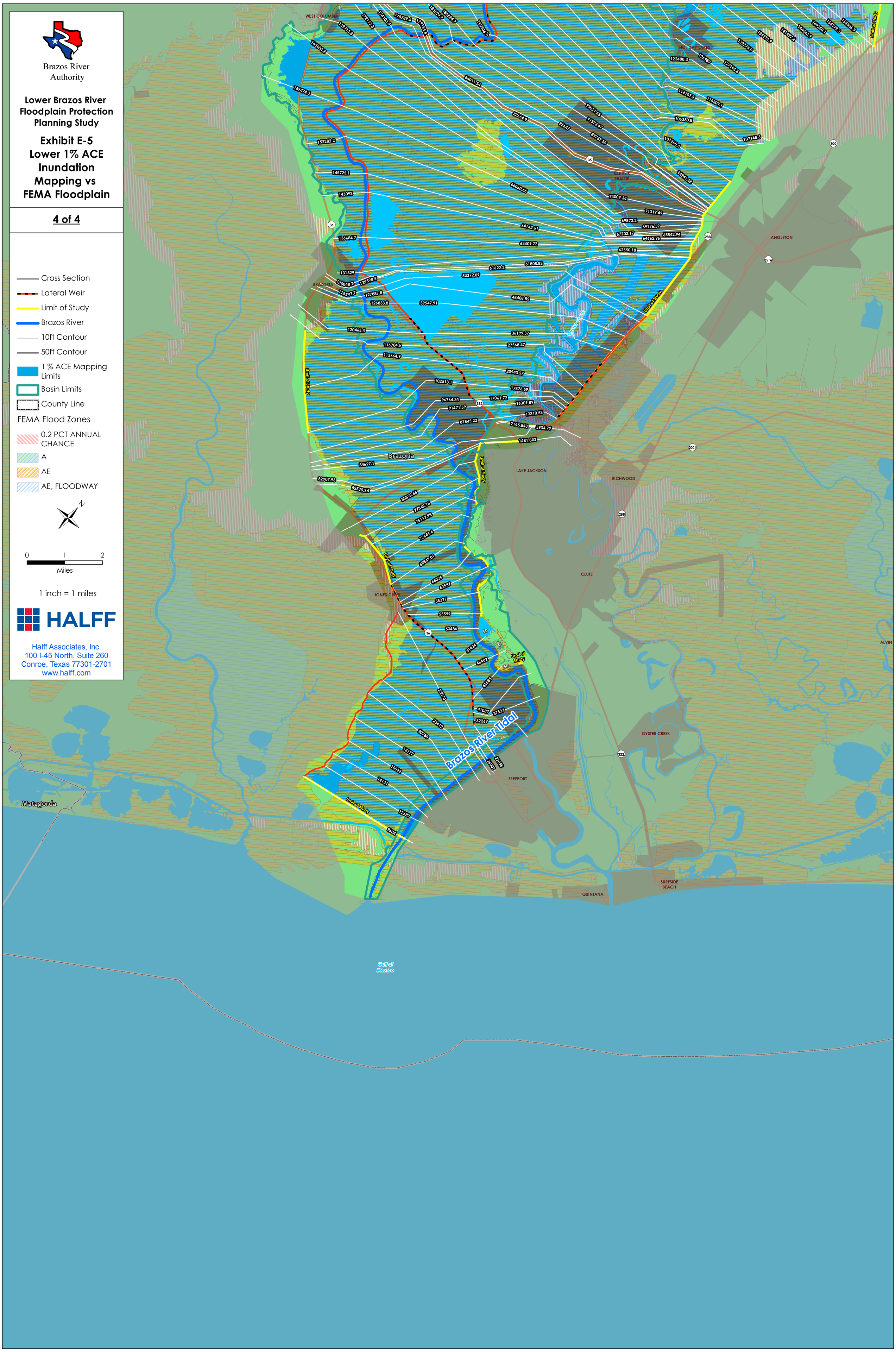

Appendix E: Hydraulic Analysis

Design Storm Water Surface Elevations

Brazos River Design Storm Water Surface Elevations				
	Water Surface Elevations (ft)			
Cross Section	10% ACE	2% ACE	1% ACE	0.2% ACE
1158482	173.26	176.63	177.40	179.88
1155776	172.98	176.22	176.96	179.37
1153048	172.86	176.00	176.71	179.06
1143752	172.26	175.28	175.97	178.22
1141313	171.96	174.94	175.61	177.80
1137562	171.25	174.13	174.75	176.78
1127605	167.86	170.63	171.29	173.50
1122071	166.46	168.95	169.61	171.91
1118372	165.94	168.44	169.09	171.42
1116668	164.47	167.38	168.12	170.63
1114038	163.30	166.44	167.26	169.93
1110530	163.04	166.15	166.96	169.63
1105409	162.52	165.64	166.46	169.17
1098272	161.79	165.09	165.94	168.75
1083008	160.79	164.47	165.40	168.36
1074880	160.44	164.19	165.15	168.16
1066052	159.89	163.70	164.69	167.75
1062971	159.09	163.00	164.05	167.24
1062340	158.73	162.75	163.83	167.07
1062059	158.62	162.05	162.92	165.66
1061296	158.09	161.81	162.73	165.54
1058398	156.97	160.89	161.92	164.93
1052788	155.76	160.26	161.37	164.51
1050724	155.50	159.99	161.11	164.28
1043028	154.99	159.51	160.66	163.87
1038285	154.52	159.17	160.35	163.60
1027560	153.41	158.45	159.72	163.13
1020731	152.89	157.86	159.16	162.63
1012206	152.44	157.36	158.68	162.19
1008328	152.34	157.24	158.57	162.08
1000049	151.99	156.86	158.18	161.66
996420	151.72	156.58	157.90	161.36
992156	150.82	155.60	156.91	160.27
989298	150.15	154.87	156.19	159.49
988222	149.80	154.55	155.86	159.14
987325	149.66	154.36	155.66	158.92
987017	149.46	154.10	155.35	158.50
986327	149.23	153.88	155.14	158.30
984643	148.89	153.49	154.75	157.87
979265	147.44	152.28	153.56	156.72
971724	145.31	150.22	151.54	154.77

Cross Section	Water Surface Elevations (ft)			
	10% ACE	2% ACE	1% ACE	0.2% ACE
968311	144.75	149.58	150.88	154.02
963127	144.08	149.00	150.31	153.40
955101	143.35	148.30	149.62	152.70
951013	142.08	146.58	147.82	150.63
948862	141.00	145.23	146.51	149.40
945875	140.19	143.92	145.14	147.84
942857	139.72	143.23	144.41	146.97
940063	139.58	143.04	144.20	146.71
937463	139.40	142.83	143.99	146.45
928147	138.83	142.42	143.62	146.07
923559	138.47	142.11	143.34	145.77
915977	138.31	142.00	143.24	145.67
905692	137.66	141.58	142.86	145.38
898958	136.44	140.90	142.29	144.93
893006	135.47	140.07	141.53	144.12
888299	134.98	139.60	141.09	143.63
885175	134.22	138.75	140.23	142.99
884491	133.98	138.43	139.91	142.61
884356	133.87	138.12	139.45	141.60
883658	133.86	138.09	139.42	141.51
882195	133.69	137.87	139.18	141.19
876731	132.64	136.85	138.15	140.25
873052	131.88	136.04	137.32	139.37
866218	130.94	135.10	136.40	138.18
858483	130.22	134.41	135.72	137.57
850587	129.47	133.83	135.28	137.26
846177	128.47	132.96	134.53	136.37
843697	128.25	132.72	134.28	136.07
838768	127.97	132.44	134.00	135.70
832301	127.32	131.88	133.47	135.50
829065	126.46	130.90	132.52	135.10
823798	125.76	130.03	131.67	134.57
818888	125.41	129.65	131.30	134.15
813827	124.56	128.99	130.77	133.68
812013	123.88	128.42	130.28	133.21
811391	123.61	128.10	130.00	132.92
811091	123.59	127.96	129.84	132.71
810118	123.40	127.73	129.60	132.46
809173	123.14	127.42	129.27	132.08
806413	122.48	126.60	128.37	131.01
801219	121.94	125.86	127.48	129.85
799346	121.81	125.66	127.25	129.53

Cross Section	Water Surface Elevations (ft)			
	10% ACE	2% ACE	1% ACE	0.2% ACE
793449	120.60	124.44	125.99	128.36
788820	119.16	122.81	124.27	126.56
786171	118.60	122.09	123.50	125.75
784803	118.27	121.60	123.02	125.27
782864	117.79	121.03	122.45	124.69
782360	117.59	120.75	122.19	124.47
782282	117.61	120.77	122.06	124.10
782228	117.54	120.52	121.77	123.71
782184	117.50	120.45	121.65	123.53
781951	117.56	120.71	121.98	124.00
781243	117.24	120.28	121.57	123.61
779607	116.93	119.57	120.74	122.68
776878	116.17	118.61	119.65	121.54
773775	115.28	117.37	118.30	120.18
769017	114.30	116.13	116.96	118.91
766102	113.65	115.46	116.09	118.10
763479	112.83	115.13	115.60	117.65
760690	112.01	114.30	114.98	117.13
754630	110.54	113.32	114.24	116.62
748714	110.16	112.87	113.78	116.10
737731	109.18	112.48	113.45	115.79
733828	108.59	112.20	113.22	115.60
720343	107.83	111.96	113.04	115.47
713598	107.10	111.74	112.89	115.37
698638	106.10	111.34	112.57	115.08
696865	105.82	111.12	112.37	114.90
696595	105.77	111.06	112.30	114.83
695975	105.64	110.91	112.16	114.70
692924	105.38	110.61	111.89	114.45
686779	104.98	110.40	111.70	114.31
681330	104.53	110.08	111.43	114.08
678582	104.22	109.86	111.23	113.91
674570	103.80	109.64	111.05	113.76
670434	103.31	109.36	110.81	113.57
662510	101.99	108.54	110.14	113.03
658600	100.58	107.82	109.60	112.66
657122	100.23	107.20	109.07	112.27
657028	100.18	107.15	109.03	112.17
654812	99.89	106.78	108.61	111.69
648982	99.01	106.00	107.86	110.97
646342	98.71	105.71	107.57	110.67
642584	98.20	105.15	106.99	110.09

Cross Section	Water Surface Elevations (ft)			
	10% ACE	2% ACE	1% ACE	0.2% ACE
638386	97.29	104.02	105.83	108.96
630512	96.20	102.74	104.49	107.60
626458	95.44	102.08	103.84	106.93
622459	94.41	100.86	102.55	105.51
618446	93.38	99.43	100.99	103.91
613273	92.31	97.92	99.32	101.82
606670	91.57	97.06	98.41	100.77
598163	90.65	96.23	97.64	100.03
590407	89.94	95.73	97.20	99.64
584343	89.61	95.46	96.94	99.38
580083	89.24	95.19	96.68	99.15
574771	88.71	94.83	96.33	98.84
567443	87.84	94.16	95.70	98.19
559374	86.77	93.18	94.70	97.32
551899	85.98	92.54	94.03	96.83
548194	85.12	92.06	93.56	96.58
548083	85.07	91.99	93.48	96.50
544383	84.09	91.33	92.88	96.07
536584	82.95	90.27	91.94	95.19
530754	81.95	89.24	90.99	94.34
528088	81.43	88.60	90.36	93.73
523938	80.70	87.66	89.32	92.59
519556	80.16	86.83	88.60	91.97
517339	79.54	86.23	87.99	91.45
512924	78.78	85.14	86.86	90.34
508365	78.22	84.43	86.25	89.68
505081	77.38	83.16	84.93	88.69
504995	77.32	83.07	84.96	88.51
504515	77.36	83.07	84.72	88.06
504430	77.38	83.13	84.80	88.18
504199	77.24	82.88	84.52	87.80
504102	77.18	82.82	84.45	87.69
500713	76.34	81.79	83.36	86.47
495782	75.64	80.96	82.51	85.72
488465	75.02	80.43	81.99	85.34
482535	74.60	80.05	81.79	85.16
479906	74.16	79.66	81.52	84.91
475510	73.64	79.36	81.26	84.69
473295	73.26	78.92	80.81	84.29
468828	72.36	77.86	79.67	82.90
466380	71.76	77.21	78.98	81.96
466239	71.71	77.16	78.92	81.84

Cross Section	Water Surface Elevations (ft)			
	10% ACE	2% ACE	1% ACE	0.2% ACE
464068	71.33	76.78	78.53	81.31
460228	70.85	76.21	77.92	80.61
459163	70.66	75.94	77.60	80.16
458977	70.63	75.90	77.56	80.09
457292	70.22	75.37	76.95	79.14
452897	69.26	74.11	75.68	77.17
447908	68.42	73.05	74.59	75.74
443035	68.42	73.05	74.59	75.74
439515	67.43	71.44	72.95	74.44
432690	65.72	68.96	70.12	72.37
427524	64.75	67.84	68.88	70.90
419177	63.46	66.60	67.52	69.34
406524	61.43	65.06	66.35	68.06
402187	60.98	64.68	66.00	67.61
392747	60.42	63.96	65.24	67.12
388559	60.02	63.36	64.58	66.74
384737	59.58	62.85	64.03	66.22
384516	59.39	62.34	63.35	64.87
378642	58.51	61.17	62.02	63.73
373899	57.68	60.05	60.91	62.67
370470	57.09	59.21	60.06	61.74
365595	56.51	58.32	59.05	60.71
361553	56.12	57.64	58.23	59.77
358262	55.90	57.27	57.78	59.21
349871	55.63	56.92	57.36	58.67
344002	55.09	56.20	56.56	57.61
336295	54.18	54.95	55.20	55.99
331351	53.62	54.26	54.46	55.11
324344	53.22	53.81	53.99	54.53
320470	52.83	53.38	53.54	54.02
317000	52.33	52.80	52.94	53.34
312930.3	51.80	52.20	52.31	52.65
308583.5	51.52	51.89	51.99	52.30
305771.6	51.08	51.44	51.54	51.84
305615.2	50.98	51.32	51.42	51.72
302875.8	50.21	50.52	50.61	50.87
297558.3	49.38	49.65	49.74	50.00
294819.1	48.95	49.21	49.30	49.56
291502.8	48.35	48.59	48.68	48.94
288627	47.85	48.08	48.18	48.46
285653.7	47.09	47.33	47.44	47.75
283809.8	46.65	46.89	47.01	47.36

Cross Section	Water Surface Elevations (ft)			
	10% ACE	2% ACE	1% ACE	0.2% ACE
281134.8	46.13	46.38	46.53	46.95
276583.3	45.12	45.44	45.65	46.33
275349.9	44.74	45.10	45.34	46.16
273833.2	44.36	44.77	45.06	46.07
271317.6	43.73	44.22	44.62	45.94
268824.9	43.16	43.80	44.29	45.75
266784.9	42.58	43.42	43.95	45.42
257935.3	40.65	42.24	42.91	44.51
255458.2	40.22	41.91	42.60	44.19
253920.7	39.95	41.64	42.30	43.84
248467.6	39.24	40.86	41.46	42.94
247254.6	39.16	40.76	41.35	42.81
246307.5	38.98	40.56	41.15	42.60
245582.1	38.85	40.42	41.00	42.44
244296.3	38.62	40.14	40.71	42.12
241798.8	38.17	39.55	40.08	41.42
238317.3	37.66	38.95	39.47	40.77
235923.4	37.08	38.11	38.55	39.62
233849.8	36.73	37.65	38.05	39.04
232926.9	36.60	37.48	37.87	38.82
232298.7	36.47	37.32	37.70	38.63
228171.5	35.70	36.39	36.71	37.53
226430.5	35.40	36.07	36.36	37.17
223178.3	34.89	35.54	35.84	36.69
220535.9	34.38	35.06	35.40	36.37
218197	33.87	34.61	35.01	36.11
215636	33.45	34.23	34.65	35.77
212690.4	33.02	33.76	34.15	35.21
206664.8	32.06	32.67	32.97	33.85
200926	31.11	31.62	31.86	32.68
196787.5	30.49	30.95	31.15	32.04
190306.2	30.03	30.49	30.68	31.73
186824.7	29.76	30.24	30.44	31.59
183829.7	29.51	30.01	30.23	31.44
179479.5	29.02	29.55	29.78	30.94
179155.4	28.95	29.48	29.71	30.84
178789.6	28.87	29.40	29.61	30.72
177914.6	28.79	29.32	29.53	30.60
174103.5	28.46	29.00	29.20	30.20
172112.3	28.18	28.74	28.94	29.94
169715.3	27.79	28.40	28.60	29.68
165604.2	27.14	27.86	28.09	29.40

Cross Section	Water Surface Elevations (ft)			
	10% ACE	2% ACE	1% ACE	0.2% ACE
159474.3	26.27	27.24	27.54	29.12
152282.2	25.33	26.68	27.12	28.93
145725.1	24.67	26.35	26.89	28.81
143092	24.41	26.15	26.74	28.69
136684.7	23.77	25.78	26.46	28.54
131329	22.95	24.83	25.43	27.14
130048.3	22.61	24.43	25.00	26.57
129598.5	22.52	24.33	24.88	26.40
128597.7	22.25	23.97	24.50	25.93
127887.8	22.12	23.79	24.30	25.67
126833.8	21.78	23.39	23.89	25.20
120463.4	20.21	21.63	22.11	23.28
116704.6	19.54	20.99	21.51	22.69
113664.9	18.77	20.27	20.80	21.98
102513.1	17.04	18.88	19.41	20.57
96764.34	16.34	18.35	18.87	20.11
91471.59	15.88	18.01	18.53	19.84
87845.22	15.38	17.66	18.20	19.53
84697.1	14.91	17.31	17.87	19.22
82907.93	14.57	17.03	17.59	18.95
82530.34	14.26	16.65	17.16	18.39
80892.66	14.04	16.42	16.93	18.15
77862.15	13.70	16.10	16.60	17.79
75117.98	13.39	15.78	16.26	17.42
72649.6	12.83	15.17	15.61	16.65
68849.01	12.17	14.52	14.91	15.82
66026	11.56	13.91	14.28	15.10
62557	11.00	13.37	13.72	14.49
58377	10.21	12.54	12.87	13.54
55599	9.43	11.67	11.98	12.56
53486	8.56	10.65	10.92	11.40
51424	8.28	10.01	10.22	10.61
48402	7.87	9.47	9.62	9.92
45585	7.57	9.09	9.23	9.49
41087	7.19	8.72	8.89	9.19
37527	6.98	8.54	8.73	9.06
32269	6.66	8.27	8.48	8.87
27098	6.07	7.63	7.88	8.40
26001	5.97	7.49	7.76	8.30
25641	5.96	7.47	7.74	8.29
25070	5.98	7.49	7.76	8.31
23412	5.92	7.43	7.70	8.25

Appendix E: Hydraulic Analysis

Model vs FIS 1% Water Surface Elevations

Model vs FIS 1% ACE Water Surface Elevations				
		Water Surface Elevations (ft)		
Cross Section	County	FIS	Model	Δ
1158482	Waller	Zone A	177.40	—
1155776			176.96	—
1153048			176.71	—
1143752			175.97	—
1141313			175.61	—
1137562			174.75	—
1127605			171.29	—
1122071			169.61	—
1118372			169.09	—
1116668			168.12	—
1114038			167.26	—
1110530			166.96	—
1105409			166.46	—
1098272			165.94	—
1083008			165.40	—
1074880			165.15	—
1066052			164.69	—
1062971			164.05	—
1062340			163.83	—
1062059		169.49	162.92	-6.57
1061296		169.41	162.73	-6.68
1058398		169.08	161.92	-7.16
1052788		168.44	161.37	-7.07
1050724		168.24	161.11	-7.13
1043028		167.50	160.66	-6.84
1038285		167.12	160.35	-6.77
1027560		166.30	159.72	-6.58
1020731		165.92	159.16	-6.76
1012206		165.27	158.68	-6.59
1008328		164.77	158.57	-6.20
1000049		163.96	158.18	-5.78
996420		163.66	157.90	-5.76
992156		163.19	156.91	-6.28
989298		162.67	156.19	-6.48
988222		162.45	155.86	-6.59
987325		162.27	155.66	-6.61
987017			155.35	—
986327			155.14	—
984643			154.75	—
979265			153.56	—
971724			151.54	—

Cross Section	County	Water Surface Elevations (ft)		
		FIS	Model	Δ
968311	Waller	Zone A	150.88	—
963127			150.31	—
955101			149.62	—
951013			147.82	—
948862			146.51	—
945875			145.14	—
942857			144.41	—
940063			144.20	—
937463			143.99	—
928147			143.62	—
923559			143.34	—
915977			143.24	—
905692			142.86	—
898958			142.29	—
893006			141.53	
888299			141.09	—
885175			140.23	—
884491			139.91	—
884356			139.45	—
883658			139.42	—
882195			139.18	—
876731			138.15	—
873052			137.32	—
866218			136.40	—
858483			135.72	—
850587			135.28	—
846177			134.53	—
843697			134.28	—
838768			134.00	—
832301			133.47	—
829065			132.52	—
823798			131.67	—
818888			131.30	—
813827			130.77	—
812013			130.28	—
811391			130.00	—
811091		127.07	129.84	2.77
810118		126.86	129.60	2.74
809173		126.66	129.27	2.61
806413		126.19	128.37	2.18
801219		125.59	127.48	1.89
799346		125.22	127.25	2.03

Cross Section	County	Water Surface Elevations (ft)		
		FIS	Model	Δ
793449	Waller	124.08	125.99	1.91
788820		123.12	124.27	1.15
786171		122.58	123.50	0.92
784803		122.30	123.02	0.72
782864		121.90	122.45	0.55
782360		121.73	122.19	0.46
782282		121.55	122.06	0.51
782228		121.43	121.77	0.34
782184		121.32	121.65	0.33
781951		120.97	121.98	1.01
781243		120.70	121.57	0.87
779607		120.33	120.74	0.41
776878		119.72	119.65	-0.07
773775		119.05	118.30	-0.75
769017		117.96	116.96	-1.00
766102		117.24	116.09	-1.15
763479	Fort Bend	114.72	115.60	0.88
760690		114.68	114.98	0.30
754630		114.57	114.24	-0.33
748714		114.44	113.78	-0.66
737731		114.25	113.45	-0.80
733828		114.20	113.22	-0.98
720343		113.76	113.04	-0.72
713598		113.27	112.89	-0.38
698638		111.58	112.57	0.99
696865		111.49	112.37	0.88
696595		111.47	112.30	0.83
695975		111.44	112.16	0.72
692924		111.21	111.89	0.68
686779		110.89	111.70	0.81
681330		110.68	111.43	0.75
678582		110.55	111.23	0.68
674570		110.32	111.05	0.73
670434		109.92	110.81	0.89
662510		107.90	110.14	2.24
658600		107.50	109.60	2.10
657122		107.33	109.07	1.74
657028		107.32	109.03	1.71
654812		107.01	108.61	1.60
648982		105.37	107.86	2.49
646342		104.67	107.57	2.90
642584		104.25	106.99	2.74

Cross Section	County	Water Surface Elevations (ft)		
		FIS	Model	Δ
638386	Fort Bend	103.72	105.83	2.11
630512		101.82	104.49	2.67
626458		100.38	103.84	3.46
622459		99.31	102.55	3.24
618446		98.87	100.99	2.12
613273		98.20	99.32	1.12
606670		97.20	98.41	1.21
598163		96.54	97.64	1.10
590407		96.11	97.20	1.09
584343		95.66	96.94	1.28
580083		95.35	96.68	1.33
574771		94.89	96.33	1.44
567443		94.12	95.70	1.58
559374		93.49	94.70	1.21
551899		92.26	94.03	1.77
548194		91.69	93.56	1.87
548083		91.68	93.48	1.80
544383		90.93	92.88	1.95
536584		88.96	91.94	2.98
530754		87.88	90.99	3.11
528088		87.27	90.36	3.09
523938		86.62	89.32	2.70
519556		85.74	88.60	2.86
517339		85.20	87.99	2.79
512924		82.75	86.86	4.11
508365		81.74	86.25	4.51
505081		81.42	84.93	3.51
504995		81.41	84.96	3.55
504515		81.36	84.72	3.36
504430		81.35	84.80	3.45
504199		81.33	84.52	3.19
504102		81.32	84.45	3.13
500713		80.99	83.36	2.37
495782		80.62	82.51	1.89
488465		80.06	81.99	1.93
482535		79.14	81.79	2.65
479906		78.49	81.52	3.03
475510		77.36	81.26	3.90
473295		76.84	80.81	3.97
468828		76.01	79.67	3.66
466380		75.33	78.98	3.65
466239		75.30	78.92	3.62

Cross Section	County	Water Surface Elevations (ft)		
		FIS	Model	Δ
464068	Fort Bend	74.80	78.53	3.73
460228		73.96	77.92	3.96
459163		73.74	77.60	3.86
458977		73.70	77.56	3.86
457292		73.34	76.95	3.61
452897		72.72	75.68	2.96
447908		71.66	74.59	2.93
443035		70.54	74.59	4.05
439515		69.84	72.95	3.11
432690		68.73	70.12	1.39
427524		67.97	68.88	0.91
419177		66.83	67.52	0.69
406524		65.65	66.35	0.70
402187		65.22	66.00	0.78
392747		62.70	65.24	2.54
388559		61.63	64.58	2.95
384737		60.76	64.03	3.27
384516		60.71	63.35	2.64
378642		59.49	62.02	2.53
373899		58.81	60.91	2.10
370470		58.48	60.06	1.58
365595		58.25	59.05	0.80
361553		58.09	58.23	0.14
358262		57.93	57.78	-0.15
349871		57.06	57.36	0.30
344002		56.14	56.56	0.42
336295		55.13	55.20	0.07
331351		54.52	54.46	-0.06
324344		53.02	53.99	0.97
320470		52.34	53.54	1.20
317000		51.85	52.94	1.09
312930.3		51.29	52.31	1.02
308583.5		50.98	51.99	1.01
305771.6		51.72	51.54	-0.18
305615.2		51.70	51.42	-0.28
302875.8		51.43	50.61	-0.82
297558.3		50.90	49.74	-1.16
294819.1		50.59	49.30	-1.29
291502.8		50.09	48.68	-1.41
288627		49.65	48.18	-1.47
285653.7		49.21	47.44	-1.77
283809.8		48.65	47.01	-1.64

Cross Section	County	Water Surface Elevations (ft)		
		FIS	Model	Δ
281134.8	Brazoria	47.84	46.53	-1.31
276583.3		46.45	45.65	-0.80
275349.9		46.10	45.34	-0.76
273833.2		46.06	45.06	-1.00
271317.6		45.95	44.62	-1.33
268824.9		45.56	44.29	-1.27
266784.9		45.25	43.95	-1.30
257935.3		43.89	42.91	-0.98
255458.2		42.98	42.60	-0.38
253920.7		42.41	42.30	-0.11
248467.6		40.85	41.46	0.61
247254.6		40.57	41.35	0.78
246307.5		40.35	41.15	0.80
245582.1		40.19	41.00	0.81
244296.3		39.99	40.71	0.72
241798.8		39.60	40.08	0.48
238317.3		39.06	39.47	0.41
235923.4		38.75	38.55	-0.20
233849.8		38.47	38.05	-0.42
232926.9		38.12	37.87	-0.25
232298.7		37.89	37.70	-0.19
228171.5		36.34	36.71	0.37
226430.5		35.68	36.36	0.68
223178.3		34.48	35.84	1.36
220535.9		33.92	35.40	1.48
218197		33.43	35.01	1.58
215636		32.89	34.65	1.76
212690.4		32.27	34.15	1.88
206664.8		31.00	32.97	1.97
200926		30.42	31.86	1.44
196787.5		30.00	31.15	1.15
190306.2		29.60	30.68	1.08
186824.7		29.26	30.44	1.18
183829.7		28.88	30.23	1.35
179479.5		28.33	29.78	1.45
179155.4		28.30	29.71	1.41
178789.6		28.27	29.61	1.34
177914.6		28.22	29.53	1.31
174103.5		27.97	29.20	1.23
172112.3		27.84	28.94	1.10
169715.3		27.58	28.60	1.02
165604.2		27.32	28.09	0.77

Cross Section	County	Water Surface Elevations (ft)		
		FIS	Model	Δ
159474.3	Brazoria	27.13	27.54	0.41
152282.2		26.81	27.12	0.31
145725.1		26.38	26.89	0.51
143092		26.21	26.74	0.53
136684.7		25.48	26.46	0.98
131329		24.44	25.43	0.99
130048.3		24.11	25.00	0.89
129598.5		24.02	24.88	0.86
128597.7		23.83	24.50	0.67
127887.8		23.70	24.30	0.60
126833.8		23.50	23.89	0.39
120463.4		22.49	22.11	-0.38
116704.6		21.94	21.51	-0.43
113664.9		21.50	20.80	-0.70
102513.1		20.67	19.41	-1.26
96764.34		20.13	18.87	-1.26
91471.59		19.60	18.53	-1.07
87845.22		19.24	18.20	-1.04
84697.1		18.82	17.87	-0.95
82907.93		18.40	17.59	-0.81
82530.34		18.32	17.16	-1.16
80892.66		17.94	16.93	-1.01
77862.15		17.14	16.60	-0.54
75117.98		16.40	16.26	-0.14
72649.6		15.79	15.61	-0.18
68849.01		15.11	14.91	-0.20
66026		14.91	14.28	-0.63
62557		14.73	13.72	-1.01
58377		14.08	12.87	-1.21
55599		13.44	11.98	-1.46
53486		12.87	10.92	-1.95
51424		12.31	10.22	-2.09
48402		11.57	9.62	-1.95
45585		10.89	9.23	-1.66
41087		10.00	8.89	-1.11
37527		9.32	8.73	-0.59
32269		7.92	8.48	0.56
27098		—	7.88	—
26001		—	7.76	—
25641		—	7.74	—
25070		—	7.76	—
23412		—	7.70	—

Cross Section	County	Water Surface Elevations (ft)		
		FIS	Model	Δ
20788		—	7.37	—
18177		—	6.80	—
15562		—	5.90	—
14131		—	5.24	—
12687		—	4.42	—
9604		—	2.88	—