CHAPTER 2
FLOOD RISK ANALYSES

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Texas Water Development Board

DRAFT CHAPTER 2 2023 REGIONAL FLOOD PLAN REGION 6 SAN JACINTO

JUNE 2022

PREPARED FOR THE **SAN JACINTO REGIONAL FLOOD PLANNING GROUP**

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Disclaimer:

MLA source citations will be provided as a part of Volume 2 for the entire draft plan on a chapter-by-chapter basis.

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Task 2. Flood Risk Analyses

A critical component of developing a Regional Flood Plan (RFP) is to first define a baseline of understanding for flood risk in the region. The following Chapter documents the effort to define flood risk throughout the San Jacinto region for both existing and future conditions. The flood risk analysis was comprised of three main components:

1. Flood Hazard Analyses - determine the source, location, magnitude, and frequency of flooding
2. Flood Exposure Analyses - to identify who and what might be harmed within the San Jacinto Region; and
3. Vulnerability Analyses - to identify vulnerabilities of communities and critical facilities

Figure 1 below demonstrates the main components that drove the flood risk analysis performed for the San Jacinto Region.

Figure 1: Flood Risk Analysis Components

Task 2.A. Existing Condition Flood Risk Analysis

2.A.1. Existing Condition Flood Hazard Analysis

2.A.1.a. Characterization of Existing Condition Floodplains

Existing flood hazard was determined based on available floodplain mapping information in the Flood Hazard Quilt provided by the TWDB in the Flood Planning Data Hub. The feature is predominately Effective FEMA Flood Hazard Data mapping supplemented by some instances of Base Level Engineering (BLE) and FEMA Effective Approximate. TWDB provided other sources as the First American Foundation Data Service (FAFDS) and cursory floodplain data from Fathom, neither of these sources were incorporated due to the fact the region has a high availability of detailed floodplain mapping data. Fathom was not included specifically due to the approximate nature of the dataset. Data source assumptions regarding areas of overlapping floodplain sources are discussed further in the section *2.A.1.c. Best Available Existing Flood Hazard Data.*

Out of the data used in the TWDB provided flood quilt, the most updated versions of rainfall used in the flood hazard mapping produced was TP-40 (which was originally released in 1960s and through updated versions only accounts for historical storms of record through the early 2010s). Atlas 14, produced by NOAA, is the most recent estimate of frequency rainfall for Texas, as it considers historical rainfall records up to and including Hurricane Harvey in 2017. There are quite significant differences between the rainfall amounts as shown in the table below.

As the differences in rainfall amounts, shown in Table 1, are significant there will be opportunity in future cycles to update the existing flood hazard features to reflect updated rainfall methodologies used in mapping to Atlas-14.

Table 1: Approximate Rainfall Increase between Atlas 14 and TP40

Location	TP40 Rainfall (in)	NOAA Atlas 14 Rainfall (in)
San Jacinto Region	11.5-13.5	13.5-20.5

Throughout the San Jacinto region, flood risk data is prevalent and there is full coverage of available regulatory flood hazard mapping. This level of data availability is not the reality for many of the other flood planning regions in the state. The main types of risk reported in the flood hazard layer are riverine and coastal. However, in future cycles of the RFP there is opportunity to include other types of risk such as urban and pluvial flood risk.

As the region is rapidly developing, the regulatory floodplains are updated through the FEMA Letter of Map Change (LOMC) process. Any modifications to the regulatory mapping products used in the existing flood hazard features that became effective after December 2020 were not included for the first planning cycle. However, data and changes that take place after 2020 can be captured and reflected in future cycles. The current risk distribution of 1% and 0.2% annual chance events (ACE) within the region can be seen in Figure 2. Harris, Montgomery, and Galveston counties have the largest amount of overall area and floodplain area within the region.

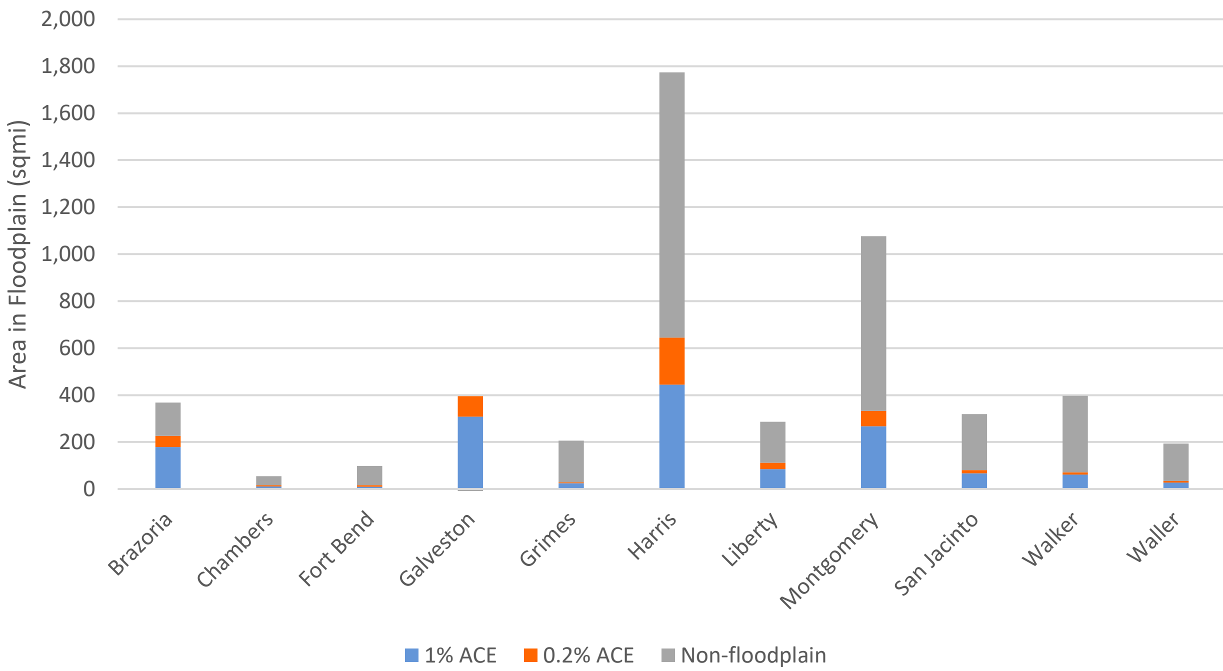

Figure 2: Flood Risk by County

2.A.1.b. Existing Hydrologic & Hydraulic Model Availability

Hydrology and hydraulic (H&H) modeling is a necessary component in determining how water flows over land and is a crucial element in developing effective flood planning strategies. Hydrology is the scientific study of earth's natural water movement with a focus on how rainfall, infiltration, and evaporation affect the amount of runoff, and hydraulics represents the analysis of the depth and flow of water.

Applied since the 1970s, H&H modeling uses computer software applications that simulate the flow of rainfall runoff over the land to predict the water level rise of creeks, rivers, and lakes as well as potential flooding extents. H&H modeling simulates flow, frequency, depth, and extent of flooding over land and frequently satisfies regulatory requirements to ensure that natural, agricultural, and social resources are not damaged by flooding induced by modifications to natural features or development.

As mentioned previously, the San Jacinto region is a data-rich areas with numerous FEMA, BLE, and detailed H&H modeling efforts. Due to the overall abundance of floodplain data and the short timeframe of the first planning cycle there was no additional non-regulatory data incorporated but can be incorporated in future RFP cycles. Several available detailed H&H models are listed in Appendix 2A-5 to show the abundance of supplemental H&H modeling. Although most of these models were available in 2021 or 2022 and used updated Atlas-14 rainfall methodologies they were not incorporated into the first planning cycle but can be incorporated in future planning cycles.

2.A.1.c. Best Available Existing Flood Hazard Data

As defined in the Scope of Work the "RFPGs shall perform existing condition flood hazard analysis to determine the location and magnitude of both 1% annual chance and 0.2% annual chance flood events." The text below is provided to highlight the process used to create the flood hazard information.

Existing flood hazard was determined based on available floodplain mapping information in the Flood Hazard Quilt provided by the TWDB in the Flood Planning Data Hub. In locations where mapping information overlapped, the information used followed the hierarchy provided by TWDB. The hierarchy list approved by the SJRFPG is provided below in order of descending data source priority.

1. **FEMA Map Service Center (MSC) (https://msc.fema.gov/portal/home)**
    a. Pending Flood Hazard data[1]
    b. Preliminary Flood Hazard data[2]
    c. Effective Flood Hazard data
2. **FEMA/USGS/TWDB Estimated Base Flood Elevation Viewer** (https://webapps.usgs.gov/infrm/estbfe/)
    a. Base Level Engineering data
3. **First American Flood Data Services (FAFDS)**
    a. No FAFDS data will be incorporated in the San Jacinto Region due to the approximate nature of the dataset.
4. **Cursory Floodplain (Fathom 3m) (Provided October 2021)** (https://firststreet.org/flood-factor/)
    a. Cursory Floodplain data will not be incorporated in the San Jacinto Region due to TWDB's recommendation that the data "may not appropriately depict flood risk associated with: Constructed features that may alter flow patterns (roadways, railroads, urban areas, storm drainage systems, dams, levees, embankments, etc.)." Since the Cursory Floodplain dataset is considered approximate due to the coarse level of detail, intended only to be used in areas where no other data is available, used in areas without constructed drainage features, and the prevalence of comprehensive existing floodplain mapping available throughout the region, the Cursory Floodplain Data has not been incorporated.

There is a region wide set of maps that show the existing flood hazard area following the above processes and hierarchy of data priority as shown in Map 4 found in Appendix 2A-1. These maps currently reflect the best-known flood risk data as seen appropriate by the SJRFPG. Figure 3 shows the overall presence of regulatory mapping within the region, most of the region is NFHL detailed supplemented by several areas of BLE in the norther part of the region and small areas of NFHL approximate at the upstream tailwater conditions of some reaches.

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[1] No Pending Flood Hazard data used due to Effective Flood Hazard data availability
[2] No Preliminary Flood Hazard data used due to Effective Flood Hazard data availability

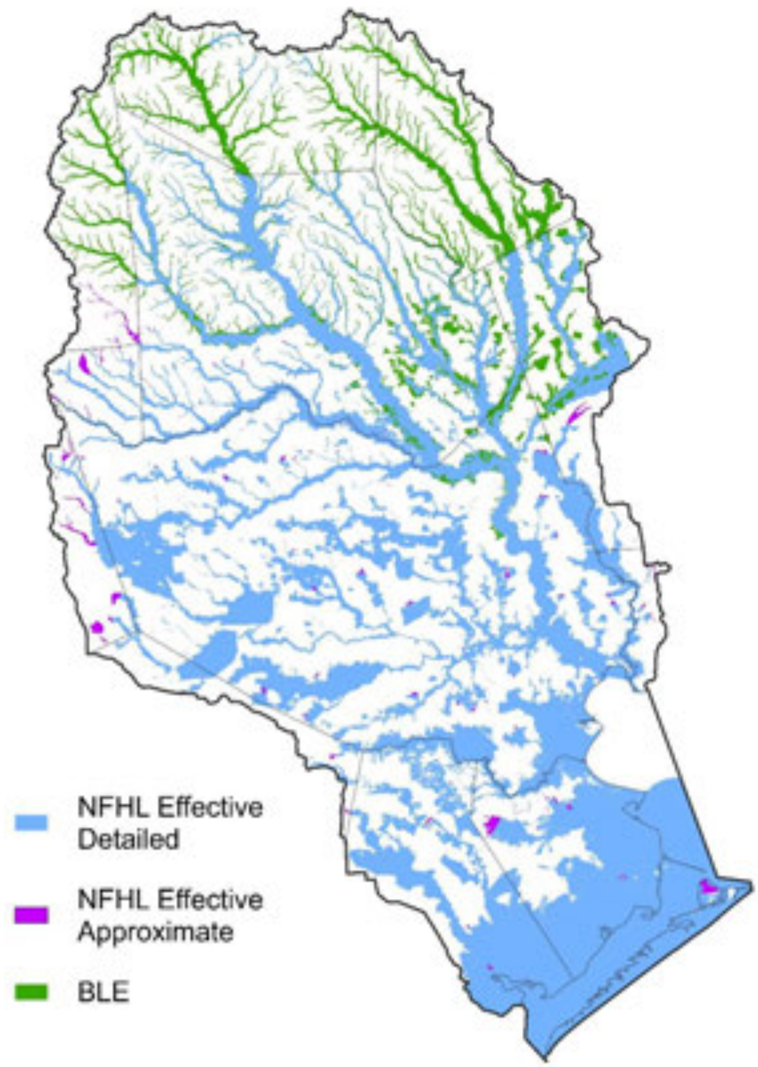


Figure 3: Best Available Flood Hazard Data

2.A.1.d. Existing Flood Map Gaps and Flood Prone Areas

Flood Map Gaps

The intent of the gap analysis is to identify areas with an absence of or outdated modeling and mapping. Watersheds, at a HUC12 level, with inadequate floodplain mapping information have been classified as map gaps. Several datasets were used as a reference to help inform the gap designations such as the urban development data from the National Landcover Database, TWDB Flood Quilt, and various FEMA Flood Insurance Study (FIS) reports. Due to significant increases in rainfall depth seen across the entire region due to NOAA's Atlas-14 as shown Figure 4, change in rainfall depth was not included as a decision point for Flood Map Gap designations, as the change in rainfall amounts would qualify the whole region as a mapping gap since the effective FEMA mapping does not incorporate Atlas 14 rainfall.

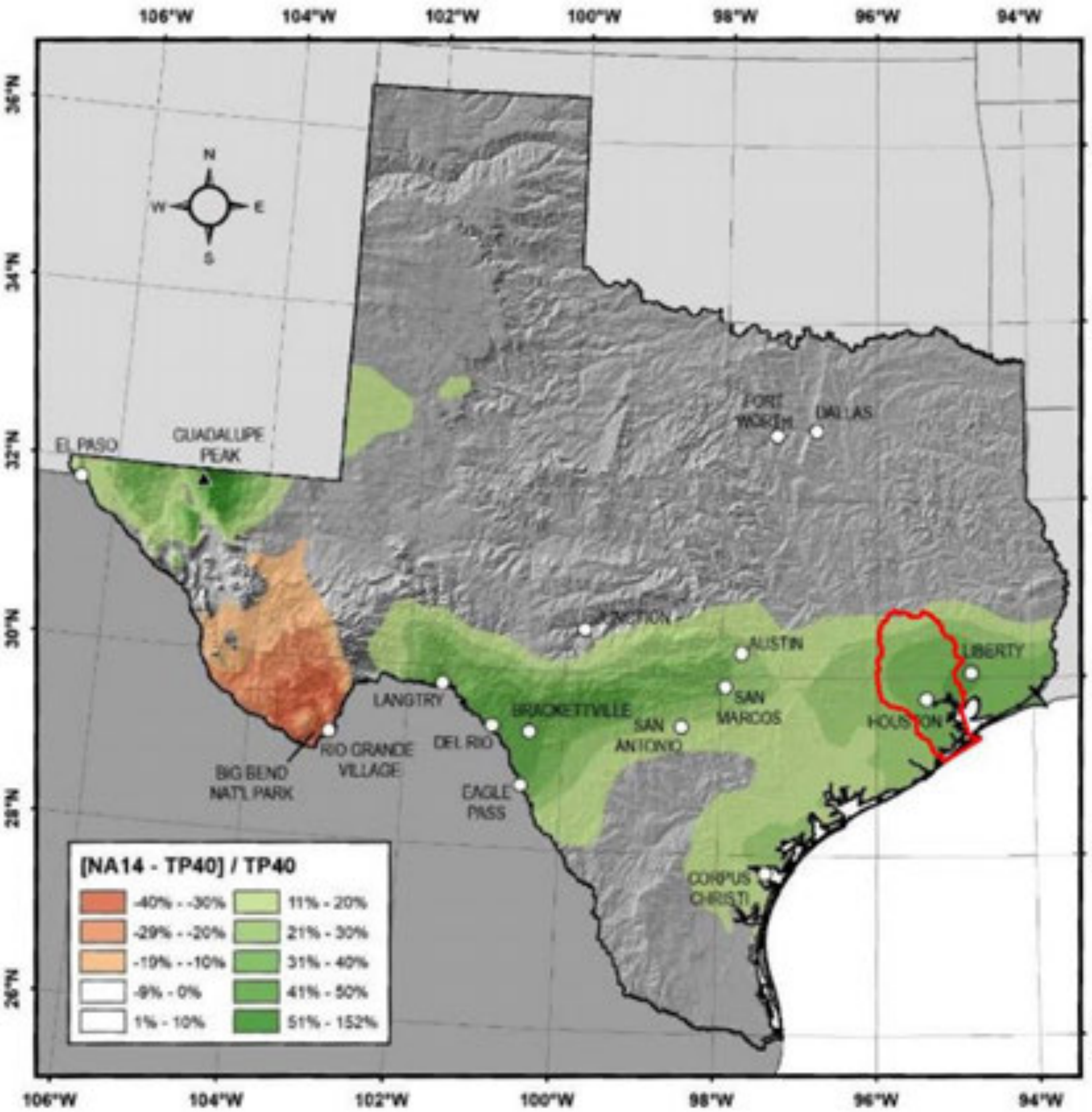


Figure 4: Rainfall Increase between Atlas 14 and TP 40

In addition, areas with known ongoing mapping efforts, such as areas captured within the Harris County MAAPnext effort, were not considered to be gaps as these studies have developed detailed mapping using current methodology (including Atlas-14 rainfall) available for incorporation in subsequent flood planning cycles. For the purposes of the mapping gap analysis, inadequate mapping in the San Jacinto Region has been defined as:

- Mapping Limited to Main Reach
  - Locations that only have detailed mapping associated with the main reach of the HUC12 but lack detailed mapping along tributaries.
- Outdated Mapping
  - Mapping produced with inputs, such as terrain or percent impervious, that no longer reflect current development conditions. The percentage of HUC12 area recently converted to urban development

and FIS reports were used to determine whether existing mapping no longer accurately reflects flood risk in that area. Depending on the development percentage either 2010 or 2000 was used as the date cutoff for outdated mapping.

- Areas of Recent Development with only BLE Mapping
    - HUC12s without detailed mapping in areas with recent development or a significant number of roadway stream crossings. BLE mapping provides an insufficient level of detail to adequately capture flood risk in these areas.
- Lacking Effective NFHL Mapping (Only includes Effective Approximate)
    - HUC12s lacking both effective detailed FEMA mapping and BLE mapping.

The gap analysis provides an understanding of the areas of the region that have modeling and mapping needs. Information on the location of flood map gaps is included in Map 5 found in Appendix 2A-2.

Flood Prone Areas

Flood-prone areas are being considered as known locations that experience flooding outside the extent of the existing flood hazard area. Members of the public and regional stakeholders were provided the opportunity to identify flood-prone areas using an online interactive map where users were allowed to provide input as points and polygons. The following four questions are required for any comment submission on the web map.

1. How often does the location flood?
2. What level of storm intensity causes the area to flood?
3. What appears to be the main cause of the flooding at each location?
4. What is impacted by the flooding?

In Figure 5, a reported flood prone area as seen by the blue rectangle is for the most part outside of the mapped floodplain, as the noted location must be outside the extent of the existing flood hazard, a requirement for an area to be noted as flood prone. This data helps inform the RFPG of flood risk that is not reflected in current flood risk mapping.

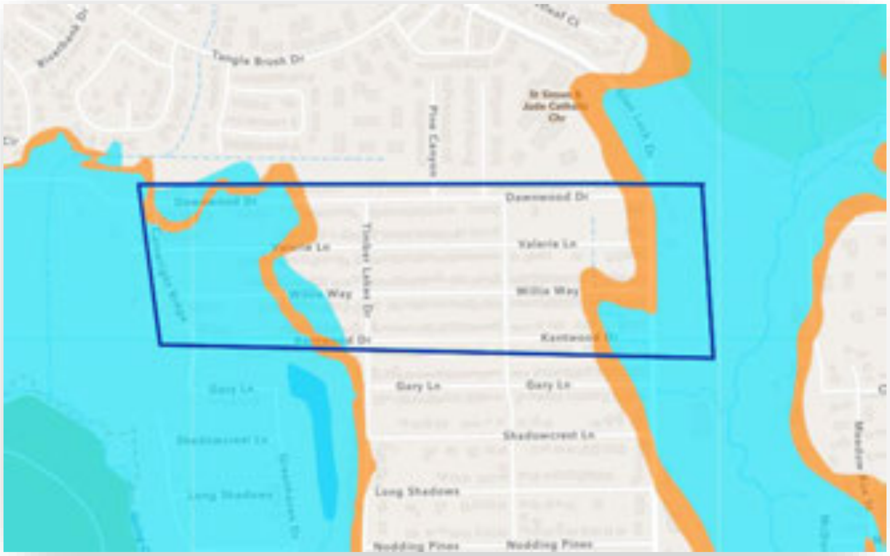


Figure 5: Example Flood Prone Area - Survey Response

In addition to the polygons and points recorded the responses to the survey questions were recorded (an example shown below) and used for planning purposes to help provide more detail into the extent and the perceived cause of the flooding. Additionally, users can provide written comments and attach photos with each submission. As future planning cycles progress, the intent is to continue to engage the public and regional stakeholders to help identify areas that experience flood risk that are not currently being reflected in regulatory risk information.

Responses:

1. How often does the location flood? *Once in the last 5 years*
2. What level of storm intensity causes the area to flood? *Only during heavy or prolonged rain events*
3. What appears to be the main cause of the flooding at each location? *Site is too low or too flat*
4. What is impacted by the flooding? *Buildings*
5. Comments: *This area floods every time there is a major flood. Water is up to the roof tops and the homes are cleaned up and rented again. The area has flooded at least 10 times in the last 30 years.*

The online interactive map was made available for public comment on August 17, 2021 and has received 22 recorded survey responses. The flood-prone areas included in the Draft RFP originated from SJRFP online webmap surveys as well as data points shared from the Texas GLO data outreach effort. Based on topography and survey responses, several point locations were digitized into polygons to represent areas of likely inundation. The flood-prone areas were included in the Existing and Future Flood Hazard spatial features with a Flood Frequency designated as 'Unknown", per Technical Guidance (Exhibit C).

The flood-prone areas shown within Map 5 were not assigned a flood frequency value due to the wide variety of survey responses received. For example, some responses identified areas of frequent street ponding while others identified areas that were inundated during Hurricane Harvey. Since a flood frequency was not estimated for survey responses, the extent of the delineated flood-prone areas remained unchanged between the existing and future flood hazard analyses.

2.A.2. Existing Condition Flood Exposure Analysis

2.A.2.a. Existing Development within the Floodplain

As defined in the Technical Guidance (Exhibit C), the goal of the exposure analysis is to identify who and what might be harmed within the region. The exposure analysis, namely a GIS exercise, was completed by intersecting roadways, agricultural areas, critical facilities, and buildings, with the flood hazard features to determine a region-wide evaluation of the infrastructure prone to risk associated with inundation from the existing and future 0.2% and 1% annual chance flood events. TWDB provided the following datasets that were used in the critical infrastructure dataset, fire stations, hospitals, shelters, schools, natural gas pipelines, and electric power transmission. The natural gas pipelines and electric power transmission lines were not included as a part of the critical infrastructure dataset used in the exposure analysis within the San Jacinto region since most of these features within the region were determined to be floodproofed, located well above or below ground, or are not in imminent risk of damage if located spatially within the floodplain. In addition to the TWDB provided building dataset, the RFPG supplemented the critical infrastructure dataset with Water and Wastewater Treatment Plants, Correctional Facilities, Aviation Facilities, Waste Disposal Facilities, Power Generation, and Chemical Manufacturing and Processing Facilities. As a result of the exposure analysis, a population estimate was generated to summarize the number of people impacted in the various floodplains. The exposure analysis information was summarized in Table 3: Existing Conditions Flood Exposure Summary Table provided as Appendix 2A-7. This exposure information will be used to not only identify areas within the region that have the greatest flood mitigation needs but to serve as a basis of comparison when assessing benefit of potential mitigation projects or strategies. The density of critical features resulting from the exposure analysis is displayed region wide in Map 6 (Appendix 2A-3) in the form of a density raster and a map book.

2.A.2.b. Potential Flood Mitigation Projects

Every HUC 12 within the region has at least one ongoing project with a project area associated inside the HUC 12 extent. There are approximately 644 identified of projects within the region aimed at reducing flood risk. Many of these projects are located within Harris County and parts of Brazoria and Galveston counties. As a general requirement, these projects often have associated model results or post-project inundation mapping; however, post-project inundation mapping was not incorporated for this first planning cycle due to the short timeframe and vast number of projects within the region. These benefits and floodplain modifications will be reflected in future planning cycles as the changes are reflected within the effective FEMA mapping or as time allows for incorporation in future planning cycles.

2.A.2.c. Flood Exposure Due to Existing Levees or Dams

Levees in the San Jacinto Region

Levees are a significant piece of flood reduction infrastructure, totaling over 152 miles throughout the San Jacinto region. Some of the most notable levees include systems along eastern Galveston Island, along Cedar Bayou in Chambers County, and the coastal levee system within Texas City, and the two systems in northern Harris County near Spring, TX. As levees are a common practice where coastal flood risk is prevalent, using levees as a common inland riverine flood reduction method is not a common practice. However, throughout the region levees are frequently used for agricultural purposes, but rarely serve any significant flood protection to property or infrastructure and therefore were not considered for this RFP cycle.

Out of the levees within the region, the Texas City systems were recognized as provisionally accredited (PAL), and the Spring Creek and Cypress Creek Systems are FEMA accredited. The details of the accreditation and risk analysis process were defined in section 1.B.3.a. The Lynchburg pump station levee system protects a critical pump system that supplies drinking water to the City of Houston. The Lynchburg system has a relatively low associated risk, as the likelihood of failure of the system prior to surge water elevations reaching the top of the levee is low according to the USACE National Levee Database. Although there are water supply and infrastructure consequences of the Lynchburg Pump System levee failing, the system does not protect thousands of people or significant amounts of property. However, the Texas City Hurricane Flood Protection (HFP) system received a high-risk classification due to the system experiencing significant water loading during Hurricane Ike and the USACE notes that the wall is likely to fail prior to the system being overtopped. As shown in Table 2, the two levees in Texas City protect a substantial amount of property and people, yielding significant flood exposure in the event of a system failure.

Levee Exposure Assessment

The most significant levees and the resources they protect according to the USACE National Levee Database within the region are found in Table 2: Levee Exposure Data. As there are other levees that exist within the region that protect millions of dollars of property, but the ones included below were seen as the most significant with property value protected over $25 million.

Table 2: Levee Exposure Data

Levee Name	Location	Length (miles)	Population Protected	Buildings Protected	Property Value Protected	FIRM/ FEMA Status
Galveston Co. Water Reservoir Levee System	Texas City	3.7	11,253	3,406	$2B	Provisionally Accredited (PAL)
Texas City Hurricane Flood Protection	Texas City	22.0	15,370	4,965	$1B	Provisionally Accredited (PAL)
Spring Creek Levee System	Spring	1.2	1,562	399	$300M	Accredited
Cypress Creek System	Spring	0.9	407	177	$47M	Accredited

Dams in the San Jacinto Region

In Texas, the Texas Commission on Environmental Quality (TCEQ) is the regulatory agency responsible for the administration of state dam safety laws. Dams with the state have both a size and hazard classification. The size classification is based on the maximum storage in the reservoir as well as height behind the dam and the hazard potential is based on the loss of human life and property damages downstream from the dam in the event of a breach. A dam's hazard classification can be low, significant, or high based on the downstream risks in the event of a failure. Although the classification data is not released publicly, TCEQ maintains and defines these classifications. Within the region there are every type of classification for both size and hazard of dams. If the hazard classification is deemed to be significant or high, an emergency action plan (EAP) is needed but is up to be developed by the dam owner. 64 dams within the region have an EAP prepared and 19 have the associated hazard that warrants an EAP but do not currently have one in place.

Dams within the region have various purposes, namely flood protection, water supply, recreation, and irrigation. The only two dams within the region that are intended for flood control purposes are the two federally United States Army Corps of Engineers (USACE) regulated reservoirs, Addicks and Barker. Addicks and Barker are the only reservoirs in the region that have flood control pools, which are operated by following specific protocols designed to protect Downtown Houston from flooding.

Other major reservoirs in the region such as Lake Houston and Lake Conroe have a primary purpose of providing water supply to the region; as such, these reservoirs do not have a dedicated flood control pool, nor the infrastructure to retain flood flows. Instead, water supply reservoirs are designed to maintain a conservation pool used for water supply, and to serve as a pass-through of flood flows by following protocols that ensure peak reservoir releases do not exceed peak inflows into the reservoir.

Any state regulated dam classified by the Texas Commission on Environmental Quality (TCEQ) or federal dam regulated by USACE as high hazard must have associated modeling and risk analysis corresponding to various dam breach scenarios. Although, this modeling and risk analysis is not readily available to the public and is not currently reflected in FEMA mapping, these types of large-scale risks are being evaluated and considered in the scope of public flood risk.

A critical aspect of dam and reservoirs is a flowage easement which is privately owned land that the Dam operator, usually the regulating entity, has the right to flood at any point in time under normal operations of the dam. Depending on the community and dam operator, the allowances with what you can do with the land, such as building or developing, are rather limited. The lack of development in these areas is an appropriate response of land use since the area is likely to see frequent inundation.

2.A.2.d. Existing Flood Exposure

Since Harris, Montgomery, and Galveston are the only counties fully contained within the region, due to spatial prominence and large relative area, these counties show the most prominent values for the exposure analysis in almost every category. An important item to note regarding the exposure analysis is that there is no elevation data associated with the flood hazard evaluation so infrastructure such as elevated roadways and buildings, appear in the exposure analysis to be at risk even if they are properly elevated and are well above the regulatory water surface elevations.

Population

The general population of people can be put at risk by flood waters in a multitude of ways such as at home, at work, commuting, or traveling to seek shelter. Within the region there are several areas that show significant populations at risk. For example, Harris County tops the list with 590,000 and 1.3 million people at risk in the 1% & 0.2% ACE risk classifications, respectively, making up around three fourths of the region's population exposed to flood risk. These population numbers are based on the TWDB provided buildings layer and are not indicative of people who are commuting in and out of these counties. Galveston County has the second highest population exposed to flood risk and Montgomery County has the third. The trend in population exposed to flood risk align with the fact that the overall population density in the region is located within these counties.

Structures

As people often stay at the home in times of danger and emergency, there is an inherent risk associated with staying at home during a flood event. Most of the structures identified at risk within the flood exposure analyses were residential. Critical facilities and public infrastructure perform essential functions that require enhanced consideration in flood planning. An explanation of critical facilities used in the exposure analysis is provided in section *2.A.2.a. Existing Development within the Floodplain.* For example, in the entire region, out of the 240,000 structures at risk in the 1% ACE, 200,000 were classified as residential. The breakdown of user types for structures within both the 1% and 0.2% ACE flood hazard area can be seen in Figure 6.

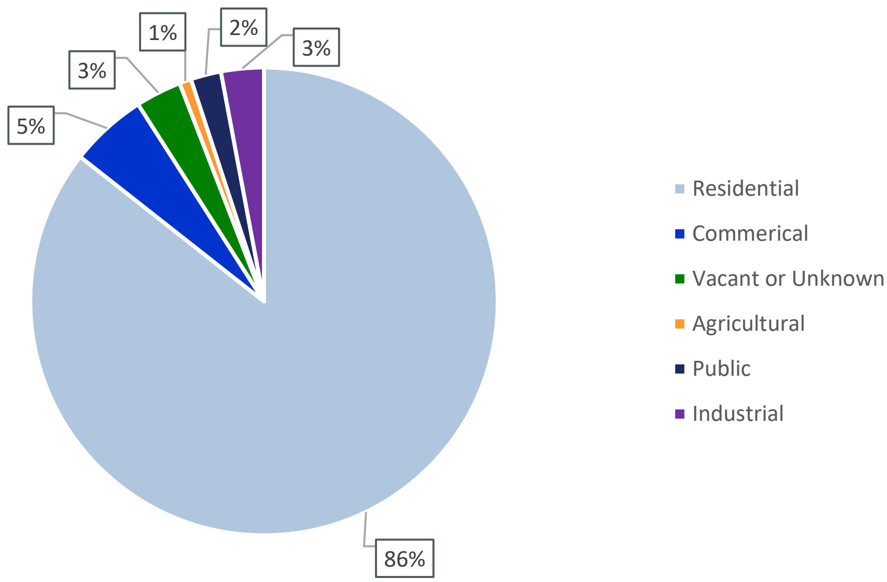


Figure 6: Distribution of User Types for Existing Structures in the 0.2% ACE Flood Hazard Area

Galveston County had the second highest number of structures for both events, almost doubling that of Montgomery County, which had the third highest number of structures exposed. Out of the 2.1 million structures located within the region (as provided by the TWDB buildings dataset), approximately 25% of the structures within the region are located within the 1% and 0.2% ACE floodplains as shown in Figure 7.

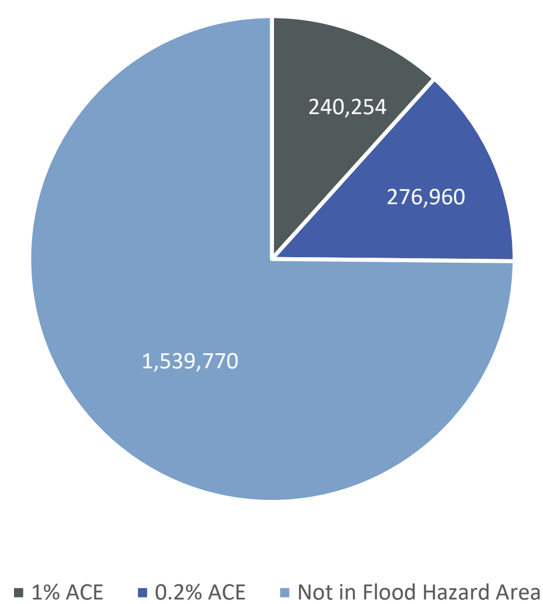


Figure 7: Flood Hazard Exposure by Structure

In terms of damages to structures resulting from flooding, the San Jacinto region has highest value of National Flood Insurance Program (NFIP) flood claims in the state of any RFP region, with a staggering total of $11.7 billion from 1975-

2019 surpassing all other regions by close to $10 billion with significant damages from storms such as Hurricane Harvey, Tropical Storm Allison, and Hurricane Ike as well as many more described in chapter 1. As this is no surprise to many of the residents of the region, flooding is a significant and prolific issue.

Critical facilities / Public Infrastructure

Critical facilities have especially high consequences associated with flood risk due to the nature and function of the facilities as they a serve a vital function to the wellbeing of the population. Critical facilities were discussed and defined in section *2.A.2.a. Existing Development within the Floodplain*. As expected, Harris County topped the list, accounting for well over half of the critical facilities in both events as shown in Appendix 2A-8. Galveston County showed the second highest values, then to highlight a slight shift in the normal trend, Brazoria County had the third highest number of critical facilities.

Roadway crossings and segments

TxDOT roadway data was provided by TWDB and included interstates and highways. Two factors were analyzed for roadways: length inundated in a flood event and number of road stream crossings. Bridge deck elevation data was not included in the analysis, so all points of intersection between streams and roads were considered in the exposure analysis. At a conceptual level, flood risk associated with flooded roadways is associated with low water crossings, cars traveling in floating in more than 6 inches of water, or people unable to escape as their car is swept away. Also, as roadways are shut down due to flooding this affects the transportation of goods along any major throughfare. For example, a large amount of shipping and logistics occur along US Interstate 10 within the region and if any part of it were to be impassable, this would cause significant financial impact and travel delays throughout the region. There were over 4,000 and 8,000 miles of roadway with associated risk in the 1 & 0.2% ACE events, respectively. Harris County topped the list for both storm events, Galveston County has the second highest miles of roadways exposed, and Montgomery County has the second highest number of roadway crossings.

Agricultural Areas

Agricultural area in the region was identified using the 2020 CropScape – Cropland Data Layer produced by USDA National Agricultural Statistics Service. Land use categories associated with farming and ranching were included in the exposure analysis as agricultural areas, while fallow or idle cropland and forestry were excluded. To highlight a break in the normal exposure analysis trend, Brazoria County had the most agricultural area within the region with around half of the entire agricultural area of the region located within the county. Next with Harris County as the second highest and Grimes County right behind with the third highest area values. These ranging values serve as an indicator of the variety of land use dynamics within the region. A total of 35 and 51 square miles of agriculture land were exposed region wide for both 1% and 0.2% ACE. Although agricultural lands are a predominately natural aspect of the landscape and rarely contain large amounts of impervious surface, prolonged and unexpected flooding can cause significant damages for crop quality and yield amounts.

2.A.2.e. Expected Loss of Function

Severe flood events can result in a loss of function for a community’s infrastructures which impacts the systems supported by the infrastructure. The impacts can include disruptions to life, business, and public services that can be essential to a community during and after a flood event. Infrastructure that becomes inundated during flooding events are often non-functional during the event and through the recovery process.

A spatial analysis was conducted in GIS using the best available data and the existing conditions floodplain quilt to generate qualitative estimates of expected loss of function for the San Jacinto region. Metrics were developed to get a general understanding of the expected loss of function of structures, transportation, health services, water supply, water treatment, utilities, energy generation, and emergency services during a 1% ACE. The table provided in Appendix 2A-6 summarizes the results of the expected loss of function analysis for each county within the San Jacinto region.

Inundated Structures

Residential structure data used in the San Jacinto region included single-family homes, town homes, mobile homes, as well as multi-family residences like apartments and condominiums. Based on the GIS analysis, an estimated 200,000 residential buildings are in the 1% ACE floodplain and have the potential to lose function during and after storm events. Harris County and Galveston County show the highest number of residential structures in the floodplain. Loss of function of residential structures can result in content loss and displacement of residents.

Non-Residential inventory data also included agricultural, commercial, industrial, and public buildings. An estimated 40,000 non-residential buildings are within the 1% ACE floodplain. These buildings are subject to a potential loss of function during storm events and during the recovery process. Loss of function of non-residential structures can result in content and inventory loss, potential relocation, and loss of short-term shelters.

Transportation

Transportation line data (roadways and railroads) from TxDOT was used to estimate road and railways crossings at-risk of flooding. Based on the GIS analysis, approximately 4,350 miles of roadways could experience a loss of function during a 1% ACE storm event.

There are approximately 239 low water crossings identified by TWDB in the San Jacinto region. These low water crossings will likely become impassable and result in a loss of function during significant storm events. The impassable roadways can cause issues for emergency responders and motorists that could be travelling on the roadways. During significant storm events, debris buildup can cause loss of conveyance at bridges and exacerbate the risk of road crossings with higher flood waters overtopping the roadways and the potential for debris to overtop the roadway.

Health and Human Services

Health and human services include hospitals, nursing homes, and other services to enhance the health and well-being of the public. Based on the spatial analysis, 20 hospitals and 42 nursing homes or assisted care facilities are located within the existing floodplain. During a flood event, potential loss of function can occur for these services due to their location within the floodplain. Loss of function of health and human services can result in loss of available beds, displacement of patients, and a potential loss in the quality of care. Harris County has the highest number of hospitals and nursing homes within the existing floodplain.

Water Supply

Floods can contaminate water supply sources such as wells, springs, and lakes/ponds through polluted runoff laden with sediment, bacteria, animal waste, pesticides, and industrial waste and chemicals. Drinking water wells have the potential to become contaminated during major flooding events, requiring disinfection and cleanup. Based on TCEQ's Public Water Supply dataset, there are 451 public water supply wells in the San Jacinto River Basin with 56 in the flood plain. Therefore, 12% of the public water supply wells in the San Jacinto region are potentially exposed to flood risk.

Water and Wastewater Treatment

Flooding has the potential to impact water and wastewater treatment facilities and reduce the effectiveness of the facilities. Failure of water and wastewater treatment systems due to flooding may consist of direct losses such as equipment damage and contamination of pipes as well as indirect impacts such as disruption of clean water supply. In the San Jacinto Region, around 800 wastewater outfalls are located within the flood plain. This means that the wastewater treatment facility is likely nearby and could potentially be within the flood plain as well and is possibly susceptible to flood risk and loss of function.

Energy Generation

Potential failure of power generation plants due to flooding can cause direct losses such as equipment damage as well as indirect impacts to surrounding facilities due to loss of power. Eight power plants are located within the flood plain and have the potential to have loss of function during a flood event.

Emergency Services

Flood events have potential to cause disruption to emergency services causing delays in response times and could hinder access to areas such as shelters or locations of emergencies. 39 fire stations are located within the flood plain and could experience a loss of function during a flood event. 38 emergency shelters are within the flood plain which could limit access to the facilities in the event of a flood.

2.A.3. Existing Condition Vulnerability Analysis

Vulnerability is an assessment of the potential negative impact of the flood hazard to communities and a description of the impacts. This task uses the data from the existing flood exposure analysis to determine the vulnerability of exposed structure and population to flooding. The existing condition vulnerability analysis uses the same data as the future vulnerability analysis. The populations and structures exposed to flood risk were evaluated for vulnerability based on the U.S. Center for Disease Control and Prevention's (CDC) Social Vulnerability Index (SVI). SVI is a ranking of recorded data from the U.S. census, analyzed at a census tract level based, "on 15 social factors, including poverty, lack of vehicle access, and crowded housing, and groups them into four related themes." For the purposes of the first planning cycle, the TWDB recommends that the vulnerability, SVI, should be used as an indicator for resiliency, which can be defined as the ability of a community or persons to recover from adverse conditions or situations, such as major flood events.

SVI values are measured from 0 to 1, where 1 is the highest resilience to a natural disaster and zero is the lowest. Throughout the region the SVI by census tract ranges from 0.0015-0.9900, this wide range shows the broad diversity of communities and how they will likely respond within the region. The RFP analysis is using SVI as a metric for vulnerability, which is being linked to resilience given a natural disaster within communities. This data provides more detail into the communities who are at risk and how they are likely to respond to a disaster given their current resources.

All vulnerability spatial features and required tables were completed in accordance with the Technical Guidance (Exhibit C & D) for both the existing flood risk. The data generated from the vulnerability analysis is shown in Map 7 (Appendix 2A-4) and average SVI of infrastructure exposed to flood risk per county as well as exposed critical facilities in Table 3 (Appendix 2A-7).

2.A.3.a. Resiliency of Communities

Increasing the overall resiliency of a community goes well beyond merely reducing flood risk, there must be a focus on the broader and systemic aspects of the community and how well they are able to respond given their current resources and systems. For example, the National Preparedness and Response Science Board noted that promoting access to public health, healthcare, and social services; promote health and wellness alongside disaster preparedness; expand communication and collaboration between networks of social services, business, academia, etc. and many more in addition to traditional public health and healthcare stakeholders; engage at risk individuals and the programs that serve them to take an active and responsible role in facilitating disaster efforts; and build social connectedness so that local assistance entities and communities can built trust amidst emergency preparedness efforts. All these efforts in addition to reducing flood risk can provide a holistic approach to reducing the impact that flood related natural disasters have on communities throughout the San Jacinto region.

2.A.3.b. Vulnerability of Critical Facilities

Critical facilities were considered for this analysis to be Hospitals, Police and Fire Stations, Shelters, Schools, Water and Wastewater Treatment Plants, Correctional Facilities, Aviation Facilities, Waste Disposal Facilities, Power Generation, and Chemical Manufacturing and Processing Facilities. Out of the 7,620 critical features in the exposure analysis, the average SVI value was 0.58 with a standard deviation of 0.28. These values generally show that the resiliency and vulnerability are greatly varied across the region. Water and wastewater treatment plants were considered critical due to the usual proximity to floodplains or bodies of water due to the need of a water source for intake or effluent. Hospitals and shelters were considered as a part of the exposure analysis as critical features due to the past flood issues and the vital role these areas play in providing essential services to the region. In addition to these areas serving a vital function, past flooding issues are prevalent for several areas within the region. For example, during Tropical Storm Allison the entire Houston Medical Center was devastated by flood waters, causing major losses of data and research and a lengthy loss of provided care for patients. Aside from the inherent importance of the previously listed features, there are certain features such as the various aspects of the ship channel and the corresponding petrochemical production, and the interstate highway system, infrastructure along these areas can experience damages from compound flooding and storm surge. These are critical pieces of infrastructure that are subject to more frequent and complex risk associated with compound flooding scenarios.

Beyond the sheer property damage associated with flooding events, there are also the longer-term damages associated with flooding losses, that although not deemed critical from an infrastructure point of view in the exposure analysis, they are no less important in the discussion of flood risk. These associated damages include, loss of work, mental health damages, or property being repaired with no intent or no feasible method to pay for repairs. Based on the SVI metric some of these damages disproportionately affect more vulnerable groups, as communities can respond in a myriad of ways given a hardship such as a flood-related natural disaster.

2.A.4. Summary of Exposure & Vulnerability Analyses

The previous sections have provided details for methodology of arriving at qualitative and quantitively description of what is in and what is greatly affected by flooding within the region. Based on the exposure analysis within the existing 1% and 0.2 % ACE floodplains there are approximately 500,000 structures, 1.7 million people, and 2,000 square miles of land area, these numbers are significant and will only continue to increase with associated increases in population and development within the region.

The existing flood risk, exposure, and vulnerability assessment for the San Jacinto Region are summarized in TWDB-required Table 3 located in Appendix 2A-7, providing the results per county of the existing flood exposure and vulnerability analysis as outlined in the Technical Guidelines for Regional Flood Planning as well as the SVI per structures in the floodplain by county.

A geodatabase with applicable layers as well as associated TWDB required Maps 4 through 7 are provided in Appendix 2A as PDFs. Table 3 below outlines the geodatabase deliverables included in the Draft RFP as well as spatial files and tables. These deliverables align with the TWDB's Exhibit D: Data Submittal Guidelines for Regional Flood Planning.

Table 3: Task 2A Geodatabase Layers and Tables

Item Name	Description	Feature Class Name	Data Format (Polygon/Line/ Point/GDB Table)
Existing Flood Hazard	Perform existing condition flood hazard analyses to determine the location and magnitude of both 1.0% annual chance and 0.2% annual chance flood events	ExFldHazard	Polygon
Existing Exposure	Develop high-level, region-wide, and largely GIS-based existing condition flood exposure analyses using the information identified in the flood hazard analysis to identify who and what might be harmed within the region for, at a minimum, both 1.0% annual chance and 0.2% annual chance flood events	ExFldExpPol	Polygon
	Develop high-level, region-wide, and largely GIS-based existing condition flood exposure analyses using the information identified in the flood hazard analysis to identify who and what might be harmed within the region for, at a minimum, both 1.0% annual chance and 0.2% annual chance flood events	ExFldExpLn	Polyline
	Develop high-level, region-wide, and largely GIS-based existing condition flood exposure analyses using the information identified in the flood hazard analysis to identify who and what might be harmed within the region for, at a minimum, both 1.0% annual chance and 0.2% annual chance flood events	ExFldExpPt	Point
	Combines the Exposure Poly, Line, and Point data into a single master layer, also includes Vulnerability data	ExFldExpAll	Point

Task 2.B. Future Condition Flood Risk Analysis

2.B.1. Future Condition Flood Hazard Analysis

For the 2020 – 2023 planning cycle, the Regional Flood Planning Groups (RFPGs) were tasked with performing a future condition flood analysis to determine the potential extent of both the 1% and 0.2% ACE flood hazard areas based on a 30-year future forecast period. The estimated flood hazard changes will be used solely for the purpose of estimating the general magnitude of potential future increases in flood risk under the equivalent of a "do-nothing" or "no-action" alternative and within the regional flood planning context should not, in any way, be used for developing new flood hazard maps for any regulatory purposes.

The first step of the task was to identify areas within each Flood Planning Region (FPR) where future condition hydrologic and hydraulic model results and maps are available and to summarize the relevant information for use in determining future flood hazard. In areas where future condition flood hazard data is not available, Exhibit C of the Technical Guidelines for Regional Flood Planning outlined the following four methods for performing future condition flood hazard identification, which are summarized in Table 4 below.

Table 4: TWDB Future Conditions Flood Hazard Methodology

Method	Description	Explanation
1	Increase water surface elevation based on projected percent population increase (as proxy for development of land areas)	Method 1 involves making certain assumptions about development, and then estimating correlations between impervious cover changes and changes to flood elevations. These results would vary based on a watershed's land use, soil type, and topography. The TWDB acknowledges that population increases do not always lead to impervious cover increases, but this simplified approach can be utilized if desired.
2	Utilize the existing condition 0.2 percent annual chance floodplain as a proxy for the future 1 percent level	Method 2 utilizes existing modeling and mapping to create the future condition 1% annual exceedance flood hazard. However, it does not yield a future 0.2% flood hazard area, so a methodology will need to be determined by the Regional Flood Planning Group on determining the future 0.2% flood hazard area. The TWDB notes that this method may be more appropriate in areas with high growth rates that are categorized as urban or suburban.
3	Combination of methods 1 and 2 or an RFPG-proposed method	Method 3 is a combination of the first two methods, and (as with the other methods), the rational/determination should be well-documented.
4	Request TWDB perform a Desktop Analysis	Method 4 has the TWDB perform a desktop analysis to determine the future condition flood hazard boundaries. This would be primarily utilized in areas where the locations do not have future condition flood hazard data already available.

The purpose of Section 2.B is to present key considerations in the development of future condition flood hazard areas and summarize the methodology utilized to determine the future 1% and 0.2% ACE flood hazard areas. Additional discussion and supporting information related to Task 2B can be found in the *Task 2B Technical Memorandum*.

2.B.1.a. Characterization of Future Condition Floodplains

Flood hazard within the San Jacinto River Basin is characterized as both riverine and coastal. Changes in flood risk for both types of flood hazard are dependent on a variety of potential factors. Riverine floodplain boundaries may be influenced by future development, population growth, subsidence, and future rainfall patterns. In addition to those factors, coastal floodplain boundaries may be affected by a combination of storm intensity, sea level change, subsidence, and coastal erosion. Each of these can influence the extent of hurricane storm surge that reaches inland, inundating communities.

Development and population growth may result in a change of land use and alter existing drainage patterns, which may result in a change of downstream discharge rates, runoff volumes and hydrograph timing. Depending on the magnitude of changes, water surface elevations and floodplain widths may increase. Many municipalities and counties in the region have development retention/detention criteria to reduce and mitigate increases in stormwater runoff as a result of development.

Subsidence is the gradual lowering of the ground elevation that in the greater Houston-Galveston region primarily results from aquifer compaction due to long-term, sustained groundwater extraction. Changes in ground elevations from non-uniform subsidence may result in wider floodplains for the region. Studies are currently underway within the region to understand the impacts of subsidence on existing flooding in the region and changing regulations are aiming to reduce the amount of subsidence.

Increased riverine discharges due to future rainfall patterns result in changes in water surface elevation and limited changes in inundation extents in areas with steep terrain. Alternatively, the increased flow results in smaller changes in water surface elevations and larger changes in inundation extents in areas with flat terrain. Since varying terrain is common throughout the region, varying results were seen for the floodplain comparisons.

Throughout the San Jacinto region, flood risk data is prevalent and there is full coverage of available regulatory flood hazard mapping. This level of data availability is not the reality for many of the other flood planning regions in the state. The main types of risk reported in the flood hazard layer are riverine and coastal. However, in future cycles of the RFP there is opportunity to include other types of risks such as urban and pluvial flood risk.

Current Land Use and Development Trends Associated with Population Increase

The TWDB's Water User Group projects that within the next 30 years, the population in the Water Planning Region H would increase by 3.5 million residents, equating to an approximate population increase of 37% between 2020 and 2050. Within the San Jacinto Flood Planning Region, the population is estimated to increase by 2.0 million, with the majority of growth being in Harris, Montgomery, and Fort Bend Counties.

Land use changes associated with the population increases in the region were considered for some of the region based on model availability. Future development land use changes in the norther portion of the watershed were analyzed in the San Jacinto Regional Watershed Master Drainage Plan (more information on the model can be found in Appendix 2B-7. The future conditions model included changes in land use based on a 50-year population outlook that was accounted for through increased impervious cover in anticipated development areas. The future conditions models reflect anticipated changes in population between 2020 and 2070, which are expected to lead to increases in impervious cover and changes in the timing of basin runoff.

An analysis of future development was not included in the southern areas due to the high density of development in Harris and Galveston Counties. While future development may have an impact on runoff, since many areas within these zones have already been relatively fully developed, other factors such as increase in rainfall, subsidence, and sea level rise will result in more substantial changes to the floodplain extents. These areas also have high standards for development within the floodplain and detention criteria which minimize the impacts from future development.

Sea Level Rise

Along with a growth in population and future rainfall patterns, sea level rise (SLR) was taken into consideration when estimating future flood hazard boundaries. SLR is an ongoing phenomenon where the relative ocean elevation is increasing and encroaching on coastal areas. Historical SLR has been analyzed by the Texas State Climatologist, Dr. Nielsen-Gammon, and the analysis has shown that the relative SLR increases at approximately 6.59 millimeters per year (0.65 feet in SLR over 30 years) in Galveston Bay at the Pier 21 measurement station.

Subsidence

Approximately 250 GPS stations are currently monitoring subsidence within the San Jacinto River Basin, operated by the Harris-Galveston Subsidence District (HGSD), Fort Bend Subsidence District (FBSD), University of Houston, Lone Star Groundwater Conservation District (LSGCD), Brazoria County Groundwater Conservation District (BCGCD), Texas Department of Transportation (TxDOT), and other local entities. Much of the subsidence is observed in the northern and southern zones of the region, as shown in Figure 8.

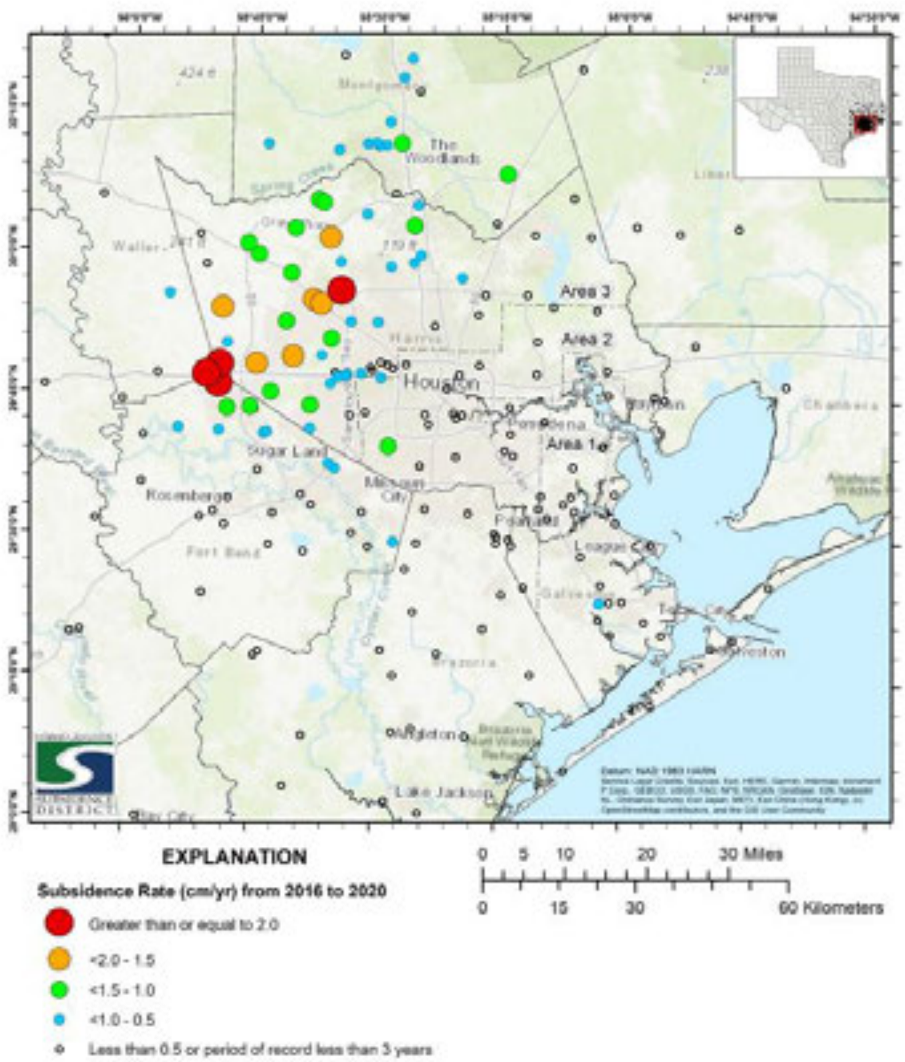


Figure 8: Subsidence Rates

Future Rainfall Patterns and Anticipated Changes to Floodplain Functionality

Projected future rainfall patterns can also have an impact on identifying future flood risk. According to the NOAA Atlas 14, Volume 11 Precipitation-Frequency Atlas, the Texas coast saw a 10-15% increase in annual precipitation between 1991 and 2012 compared to the average annual precipitation between 1901 and 1960.

The Office of the Texas State Climatologist provided TWDB with guidance on how to incorporate projected future rainfall patterns in their April 16, 2021 report, titled "Climate Change Recommendations for Regional Flood Planning." The report states that 1-day, 1% ACE rainfall depths increased by approximately 15% between 1960 and 2020. The climatologist coupled historical rainfall data with results from climate models to develop a relationship between extreme rainfall depths and future increases in global temperature. Percent increase in future precipitation was developed for both urbanized and rural watershed conditions. Due to the uncertainty of predicting weather patterns for extreme rainfall events[3], the climatologist provided a minimum and maximum range for estimating future rainfall patterns. The climatologist found even more uncertainty when analyzing rural and large river catchments due to future decreases in soil moisture. This led them to providing a percent decrease as a minimum range. The report did not mention storm events more frequent than the 1% ACE rainfall (for instance, the 10- or 25-year storm events), but this information could be available for analysis during future flood planning phases.

Table 5 was obtained from the climatologist's report and represents additional changes in rainfall depths that need to be applied to the Atlas 14 rainfall depths across the entire state.

Table 5: Range of Potential Future Rainfall Patterns

Location	Minimum	Maximum
Urban Areas	12%	20%
Rural Areas / River	-5%	10%

The San Jacinto River Basin includes a combination of urban and rural areas. Therefore, the averaged maximum for urban and rural areas of 15% on top of the Atlas 14 rainfall was used to increase rainfall depths for any future flood hazard modeling efforts within the watershed.

Anticipated Sedimentation in Flood Control Structures and Major Geomorphic Changes

Flood control structures prevent floodwaters, either stormwater or coastal water, from inundating vast amounts of land and property. Hydraulic works (levees, flood walls, dams, river diversions, etc.) represent human modification to the flood hazard. In the San Jacinto River basin, the most prominent flood control structures at a regional scale are levees, dams, and reservoirs.

Sedimentation occurs throughout all flood control structures and is often accounted for during the design of the facility. Sedimentation in water supply reservoirs primarily impact the conservation pool or water supply available. The TWDB has completed sedimentation studies on both Lake Conroe and Lake Houston to determine the water supply capacity amount of sedimentary accumulation in each lake. These studies show that the sedimentation occurs at the bottom of the reservoir which has minimal impact on the flood storage volume.

Dredging is being conducted in both the Addicks and Barker reservoirs as well as the West Fork San Jacinto River and East Fork San Jacinto River. These projects are aiming to remove sediment deposited in Hurricane Harvey while ongoing studies aim to find solutions to prevent sedimentation from reaching these areas.

[3] Typically defined as the 100- and 500-year storm events.

Sediment deposition in a channel can reduce its cross-section area over time or block storm sewer outfalls from local drainage systems. During high-frequency, low-intensity events, reduced channel conveyance may result in increased water surface elevations. But during low-frequency, high intensity storms (such as the 1% ACE), flood flows are typically conveyed by the floodplain and reduced channel conveyance may have a lesser effect on water surface elevations.

Sediment deposition throughout the region is also dynamic. During flood events, rushing water can scour deposited sediment and transport it downstream. As the flood recedes and waters slow down, sediments from upstream may begin to deposit and can reform the obstruction. This shifting sediment complicates the calculation of water surface elevations during the peak of the flood.

Since additional analysis is needed to understand the impacts of geomorphic changes to the floodplain, this aspect was not included within the future conditions flood hazard layer.

Completion of Proposed or Ongoing Flood Mitigation Projects

There are multiple Flood Mitigation Projects (FMPs) throughout the San Jacinto Basin that are either under construction or have dedicated construction funding. Additional detail regarding the types of ongoing mitigation projects in the region can be found in Chapter 1. In summary, there are 512 identified or ongoing projects in the region. These include land acquisition, channel conveyance improvements, levees and flood walls, local storm drainage systems, nature-based solutions, dams/retention/detention basins, roadway crossing improvements, and coastal projects.

Although flood mitigation projects impact the floodplains in their localized area, they were not included in the future floodplain analysis. Individual project models would have needed to be compiled, reviewed, and incorporated into the analysis to incorporate into the future condition analysis. In addition, models would have required calibration to ensure that inputs and assumptions were the same throughout the region. This information could be included in the next phase of the regional flood plan as many of the flood mitigation projects are currently under construction and are not included in the future flood hazard analysis.

2.B.1.b. Available Hydrologic & Hydraulic Models

Available hydrologic and hydraulic models containing future flood risk data were compiled and analyzed to understand how future conditions may affect future flood risk. The models collected included those related to the San Jacinto River Regional Master Drainage Plan (SJRMDP), developed in 2020, and the FEMA Effective modeling within Harris County developed in the late 2000s. Results from these models served as a reference to guide the estimation of how future conditions may impact flood hazard elevations and widths.

- SJRMDP – The HCFCD, City of Houston, Montgomery County, and San Jacinto River Authority completed the SJRMDP in 2020 which was a comprehensive plan for all major streams in the upper San Jacinto River basin. The SJRMDP included updated existing conditions hydrologic and hydraulic models for the main streams within the watershed as well as a high-level analysis of future floodplains as the region continues to grow. The SJRMDP future conditions included changes in land use based on a 50-year population outlook that was accounted for through increased impervious cover in anticipated development areas. The future conditions models reflect anticipated changes in population between 2020 and 2070, which are expected to lead to increases in impervious cover and changes in the timing of basin runoff. While these models were developed for the purpose of high-level planning, they serve as a valuable guide for understanding the potential future flood risk for the basin. The modeling extents of the SJRMDP are shown below in Figure 9.

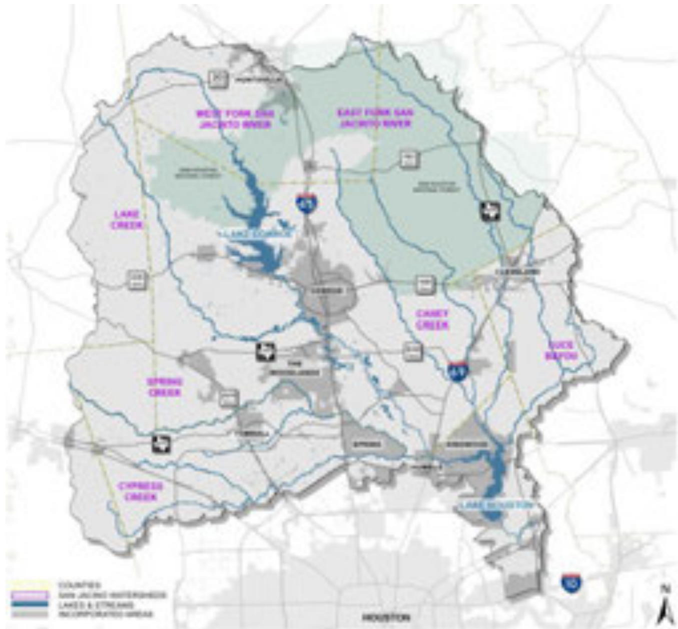


Figure 9 : Modeling Extents of SJRMDP

- HCFCD FEMA Models – The HCFCD maintains the effective FEMA models for mapped streams within Harris County. The models are open-source and can be obtained from HCFCD's website. These steady state HEC-RAS models were developed in the late 2000s by HCFCD and were calibrated to historical storm events. As part of previous efforts prepared for the HCFCD, Atlas 14 rainfall had been incorporated in several of the HCFCD models, which provided an approximate representation of what flood elevations may look like with future precipitation. This information was used to inform the future flood hazard recommended approach for the regional flood plan. Modifications to the HCFCD models included Atlas 14 precipitation and extrapolated storage-discharge curves to create updated steady state hydraulic models.

2.B.1.c. Determination of Future 1% and 0.2% Annual Chance Exceedance Floodplains

The assessment of future flood risk requires the estimation of the extent of the future flood hazard area. The determination of potential increases in the San Jacinto Region's future 1% and 0.2% ACE flood hazard areas is based on a "do-nothing" or "no-action" scenario for approximately 30 years of continued growth with existing flood regulations and policies. Since there is limited information regarding future flood hazard within the region, the future condition flood hazard layer is based on a horizontal offset of the existing conditions flood hazard.

Based on review of available information and the categorization of future conditions within the San Jacinto Region, future conditions flood hazard considers changes in rainfall, development, subsidence, and sea level rise for this planning cycle. Additional analysis on other contributing factors such as flood mitigation projects and geomorphic should be included once information is available to incorporate. Figure 10 below illustrates how the individual horizontal buffers determined for each of the future condition considerations were combined and applied to generate the future flood hazard.

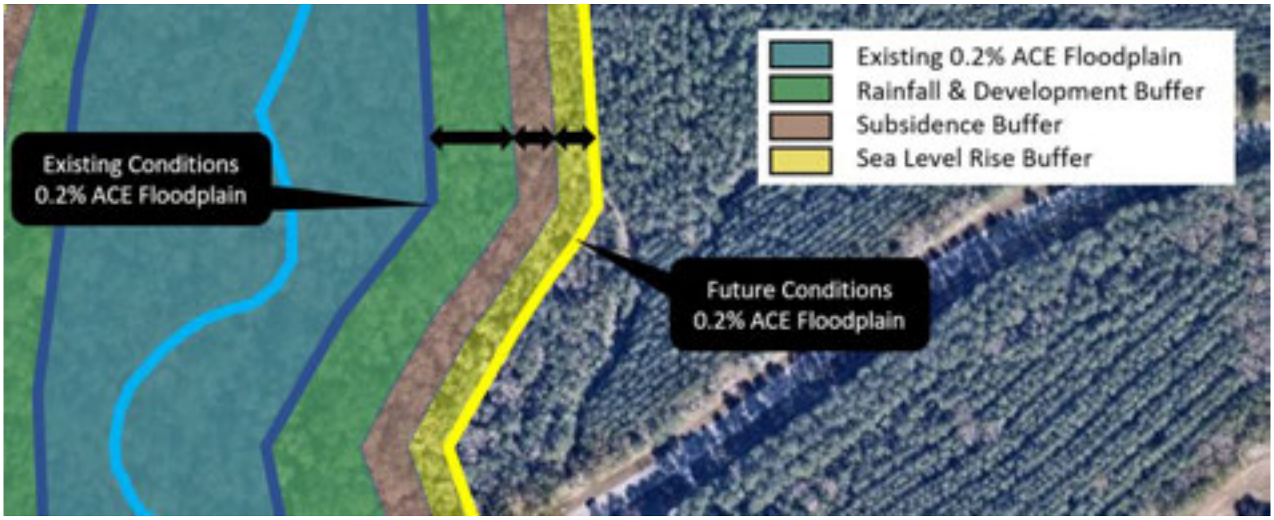


Figure 10: Combined Horizontal Buffer Approach to Future Flood Hazard

The region was also divided into three different zones to represent varying watershed characteristics and the different driving factors affecting change in flood hazard to estimate the future condition flood hazard. The zones were designated as Northern, Southern, and Coastal as shown below in Figure 11.

- The Northern Zone includes the areas within Montgomery, Grimes, Walker, San Jacinto, and Liberty Counties that flow into Lake Houston. This zone is characterized by rural development and rolling hill topography which is steeper than the topography in other zones.
- The Southern Zone includes Harris, Chambers, and Liberty Counties, which are watersheds that drain into the Houston Ship Channel. This zone is characterized by urban development with flat terrain that is mostly influenced by riverine flooding.
- The Coastal Zone includes the areas that drain into Galveston Bay in Brazoria, Galveston, and southern Harris Counties. This zone is characterized by flat and coastal topography that experiences both riverine as well as coastal storm surge flooding.

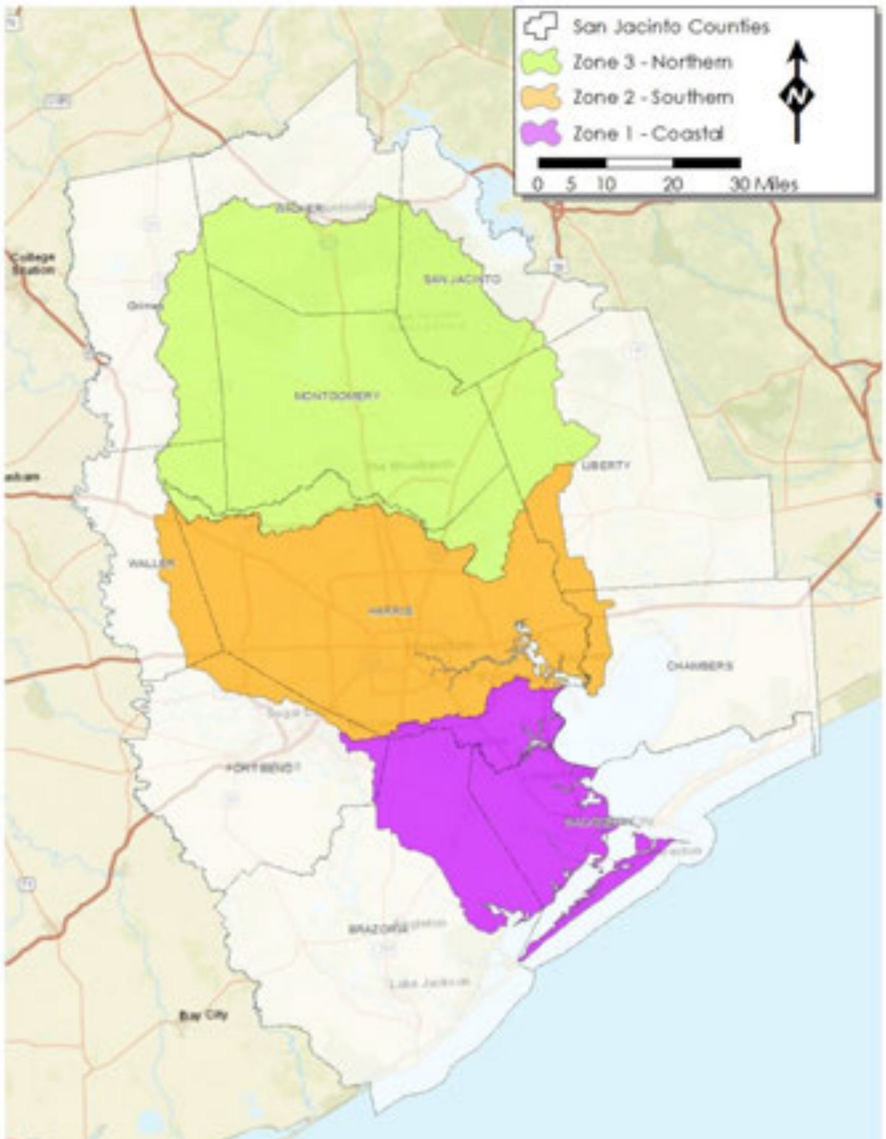


Figure 11: San Jacinto Zone Designations

Future 1% Annual Chance Exceedance Flood Hazard Area

The Method 2 approach as outlined by the TWDB was followed for developing the future 1% ACE flood hazard area. The method involves using the existing 0.2% ACE flood hazard area as an approximation for the future 1% ACE flood hazard area.

Unique to the nature of the comprehensive analysis, the San Jacinto Regional Master Drainage Plan (SJRMDP) included models for future flood hazard 1% ACE floodplains for the main tributaries for the upper basin. The modeled future 1% ACE flood hazard was compared to the effective 0.2% ACE flood hazard to identify similarities and differences in the floodplains for the Northern Zone.

The Southern and Coastal Zones have similar topography and channel features and therefore were grouped into one analysis. The available effective HCFCD models were updated with higher Atlas 14 rainfall depths to generate estimated future flood hazard water surface elevations for the Southern and Coastal Zones. An analysis of future development was not included for the Southern or Coastal Zones due to the high density of existing development within these zones. While future development may have an impact on runoff, since many areas have already been developed, other factors such as increase in rainfall, subsidence, and sea level rise will result in more substantial changes to the floodplain extents. These zones also have high standards of floodplain development and detention criteria which minimize the impacts of future development.

Future 1% ACE Flood Hazard Conclusion – All Zones

The SJRMDP modeling showed that the anticipated future 1% ACE flood hazard extents are reasonably consistent with the existing conditions 0.2% flood hazard extents for the Northern Zone. This conclusion was also supported by the HCFCD model comparisons between the FEMA existing 0.2% ACE and Atlas 14 1% ACE for the Southern and Coastal Zones. While differences exist in flood hazard widths and water surface elevations, they were typically within an acceptable range for the purpose of Task 2B and support the general agreement between the future 1% and 0.2% ACE flood hazard comparison. The differences shown in water surface elevations and flood hazard extents are attributed to different modeling approaches and the approximate nature of the comparison analysis.

The comparisons show that the existing 0.2% ACE flood hazard area can be used as an appropriate estimate of the future 1% ACE flood hazard area. However, due to potential land changes due to subsidence and sea level rise, buffers for those two factors were determined separately and applied to the existing 0.2% ACE flood hazard area to create the future 1% ACE floodplain extents. The general approach for the future 1% ACE flood hazard area is outlined in Figure 12. The determination of the subsidence and sea level rise buffers is discussed further in subsequent sections.

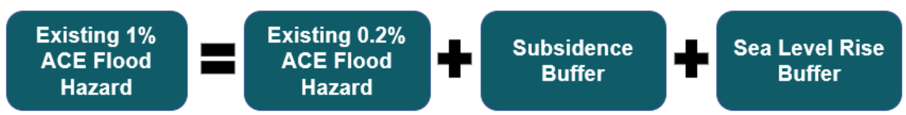


Figure 12: Future 1% ACE Flood Hazard Determination Process

Future 0.2% Annual Chance Exceedance Flood Hazard Area

The existing available information was reviewed to identify the approach for the future 0.2% ACE flood hazard based on the recommended approaches from the TWDB. As discussed previously, future floodplains will consider increases in rainfall, changes in development, subsidence, and sea level rise. Since future condition modeling is not widely available for the region, applying a horizontal buffer to existing flood hazard area boundaries was used as a reasonable approach to estimating future flood hazard area widths.

It is noted that floodplain widths are not standard or typical and depend on numerous variables including topography, development type, stream condition, discharge rates, and downstream conditions. However, the horizontal buffer approach provides reasonable results for the initial planning cycle and can be refined in future studies. Separate approaches for determining the 0.2% ACE flood hazard area were followed for the Northern, Southern, and Coastal Zones due to the differences in topography and flooding sources. A more detailed discussion of the methodology used is provided in the *Task 2B Technical Memorandum*. The approach for the 0.2% ACE flood hazard area determination is outline below in Figure 13.

Figure 13: Future 0.2% ACE Flood Hazard Determination Process

Northern Zone – Future 0.2% ACE Development & Rainfall Buffer

Information from the SJRMDP was used to compare the effective floodplain widths to the estimated future floodplain widths to establish the Development and Rainfall Buffer to be used for the future 0.2% ACE floodplain. The model was simulated for both the effective rainfall (pre-Atlas 14) and the TWDB recommended rainfall (Atlas 14 + 15%). The average difference in flood hazard layer top width for each modeled watershed was calculated, and then utilized as a 'Development and Rainfall Patterns Buffer' that could be added to the existing 0.2% ACE floodplain. The horizontal buffer is applied to the floodplain so the calculated values include an increase on both sides of the channel. For example, a 500-foot buffer would be applied as 250 feet on either side of the channel. The results for the Northern Zone are provided below in Table 6. For reference, the average top width of the existing conditions 1% annual chance floodplain of the main stems is also included in the table.

Table 6: Northern Zone 0.2% ACE Top Width Comparison

Channel	Existing Average Width of Floodplain (ft)	Average Difference of Flood Hazard Layer Top Width (ft)
Lake Creek	4,134	343
Peach Creek	2,100	488
Willow Creek	2,761	497
Spring Creek	3,335	565
Caney Creek	3,027	612
Recommended Development and Rainfall Patterns Top Width Buffer (Northern Zone)		500

Southern & Coastal Zones – Future 0.2% ACE Development & Rainfall Buffer

Information from available HCFCD models was used to compare the effective floodplain widths to the estimated future floodplain widths to establish the Development and Rainfall Buffer to be used for the future 0.2% ACE floodplain. The model was updated with the rainfall and simulated for both the effective rainfall and Atlas 14 rainfall. The average difference in flood hazard layer top width for each modeled watershed was calculated, and then utilized as a 'Development and Rainfall Patterns Buffer' that could be added to the existing 0.2% ACE floodplain. The horizontal buffer is applied to the floodplain, so the calculated values include an increase on both sides of the channel. For example, a 500-foot buffer would be applied as 250 feet on either side of the channel. The results for the Southern and Coastal Zones can be seen in Table 7. For reference, the average top width of the existing conditions 1% annual chance floodplain of the main stems is also included in the table.

Table 7: Southern & Coastal Zone 0.2% ACE Top Width Comparison

Channel	Existing Average Width of Floodplain (ft)	Average Difference of Flood Hazard Layer Top Width (ft)
Greens Bayou	4,502	701
Buffalo Bayou	1,210	817
White Oak Bayou	2,932	843
Sims Bayou	1,399	1,096
Recommended Development and Rainfall Patterns Top Width Buffer (Southern and Coastal Zones)		850

Future 0.2% ACE Flood Hazard Conclusion – All Zones

The comparisons show that with the addition of a calculated buffer, the existing 0.2% ACE flood hazard area can be used as an appropriate estimate of the future 0.2% ACE flood hazard area. Buffer factors include a development and rainfall patterns buffer as well as sea level rise and subsidence buffers. The buffers for all three factors were determined separately and applied to the existing 0.2% ACE flood hazard area to create the future 0.2% ACE flood hazard extents.

The flood width boundaries calculated for the Southern and Coastal Zones are much larger than those calculated for the Northern Zone. This is due to the primarily flat topography of the Southern and Coastal watersheds when compared to the Northern Zone watersheds.

Sea Level Rise Buffer

The United States Army Corps of Engineers (USACE) has developed a tool to calculate the approximate Sea Level Rise (SLR) for a “high”, “intermediate”, and “low” scenario (Figure 14). The rate computed for the “high” scenario builds from the most recent Intergovernmental Panel on Climate Change (IPCC) and modified National Research Council (NRC) projections for a high rate of SLR. In Galveston Bay, the approximate “high” SLR projected by USACE over the next 30 years is 1.6 feet of SLR. The rate computed for the “intermediate” scenario builds from the most recent IPCC and modified NRC projections for a moderate rate of SLR. In Galveston Bay, the approximate “intermediate” SLR projected by USACE over the next 30 years is 0.85 feet of SLR. The rate computed for the “low” scenario builds from historical rates of SLR to determine the low rate of SLR. In Galveston Bay, the approximate “low” SLR projected by USACE over the next 30 years is 0.6 feet of SLR. The “intermediate” scenario (0.85 feet of SLR) is the recommended estimation of SLR over the next 30 years.

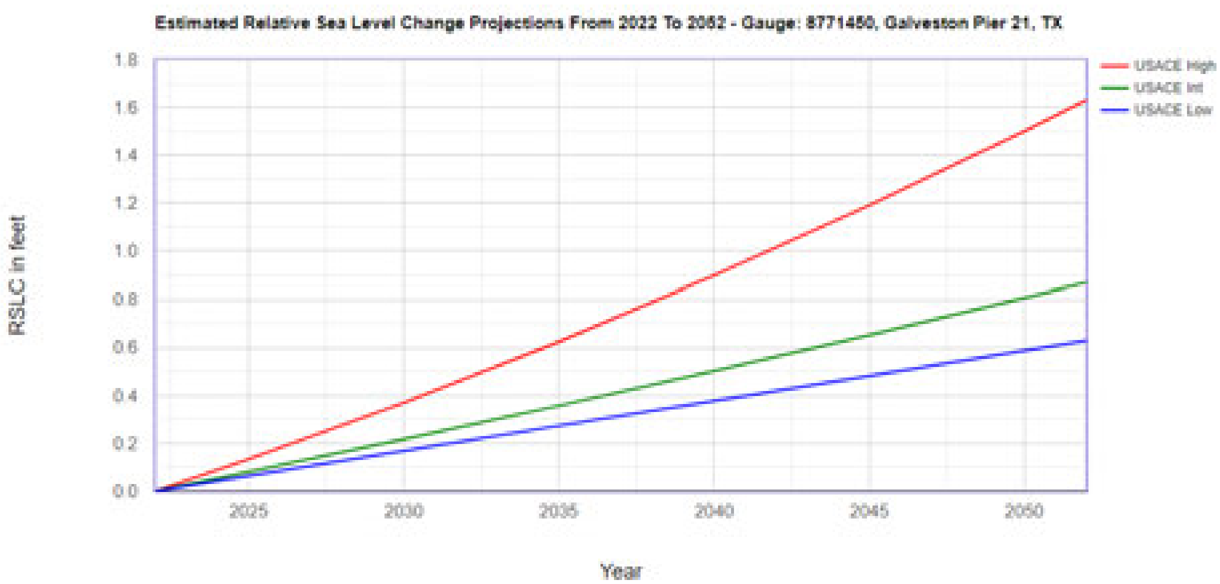


Figure 14: Estimated Sea Level Rise in Galveston Bay from 2022 to 2052 (USACE 2021)

Using the “intermediate” SLR estimate, a horizontal buffer was determined to approximate the influence of SLR on the future condition coastal flood hazard. From the best available terrain data, transects of the coast were cut to determine the average overland slope in the Southern and Coastal Zones. The average overland slope for sea level rise was limited specifically to the coastal areas and does not include overland slopes further inland.

Using best available terrain data, an average slope of was calculated for the Coastal Zone of the San Jacinto River Basin. The slope, refined to remove the channel bank slopes, was found for each zone and is detailed in

Table 8 below. below. The slope was then translated into a horizontal distance for 0.85 feet of rise to determine the recommended buffer distance accounting for sea level rise. Ultimately, the recommended buffer for 0.85 feet of sea level rise was determined to be 315 feet of additional buffer for the Southern Zone and 570 feet for the Coastal Zone to be incorporated in the future flood hazard 1% and 0.2% ACE flood hazard layer within the Coastal Zone and applicable portions of the Southern Zone.

Table 8: Sea Level Rise Buffer Estimate

	San Jacinto River Basin Zone

	Northern	Southern	Coastal
Estimated Sea Level Rise over 30 years (feet)	N/A	0.85	0.85
Average Overland Slope (%)	N/A	0.27%	0.15%
Estimated Zonal Sea Level Rise Buffer (Feet)	N/A	315	570

Subsidence Buffer

Actual ground level subsidence varies spatially. For the purposes of this study, subsidence is adopted as the average for each regulatory subsidence regions defined by the Harris Galveston Subsidence District. Future flood floodplains residing in corresponding subsidence regions are assumed to adopt subsidence projections unique to that region (this projection is subsequently transformed into a horizontal buffer onto the future floodplain). In this study, it is assumed that subsidence projections on a per subsidence region basis experience consistent subsidence rates for both creek bed and flood plain. This is an assumption that airs on the side of conservatism using available data and for informing future flood risk.

For each zone of the San Jacinto River Basin, an average subsidence rate was calculated using historical rates provided by HGSD and was then projected over 30 years to determine an approximate future ground elevation change (HGSD 2021). A similar approach as was used for SLR was utilized to determine the relationship between the vertical change of subsidence and a horizontal distance that would be incorporated into the total buffer distance. Using best available terrain data, an average slope was determined for each zone of the San Jacinto River Basin using a combination of coastal transects and inland cross sections. The slope was then translated into a horizontal distance to determine the recommended buffer distance accounting for subsidence. Table 9 provides a summary of the approximate average subsidence rate, estimated subsidence over 30 years, average slopes calculated, and the estimated buffer distance for each zone. The recommended buffer for accounting for future subsidence is 55 feet for the Northern Zone, 340 feet for the Southern Zone, and 80 feet for the Coastal Zone to be incorporated in the future flood hazard 1% and 0.2% ACE flood hazard layer.

Table 9: San Jacinto River Basin Subsidence Recommendation

	San Jacinto River Basin Zone		
	Northern	Southern	Coastal
Approximate Average Subsidence Rate (cm/yr)	-0.86	-1.10	-0.20
Estimated Subsidence over 30 years (feet)	-0.85	-1.08	-0.19
Average Overland Slope (%)	1.62%	0.32%	0.25%
Estimated Zonal Subsidence Buffer (feet)	55	340	80

Future Flood Hazard Buffer Exceptions

The flood hazard area buffers described above were applied across the region to determine the extents of the future 100- and 500-year floodplains. These buffers were applied to all flood hazard areas except in a few instances where regional, man-made structures influence the flood hazard area. For all areas mentioned, additional analysis should be conducted to understand the implications of future growth in the region.

Within Harris County there are two accredited levee systems in the Spring Creek and the Cypress Creek watersheds. Since these levees were constructed with freeboard, it is anticipated that the future flood hazard areas would remain within the existing. Therefore, the floodplains were clipped to the extent of the existing conditions within the Inverness Forest Levee and Northgate Levee.

Within the planning region, there are two water supply reservoirs, Lake Houston and Lake Conroe. Lake Houston water surface elevations during flood events are influenced mostly by the large uncontrolled spillway. Therefore, horizontal buffers as described above were applied to the region upstream of Lake Houston. Elevations in Lake Conroe are controlled by operational gates. Future flows into Lake Conroe are not anticipated to result in significant changes to elevations within the lake. Therefore, within the area influenced by the Lake Conroe Dam, the existing conditions flood hazard areas were used as the future conditions flood hazard areas for both the 1% and 0.2% ACE. Additional analysis should be conducted in future planning cycles to understand potential changes to future floodplains within the influence area of these reservoirs.

Within the region there are also two regional flood control facilities (Addicks and Barker Reservoirs) where water surface elevations are strictly controlled by operational gates. The gated structures allow storm runoff to pass downstream and gate operations are based on reservoir elevations. Therefore, for areas influenced by the Addicks and Barker Reservoirs, the existing conditions flood hazard areas were used as the future conditions flood hazard areas for both the 1% and 0.2% ACE. Additional analysis should be conducted in future planning cycles to understand potential changes to future floodplains based on reservoir operations and future inflows.

Summary Future Flood Hazard Delineation

The Region 6 Flood Planning Group future 1% and 0.2% ACE flood hazard areas were developed following the Method 3 approach (a combination of Methods 1 and 2) from the TWDB’s Technical Guidance document.

Recommendations were developed for each of the three zones within the San Jacinto FPR to reflect differences in watershed characteristics throughout the region.

Future 1% ACE Flood Hazard

- The existing 0.2% ACE flood hazard area was selected to serve as a proxy for the future 1% ACE flood hazard area.
- An additional horizontal buffer to account for subsidence and sea level rise was applied to the existing 0.2% ACE flood hazard area boundary.

Future 0.2% ACE Flood Hazard

- The existing 0.2% ACE flood hazard area was buffered by either 500-feet or 850-feet to reflect the impact of development and future rainfall patterns on the flood hazard area.
- An additional horizontal buffer to account for subsidence and sea level rise was applied to the existing 0.2% ACE flood hazard area boundary.

Table 10 shows the recommended buffer widths that were utilized to determine the future flood hazard boundary. Note that the buffers listed represent a total top width buffer and should be divided in half to determine the expansion of the flood hazard boundary on each side of an associated water feature.

Table 10: Future Flood Conditions Flood Hazard Approach

Future Flood Hazard 1% Storm Event

Existing 0.2% ACE + Buffer

		Development and Rainfall Patterns Buffer (ft)	Subsidence Buffer (ft)	Sea Level Rise Buffer (ft)	Total Top Width Buffer (ft)
Northern Zone	All	0	55	0	55
Southern Zone	Riverine	0	340	0	340
	Coastal	0	340	315	655
Coastal Zone	Riverine	0	80	0	80
	Coastal	0	80	570	650

Future Flood Hazard 0.2% Storm Event

Existing 0.2% ACE + Buffer

		Development and Rainfall Patterns Buffer (ft)	Subsidence Buffer (ft)	Sea Level Rise Buffer (ft)	Total Top Width Buffer (ft)
Northern Zone	All	500	55	0	555
Southern Zone	Riverine	850	340	0	1,190
	Coastal	850	340	315	1,505
Coastal Zone	Riverine	850	80	0	930
	Coastal	850	80	570	1,500

This methodology and approach were presented to the Technical Committee on February 3, 2022 and gained consensus and approval by the committee. Approval by the members of the RFPG board was obtained during the March 3, 2022 meeting.

Appendix 2B-1 includes Map 8 and the future condition flood hazard areas for the San Jacinto region. The future conditions risk distribution of 1% and 0.2% annual chance events (ACE) within the region can be seen in Figure 15. Harris, Montgomery, and Galveston counties have the largest amount of overall area and future conditions floodplain area within the region.

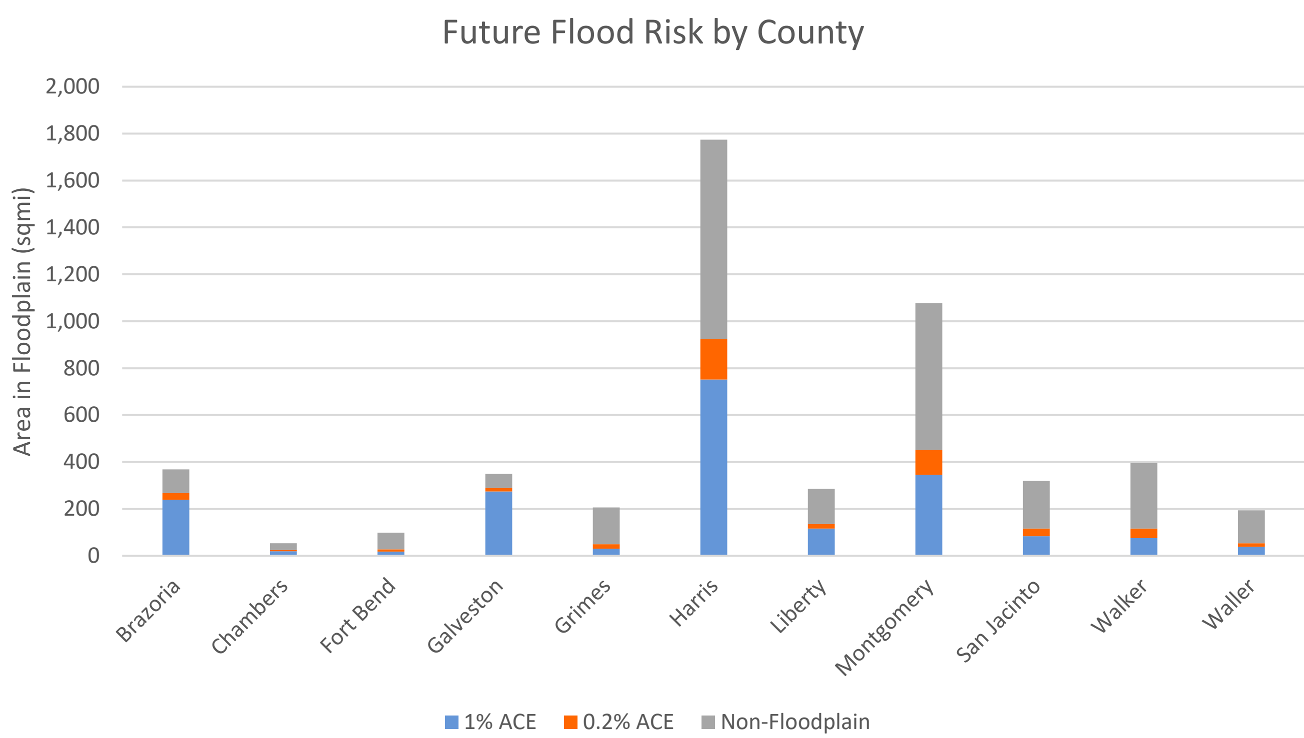


Figure 15: Future Flood Risk by County

2.B.1.d. Flood Map Gaps and Future Flood Prone Areas

Minor Tributaries

Upon determining the buffer, an evaluation was done to determine how to apply the buffer across the region. The buffers were generated based on approximate models for the major streams within each zone. Minor tributaries to the streams may vary in characteristics which can affect the flood hazard layer width. Such characteristics include urbanization, topography, channel improvements, and existing channel capacity. While an overall flood hazard buffer applied to each major stream and minor tributary may not most accurately show the future flood hazard, varying tributary buffers would require substantially more information than is currently available. These models would require significant time and effort to create and analyze. Therefore, it was determined that the same flood hazard buffer for the main stems would also be applied to the tributaries. During future regional flood plans, reviewing the proposed buffer width along tributaries should be explored further. It would provide the most accurate representation of the future flood hazard boundary if additional information for that analysis becomes available.

Modeling

One of the comments that was discussed with the Regional Flood Planning Group reflected the models that were utilized for the future floodplain development. Floodplain extents are a good indication of flood risk for an area. However, flood depth is also critical for understanding the risk the flooding poses to residents and property. That information was not available for utilization during this Regional Flood Planning cycle but could be available for future flood planning cycles.

The unavailability of extensive future flood models and associated mapping data resulted in the future flood hazard mapping assumptions and approach discussed earlier. In addition, the same data gaps exist for future flood hazard mapping as existing conditions mapping since the existing conditions were used to develop the future extents. The data gaps are shown in Map 9 in Appendix B2-2.

2.B.1.e. Comparison to Existing Conditions Floodplains

Map 10 in Appendix B2-3 shows the changes in flood hazard areas from existing to future conditions. Table 11 compares the existing and future conditions extent for the entire region.

Table 11 : Existing and Future Conditions Flood Hazard Area Comparison

Annual Chance Storm Event	Existing Conditions (Sq. Mi.)	Future Conditions (Sq. Mi.)	Difference (Sq. Mi.)	Difference (%)
1 % ACE	1,484	1,993	509	34%
0.2% ACE	1,956	2,457	501	25%

2.B.2. Future Condition Flood Exposure Analysis

An exposure analysis was performed to identify the population and structures in the region that may be affected during the future 1% and 0.2% ACE. ArcGIS was utilized to intersect the future flood hazard layer and the features identified by TWDB to determine the affected existing development, critical infrastructure, and low water crossings at risk of flooding.

2.B.2.a. Existing and Future Development within the Floodplain

The analysis performed for future flood hazard exposure was based on the flood exposure dataset developed as part of Task 2A: Existing Condition Flood Risk Analyses. Future development was not accounted for as part of this analysis due the complexity and variability with predicting future structure locations as well as current floodplain ordinances within the region that regulate development within existing flood zones. The existing buildings (and associated population), roadway crossings, agricultural areas, and other metrics were used in the future flood exposure analysis by intersecting this existing data with the future 1% and 0.2% ACE flood hazard areas. Because the future flood hazard layer generally resulted in larger mapping extents when compared to the existing conditions floodplain quilt, the number of people and structures at risk in the future conditions flood exposure analysis is larger than under the existing condition analysis.

The types of critical infrastructure that were considered for the analysis of future flood risk included medical facilities, government buildings, emergency ops and shelters, law enforcement facilities, fire stations, schools, nursing homes, airports, railyards, ports, power generating plants, transmission facilities and water/wastewater treatment plants. To facilitate alignment with concurrent GLO and USACE coastal studies, additional structure types added to the critical infrastructure list included chemical plants, refineries, chemical storage facilities, oil and gas infrastructure and correctional facilities. The full list of critical infrastructures is subject to revision and requires approval from the San Jacinto Regional Flood Planning Group members.

2.B.2.b. Proposed and Ongoing Flood Mitigation Projects

The existing conditions flood hazard areas did not include post project inundation mapping due to the vast number of projects within the region as well as lack of information of the future conditions floodplain. Many of these projects do not have significant impact of the less frequent storm event floodplains such as the 1% and 0.2% identified in this analysis. Future projects, such as those recommended in the regional flood plan, should consider the increase in flood risk associated with future conditions variables over the life of the structure.

2.B.2.c. Future Flood Exposure

The summary of future flood exposure by county can be found in Appendix 2B-6 Table 5 and Map 11 located in Appendix B. The increase in future flood hazard exposure compared with existing conditions exposure is summarized in Table 12.

Table 13 below.

Table 12: Summary of Increased Exposure in Flood Hazard Area for 1% Annual Flood Risk

	Existing Conditions	Future Conditions	Increase	% Increase
Population	785,911	2,225,624	1,439,713	65%
Total Structures	240,254	653,872	413,618	63%
Residential Structures	199,918	562,108	362,190	64%
Non-Residential Structures	40,336	91,764	51,428	56%
Critical Facilities	3,411	10,253	6,842	67%
Roadway Crossings	4,257	8,005	3,748	47%
Roadway Segments (miles)	4,350	9,726	5,376	55%
Agricultural Area (sq. mi)	35	56	21	38%

Table 13: Summary of Increased Exposure in Flood Hazard Area for 0.2% Annual Flood Risk

	Existing Conditions	Future Conditions	Increase	% Increase
Population	1,705,926	2,960,702	1,254,776	74%
Total Structures	517,214	895,112	377,898	73%
Residential Structures	442,768	775,464	332,696	75%
Non-Residential Structures	74,446	119,648	45,202	61%
Critical Facilities	8,091	12,922	4,831	60%
Roadway Crossings	5,208	9,109	3,901	75%
Roadway Segments (miles)	7,984	12,814	4,830	61%
Agricultural Area (sq. mi)	51	66.2	15	30%

Population Totals by County

The population associated with existing structures was not altered for the future exposure analysis. Future development was not accounted for as part of this analysis due the complexity and variability with predicting future structure locations as well as current floodplain ordinances within the region that regulate development within existing flood zones. The existing buildings (and associated population) was used in the future flood exposure analysis by intersecting this existing data with the future 1% and 0.2% ACE flood hazard areas.

Approximately 2,225,624 people are anticipated to be located within the future 1% ACE flood hazard area, and 2,960,702 within the future 0.2% ACE flood hazard area. Over 2,154 people are estimated to be in future flood prone areas.

Structures

Future flood exposure analysis was performed by overlaying the future flood hazard area developed for the San Jacinto Region with the buildings, critical facilities, infrastructure, and agriculture areas that were determined to be in the region. Table 5: Future Condition Flood Risk Summary Table, by County (Appendix 2B-6) shows the total number of buildings, critical facilities, and agricultural areas exposed to the future flood hazard areas, summarized by county. A total of 653,872 structures are exposed to the 1% annual chance flood risk regionwide.

As people often stay at the home in times of danger and emergency, there is an inherent risk associated with staying at home during a flood event. Most of the structures identified at risk within the flood exposure analyses were residential. Critical facilities and public infrastructure perform essential functions that require enhanced consideration in flood planning. An explanation of critical facilities used in the exposure analysis is provided in Section *2.A.2.a. Existing Development within the Floodplain.* For example, in the entire region, out of the 654,000 structures at risk in the future conditions 1% ACE, 443,000 were classified as residential. The breakdown of user types for structures within both the 1% and 0.2% future conditions ACE flood hazard area can be seen in Figure 16.

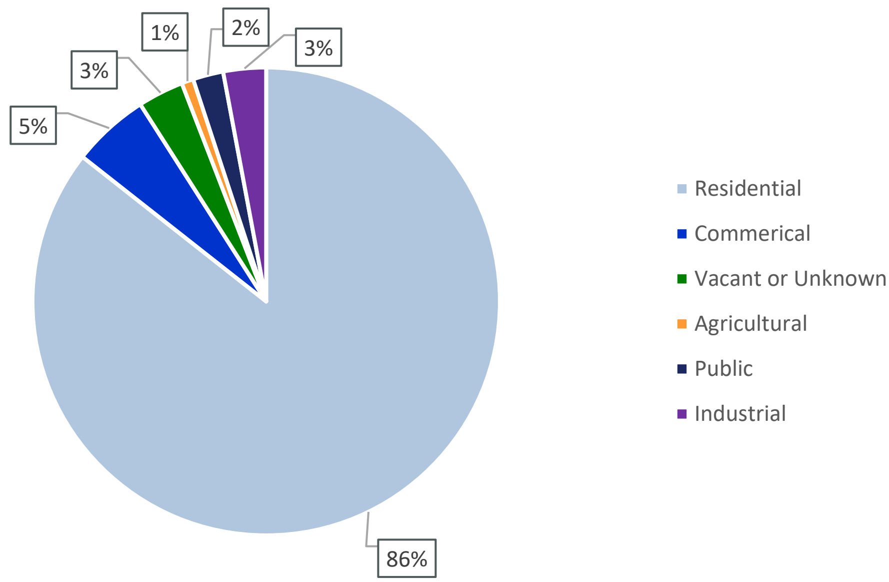


Figure 16: Flood Hazard Exposure by Structure

Harris County had the largest number of structures in the future conditions floodplain. Similar to the results for the existing conditions floodplains, Galveston County had the second highest number of structures for both events. Out of the 2.1 million structures located within the region (as provided by the TWDB buildings dataset), approximately 44% of the structures within the region are located within the future conditions 1% and 0.2% ACE floodplains as shown in Figure 17.

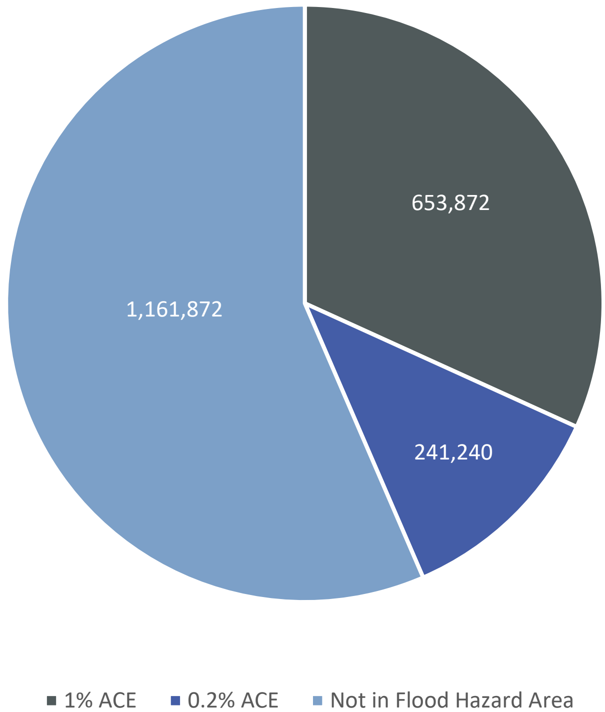


Figure 17: Distribution of User Types for Future Structures in the 0.2% ACE Flood Hazard Area

Critical Facilities and Public Infrastructure

Critical facilities and public infrastructure were analyzed with the future flood hazard areas to determine future flood risk exposure of these features. No additional features were added to the dataset compiled in the existing conditions flood exposure analysis previously described. An additional 6,842 critical facilities were identified in the future condition flood exposure analysis that were not previously located within in existing conditions floodplains.

Roadway Crossings and Roadway Segments

The future flood risk exposure analysis for roadways used only the existing roadway data available from TxDOT. Without considering additional future roads, the future flood risk exposure resulted in a 47% increase in roadway crossings and 55% increase in miles of inundated roadways. Similar to the existing condition exposure analysis, bridge deck height was not considered in the future condition exposure analysis. Larger flood hazard areas resulted in a significant increase in inundated roadway miles.

Agricultural Area

Agricultural area in the planning region was also evaluated to determine future flood exposure. The same area classified as agricultural in the existing exposure analysis was used in the future flood risk exposure analysis. Without altering the agricultural land dataset, the future flood risk exposure resulted in a 38% increase in agricultural land in future conditions.

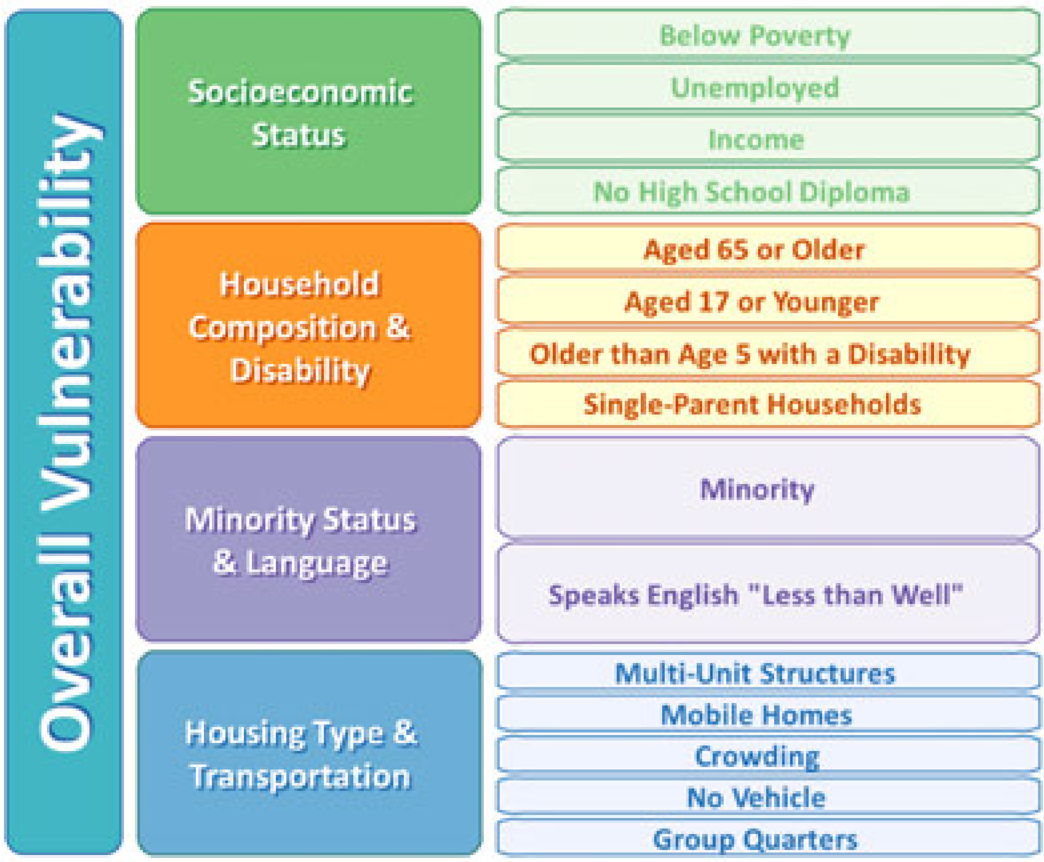
2B.2.d. Flood Prone Areas

Flood prone areas were not changed between existing and proposed conditions. These areas were created by residents and the public using the online dashboard; therefore, future conditions flood prone areas cannot be known at this time.

2.B.3. Future Condition Vulnerability Analysis

Vulnerability is an assessment of the potential negative impact of the flood hazard to communities and a description of the impacts. This task uses the data from the existing flood exposure analysis to determine the vulnerability of exposed structure and population to flooding. The existing condition vulnerability analysis uses the same data as the future vulnerability analysis. The analysis also utilizes the 2018 Social Vulnerability Index (SVI) data developed by the U.S. Centers for Disease Control and Prevention (CDC). The CDC calculates the SVI at the census tract level within a specified county using 15 sociable factors such as poverty, housing, ethnicity, and vehicle access. The CDC groups these factors into four related themes: Socioeconomic Status, Household Composition, Race/Ethnicity/Language, and Housing/Transportation. Table 14 shows the CDC themes used for SVI calculation. Each census tract receives a separate ranking for each of the four themes, as well as an overall ranking.

Table 14: Graphic for CDC Themes



2.B.3.a. Resiliency of Communities

A community's Social Vulnerability score is proportional to a community's risk. Social vulnerability is a consequence enhancing risk component and community risk factor that represents the susceptibility of social groups to the adverse effects of natural hazards like floods, including disproportionate death, injury, loss, or disruption of livelihood. An SVI score and rating represent the relative level of a community's social vulnerability compared to all other communities, with a higher SVI score resulting in a higher Risk Index score.

2.B.3.b. Vulnerability of Critical Facilities

Based on the analysis of future conditions flood exposure data, there is a large increase in critical facilities vulnerable to flooding during the 1% and 0.2% annual chance exceedance storms. In order to protect critical facilities and other infrastructure from flooding in future storm events, mitigation and protection measures should be taken in advance to reduce risk of functionality during future storm events.

2.B.4. Summary of Exposure & Vulnerability Analyses

The future floodplain adds 63% more structures and 65% more people potentially impacted than existing conditions while just adding 40% of more land area. As mentioned previously, no additional structures or population were accounted for under future conditions to reflect future development or population growth. Actual future flood risk would be higher when considering new structures that would be constructed and changes in population, which would increase flood risk beyond just the expansion of flood hazard areas under a future condition scenario.

The future flood risk, exposure, and vulnerability assessment for the San Jacinto Region are summarized in TWDB-required Table 5 located in Appendix 2B-6, providing the results per county of the future flood exposure and vulnerability analysis as outlined in the Technical Guidelines for Regional Flood Planning.

A geodatabase with applicable layers as well as associated TWDB required Maps 8 through 12 are provided in Appendix 2B-2 through Appendix 2B-5 as digital data. Table 15 below outlines the geodatabase deliverables included in this Technical Memorandum as well as spatial files and tables. These deliverables align with the TWDB's Exhibit D: Data Submittal Guidelines for Regional Flood Planning.

Table 15: Task 2B Geodatabase Layers and Tables

Item Name	Description	Feature Class Name	Data Format (Polygon/Line/ Point/GDB Table)
Future Flood Hazard	Perform future condition flood hazard analyses to determine the location and magnitude of both 1.0% annual chance and 0.2% annual chance flood events	FutFldHazard	Polygon
Future Exposure	Develop high-level, region-wide, and largely GIS-based future condition flood exposure analyses using the information identified in the flood hazard analysis to identify who and what might be harmed within the region for, at a minimum, both 1.0% annual chance and 0.2% annual chance flood events	FutFldExpPol	Polygon
	Develop high-level, region-wide, and largely GIS-based future condition flood exposure analyses using the information identified in the flood hazard analysis to identify who and what might be harmed within the region for, at a minimum, both 1.0% annual chance and 0.2% annual chance flood events	FutFldExpLn	Polyline
	Develop high-level, region-wide, and largely GIS-based Future condition flood exposure analyses using the information identified in the flood hazard analysis to identify who and what might be harmed within the region for, at a minimum, both 1.0% annual chance and 0.2% annual chance flood events	FutFldExpPt	Point
	Combines the Exposure Poly, Line, and Point data into a single master layer, also includes Vulnerability data	FutFldExpAll	Point

APPENDIX 2A-1
MAP 4: EXISTING CONDITION FLOOD HAZARD

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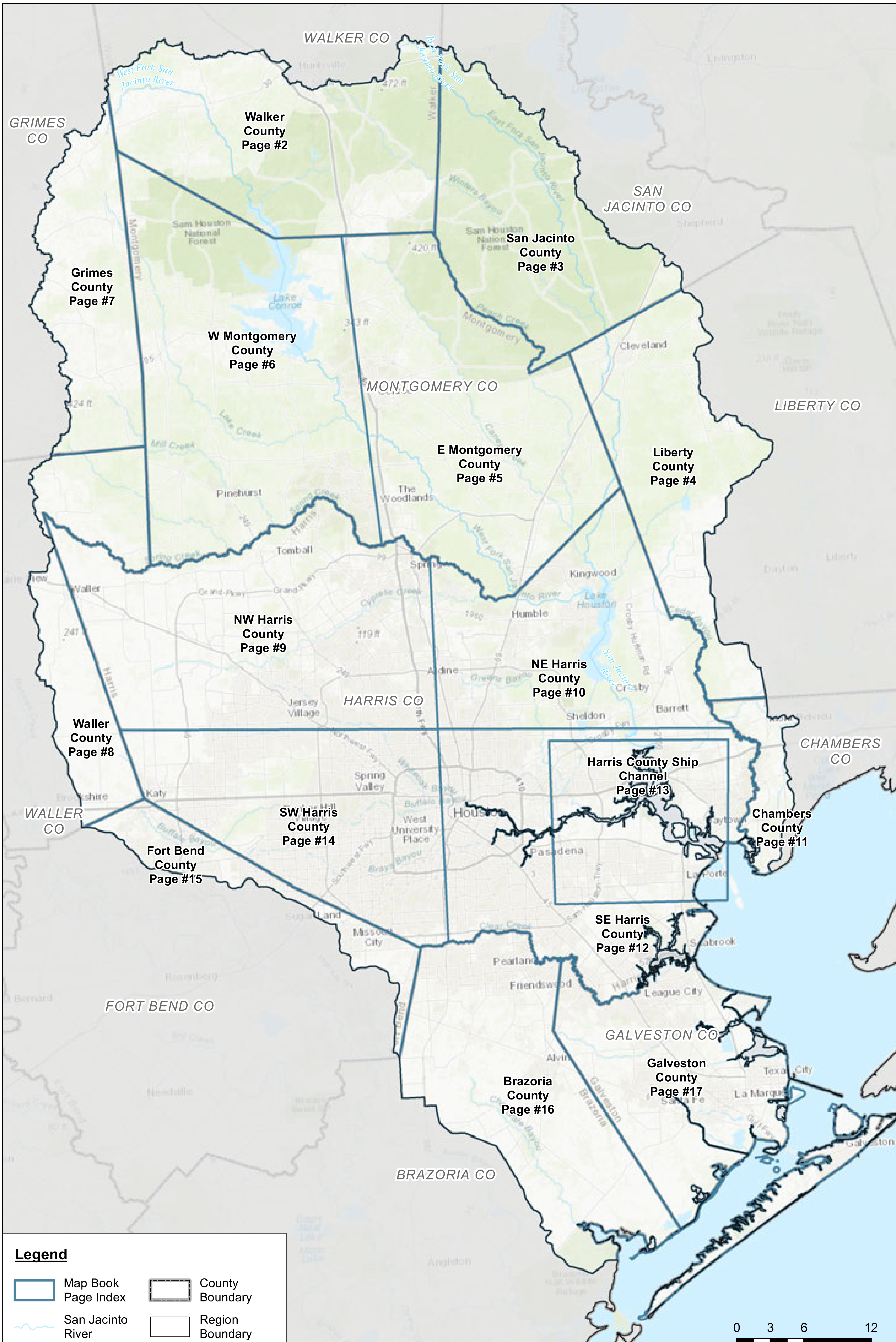
SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

Existing Condition Flood Hazard

MAP 4
Overview

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

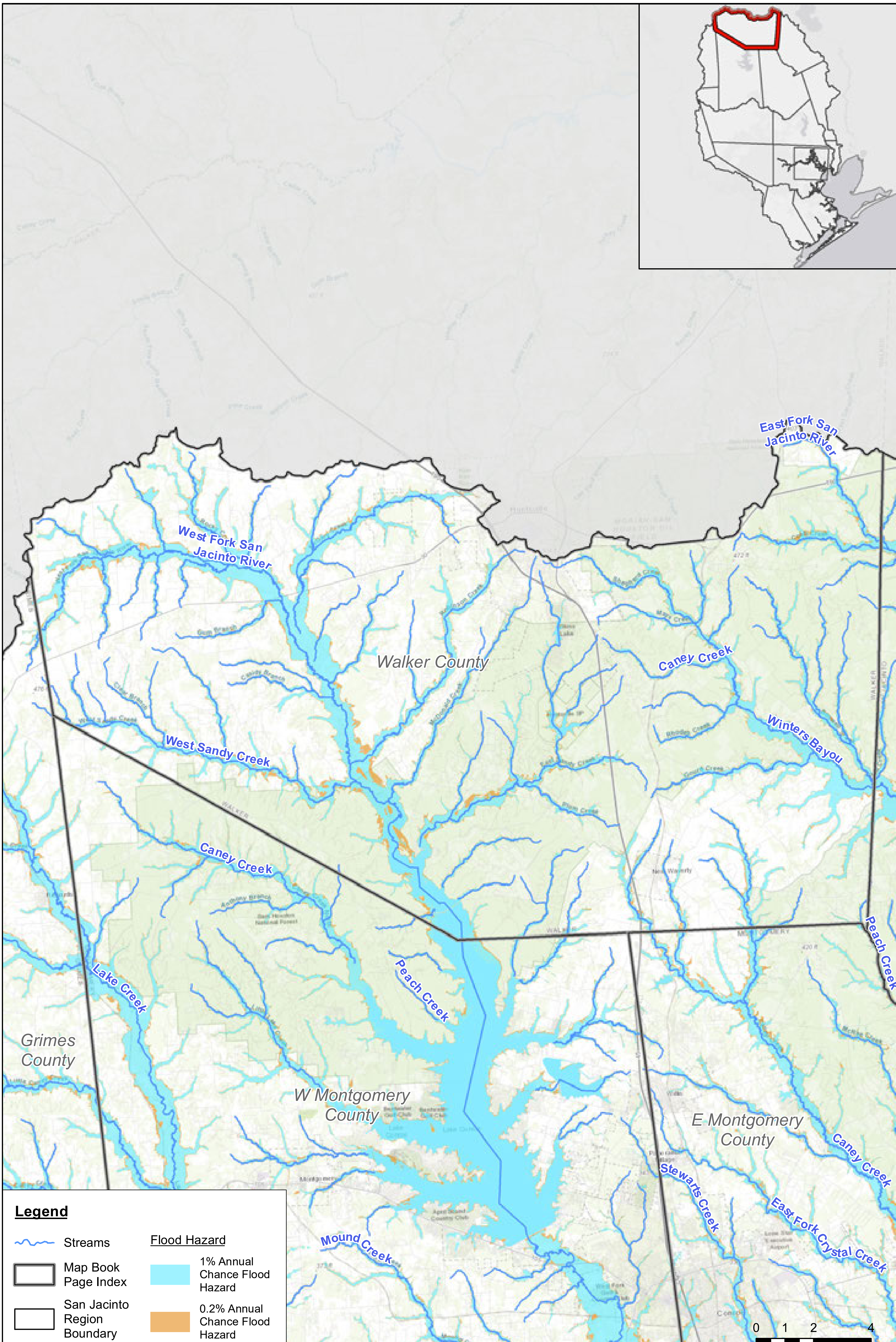
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard Index

MAP 4

FIGURE 1 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

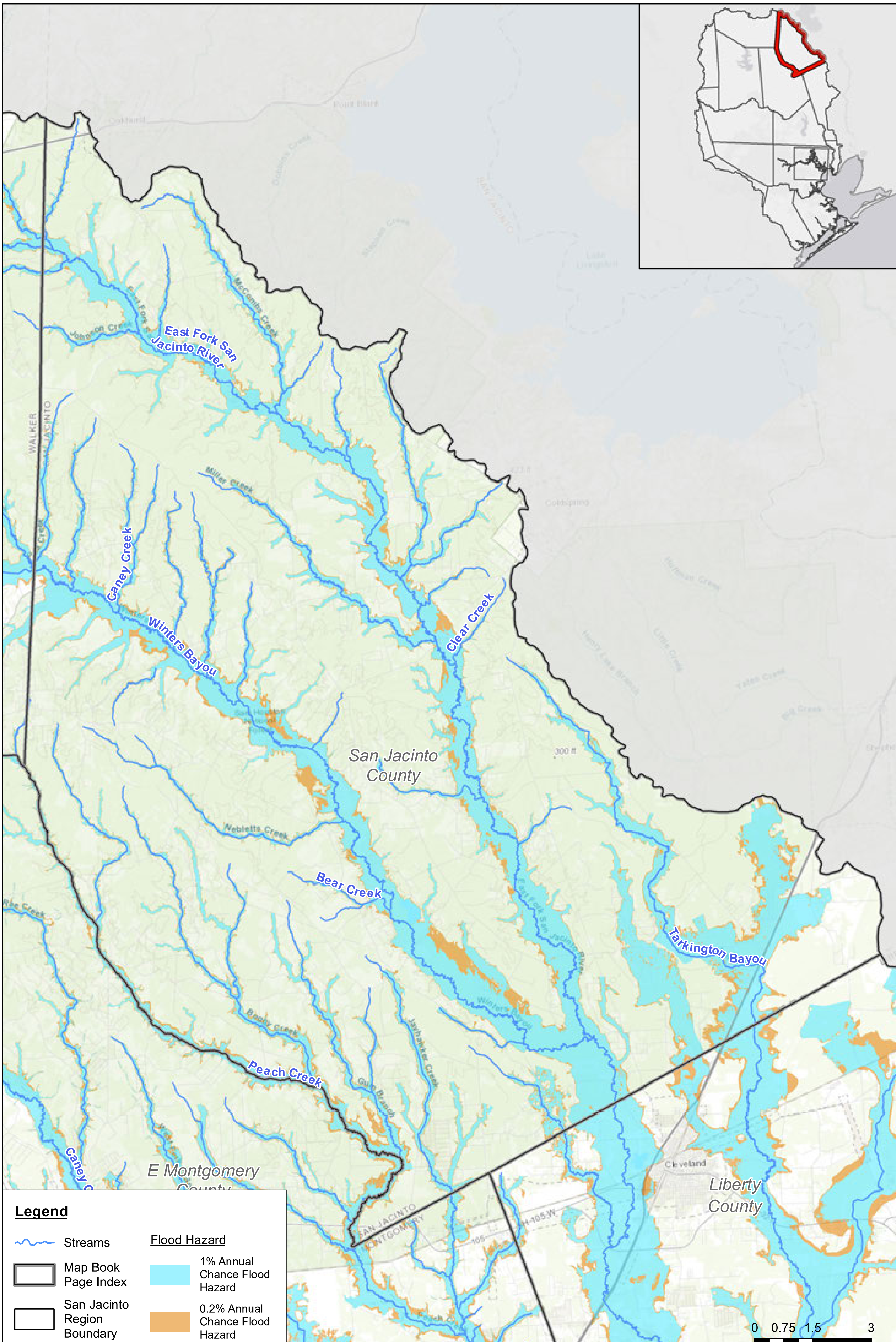
Existing Condition Flood Hazard - Walker

N W E S

MAP 4

FIGURE 2 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

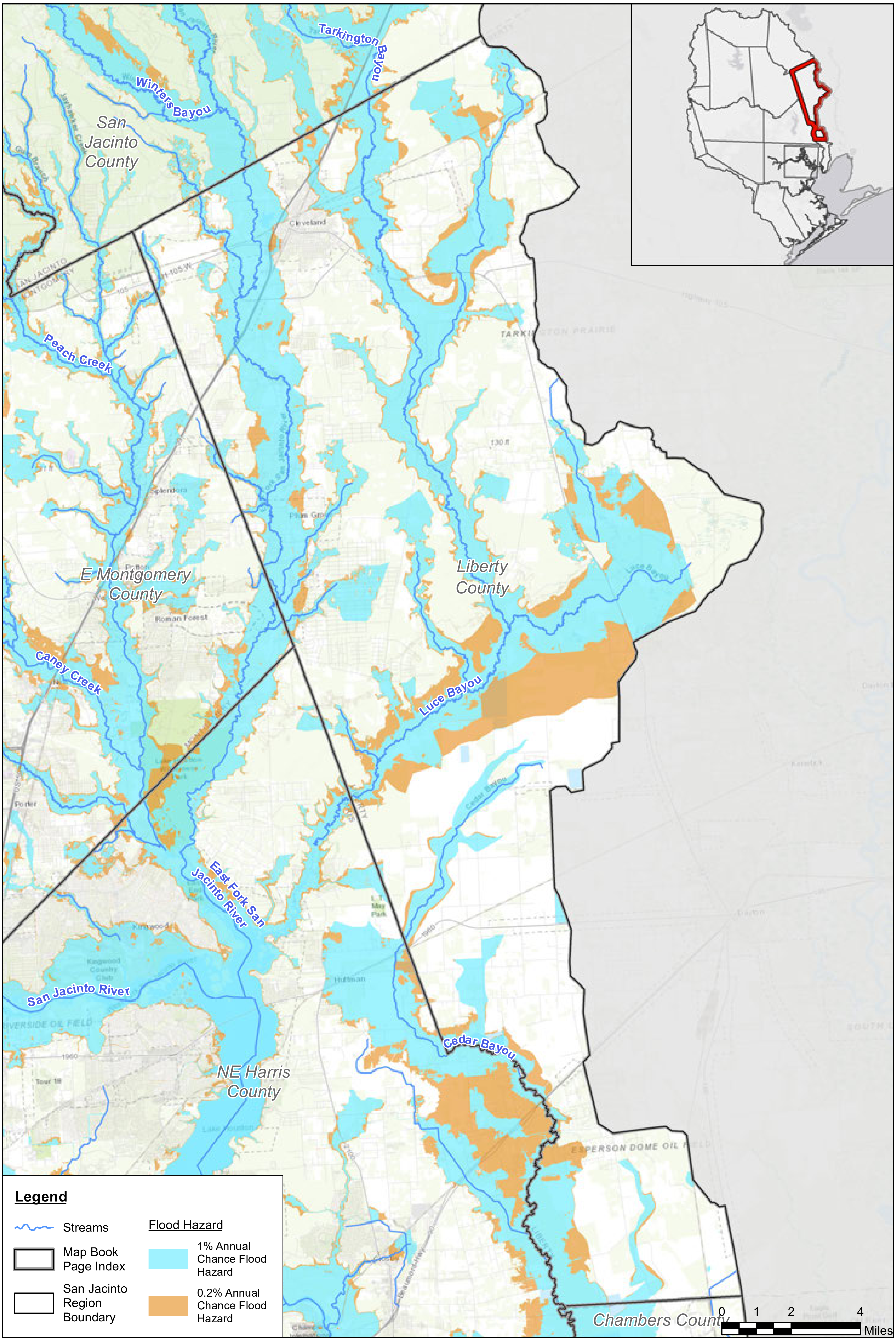
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - San Jacinto

MAP 4

FIGURE 3 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

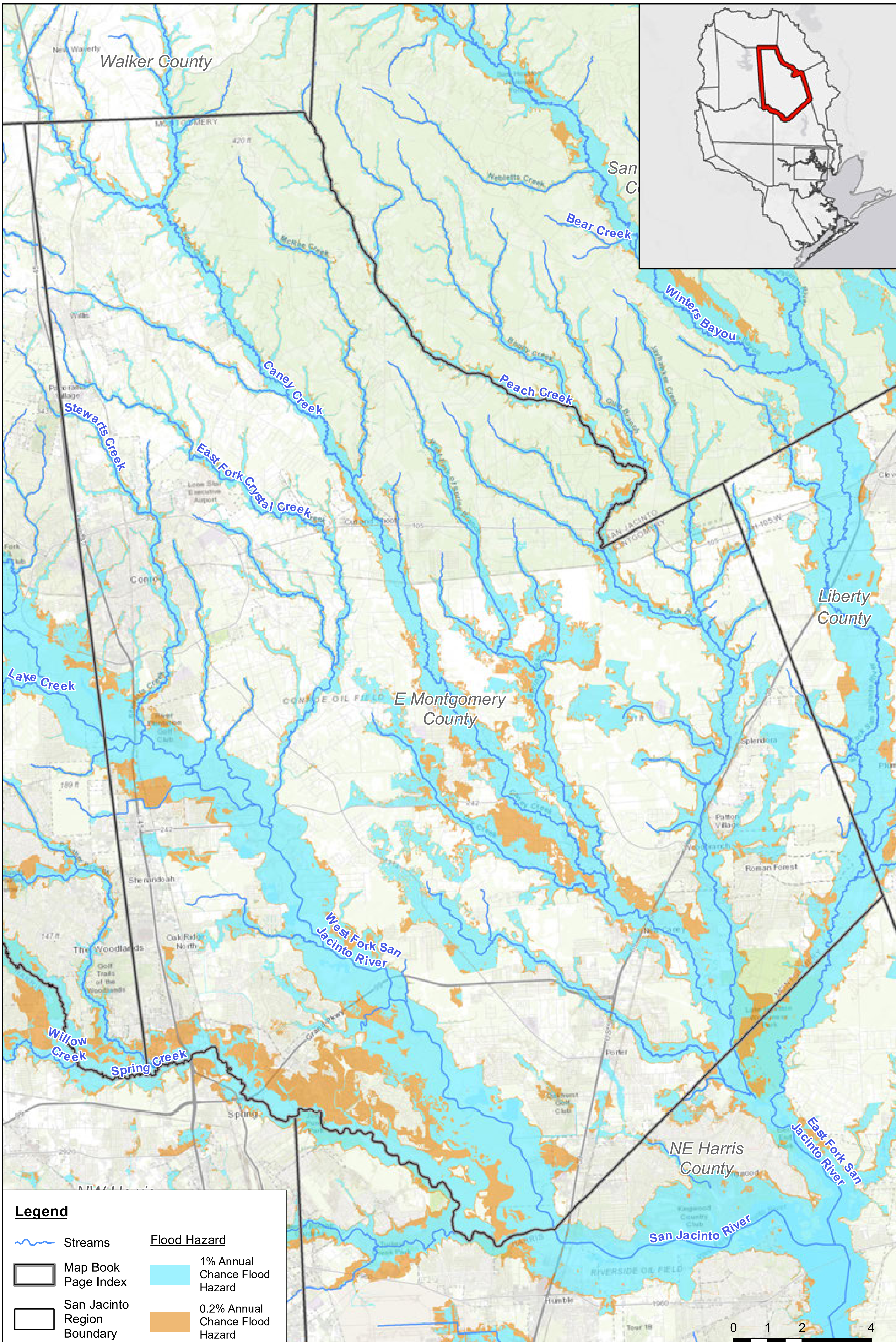
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - Liberty

MAP 4

FIGURE 4 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



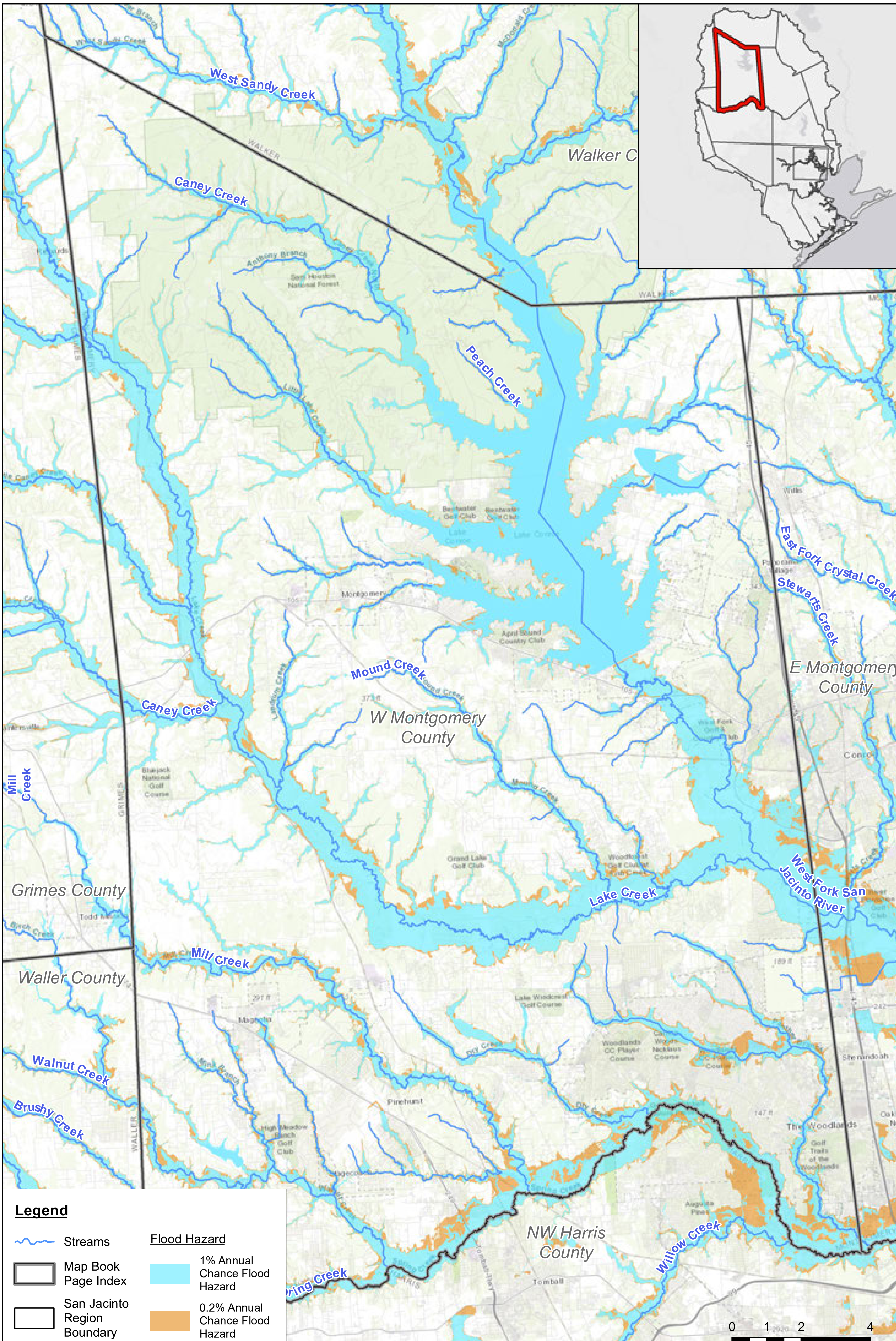
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - E Montgomery

MAP 4

FIGURE 5 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

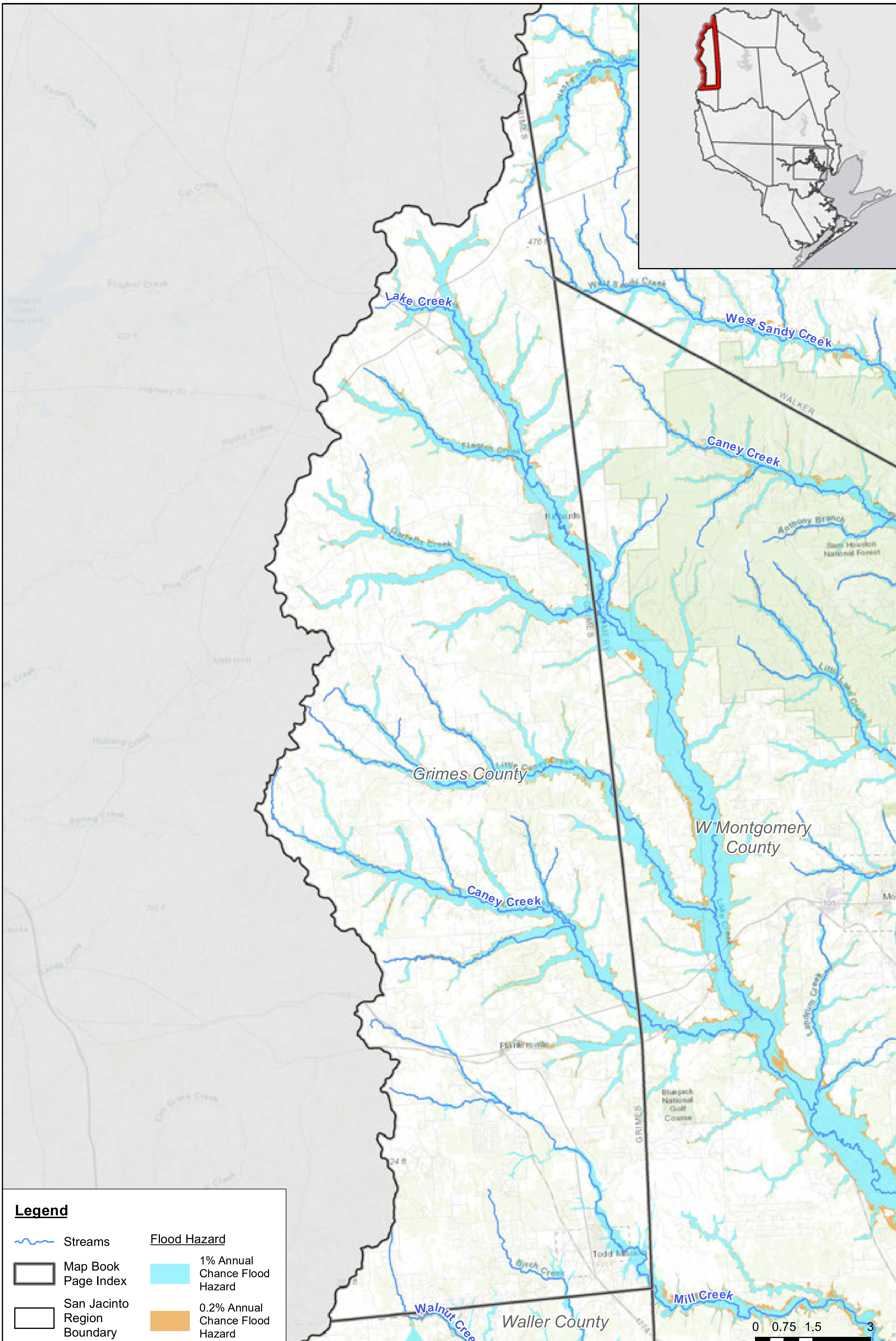
Existing Condition Flood Hazard - W Montgomery

N W E S

MAP 4

FIGURE 6 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

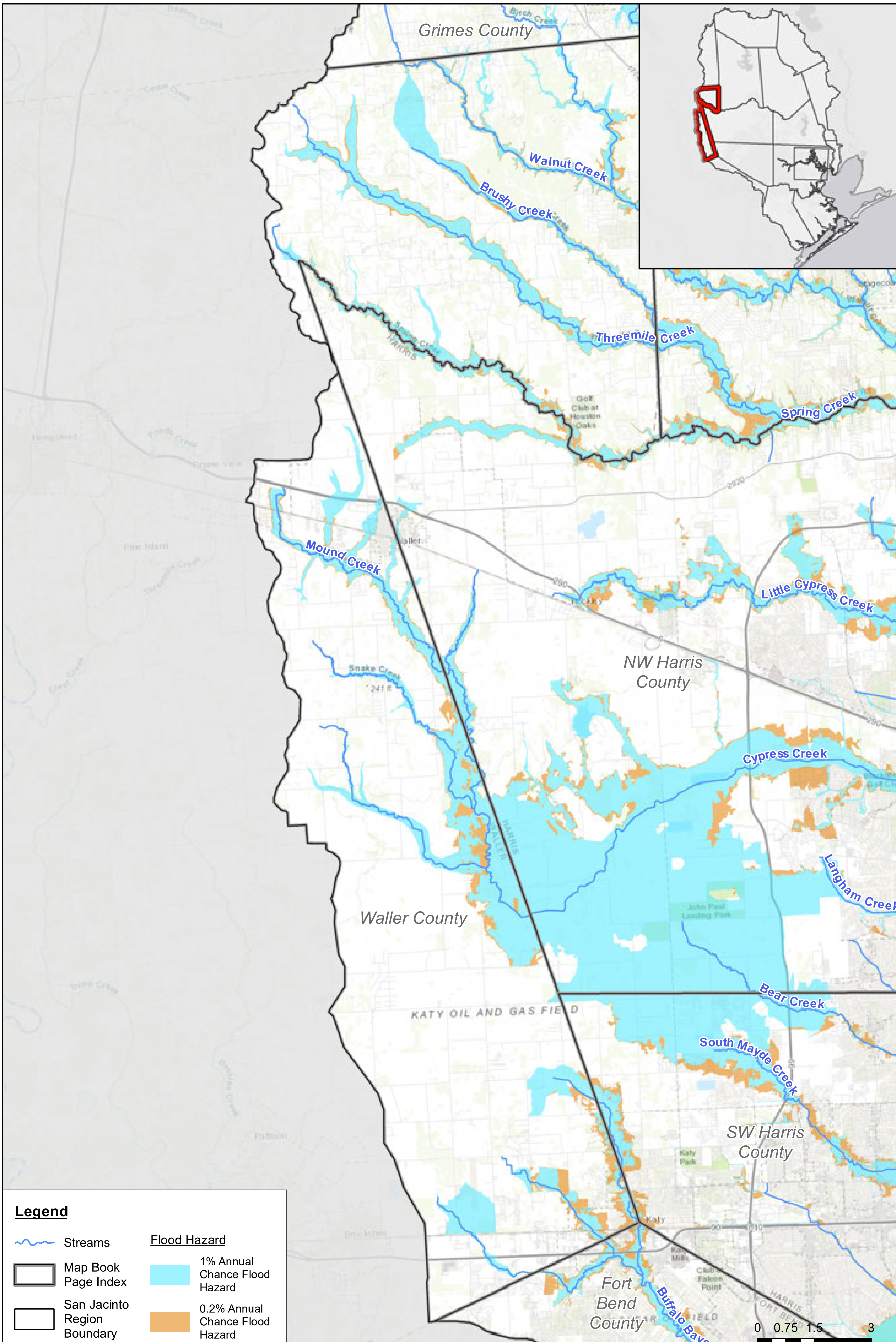
Existing Condition Flood Hazard - Grimes

N W E S

MAP 4

FIGURE 7 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

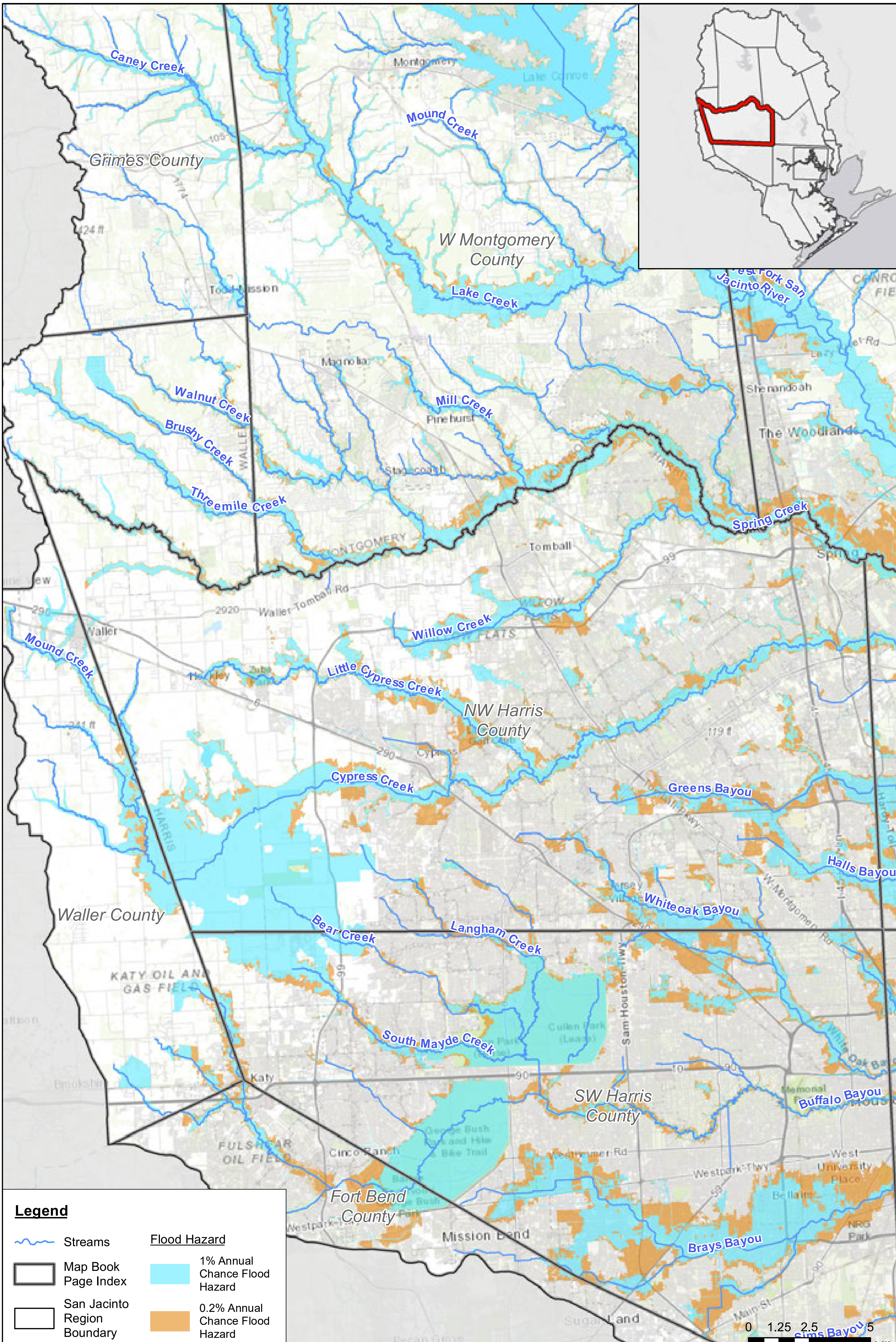
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - Waller

N
W E
S

MAP
4
FIGURE
8 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

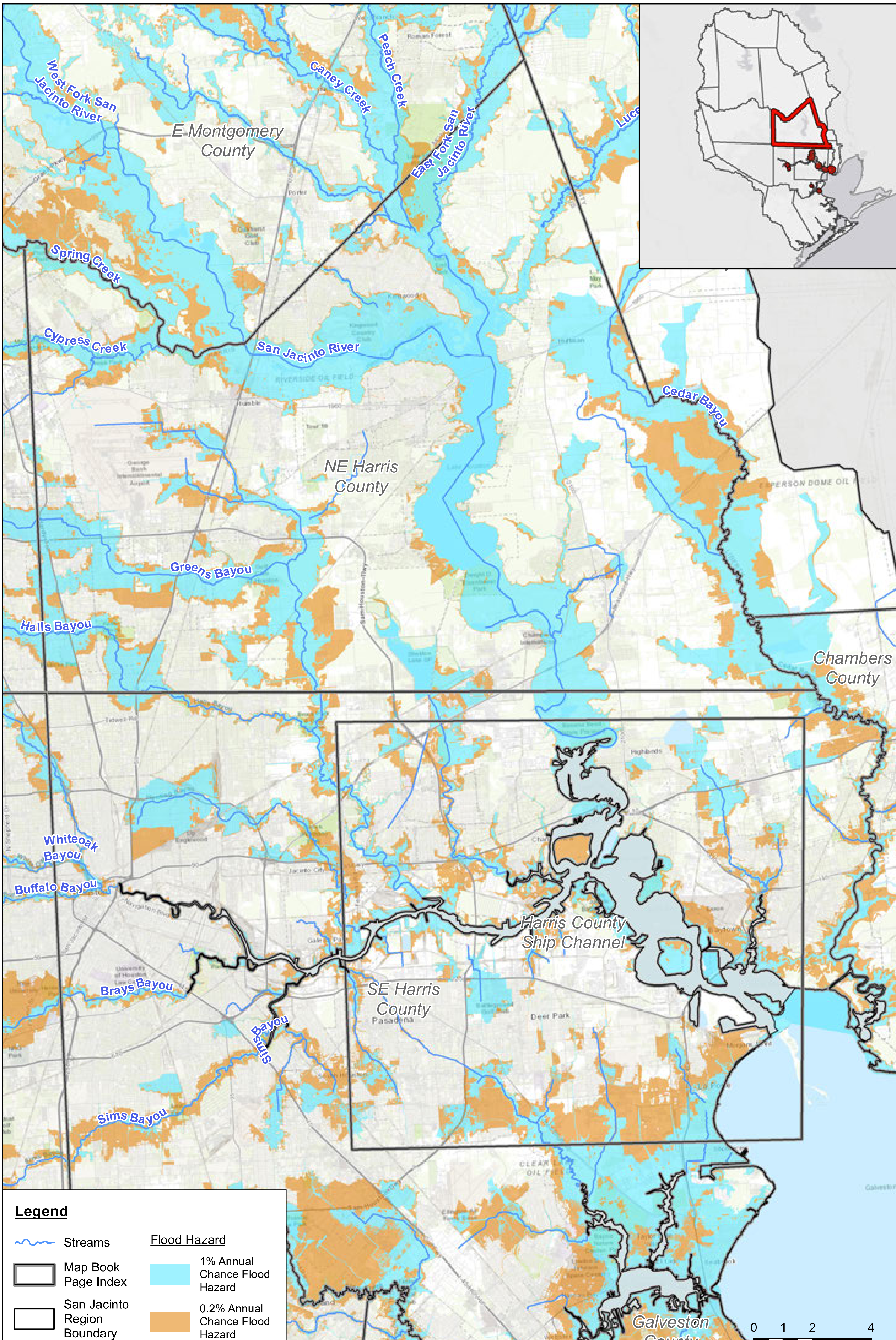
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - NW Harris

MAP 4

FIGURE 9 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

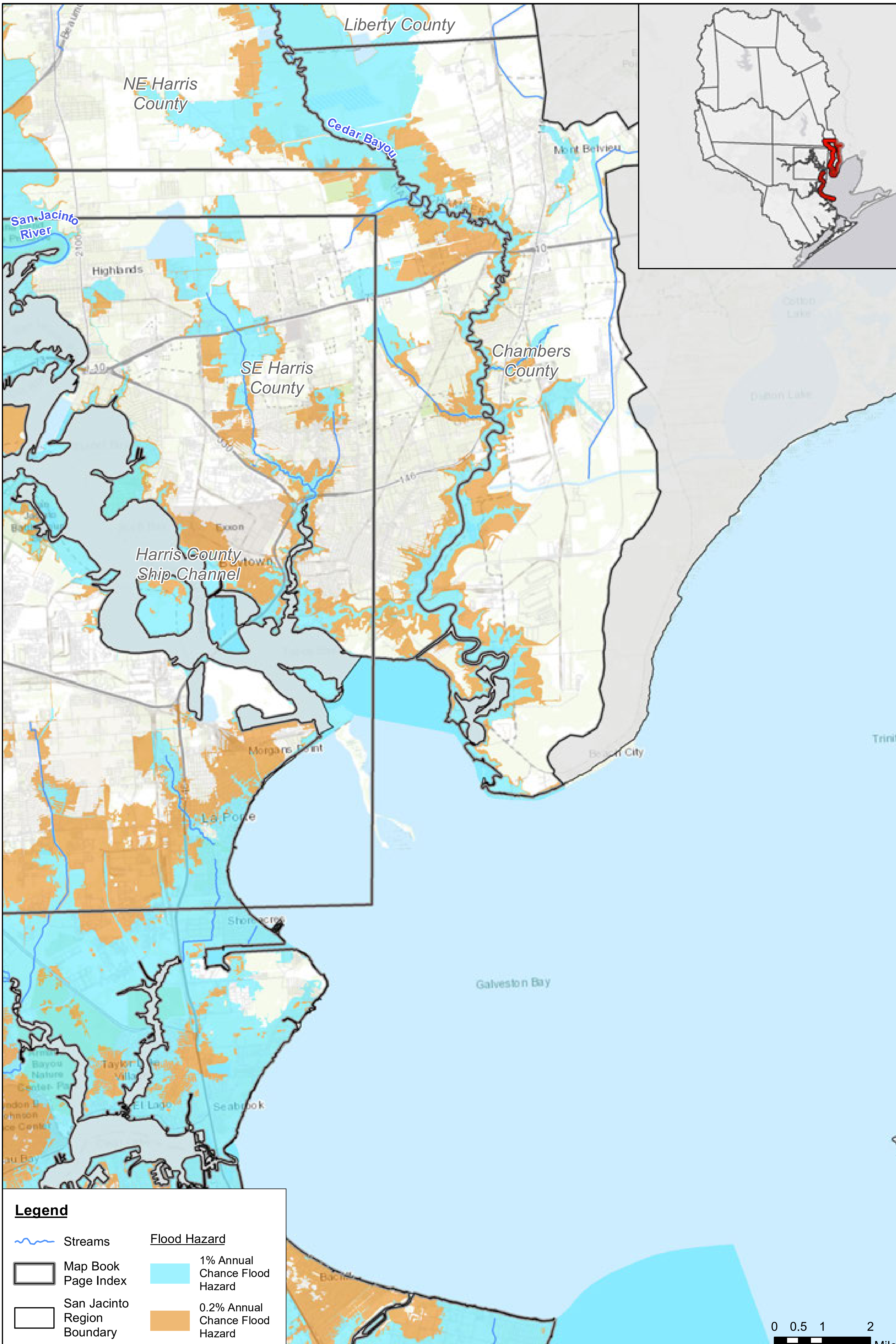
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - NE Harris

MAP 4

FIGURE 10 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

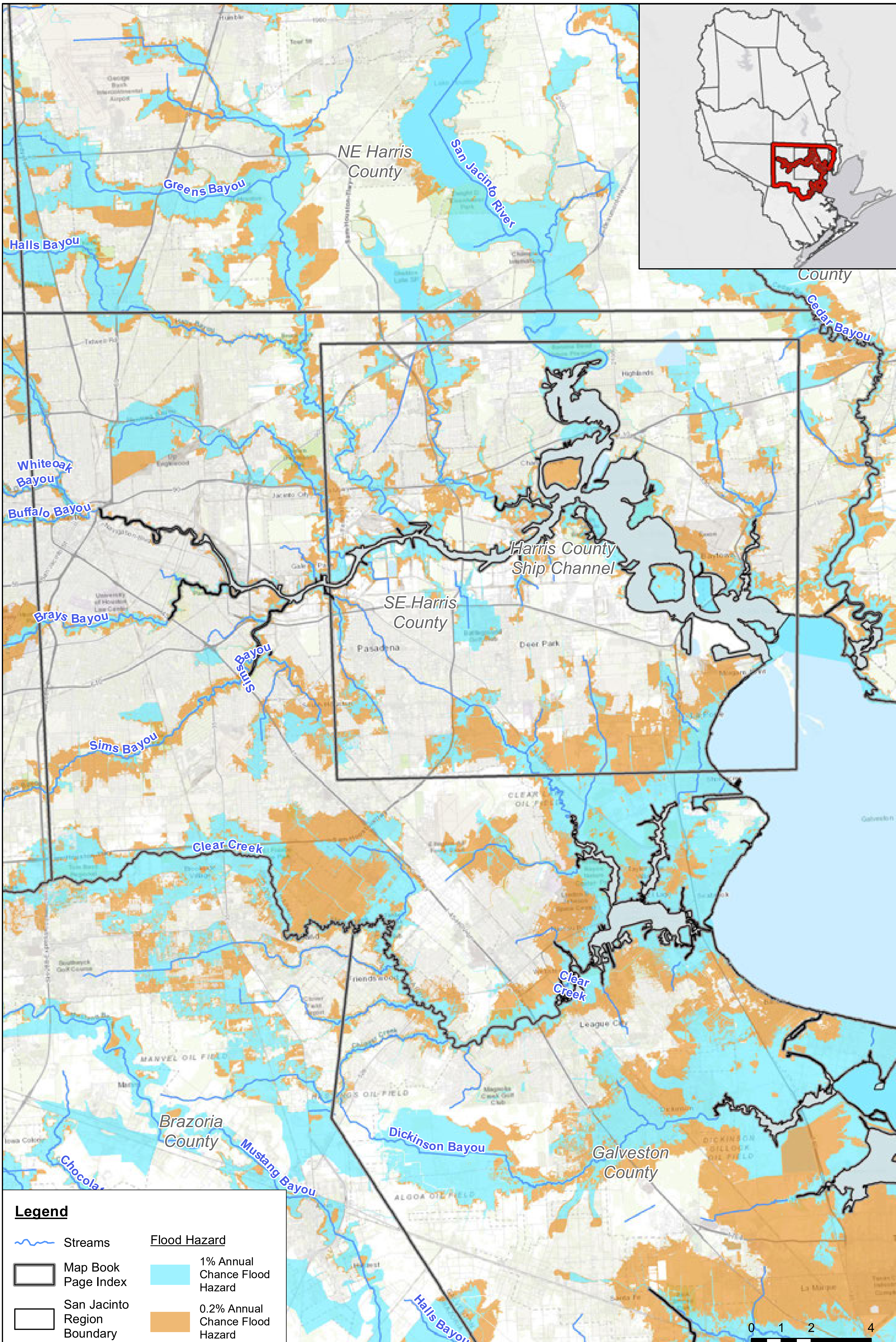
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - Chambers

MAP 4

FIGURE 11 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

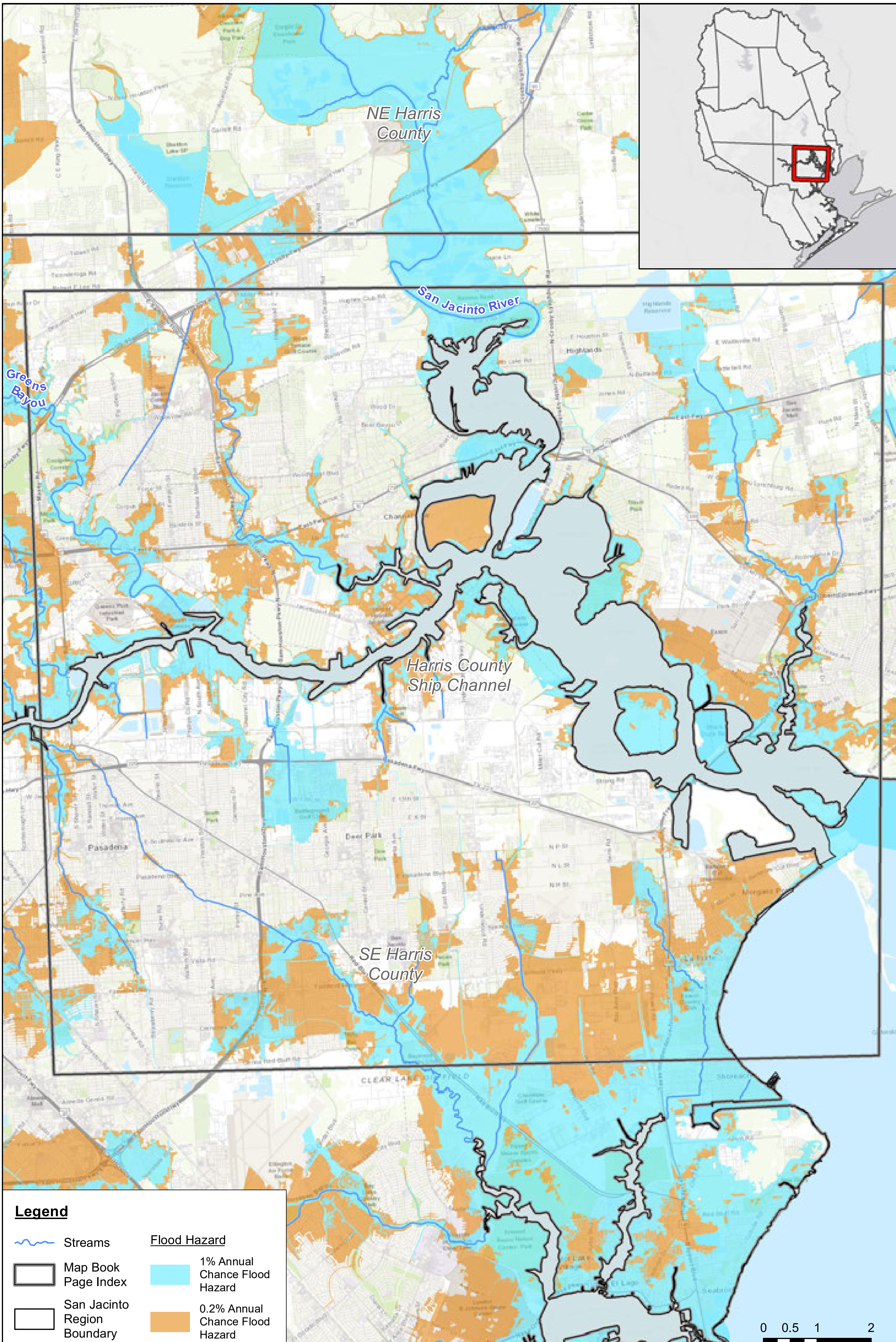
Existing Condition Flood Hazard - SE Harris

N
W E
S

MAP 4

FIGURE 12 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

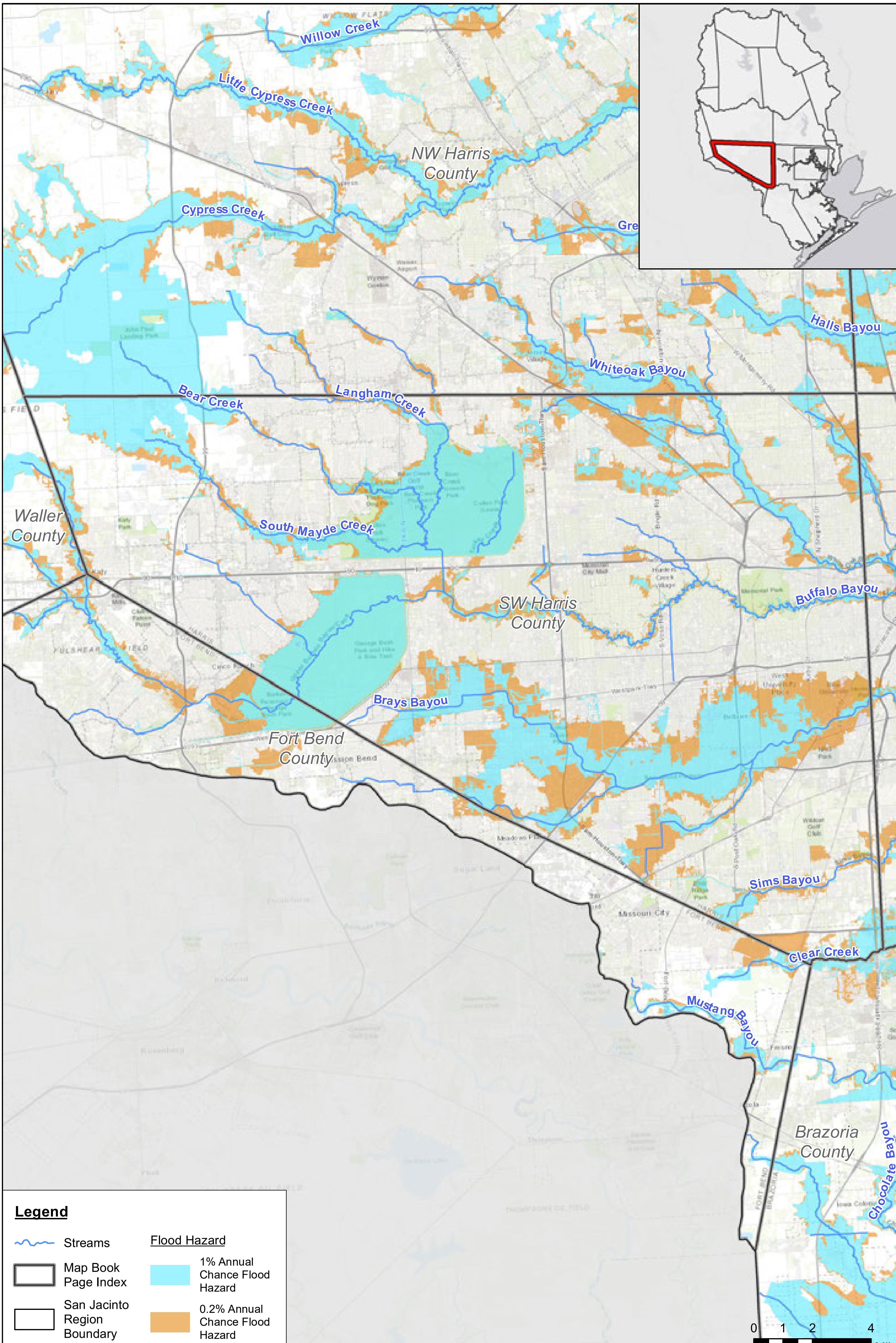
Existing Condition Flood Hazard - Ship Channel

N W E S

MAP 4

FIGURE 13 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



San Jacinto Regional Flood Plan

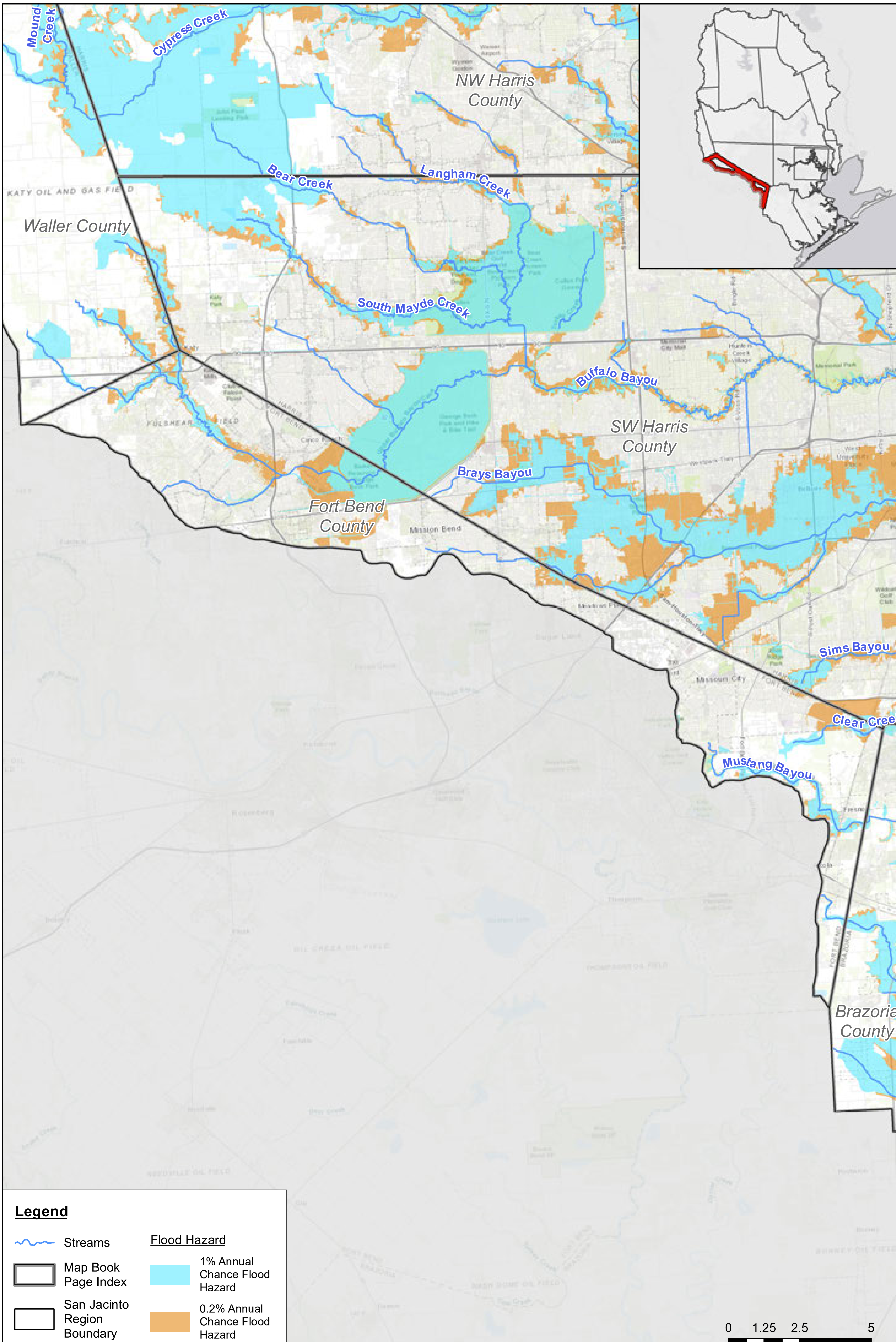
Existing Condition Flood Hazard - SW Harris

SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

MAP 4

FIGURE 14 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

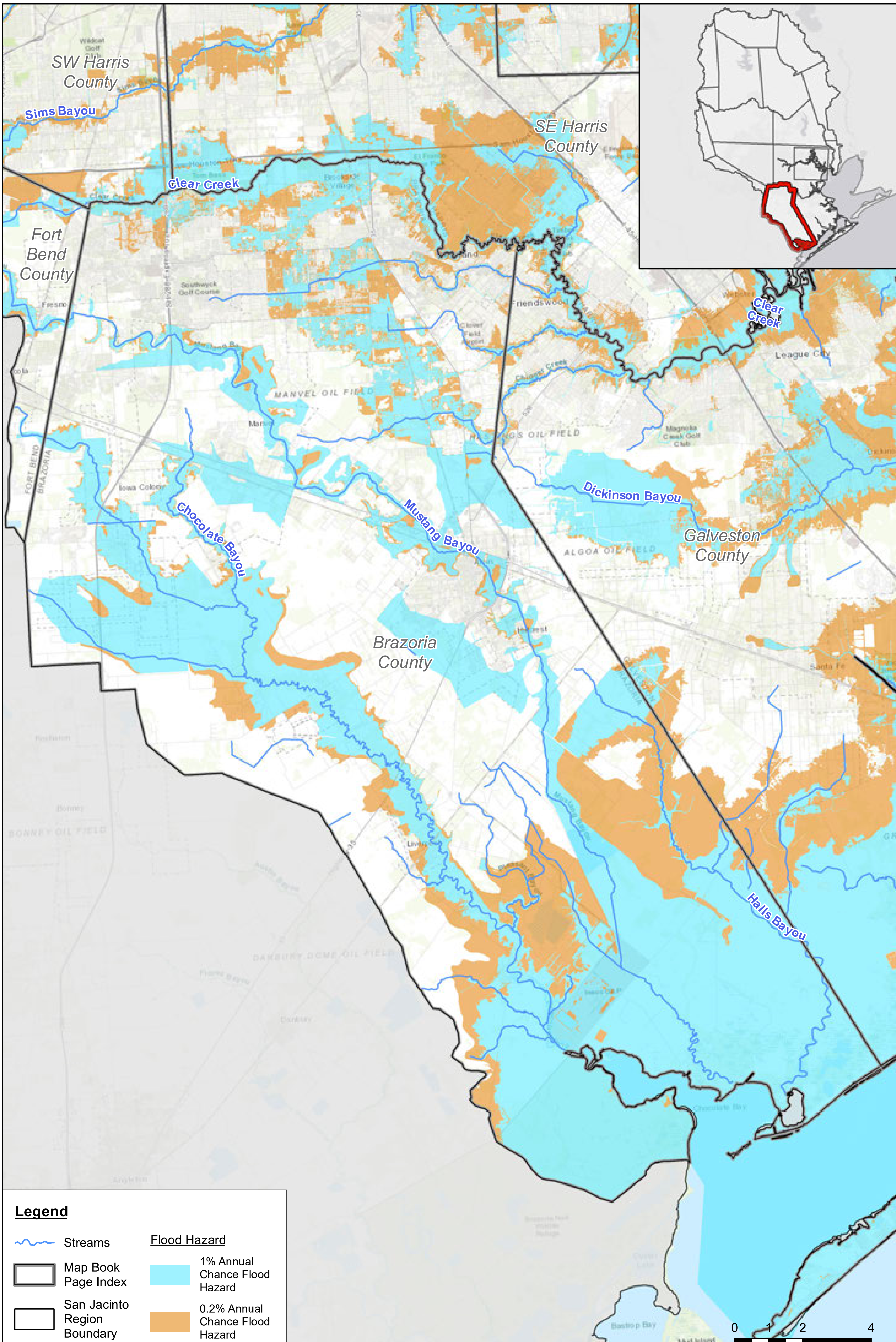
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - Fort Bend

MAP 4

FIGURE 15 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

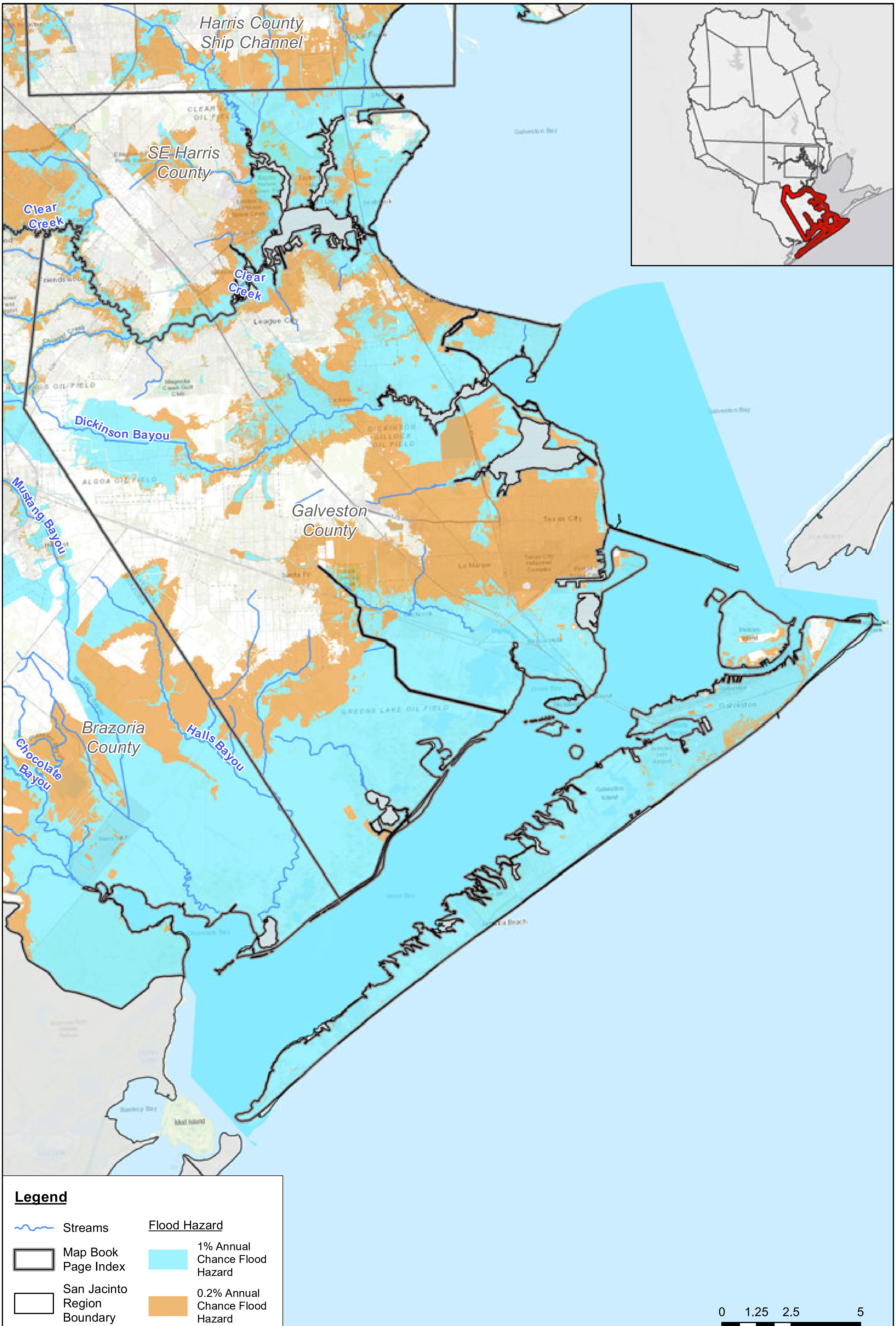
San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - Brazoria

MAP 4

FIGURE 16 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

San Jacinto Regional Flood Plan

Existing Condition Flood Hazard - Galveston

MAP 4

FIGURE 17 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert

APPENDIX 2A-2
MAP 5: GAPS IN INUNDATION MAPPING AND FLOOD-PRONE AREAS

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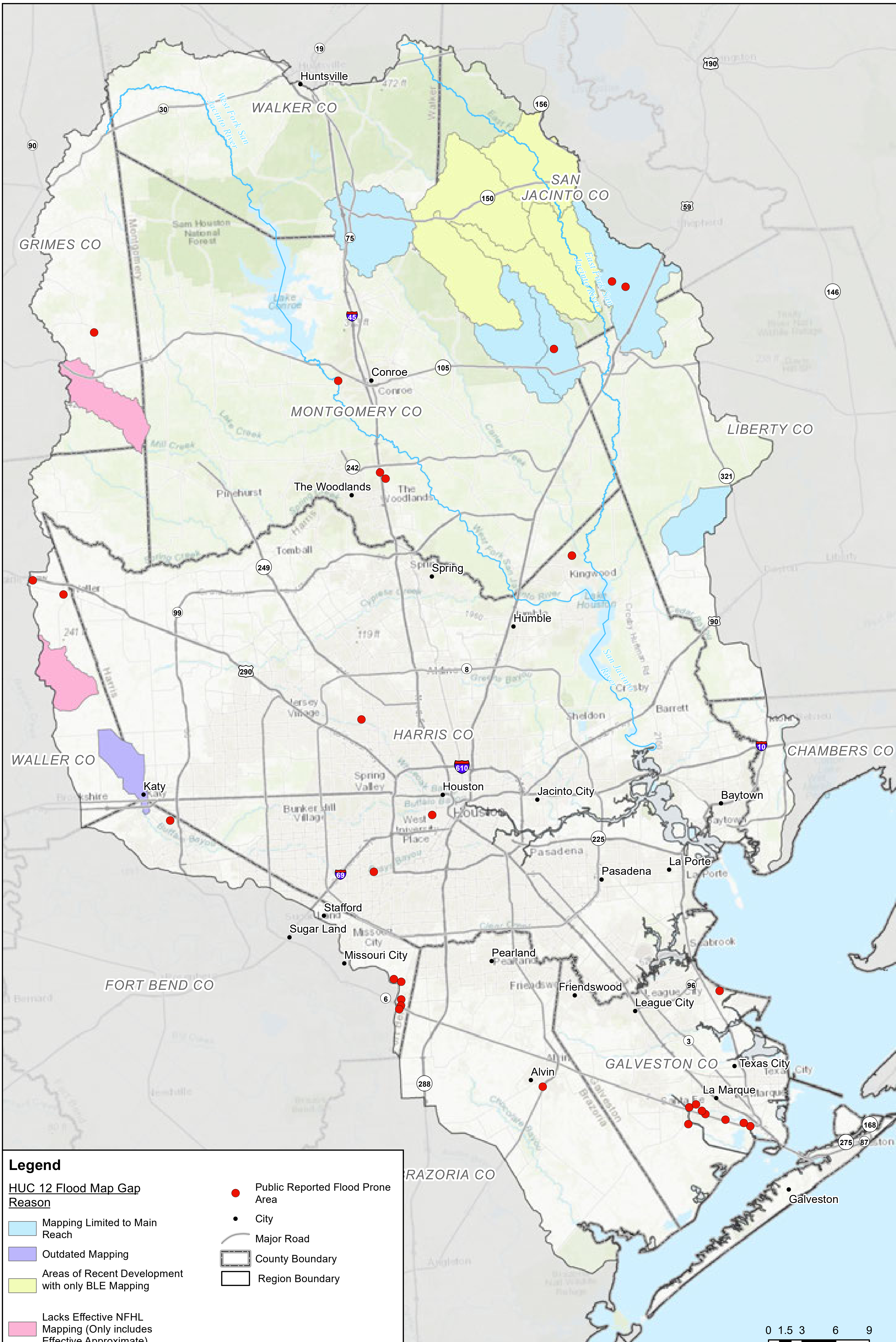

San Jacinto Regional Flood Plan

Flood Map Gaps & Flood Prone Areas

MAP 5

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert

APPENDIX 2A-3
MAP 6: EXISTING CONDITION FLOOD EXPOSURE

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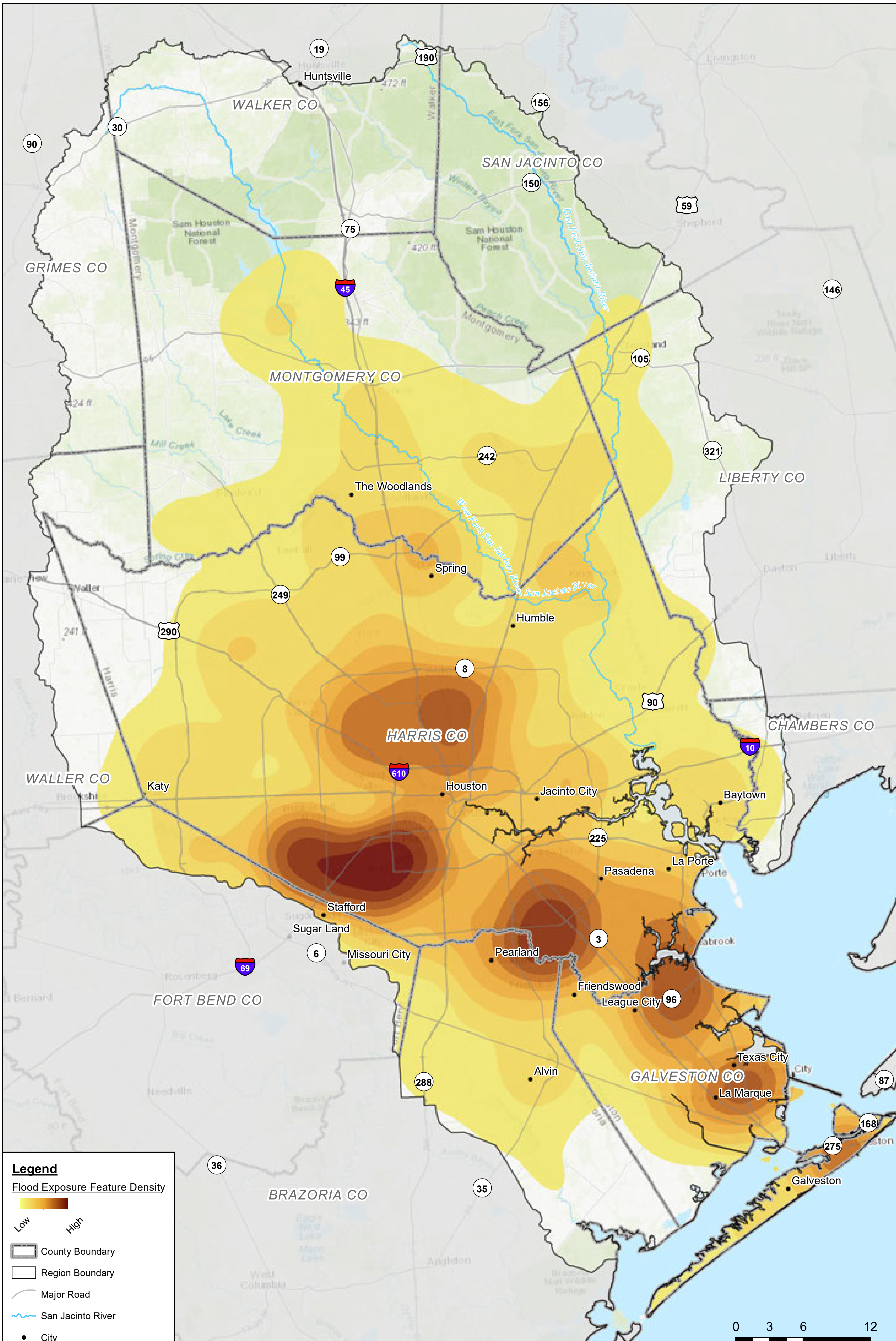

San Jacinto Regional Flood Plan

Existing Flood Infrastructure

MAP 6

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert

APPENDIX 2A-4

MAP 7: EXISTING CONDITION VULNERABILITY AND CRITICAL INFRASTRUCTURE

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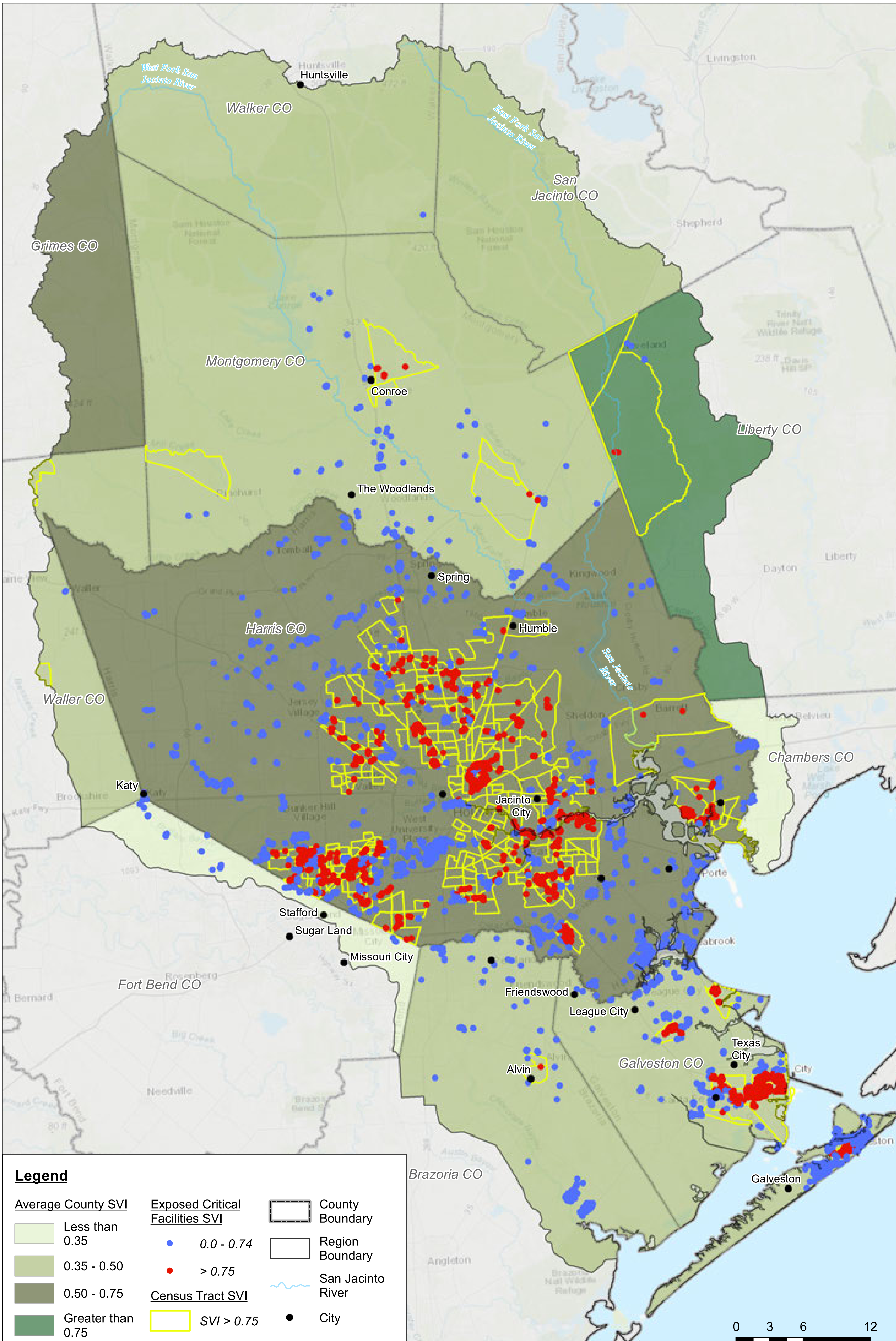

San Jacinto Regional Flood Plan

Existing Condition Vulnerability and Critical Infrastructure

MAP 7

SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert

APPENDIX 2A-5
TABLE: EXISTING HYDROLOGIC AND HYDRAULIC MODELS

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Appendix 2A-5: Available Hydrologic and Hydraulic Models

Model Name	Date Available
Dickinson Bayou Model	2021
Clear Creek Model	2021
Addick's Reservoir Model	2021
Carpenters Bayou Model	2021
Buffalo Bayou Model	2021
Barker Reservoir Model	2021
Hunting Bayou Model	2021
Sims Bayou Model	2021
White Oak Bayou Model	2021
Cypress Creek Model	2021
Spring Creek Model	2021
Willow Creek Model	2021
Luce Bayou Model	2021
Cedar Bayou Model	2021
Brays Bayou Model	2021
Clear Creek Model	2021
Vince Bayou Model	2021
Armand Bayou Model	2021
Little Cypress Creek Model	2021
Jackson Bayou Model	2021
San Jacinto River Model	2021
Greens Bayou Model	2021
Spring Gully & Goose Creek Model	2021
San Jacinto & Galveston Bay Model	2021
Crystal Creek-West Fork San Jacinto River	2022
Frontal Lake Houston	2022
Little Cypress Creek-Cypress Creek	2022
Walnut Creek-Spring Creek	2022
Peach Creek-Caney Creek	2022
Tarkington Bayou-Luce Bayou	2022
East Fork San Jacinto River-Frontal Lake Houston	2022
West Fork San Jacinto River-Conroe Lake	2022
Caney Creek-Lake Creek	2022
Winters Bayou-East Fork San Jacinto River	2022
Oyster Creek	2022
Chocolate Bayou	2022
CH100	2022
League City Channel Analysis	2022
BMW	2022
Prairie Estates	2022
Lake Houston Dam Spillway	2022

APPENDIX 2A-6
TABLE: EXPECTED LOSS OF FUNCTION SUMMARY

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Appendix 2A-6: Expected Loss of Function Summary

County	Residential Structures in 1% AEP Flood Plain	Non-Residential Structures in 1% AEP Flood Plain	Low Water Crossings in 1% AEP Flood Plain	Health and Human Services in 1% AEP Flood Plain	Water Wells in 1% AEP Flood Plain	Wastewater Outfalls in Flood 1% AEP Plain	Power Plants in 1% AEP Flood Plain	Fire Stations in 1% AEP Flood Plain	Emergency Shelters in 1% AEP Flood Plain
Brazoria	14,341	4,493	0	4	4	35	1	2	2
Chambers	54	93	1	0	0	15	0	0	0
Fort Bend	1,208	330	7	0	0	19	0	0	0
Galveston	42,141	6,355	30	8	3	53	1	10	7
Grimes	76	68	1	0	0	1	0	0	0
Harris	120,800	22,803	90	46	46	548	6	22	25
Liberty	2,273	1,344	7	0	0	7	0	1	1
Montgomery	16,927	4,256	81	3	1	128	0	4	3
San Jacinto	939	95	1	0	2	0	0	0	0
Walker	430	69	2	0	0	4	0	0	0
Waller	703	357	19	1	0	8	0	0	0
Total	199,892	40,263	239	62	56	818	8	39	38

APPENDIX 2A-7
TABLE 3: EXISTING CONDITIONS FLOOD EXPOSURE SUMMARY TABLE

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Appendix 2A-7: Table 3 - Existing Condition Flood Risk Summary Table

1% Annual Chance Flood Risk

	RFPG No.	RFPG Name	County	Area in Flood Planning Region (sqmi)	Area in Floodplain (sqmi)	Number of Structures in Floodplain	Residential Structures in Floodplain	Population (daytime)	Population (nighttime)	Population	Roadway Stream Crossings (#)	Roadways Segments (miles)	Agricultural Areas (sqmi)	Critical Facilities (#)
1	6	San Jacinto	Brazoria	368	179	18,848	14,344	38,626	35,449	38,626	360	328	13	248
2	6	San Jacinto	Chambers	54	11	150	56	714	126	714	14	7	1	0
3	6	San Jacinto	Fort Bend	98	10	1,537	1,207	3,165	3,408	3,408	67	18	0	11
4	6	San Jacinto	Galveston	350	308	48,560	42,179	99,949	102,716	102,716	322	910	5	681
5	6	San Jacinto	Grimes	206	25	145	76	50	95	95	83	11	0	0
6	6	San Jacinto	Harris	1,774	444	143,623	120,793	590,903	545,459	590,903	2,074	2,408	9	2,331
7	6	San Jacinto	Liberty	286	84	3,617	2,271	2,545	3,573	3,573	147	144	2	8
8	6	San Jacinto	Montgomery	1,077	267	21,181	16,919	37,827	42,126	42,126	784	409	1	125
9	6	San Jacinto	San Jacinto	319	67	1,027	933	580	1,376	1,376	122	48	0	0
10	6	San Jacinto	Walker	396	61	505	437	266	545	545	177	25	0	1
11	6	San Jacinto	Waller	194	28	1,061	703	1,145	1,829	1,829	107	41	2	6
Total				**5,123**	**1,484**	**240,254**	**199,918**	**775,770**	**736,702**	**785,911**	**4,257**	**4,350**	**35**	**3,411**

0.2% Annual Chance Flood Risk

	RFPG No.	RFPG Name	County	Area in Flood Planning Region (sqmi)	Area in Floodplain (sqmi)	Number of Structures in Floodplain	Residential Structures in Floodplain	Population (daytime)	Population (nighttime)	Population	Roadway Stream Crossings (#)	Roadways Segments (miles)	Agricultural Areas (sqmi)	Critical Facilities (#)
1	6	San Jacinto	Brazoria	368	226	28,898	22,887	59,679	60,858	64,035	433	493	19	445
2	6	San Jacinto	Chambers	54	16	609	270	1,658	753	1,658	17	16	1	15
3	6	San Jacinto	Fort Bend	98	17	10,668	9,882	24,550	34,027	34,027	96	109	0	62
4	6	San Jacinto	Galveston	350	395	97,088	83,539	199,153	220,080	220,080	507	1,617	9	1,858
5	6	San Jacinto	Grimes	206	29	195	88	76	129	129	89	15	0	0
6	6	San Jacinto	Harris	1,774	644	325,957	282,713	1,275,716	1,187,739	1,275,716	2,509	4,635	13	5,448
7	6	San Jacinto	Liberty	286	112	5,279	3,414	3,900	5,831	5,831	160	209	3	10
8	6	San Jacinto	Montgomery	1,077	332	44,663	36,832	75,216	98,823	98,823	952	737	1	245
9	6	San Jacinto	San Jacinto	319	80	1,367	1,236	760	1,796	1,796	135	64	0	0
10	6	San Jacinto	Walker	396	71	739	634	393	831	831	200	35	0	2
11	6	San Jacinto	Waller	194	34	1,751	1,273	1,609	3,000	3,000	110	54	2	6
Total				**5,123**	**1,955**	**517,214**	**442,768**	**1,642,710**	**1,613,867**	**1,705,926**	**5,208**	**7,985**	**51**	**8,091**

Possible Flood Prone Areas

	RFPG No.	RFPG Name	County	Area (sqmi)	Number of Structures in Flood Prone Area	Residential Structures in in Flood Prone Area	Population	Roadway Stream Crossings (#)	Roadways Segments (miles)	Agricultural Areas (sqmi)	Critical Facilities (#)	Average SVI of features in floodplain or flood prone areas
1	6	San Jacinto	Brazoria	-	-	-	-	-	-	-	-	0.36
2	6	San Jacinto	Chambers	-	-	-	-	-	-	-	-	0.22
3	6	San Jacinto	Fort Bend	0.19	126	123	359	0	2	0	0	0.35
4	6	San Jacinto	Galveston	-	-	-	-	-	-	-	-	0.47
5	6	San Jacinto	Grimes	-	-	-	-	-	-	-	-	0.60
6	6	San Jacinto	Harris	0.70	515	473	1,436	1	8	0	1	0.50
7	6	San Jacinto	Liberty	-	-	-	-	-	-	-	-	0.75
8	6	San Jacinto	Montgomery	0	157	136	333	0	4	0	5	0.37
9	6	San Jacinto	San Jacinto	0.07	30	29	78	0	0	0	0	0.49
10	6	San Jacinto	Walker	-	-	-	-	-	-	-	-	0.37
11	6	San Jacinto	Waller	0.03	0	0	0	0	0	0	0	0.40
Total				**1.25**	**828**	**761**	**2,206**	**1**	**14**	**0**	**6**	**-**

APPENDIX 2A-8
EXISTING CONDITIONS FLOOD SUMMARY TABLES

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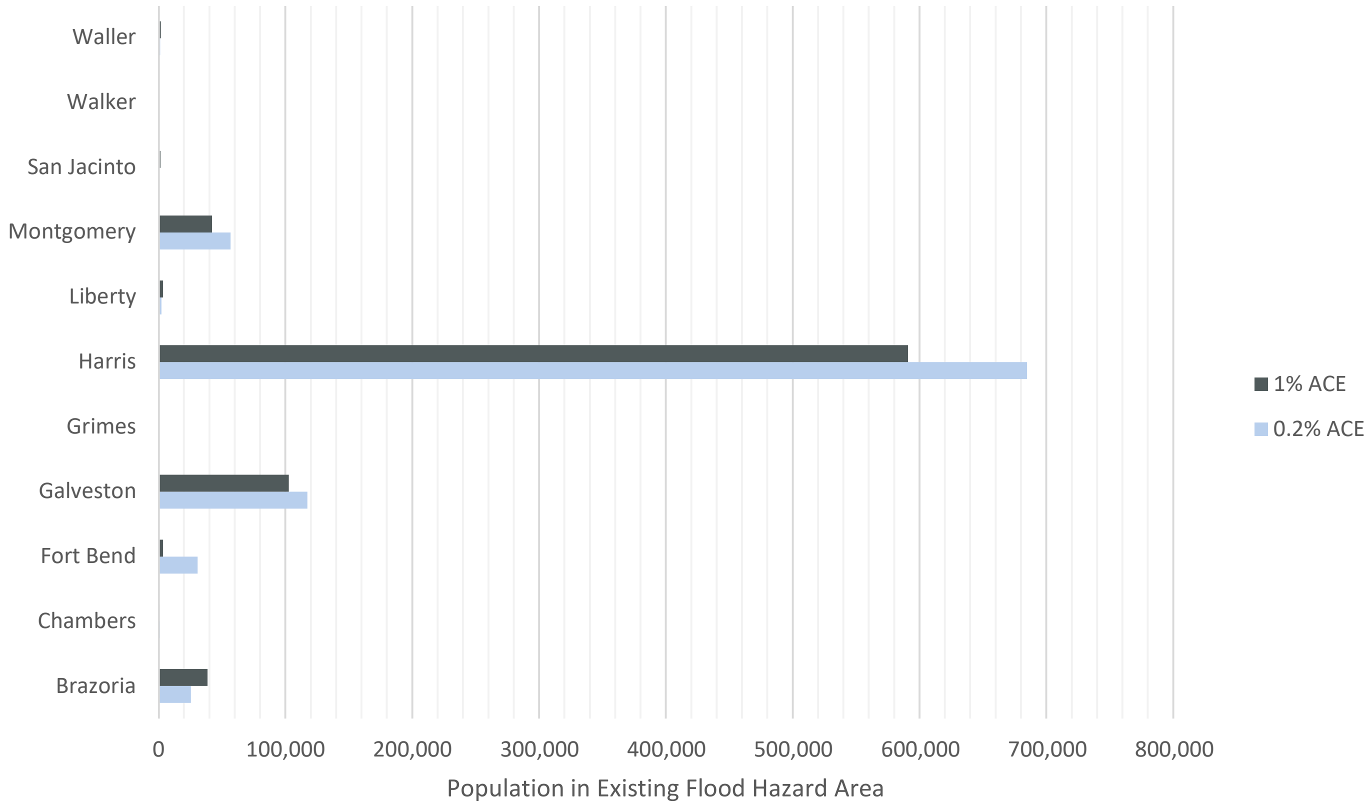
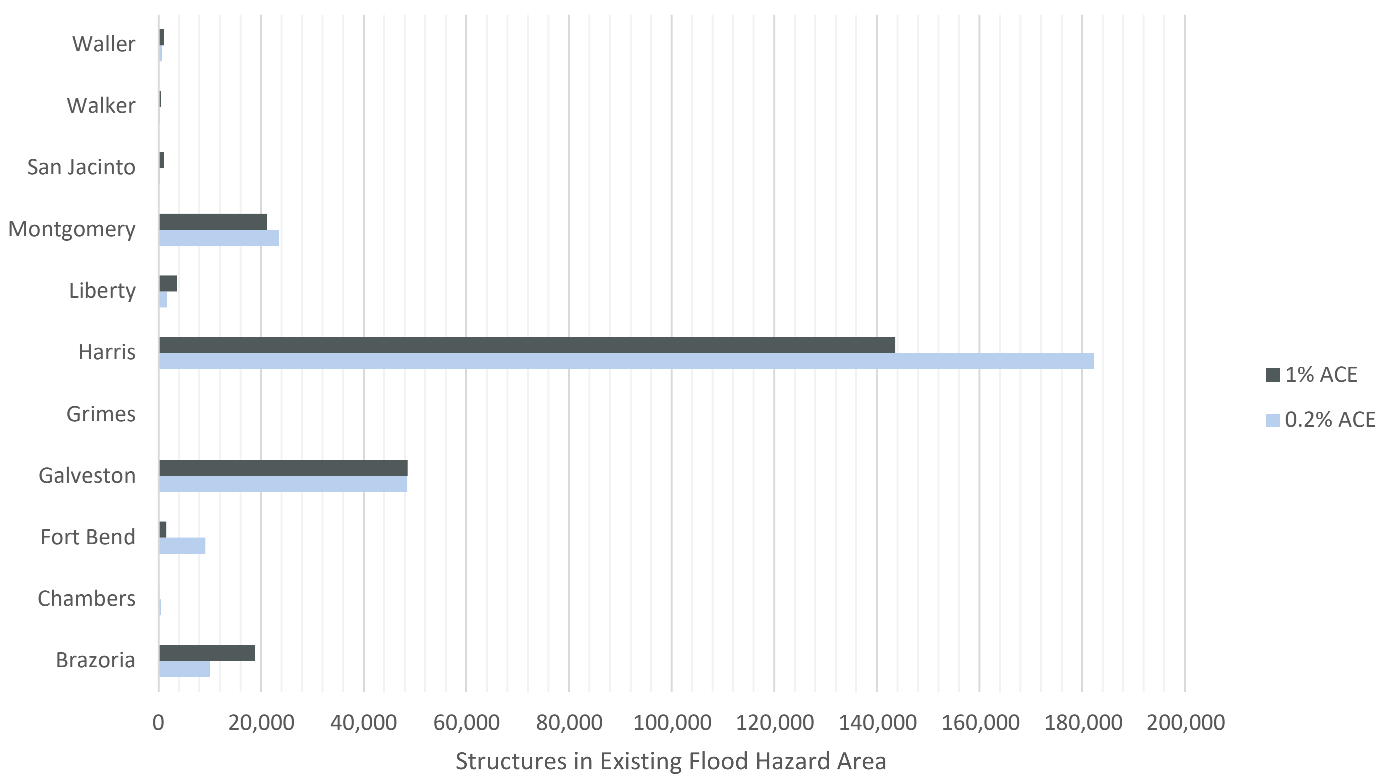
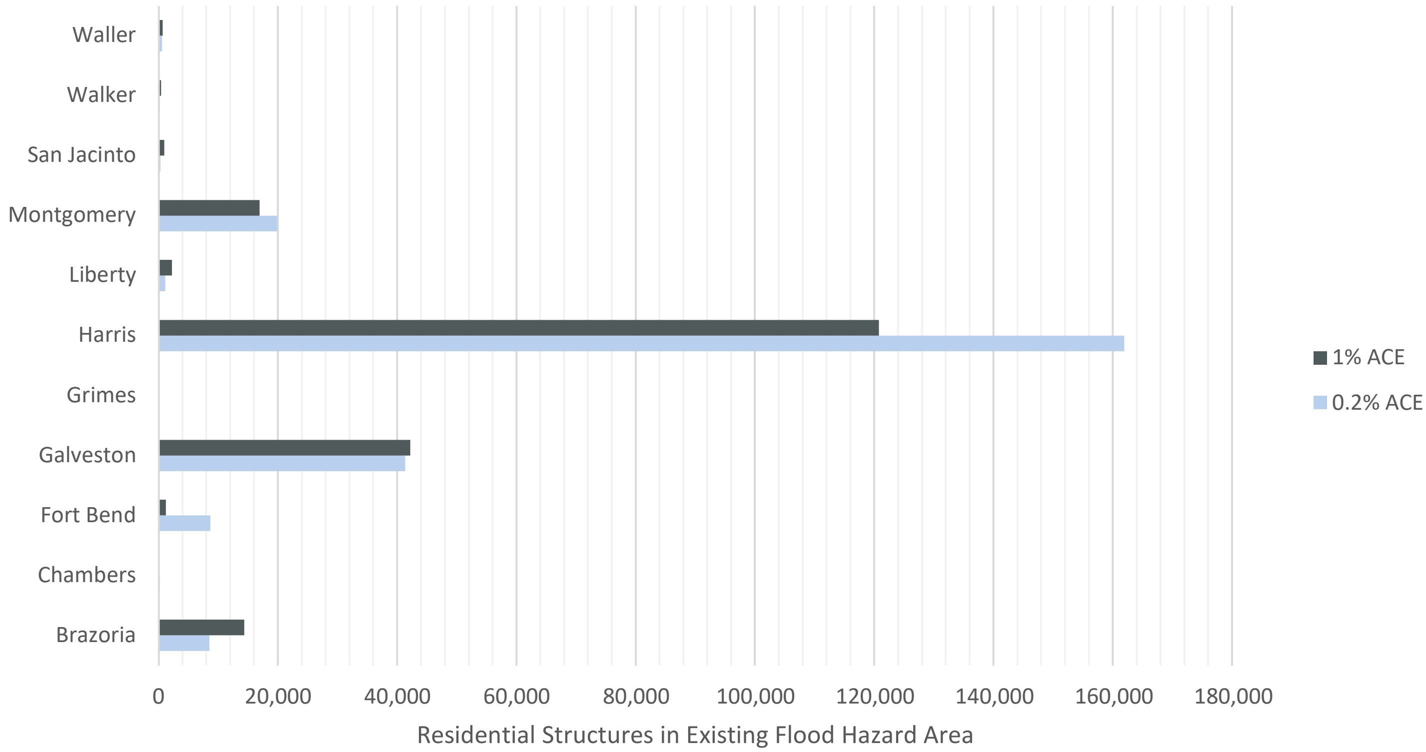
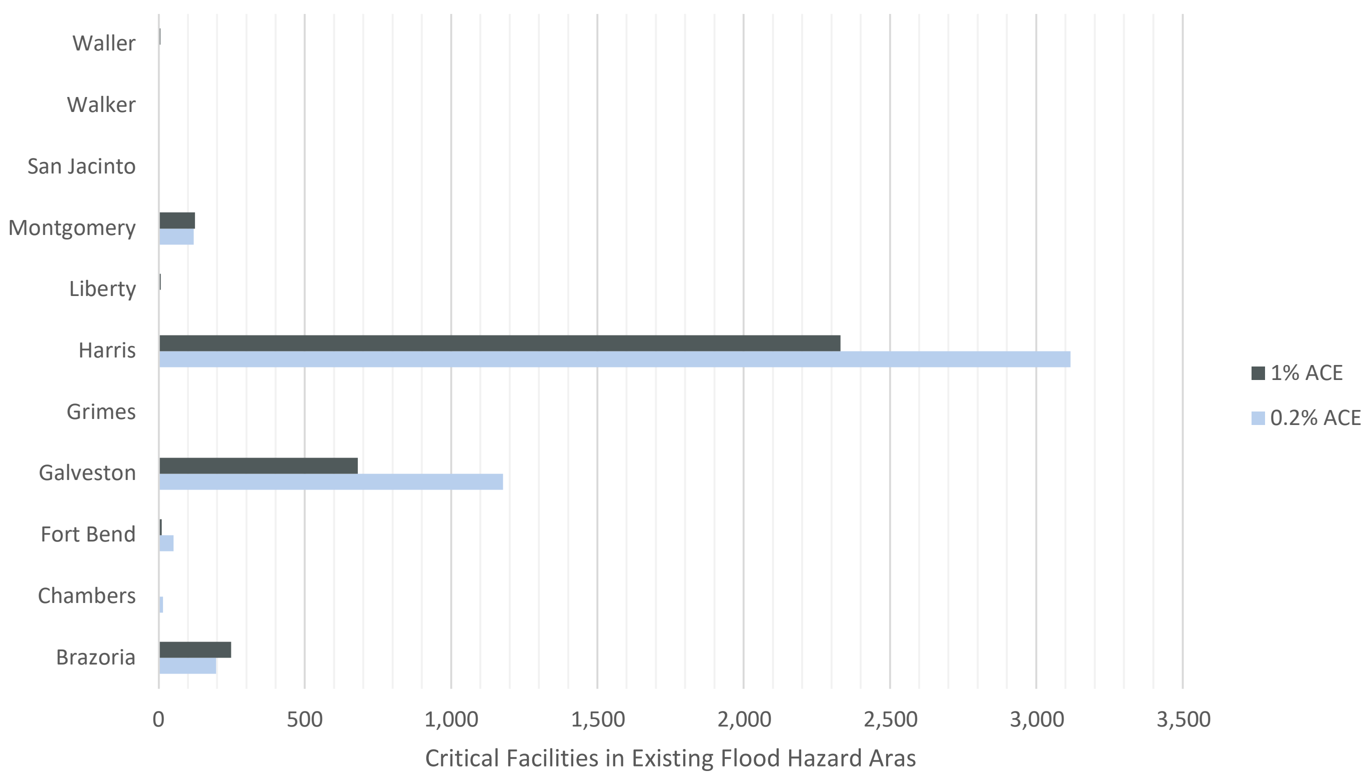

Waller
Walker
San Jacinto
Montgomery
Liberty
Harris
Grimes
Galveston
Fort Bend
Chambers
Brazoria
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
Population in Existing Flood Hazard Area
1% ACE
0.2% ACE


Waller
Walker
San Jacinto
Montgomery
Liberty
Harris
Grimes
Galveston
Fort Bend
Chambers
Brazoria
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
180,000
200,000
Structures in Existing Flood Hazard Area
1% ACE
0.2% ACE


Waller
Walker
San Jacinto
Montgomery
Liberty
Harris
Grimes
Galveston
Fort Bend
Chambers
Brazoria
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
180,000
Residential Structures in Existing Flood Hazard Area
1% ACE
0.2% ACE


Waller
Walker
San Jacinto
Montgomery
Liberty
Harris
Grimes
Galveston
Fort Bend
Chambers
Brazoria
0
500
1,000
1,500
2,000
2,500
3,000
3,500
Critical Facilities in Existing Flood Hazard Aras
1% ACE
0.2% ACE

APPENDIX 2B-1
MAP 8: FUTURE CONDITION FLOOD HAZARD

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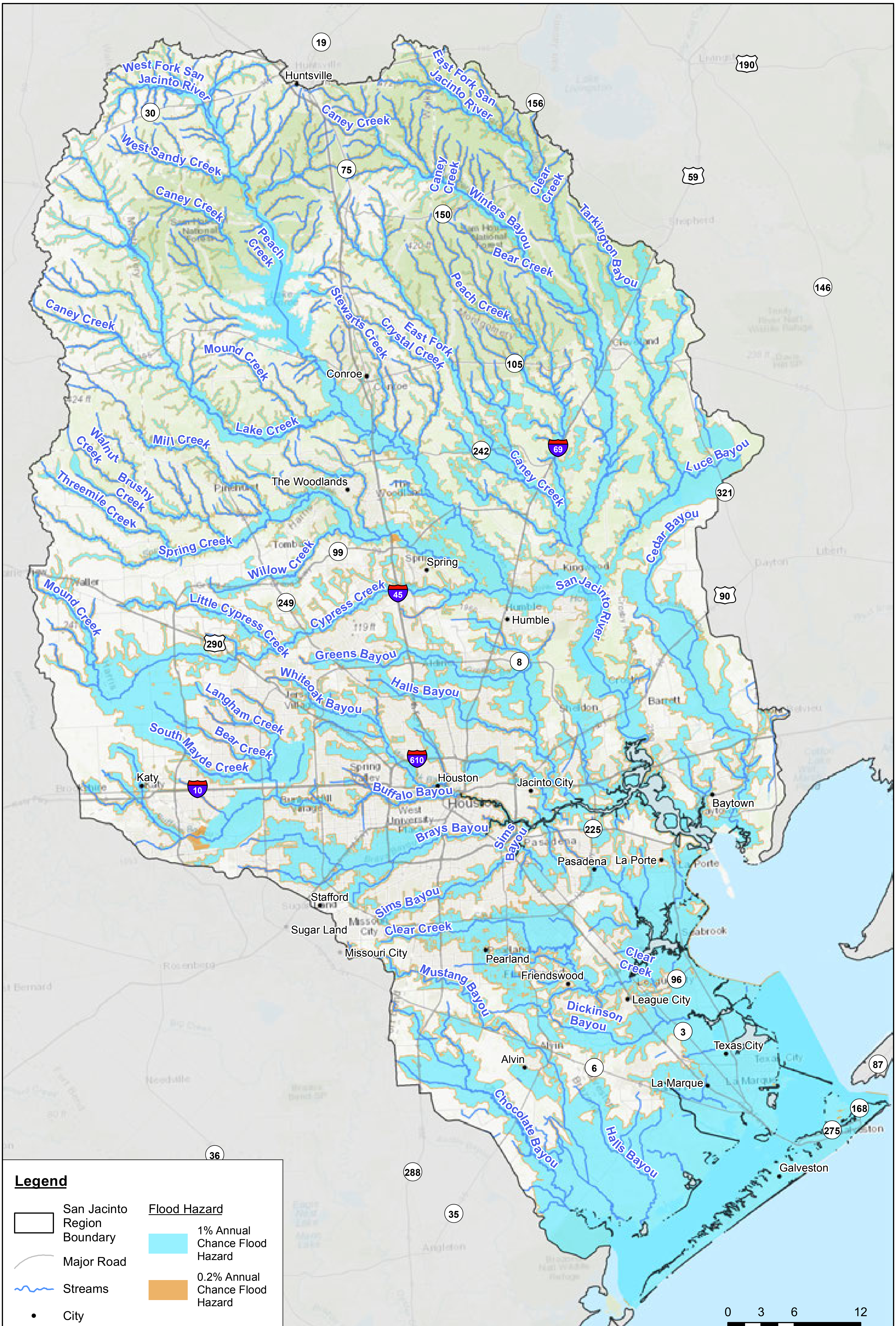


San Jacinto Regional Flood Plan

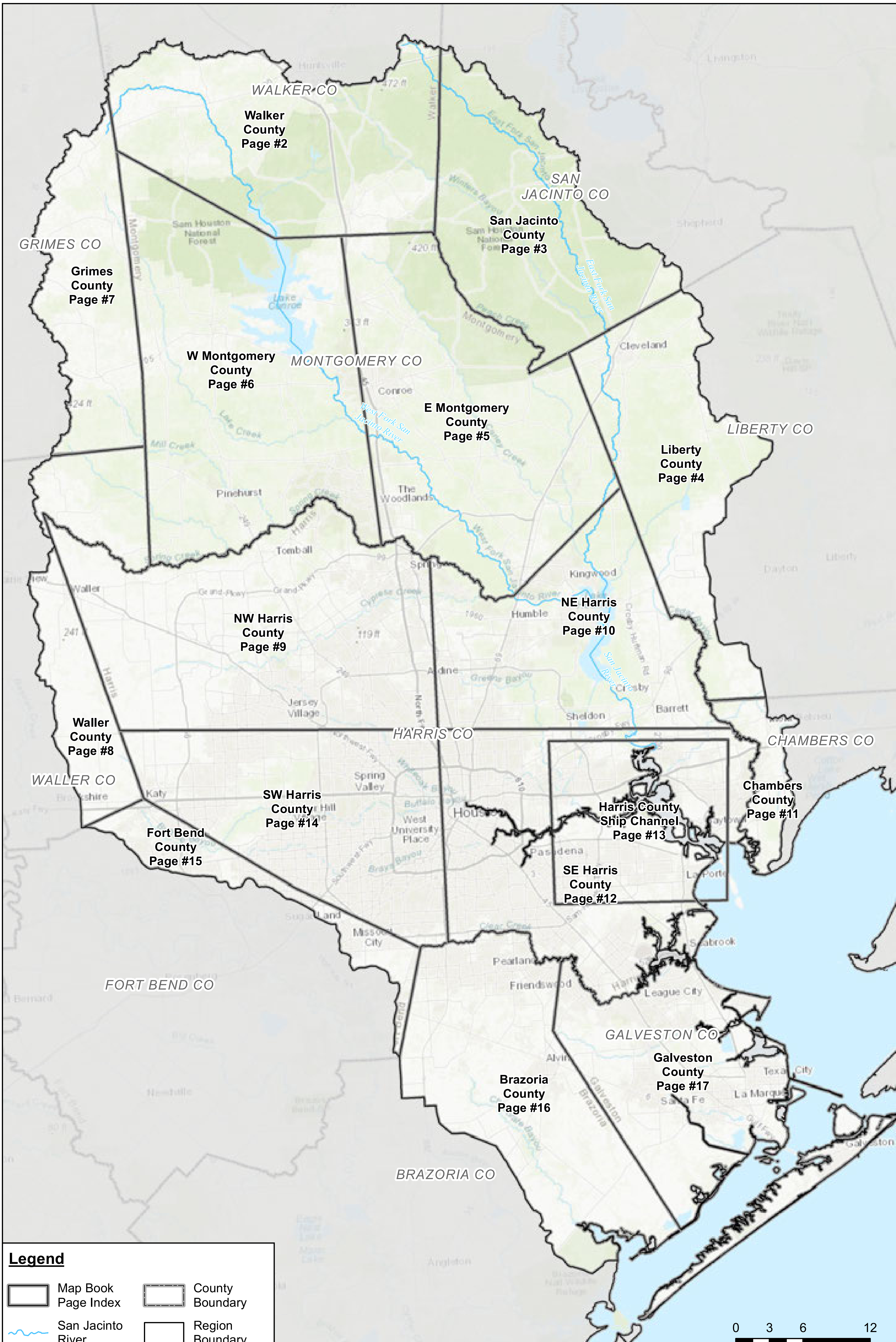
Future Condition Flood Hazard

MAP 8

OVERVIEW

SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

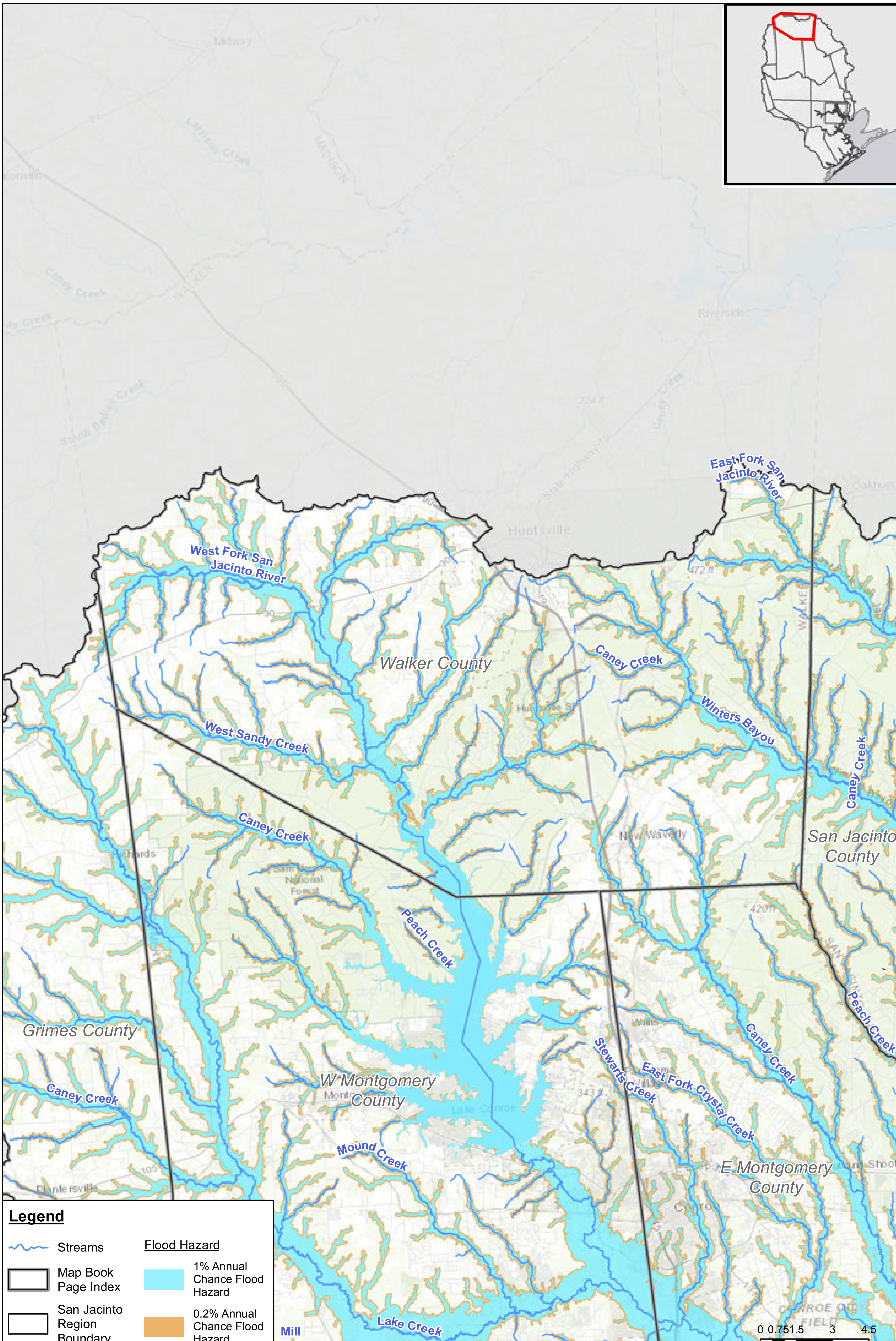
San Jacinto Regional Flood Plan

Future Condition Flood Hazard Index

MAP 8

FIGURE 1 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



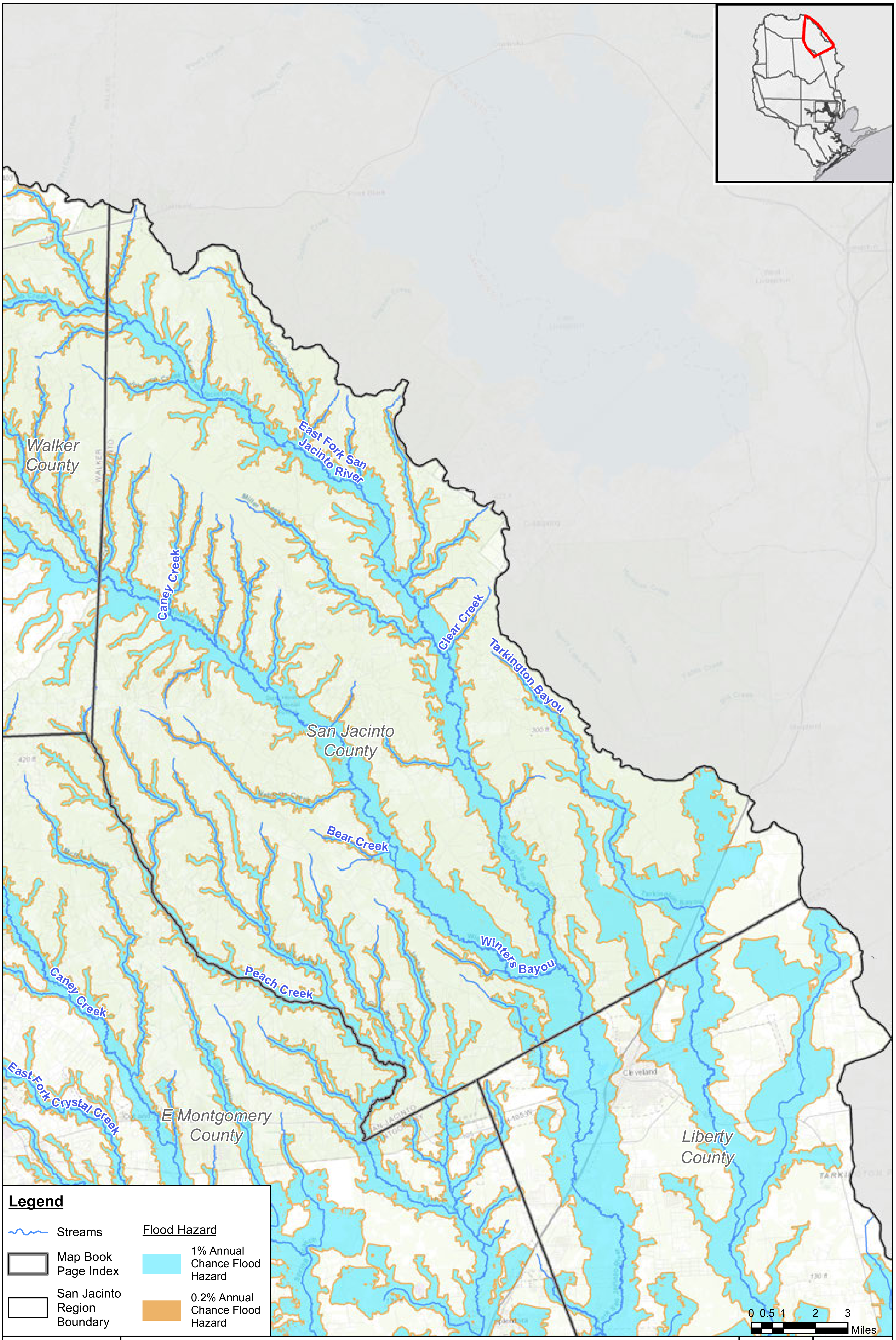
San Jacinto Regional Flood Plan

Future Condition Flood Hazard - Walker

MAP 8

FIGURE 2 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

San Jacinto Regional Flood Plan

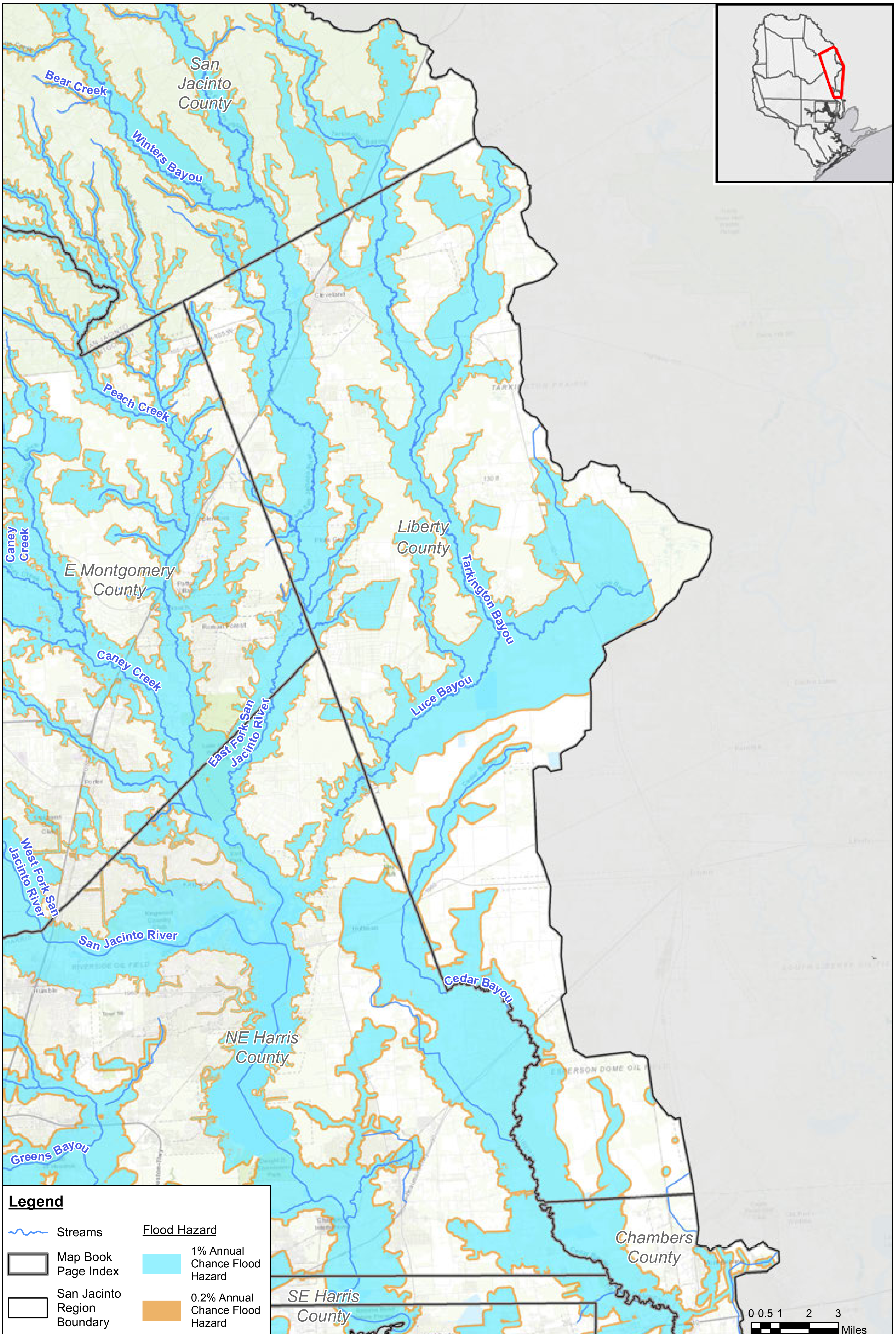
Future Condition Flood Hazard - San Jacinto

N W E S

MAP 8

FIGURE 3 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

San Jacinto Regional Flood Plan

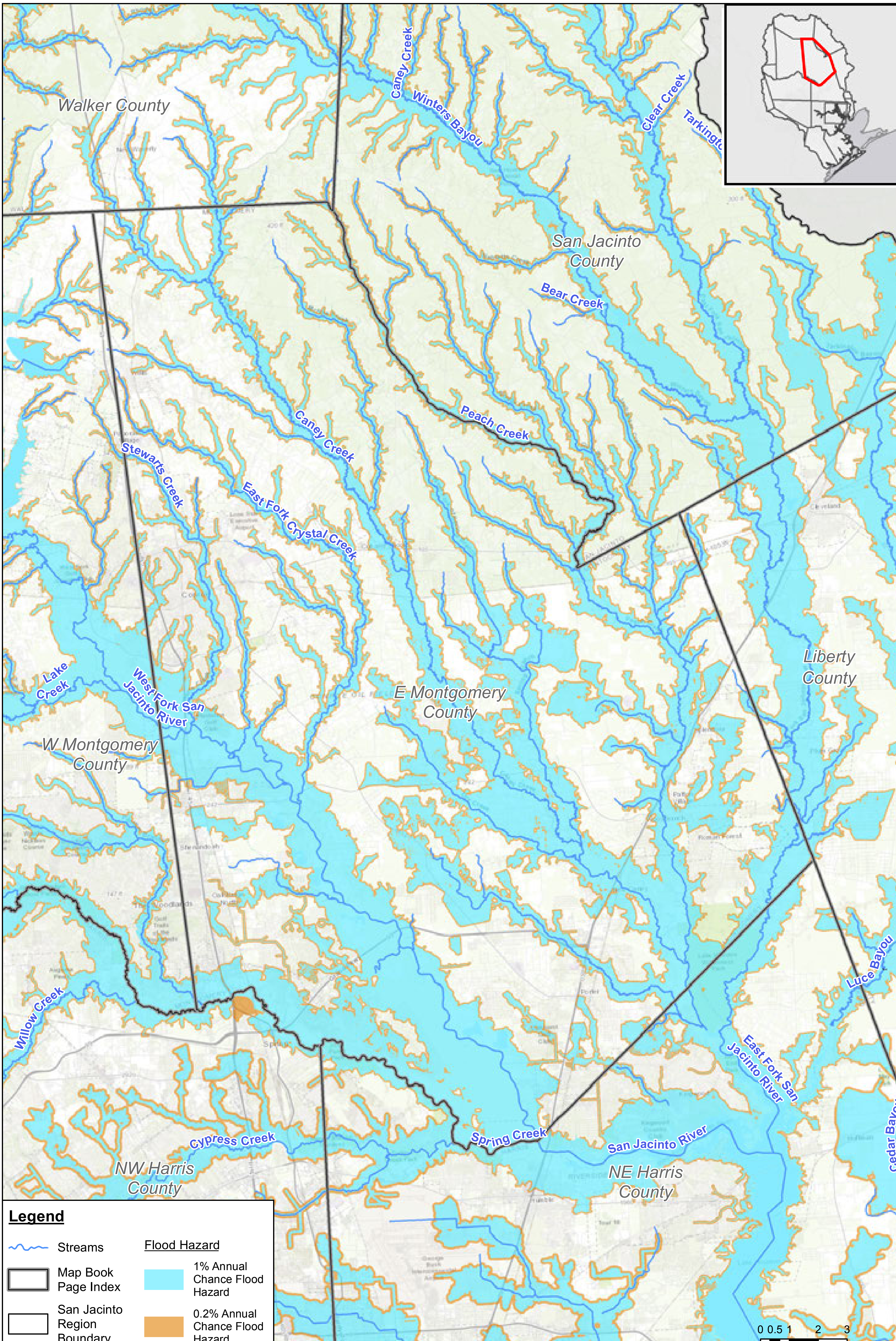
Future Condition Flood Hazard - Liberty

N W E S

MAP 8

FIGURE 4 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



San Jacinto Regional Flood Plan

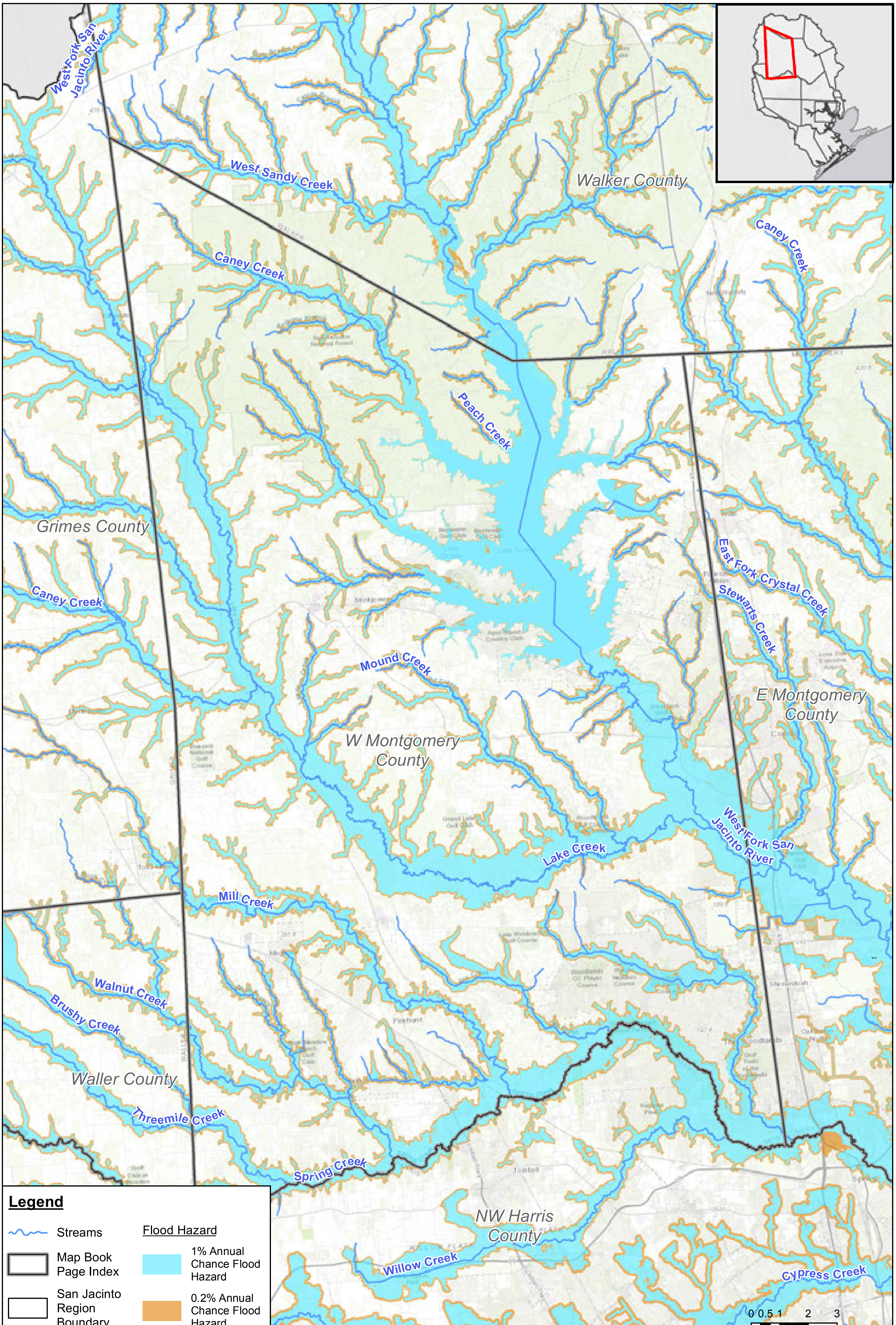
Future Condition Flood Hazard - E Montgomery

SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

MAP 8

FIGURE 5 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

Future Condition Flood Hazard - W Montgomery

N W E S

MAP 8

FIGURE 6 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert

SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

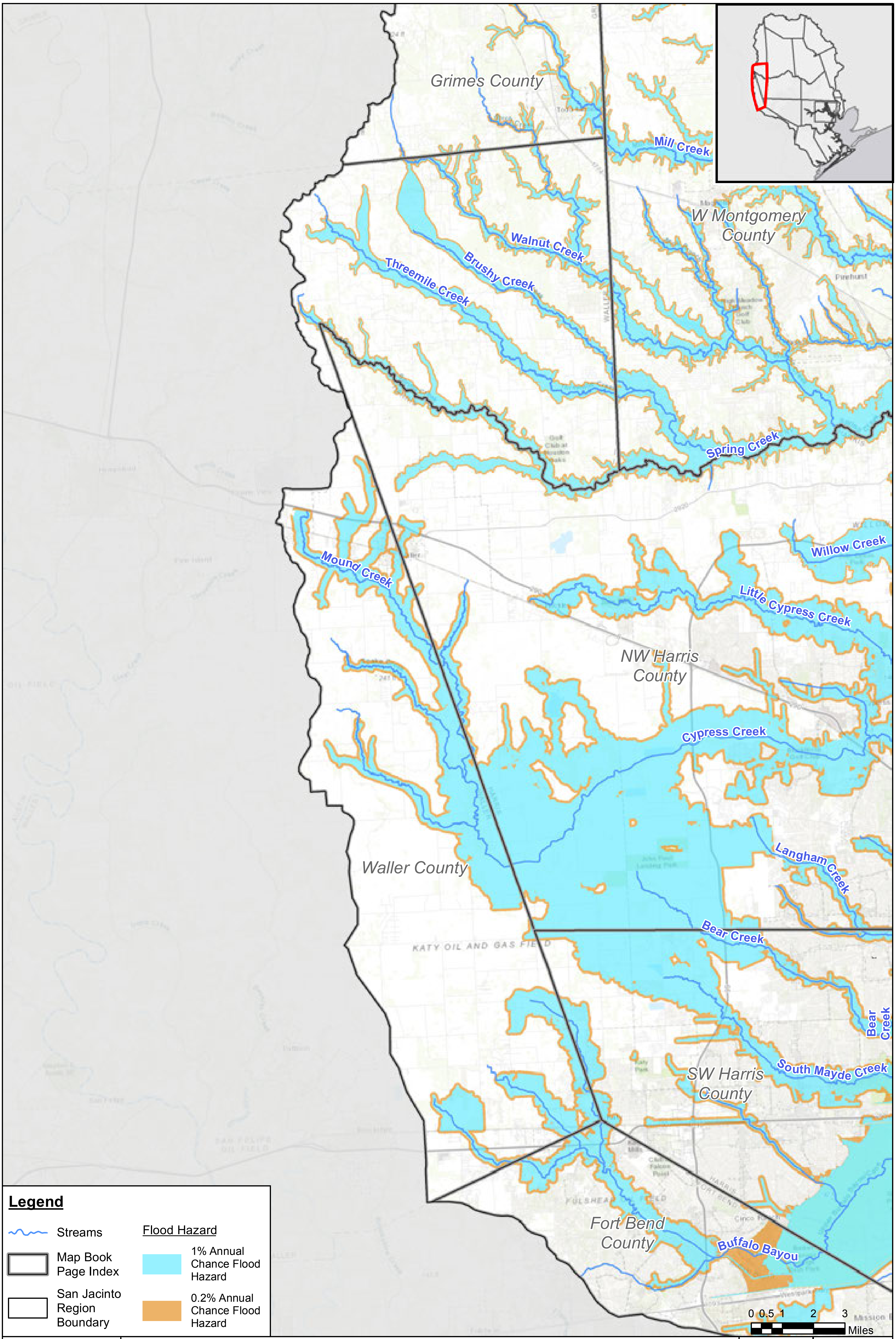
San Jacinto Regional Flood Plan

Future Condition Flood Hazard - Grimes

MAP 8

FIGURE 7 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



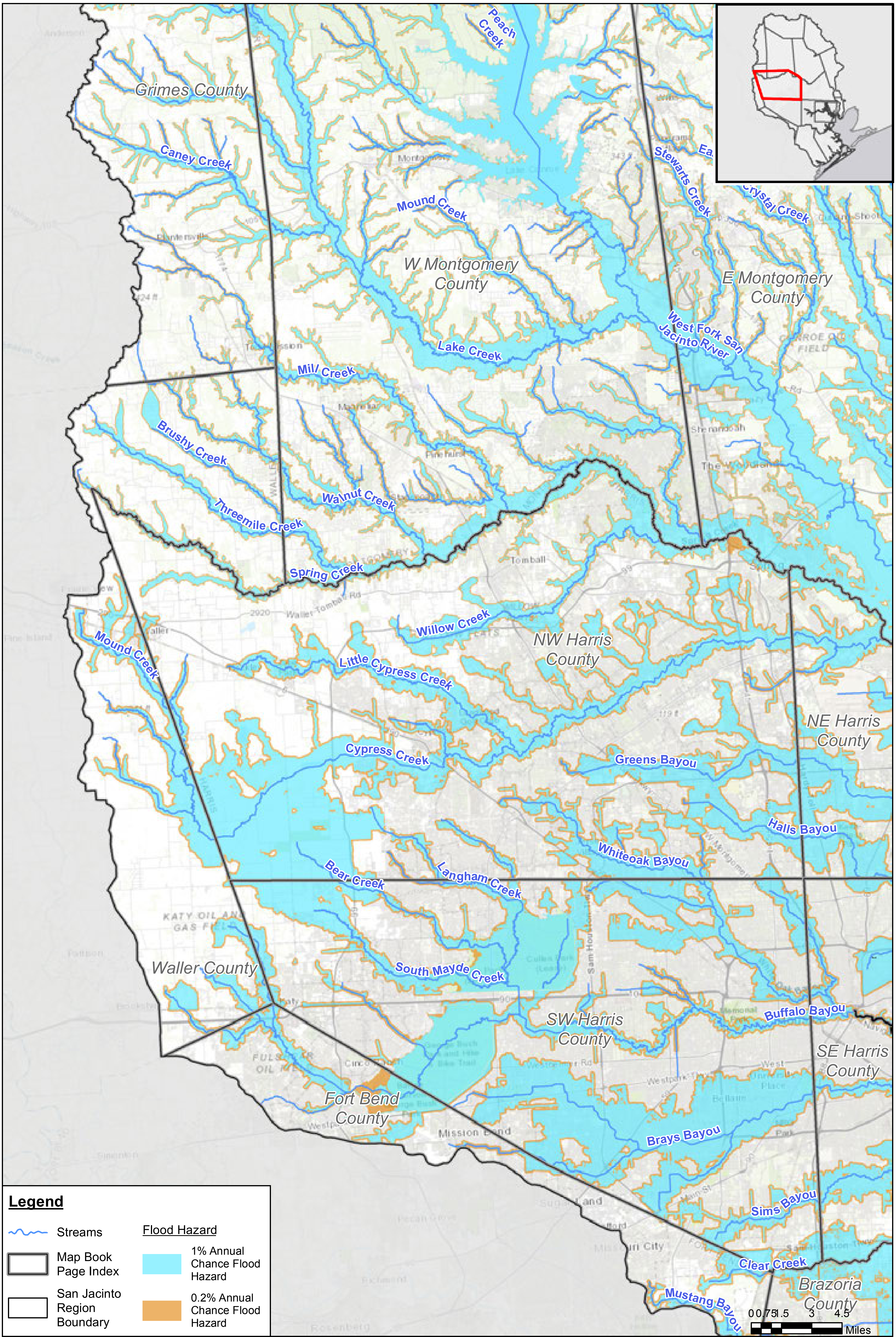
San Jacinto Regional Flood Plan

Future Condition Flood Hazard - Waller

MAP 8

FIGURE 8 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

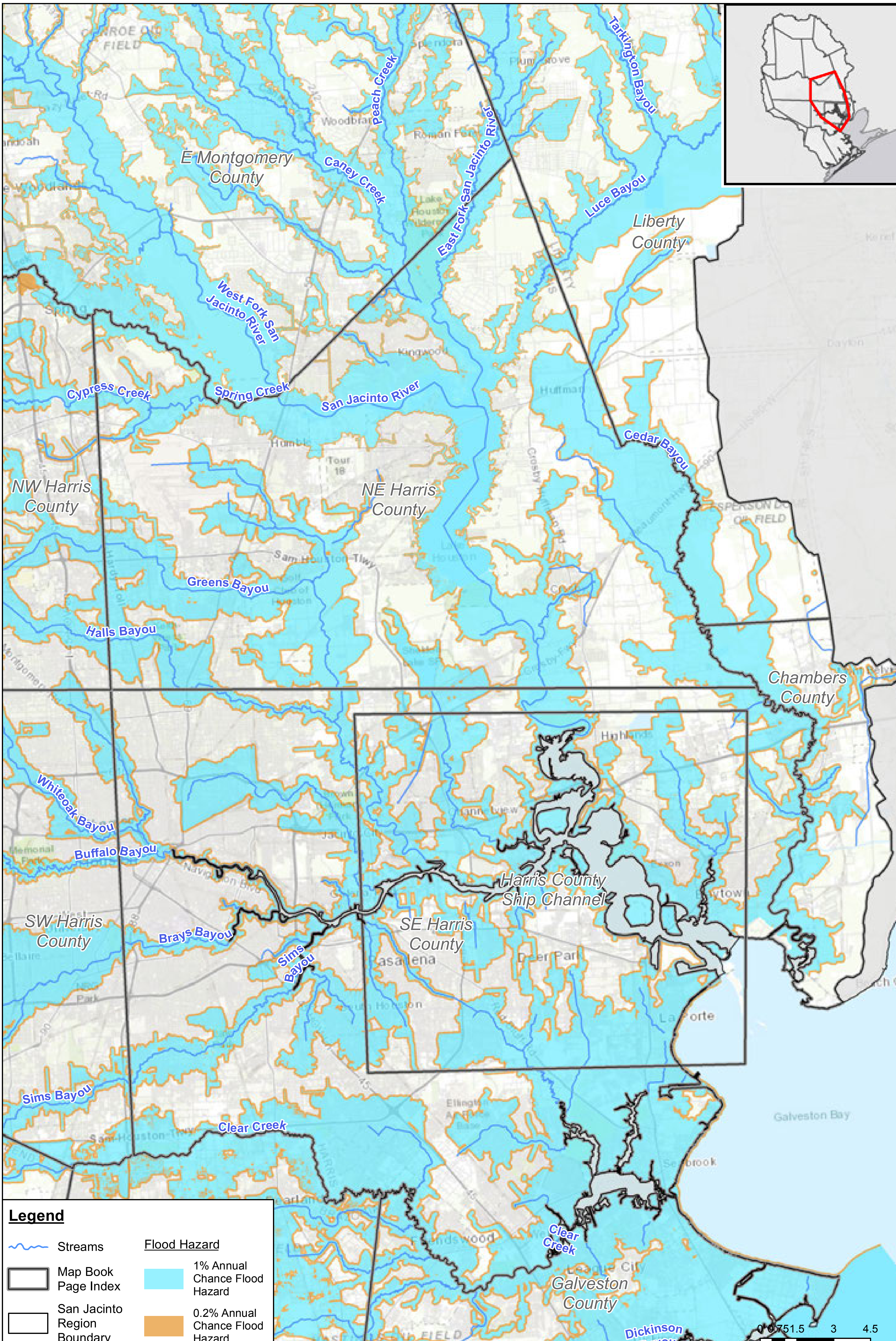
San Jacinto Regional Flood Plan

Future Condition Flood Hazard - NW Harris

MAP 8

FIGURE 9 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

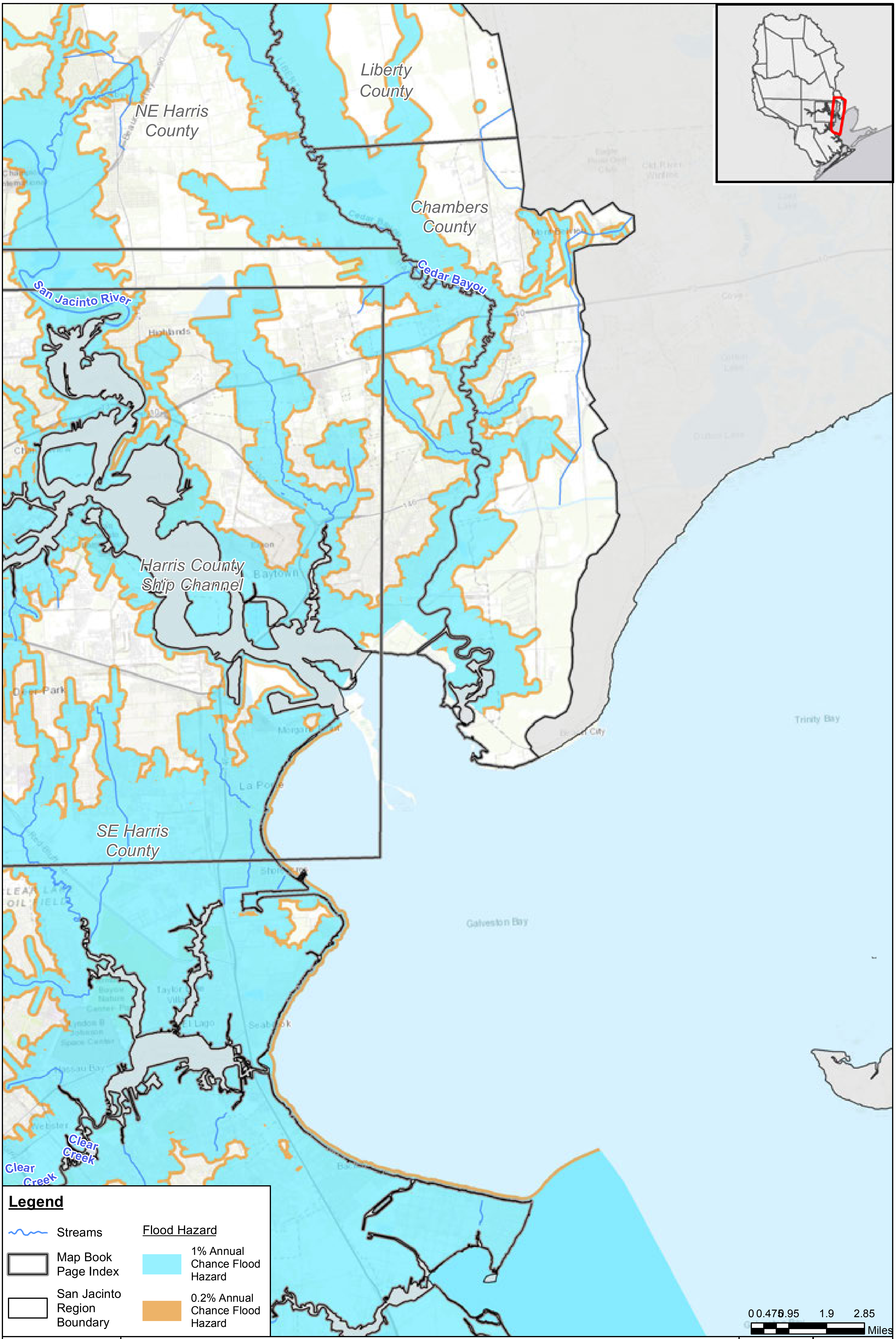
San Jacinto Regional Flood Plan

Future Condition Flood Hazard - NE Harris

MAP 8

FIGURE
10 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



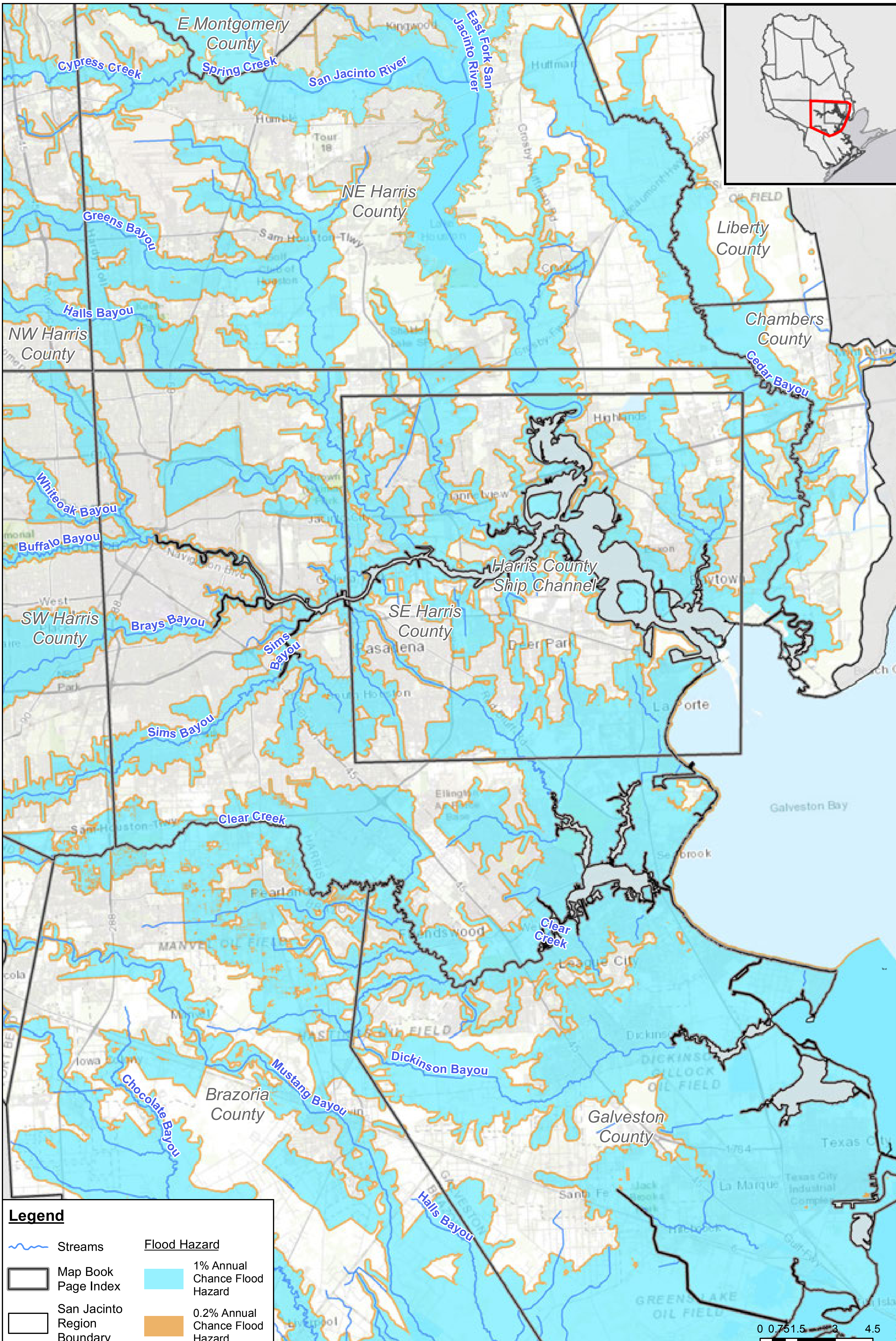
San Jacinto Regional Flood Plan

Future Condition Flood Hazard - Chambers

MAP 8

FIGURE 11 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



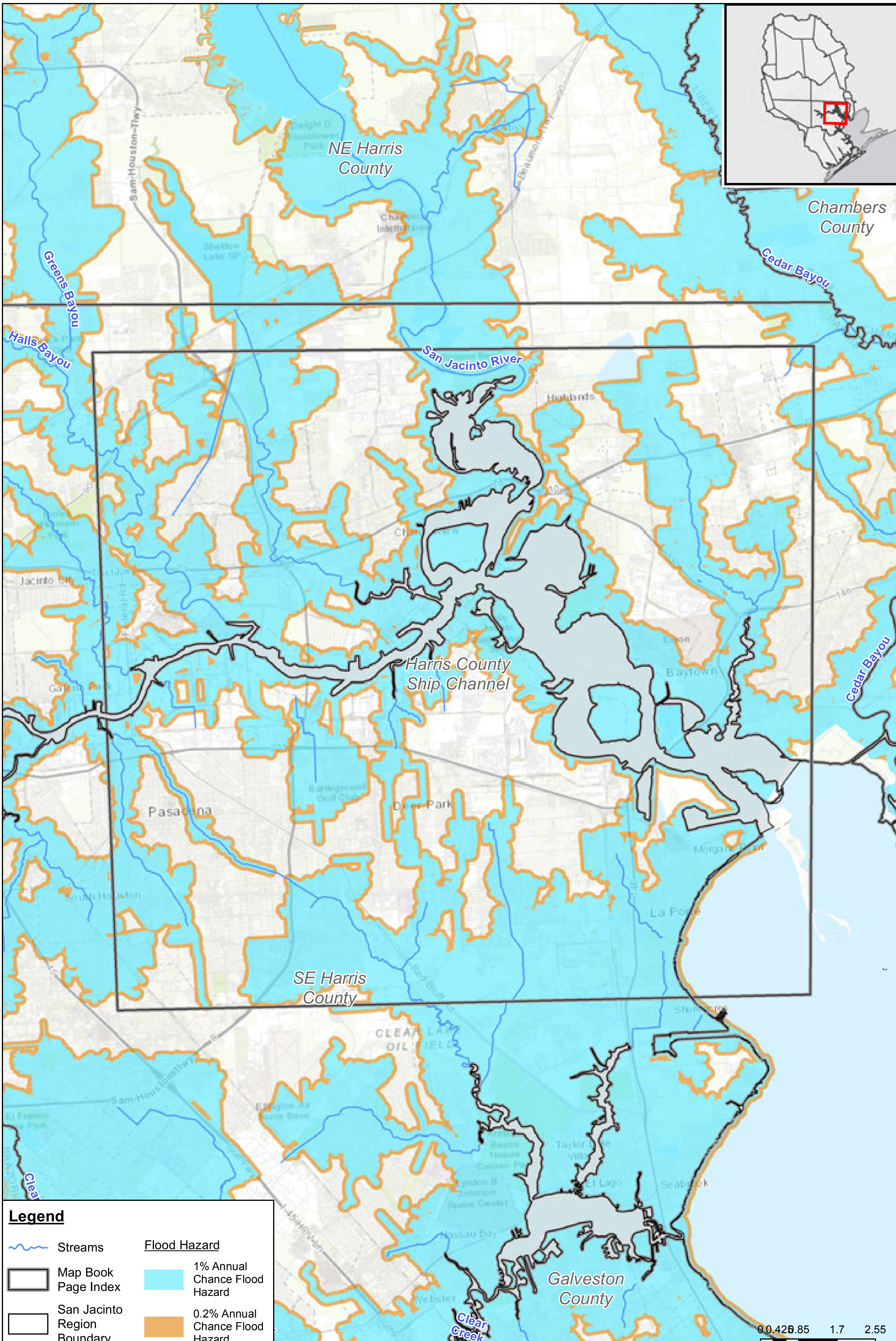
San Jacinto Regional Flood Plan

Future Condition Flood Hazard - SE Harris

MAP 8

FIGURE
12 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

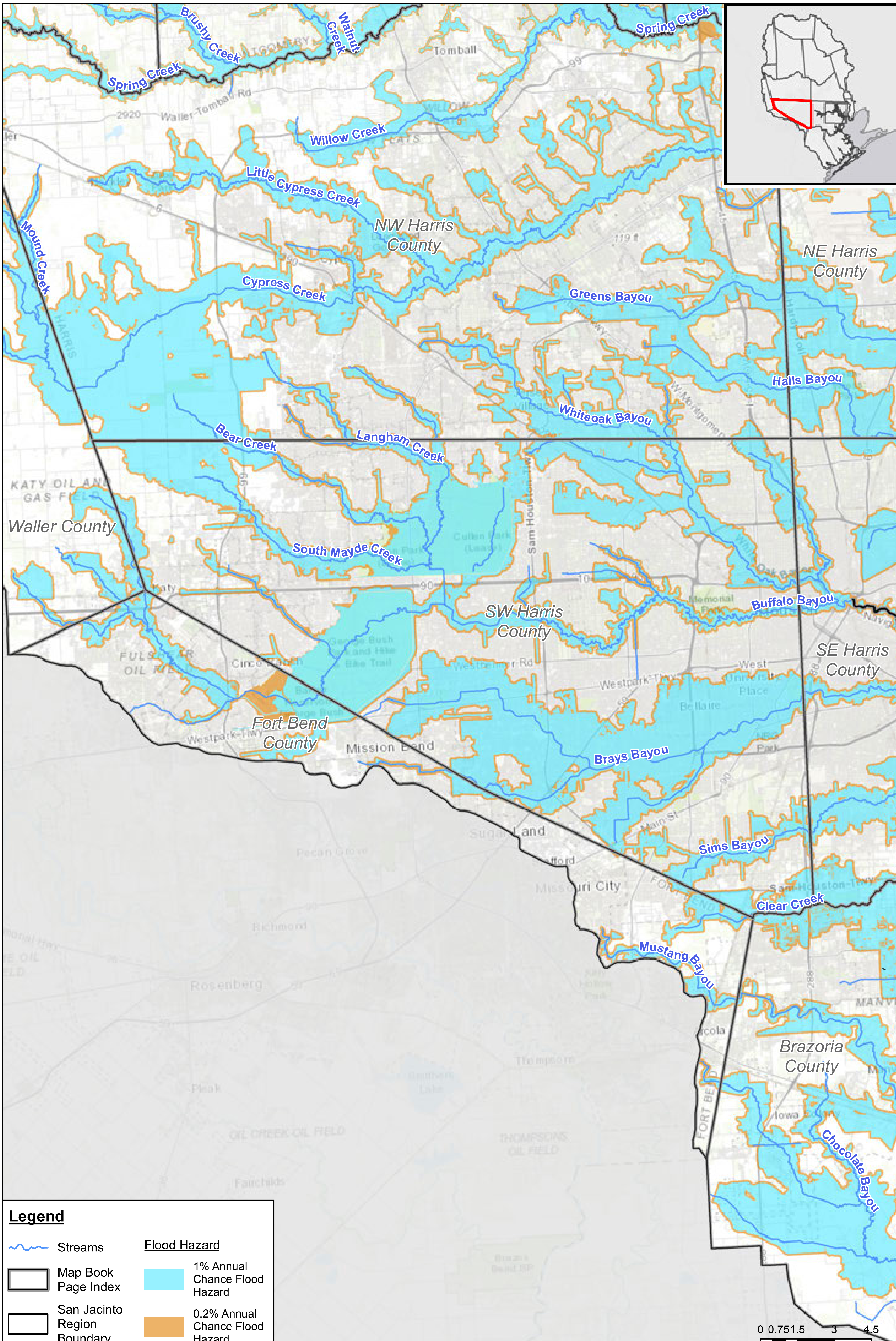
Future Condition Flood Hazard - Ship Channel

N S E W

MAP 8

FIGURE 13 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



San Jacinto Regional Flood Plan

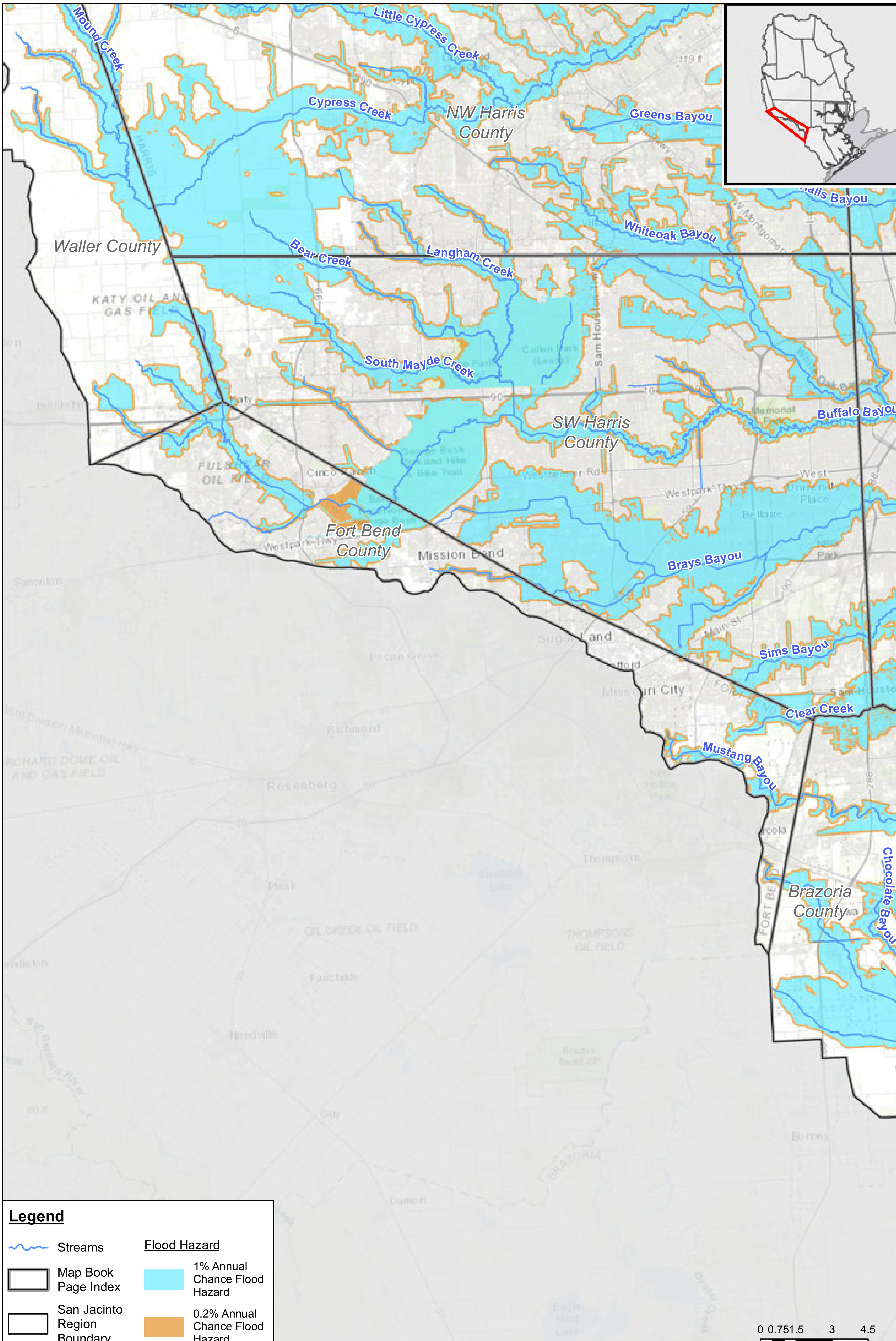
Future Condition Flood Hazard - SW Harris

SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

MAP 8

FIGURE 14 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



San Jacinto Regional Flood Plan

Future Condition Flood Hazard - Fort Bend

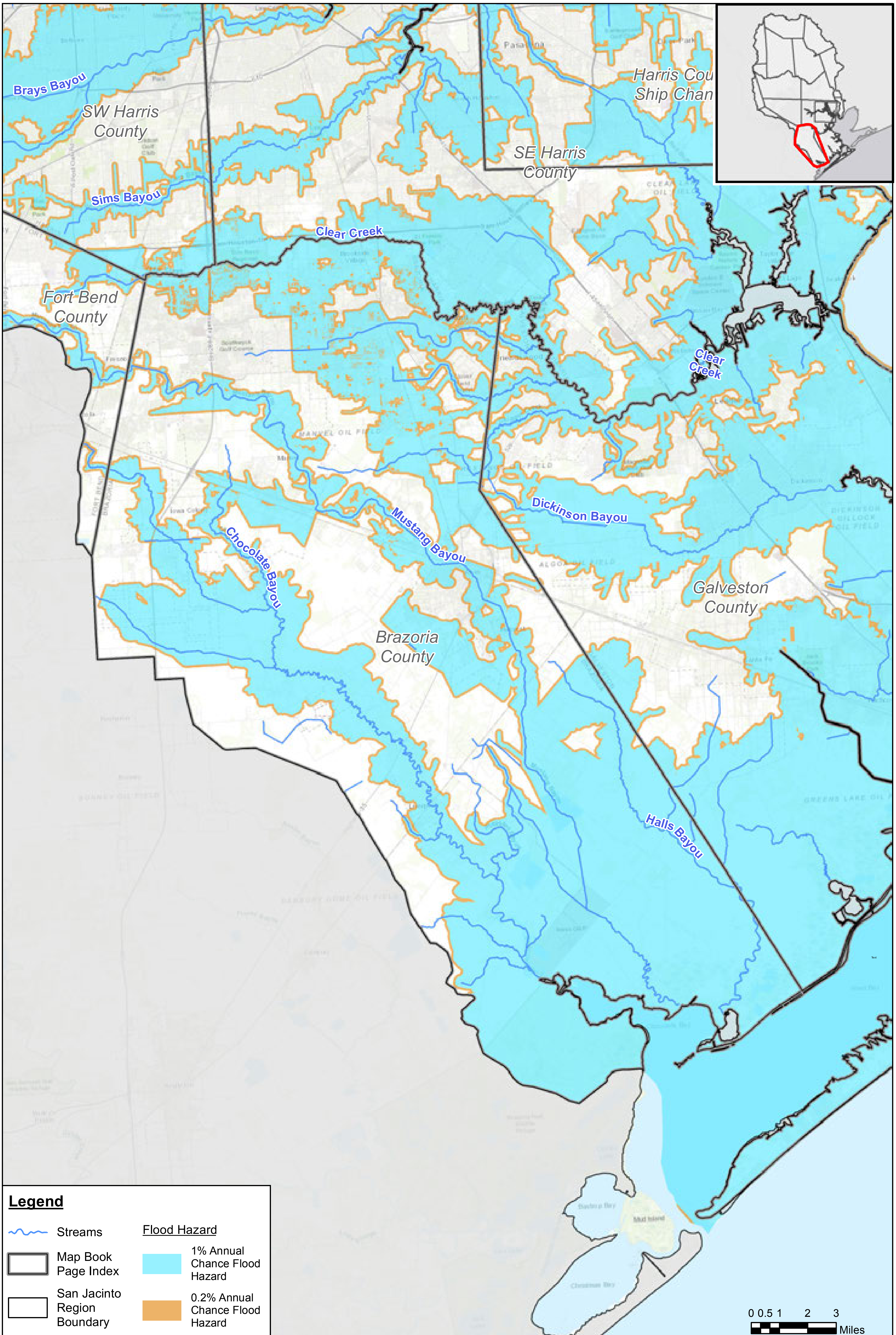
SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

N W E S

MAP 8

FIGURE 15 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



San Jacinto Regional Flood Plan

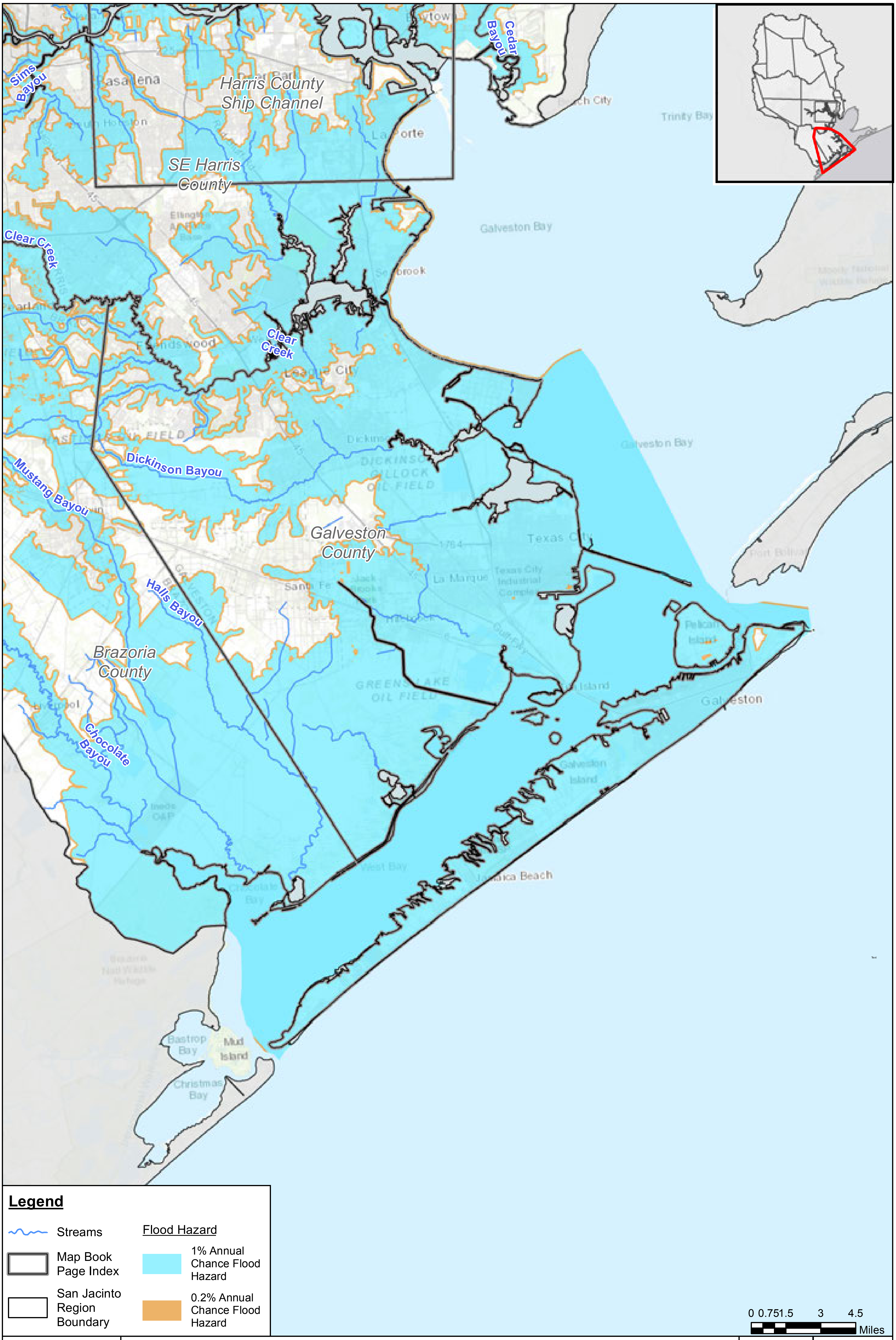
Future Condition Flood Hazard - Brazoria

SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

MAP 8

FIGURE 16 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

San Jacinto Regional Flood Plan

Future Condition Flood Hazard - Galveston

N W E S

MAP 8

FIGURE 17 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert

APPENDIX 2B-2

MAP 9: GAPS IN INUNDATION MAPPING AND FLOOD-PRONE AREAS

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APPENDIX 2B-3

MAP 10: EXTENT OF INCREASE OF FLOOD HAZARD COMPARED TO EXISTING CONDITION

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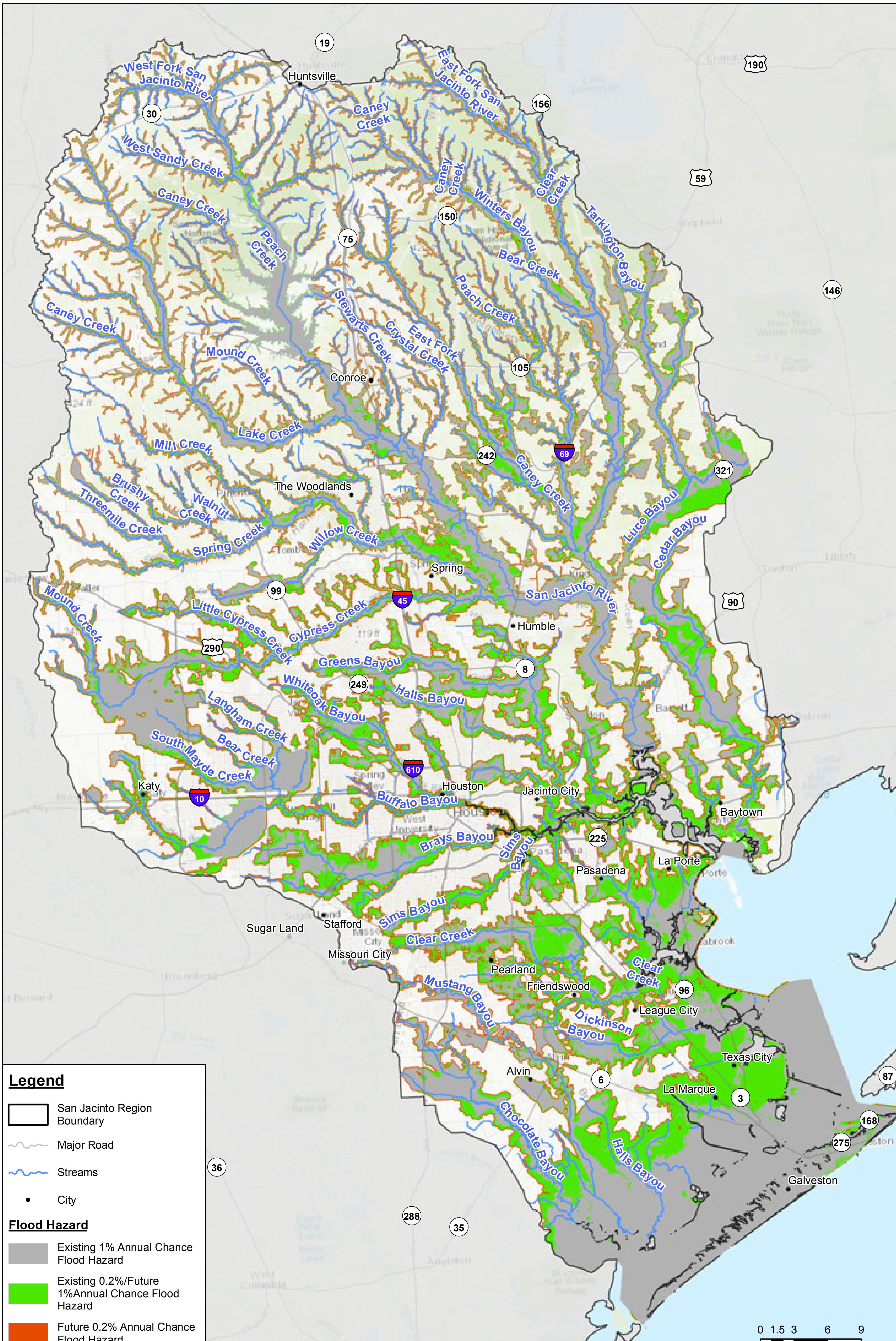


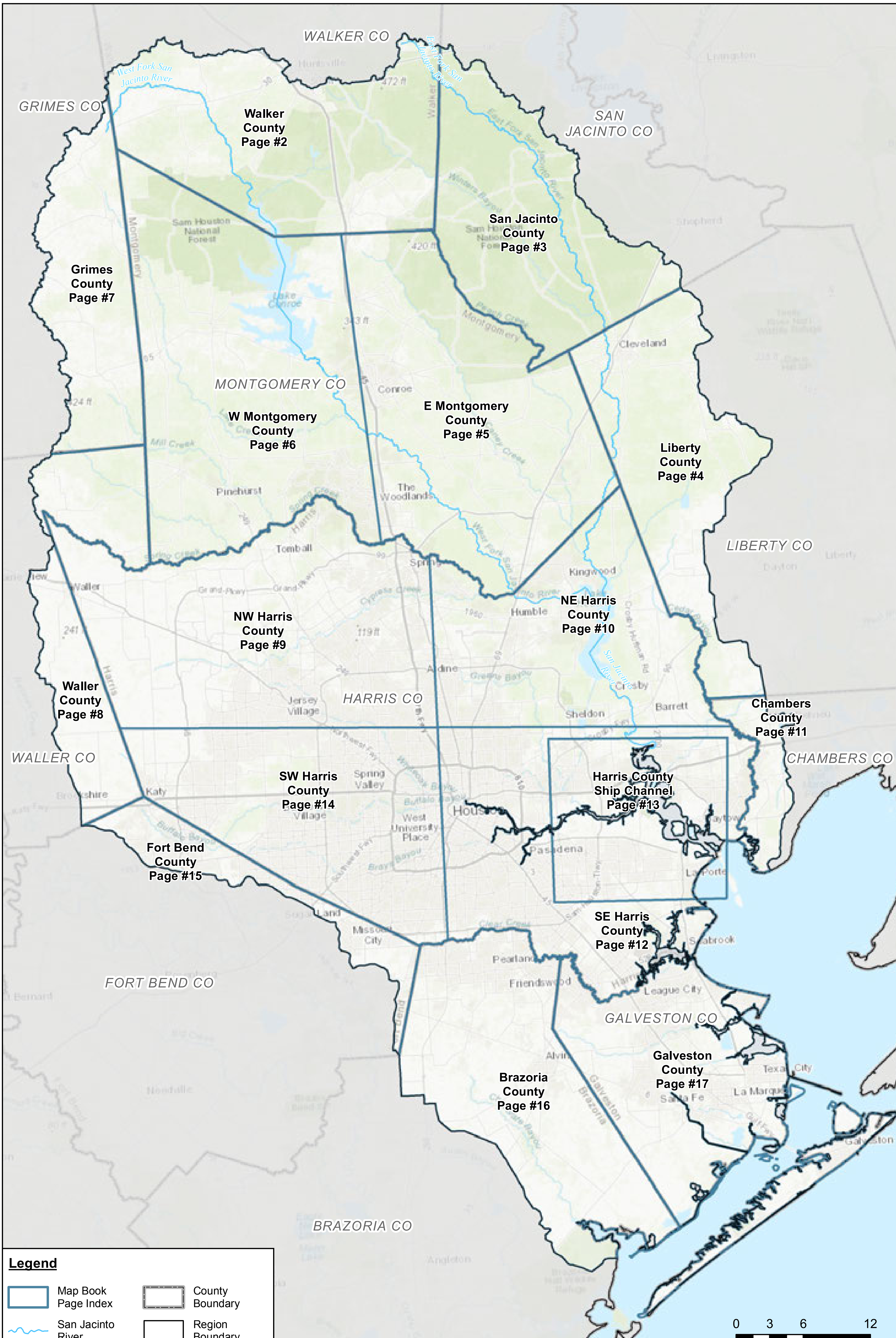
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition

SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

MAP 10
OVERVIEW

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



San Jacinto Regional Flood Plan

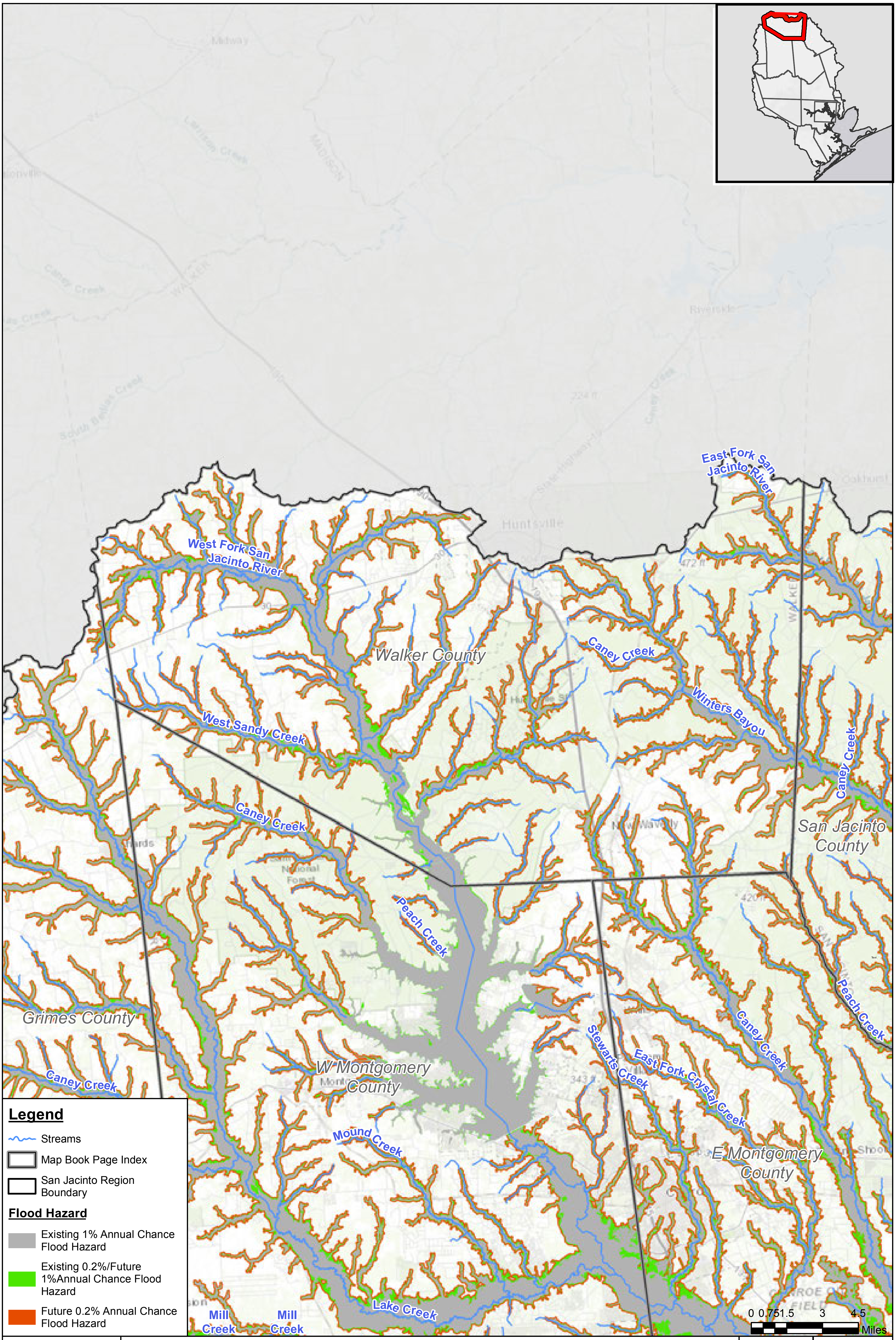
Extent of Increase of Flood Hazard Compared to Existing Condition Index

SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

MAP 10

FIGURE 1 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

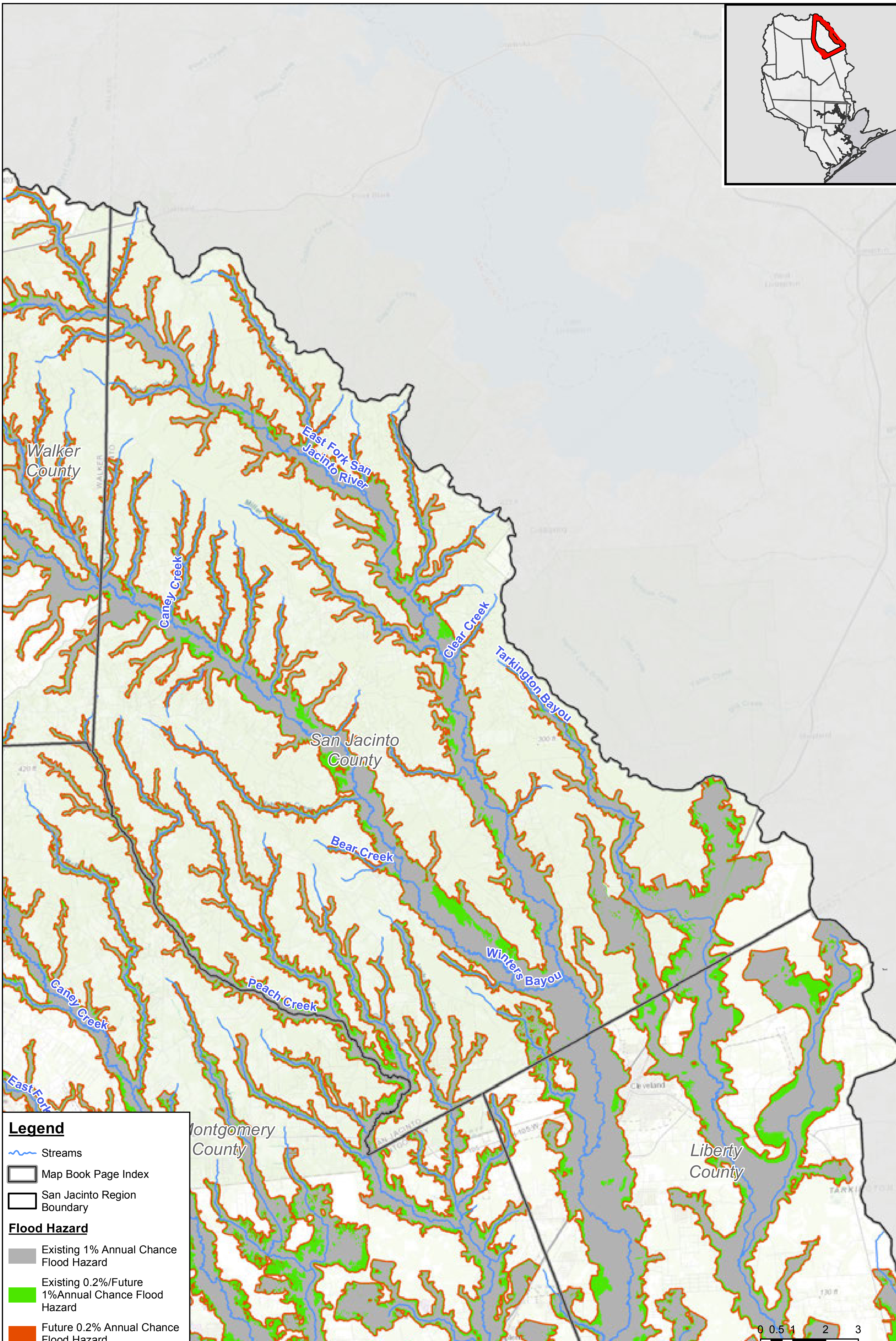
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - Walker

MAP 10

FIGURE 2 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



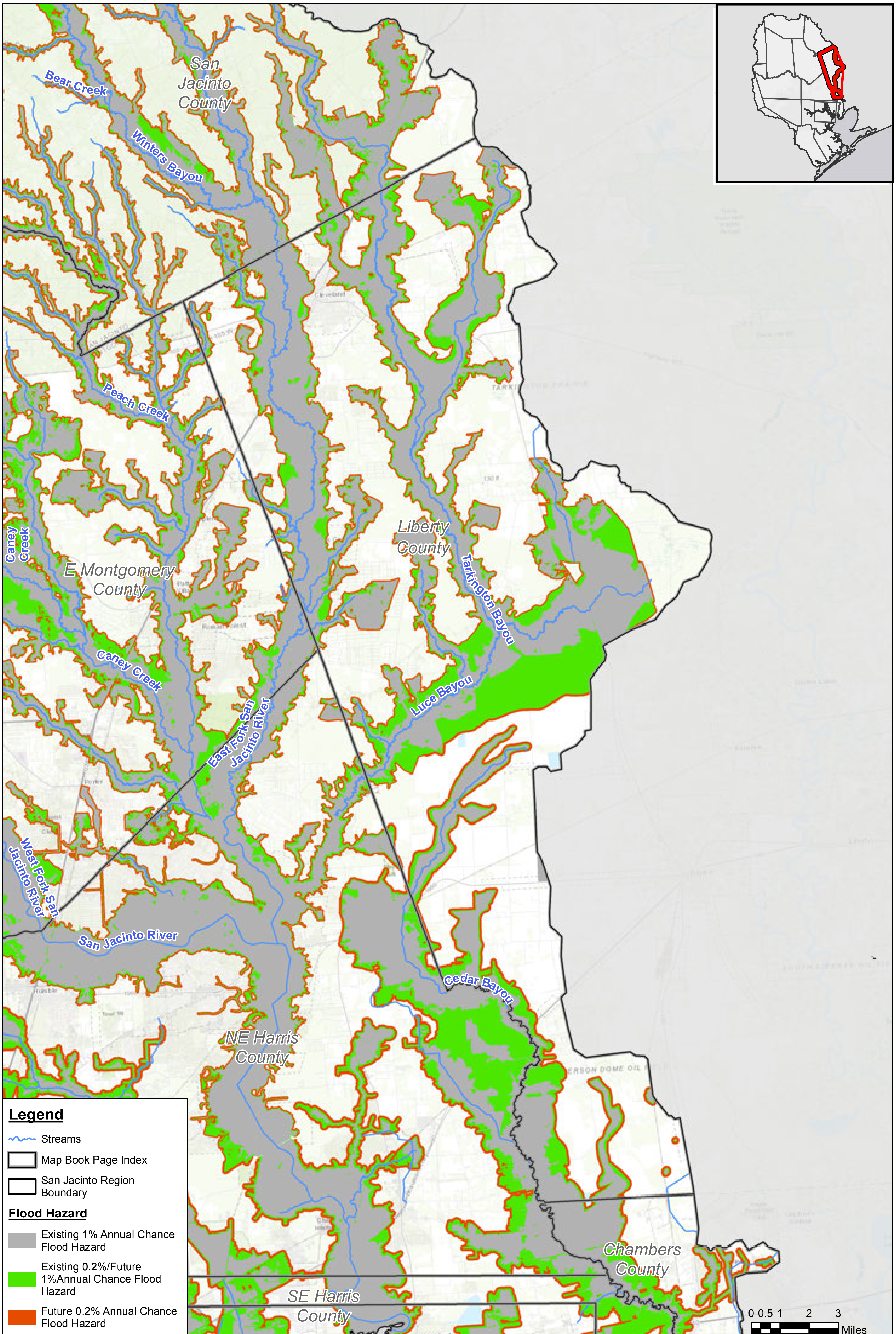
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - San Jacinto

MAP 10

FIGURE
3 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

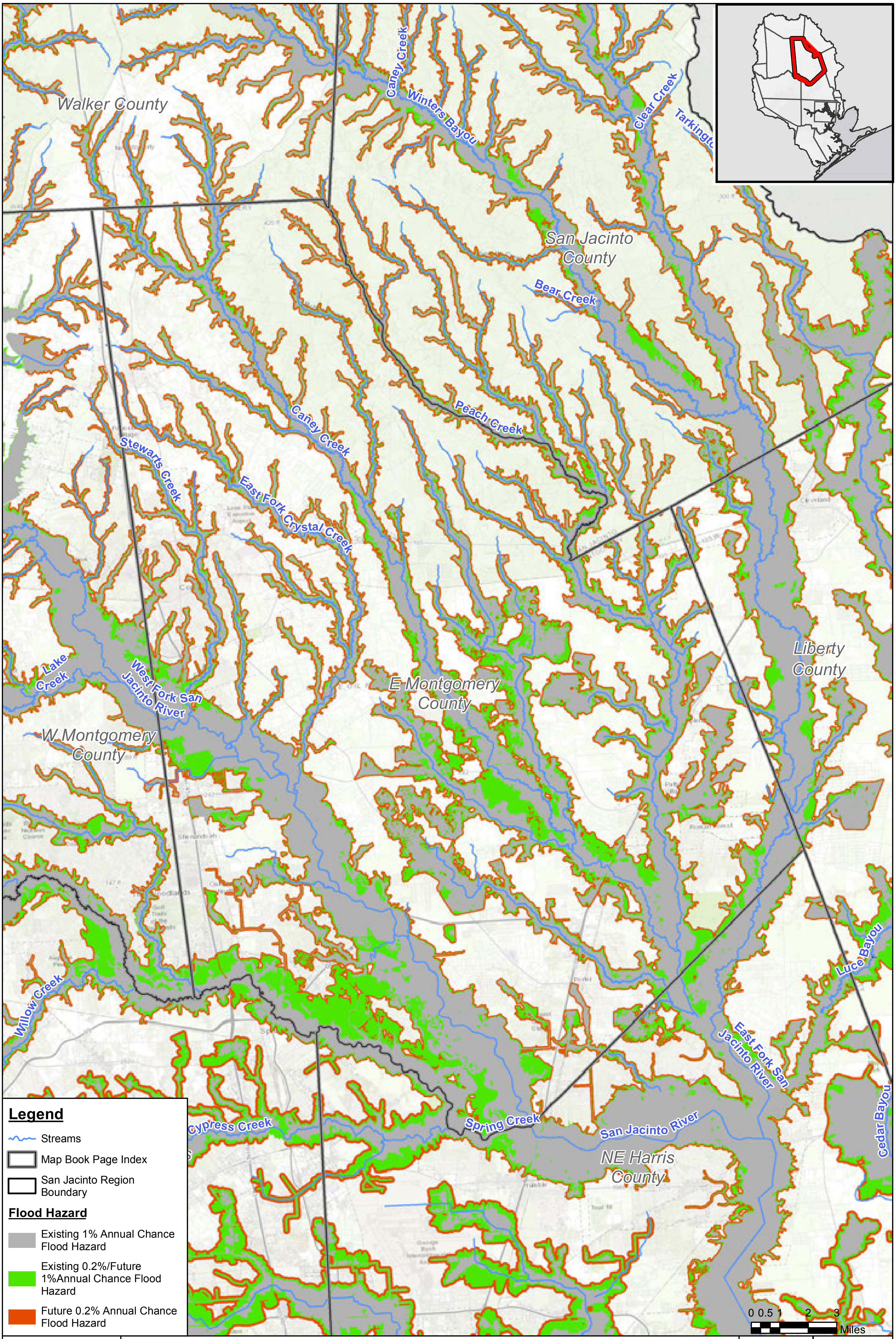
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - Liberty

MAP 10

FIGURE
4 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

San Jacinto Regional Flood Plan

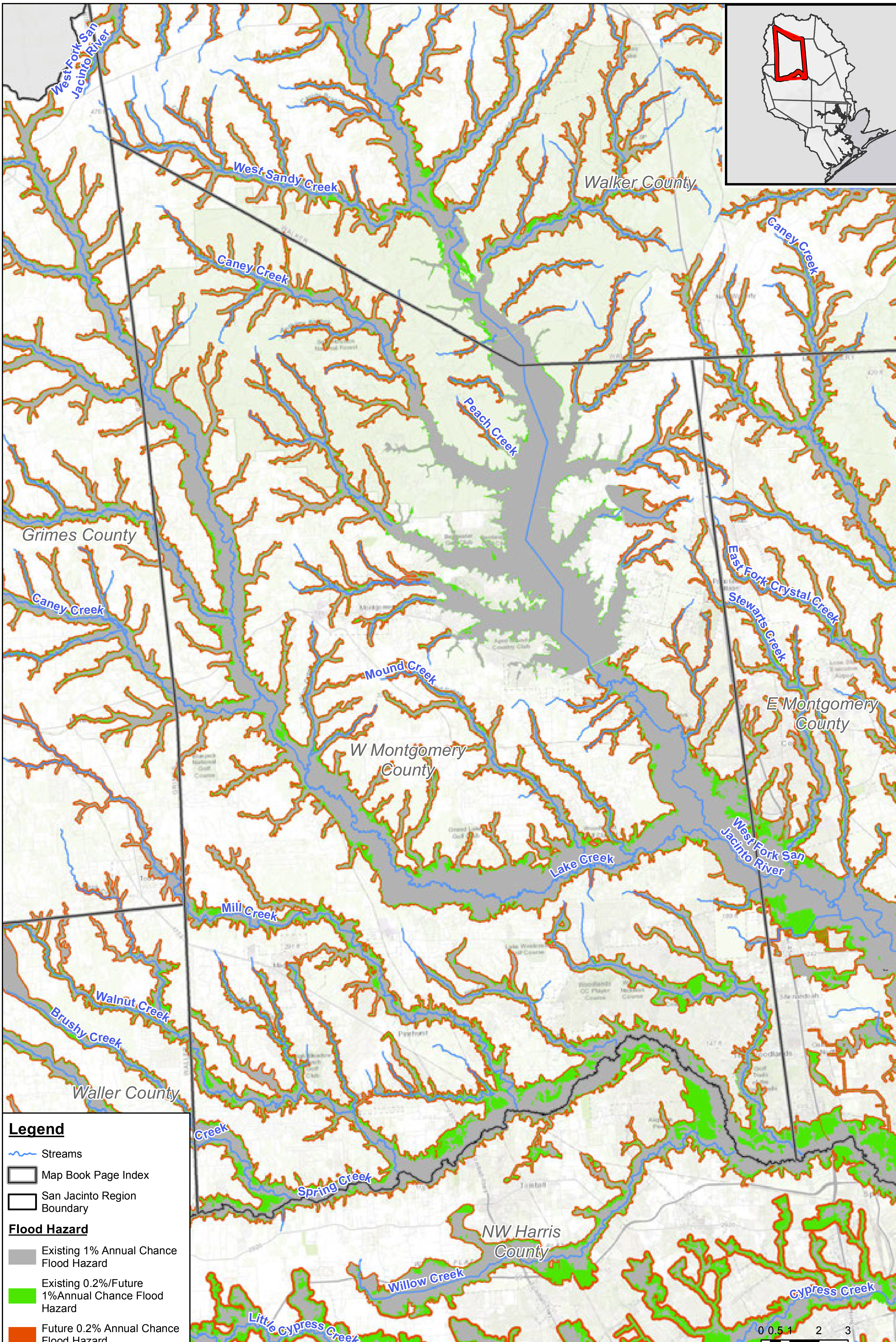
Extent of Increase of Flood Hazard Compared to Existing Condition - E Montgomery

N W E S

MAP 10

FIGURE 5 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

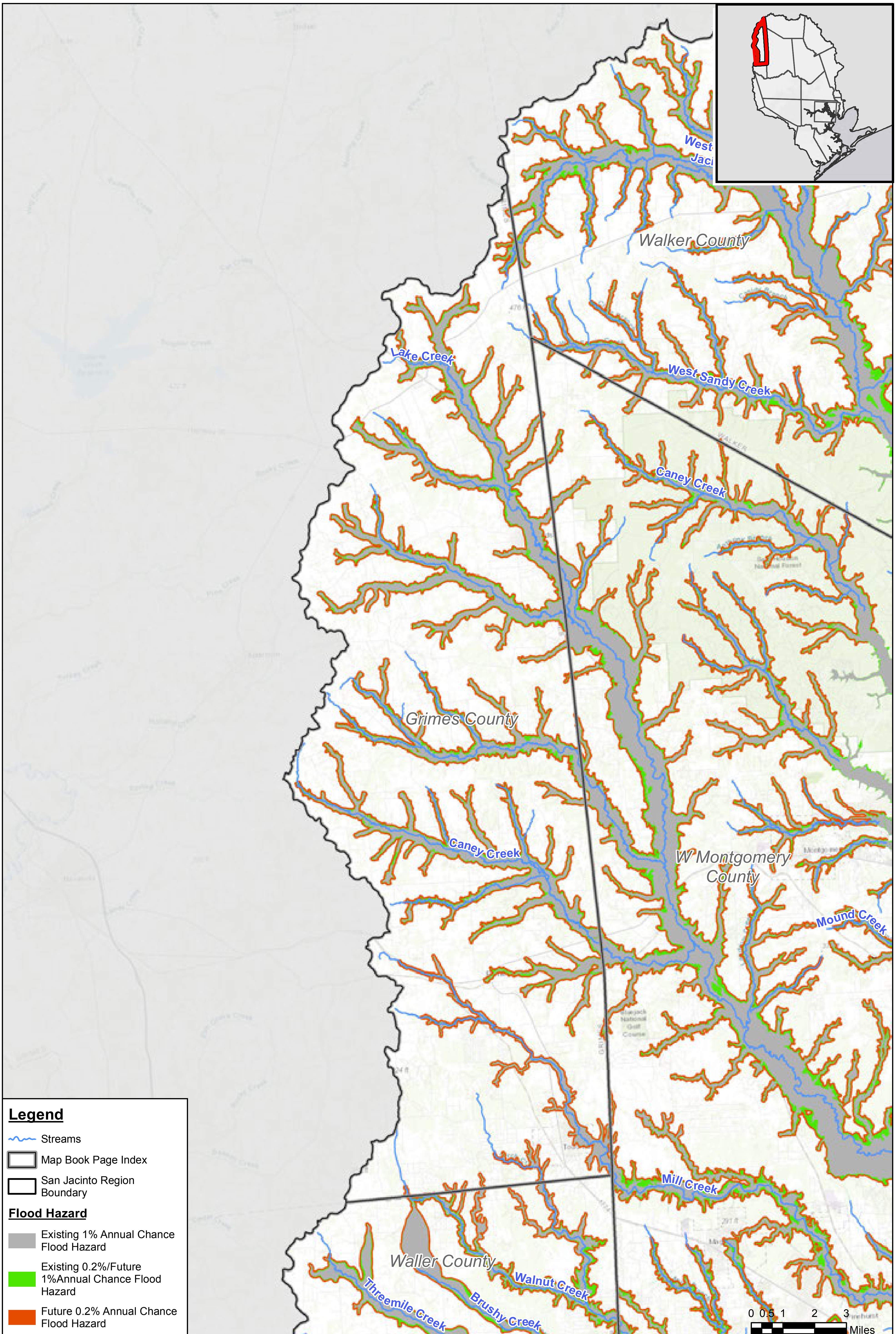
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - W Montgomery

MAP 10

FIGURE 6 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

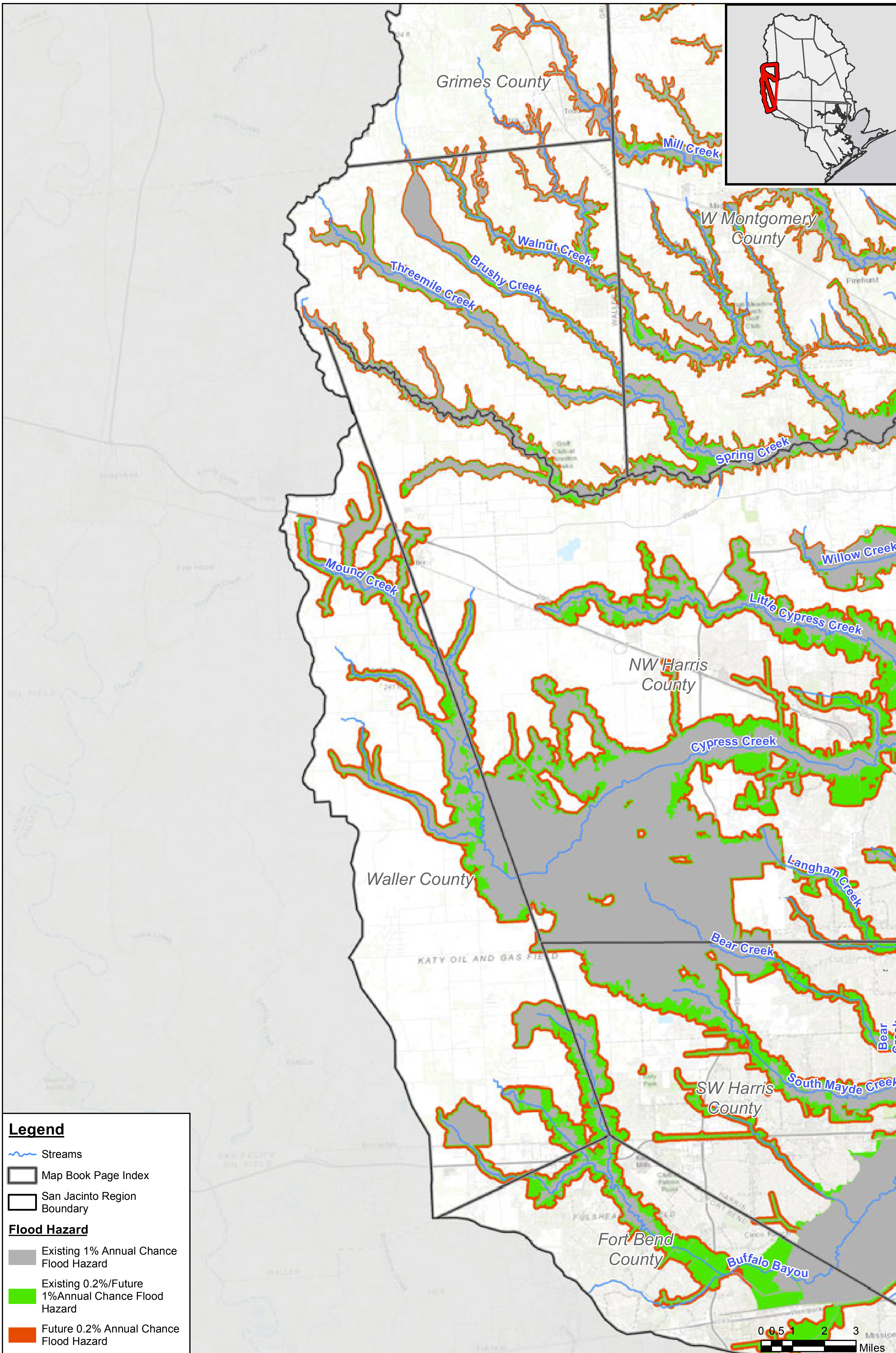
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - Grimes

MAP 10

FIGURE 7 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

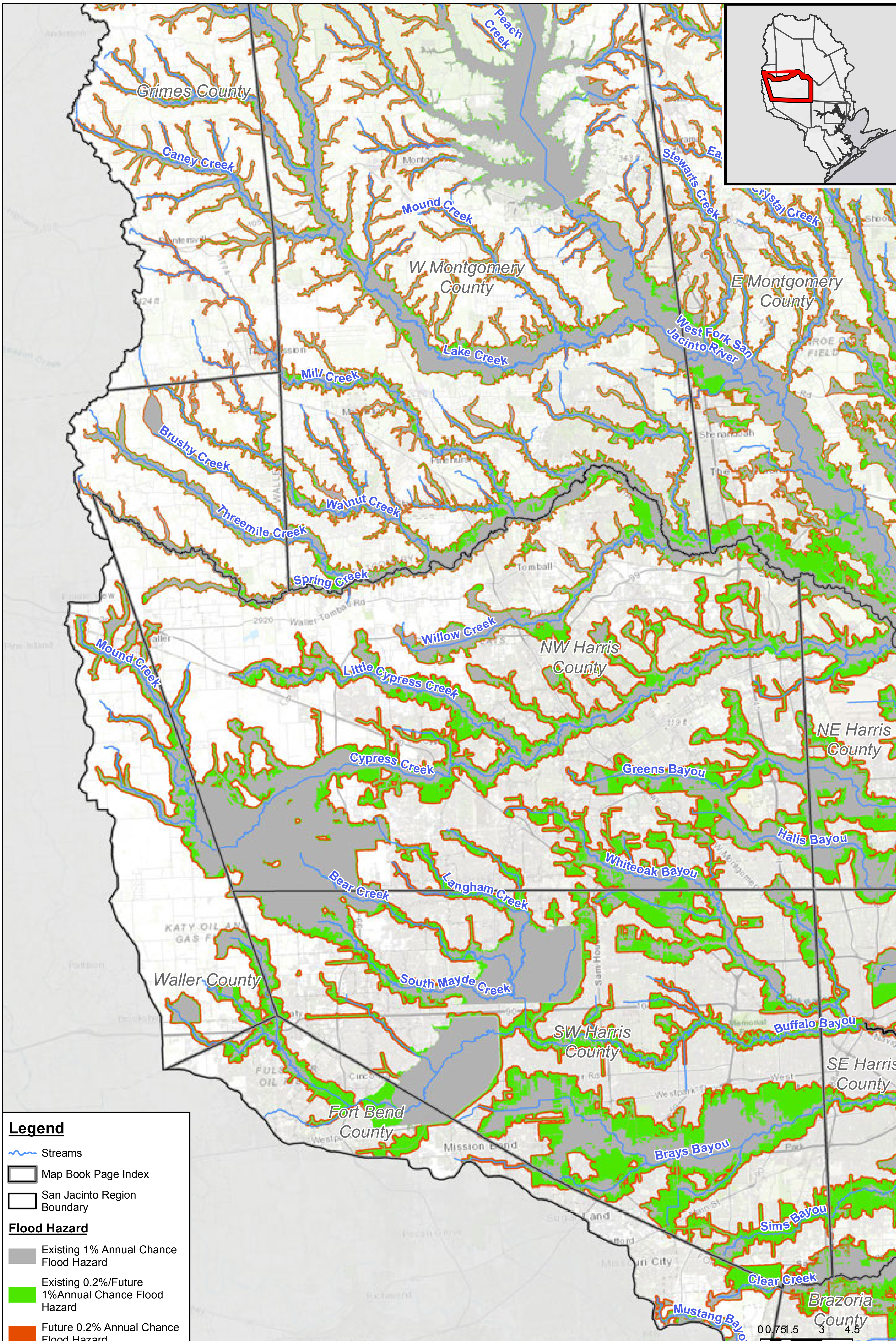
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - Waller

MAP 10

FIGURE 8 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

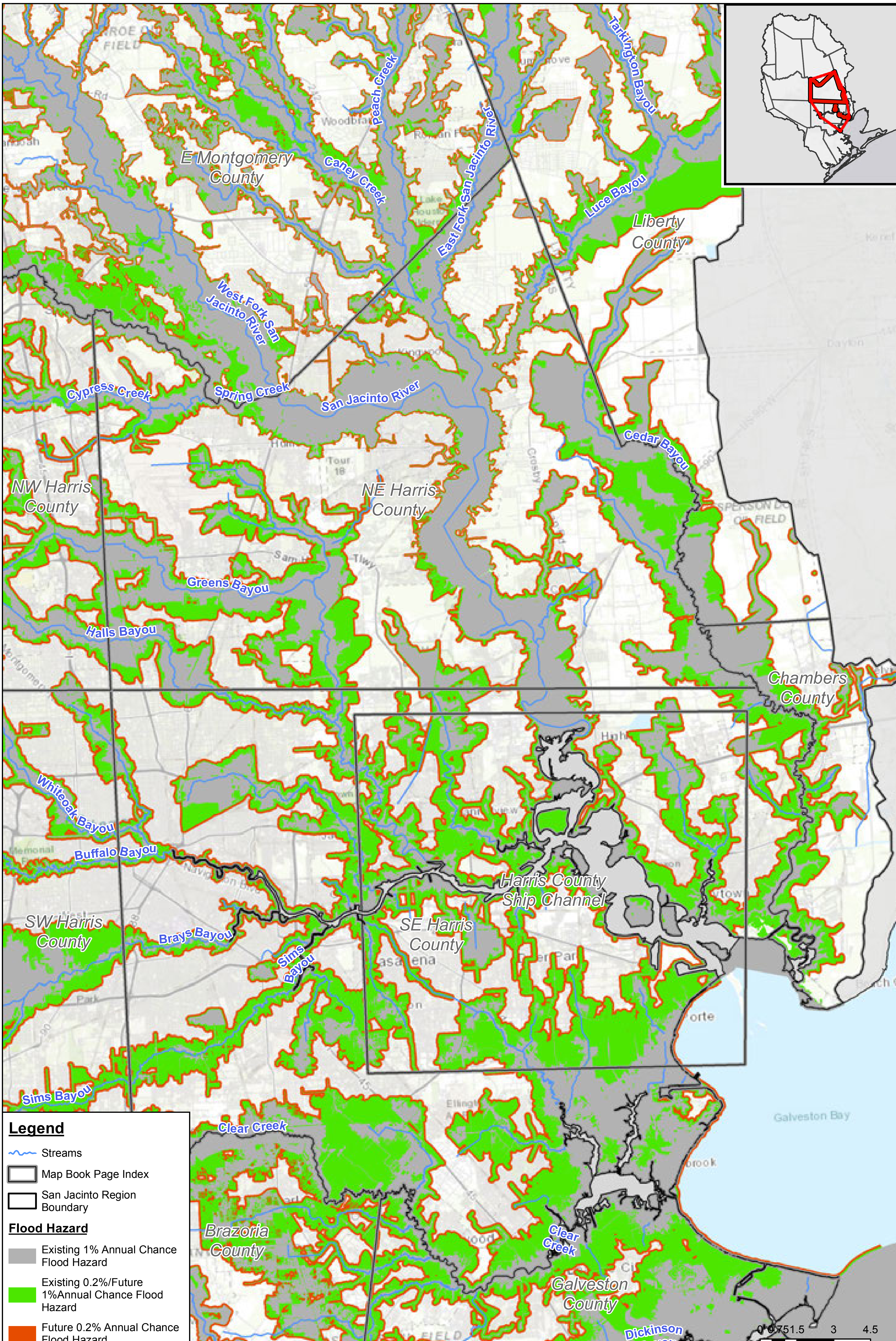
Extent of Increase of Flood Hazard Compared to Existing Condition - NW Harris

N W E S

MAP 10

FIGURE 9 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

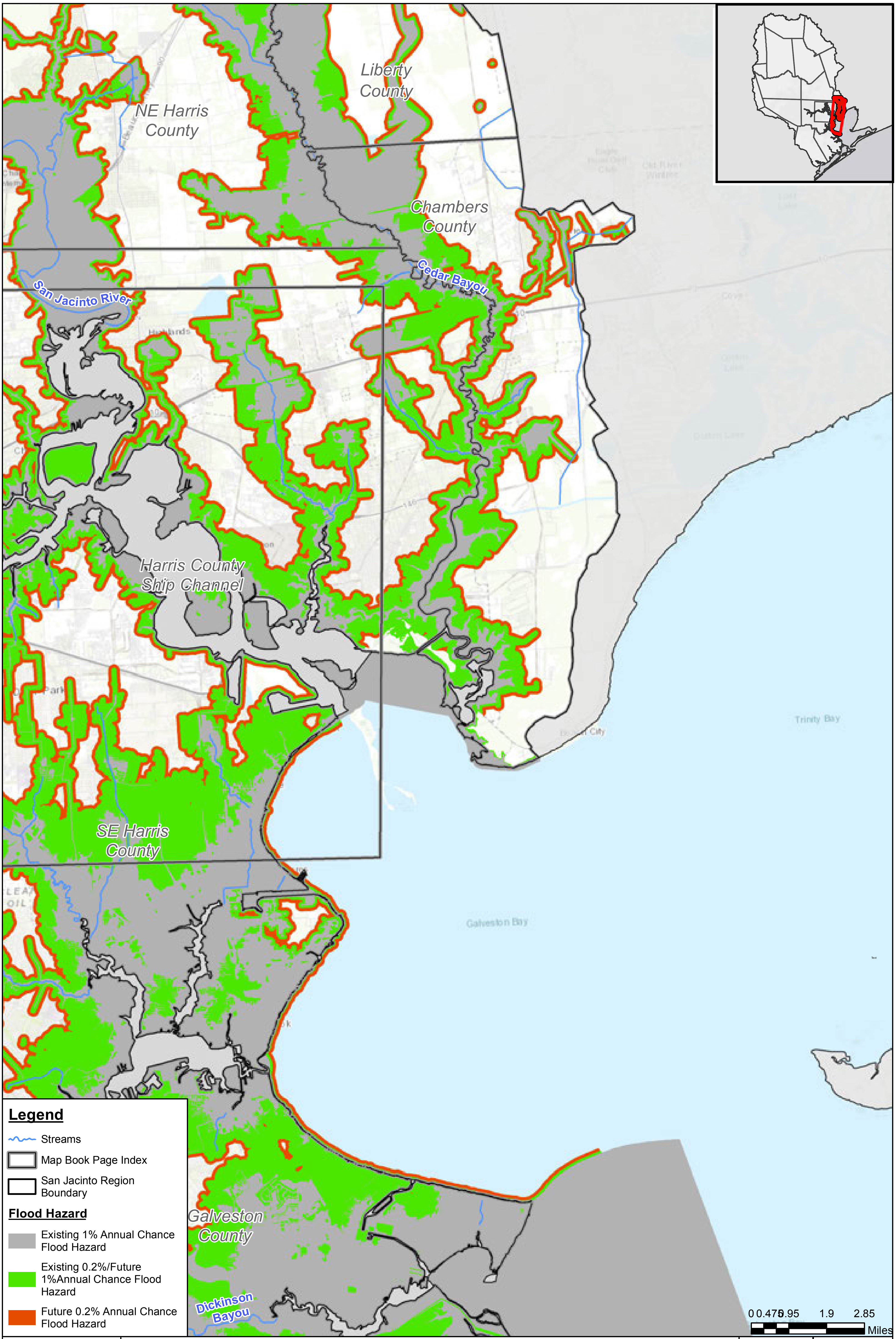
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - NE Harris

MAP 10

FIGURE
10 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



San Jacinto Regional Flood Plan

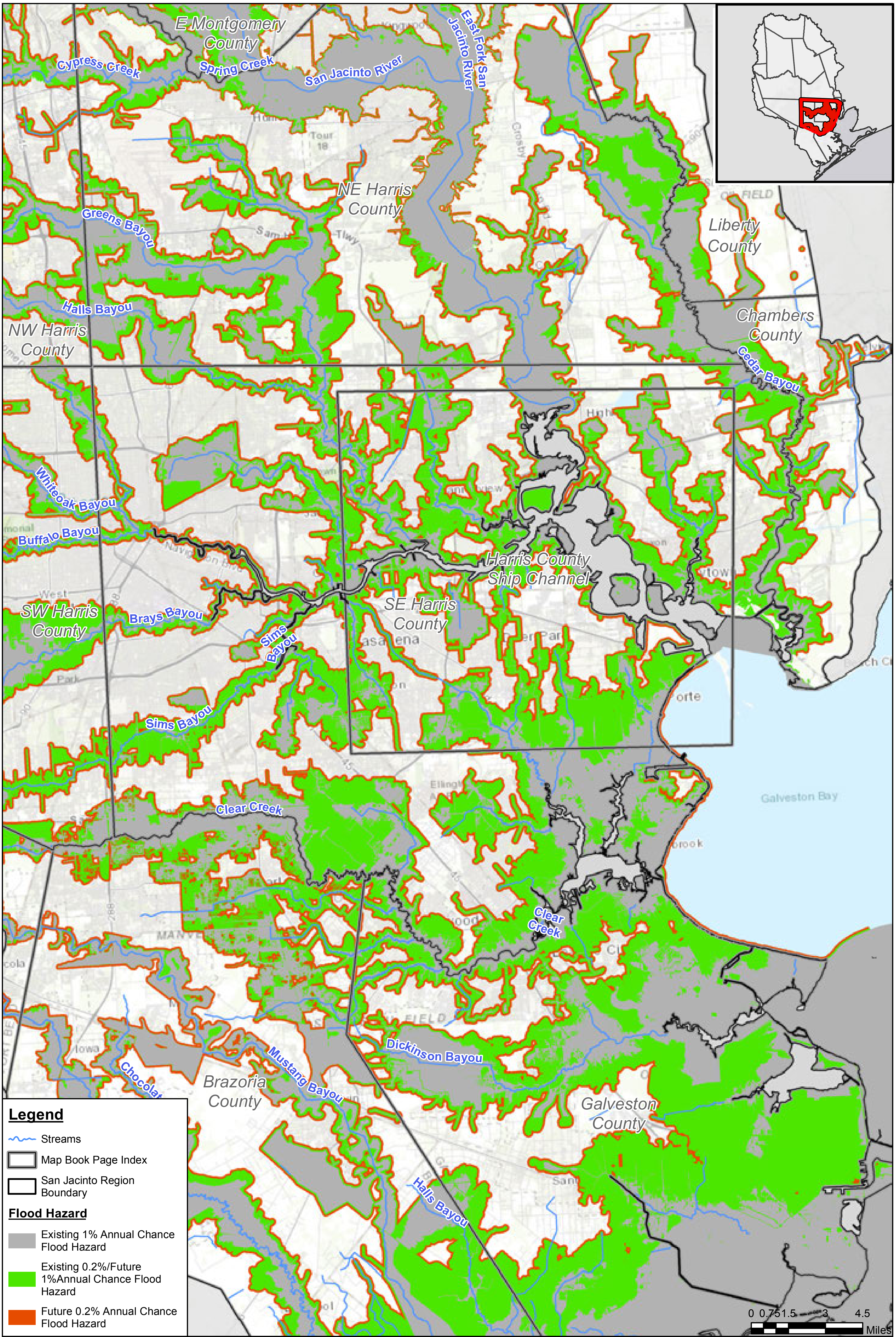
Extent of Increase of Flood Hazard Compared to Existing Condition - Chambers

SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

MAP 10

FIGURE 11 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



San Jacinto Regional Flood Plan

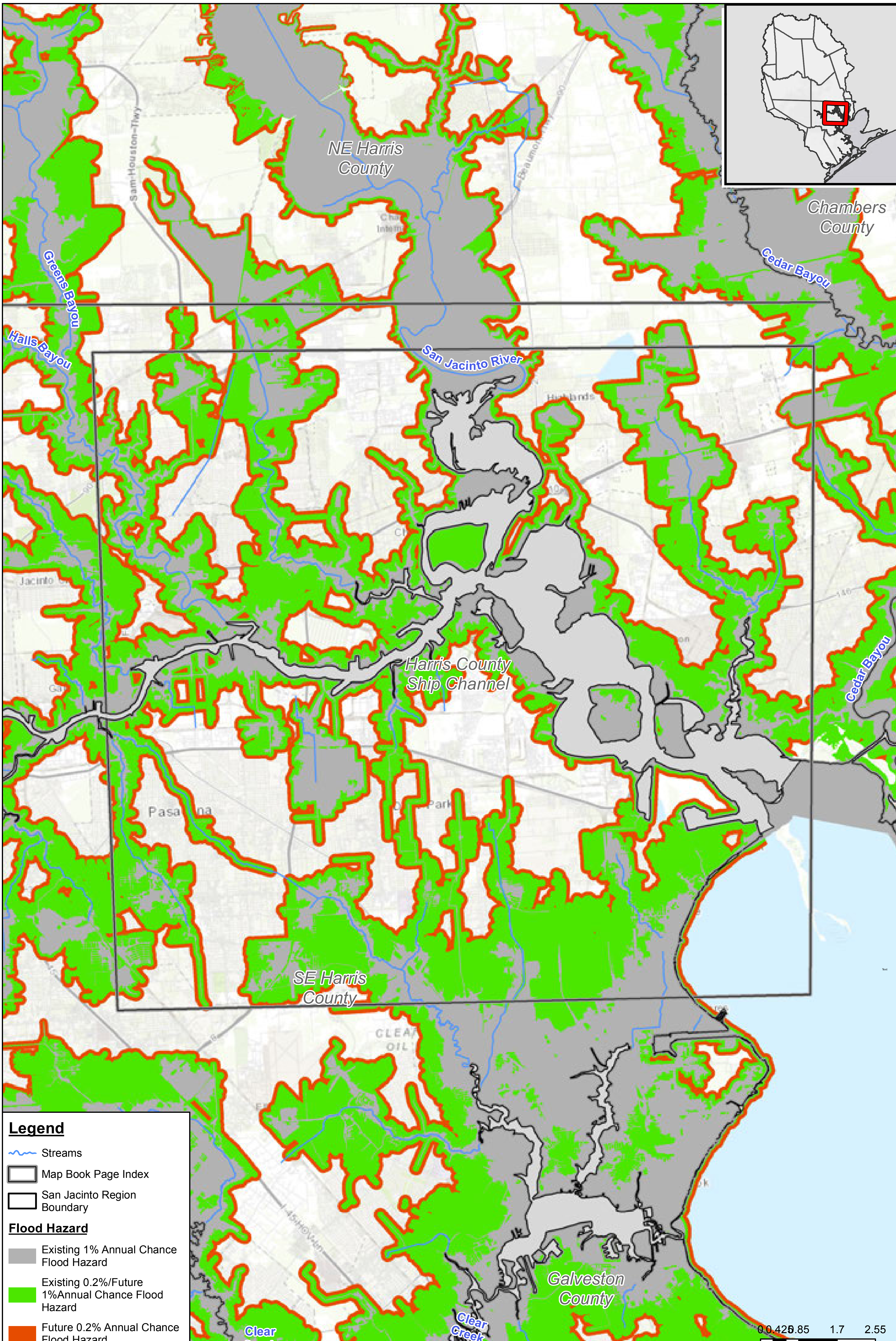
Extent of Increase of Flood Hazard Compared to Existing Condition - SE Harris

SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

MAP 10

FIGURE
12 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



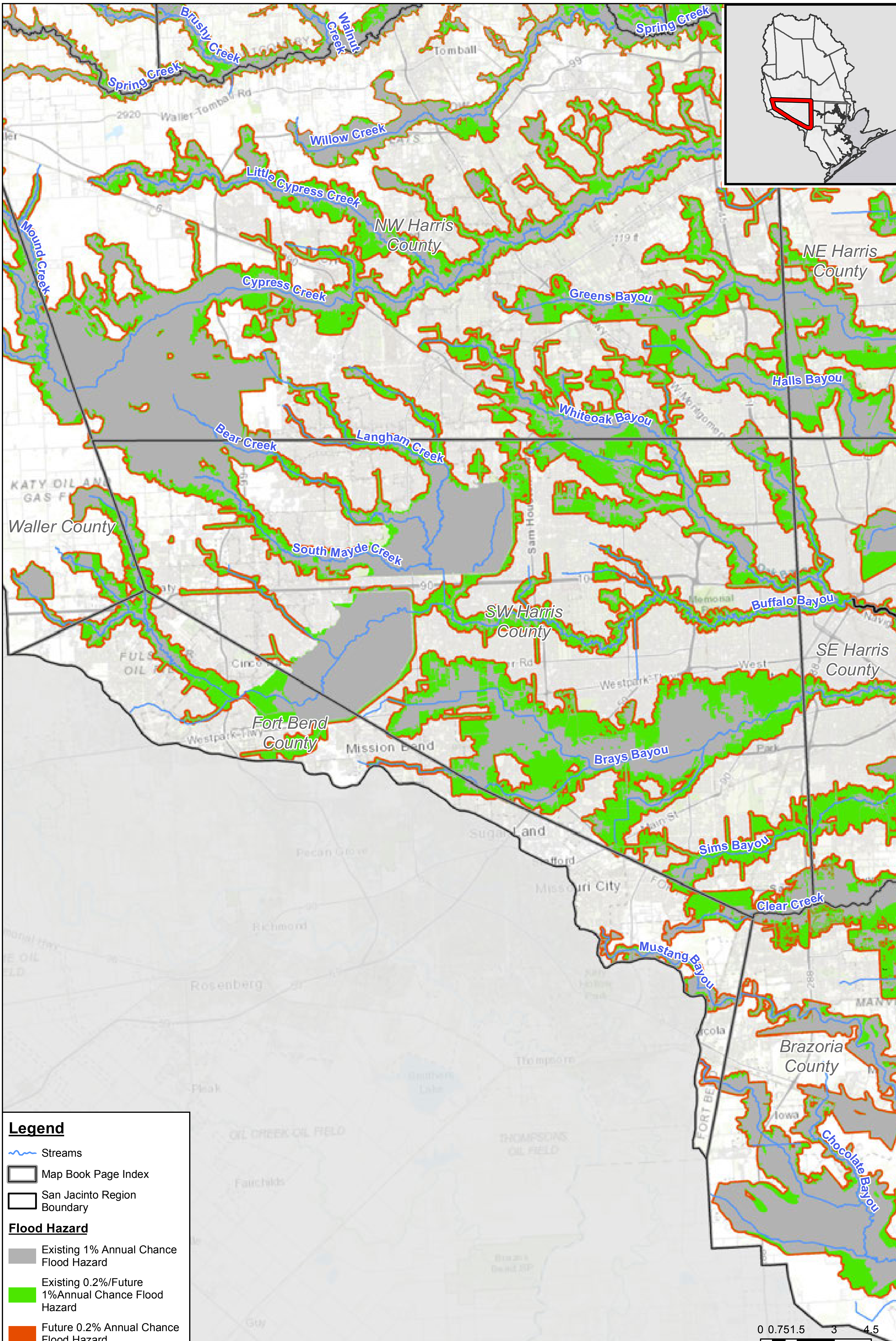
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - Ship Channel

MAP 10

FIGURE 13 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

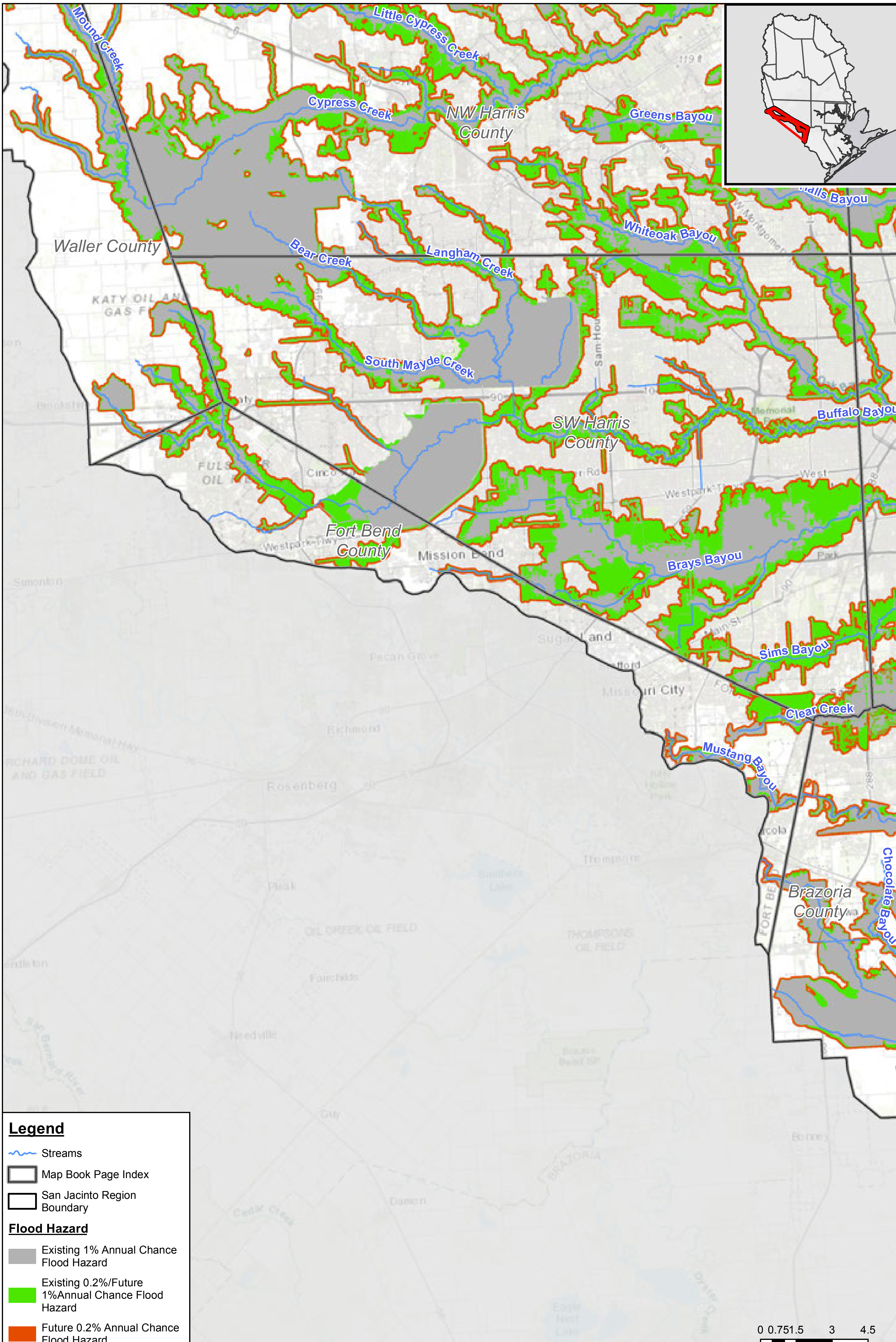
San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - SW Harris

MAP 10

FIGURE 14 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP
REGION 6

San Jacinto Regional Flood Plan

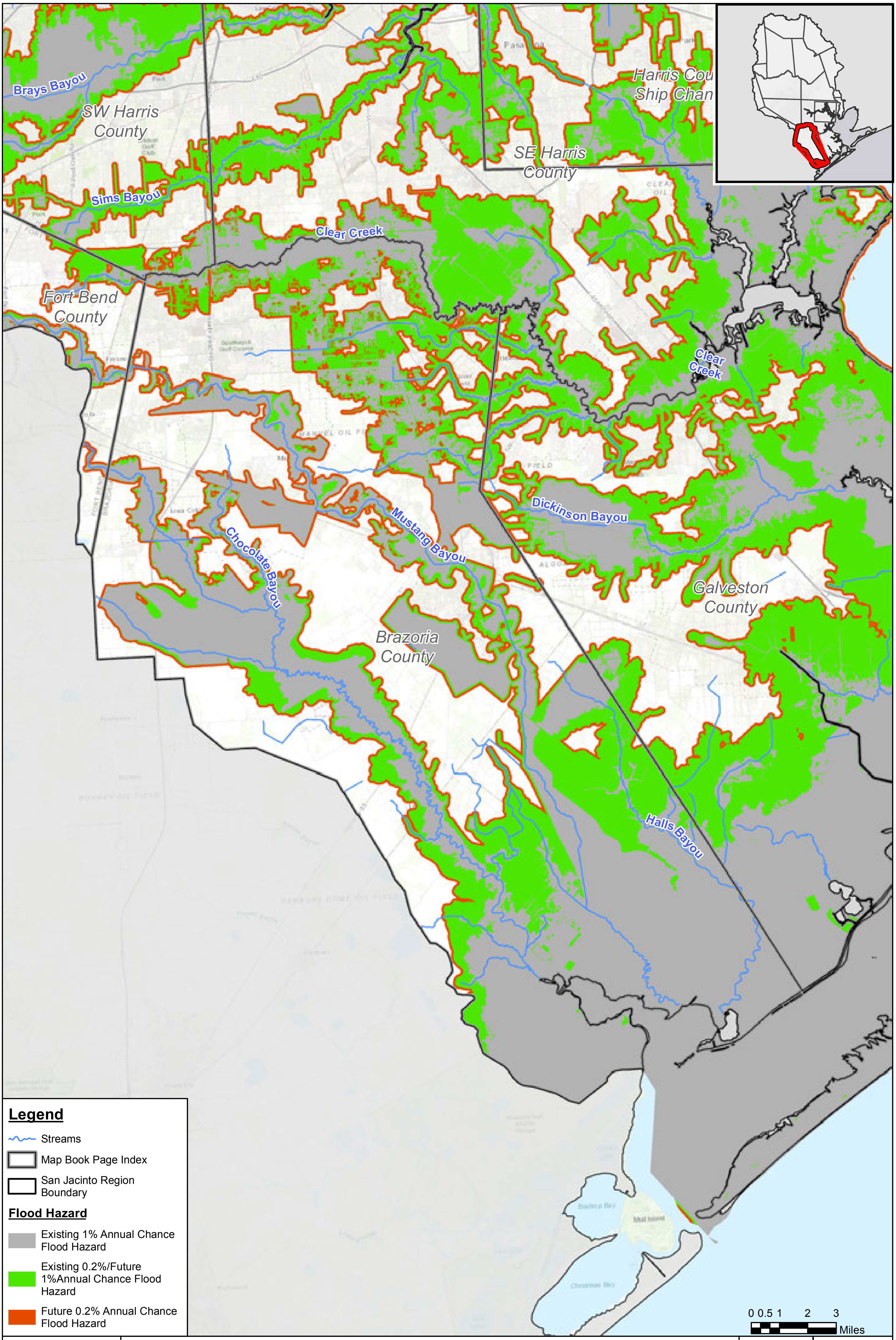
Extent of Increase of Flood Hazard Compared to Existing Condition - Fort Bend

N W E S

MAP 10

FIGURE 15 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

San Jacinto Regional Flood Plan

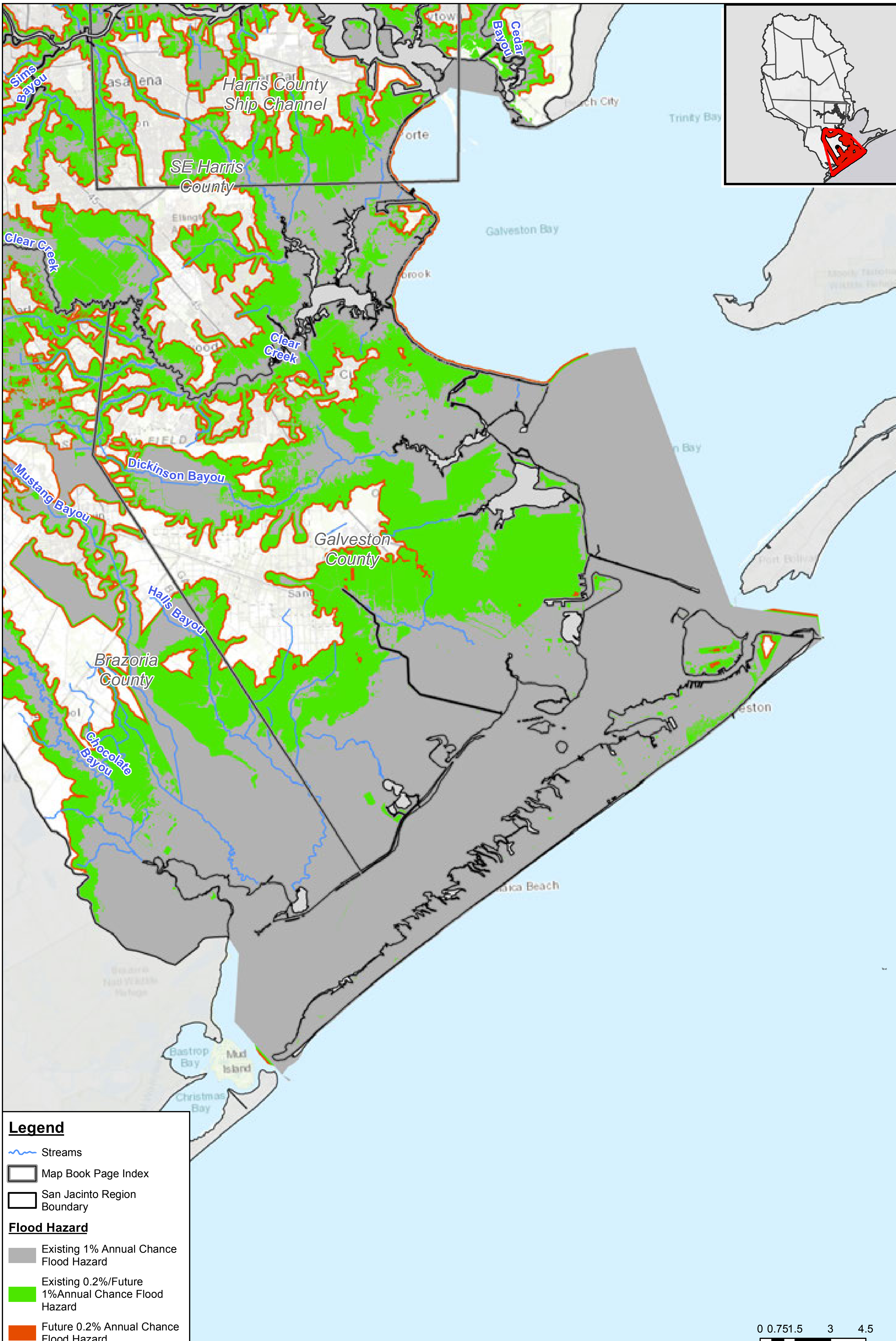
Extent of Increase of Flood Hazard Compared to Existing Condition - Brazoria

N W E S

MAP 10

FIGURE 16 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert



SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

San Jacinto Regional Flood Plan

Extent of Increase of Flood Hazard Compared to Existing Condition - Galveston

MAP 10

FIGURE 17 of 17

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert

APPENDIX 2B-4
MAP 11: FUTURE CONDITION FLOOD EXPOSURE

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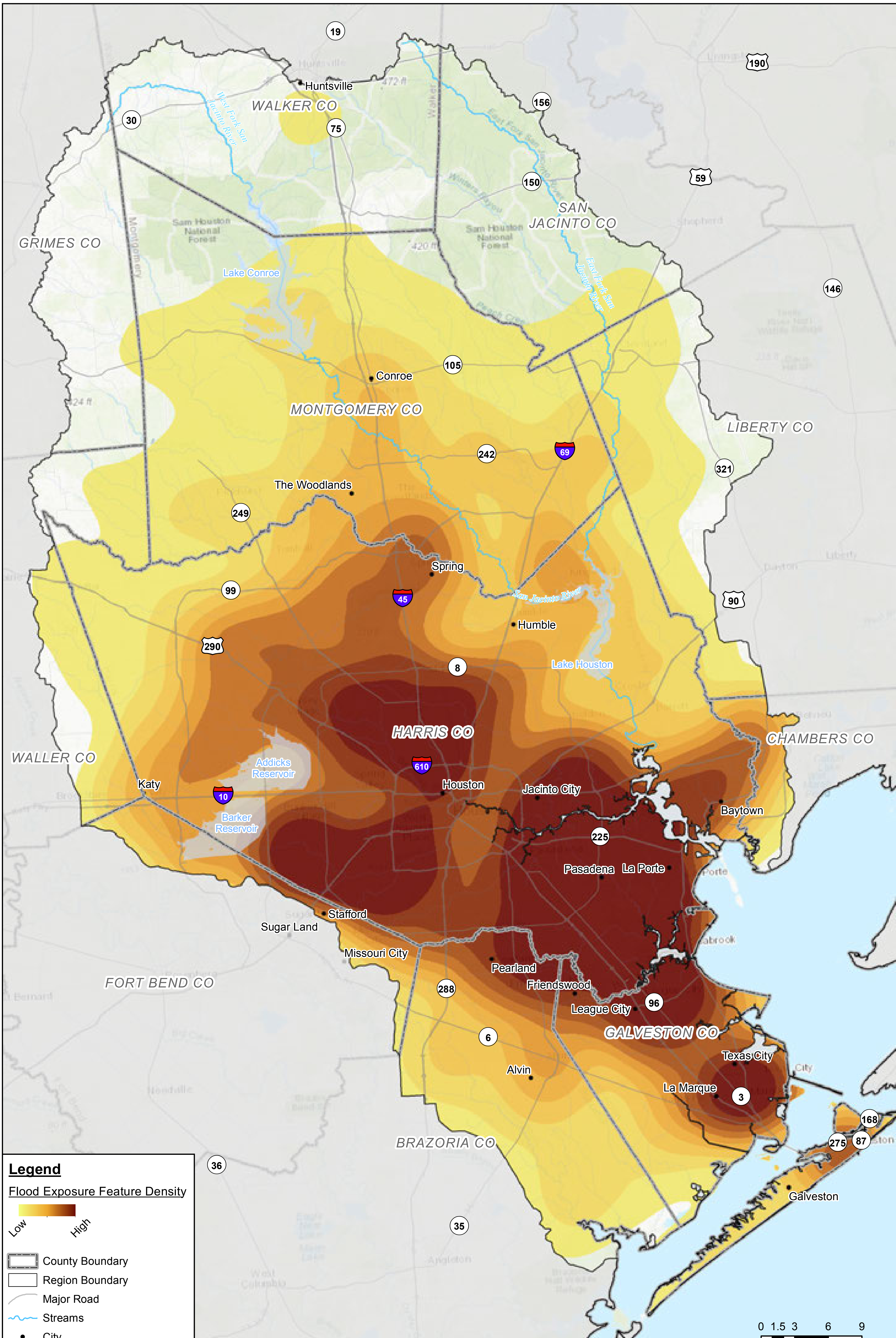

SAN JACINTO REGIONAL FLOOD PLANNING GROUP REGION 6

San Jacinto Regional Flood Plan

Future Condition Flood Exposure

MAP 11

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert

APPENDIX 2B-5

MAP 12: FUTURE CONDITION VULNERABILITY AND CRITICAL INFRASTRUCTURE

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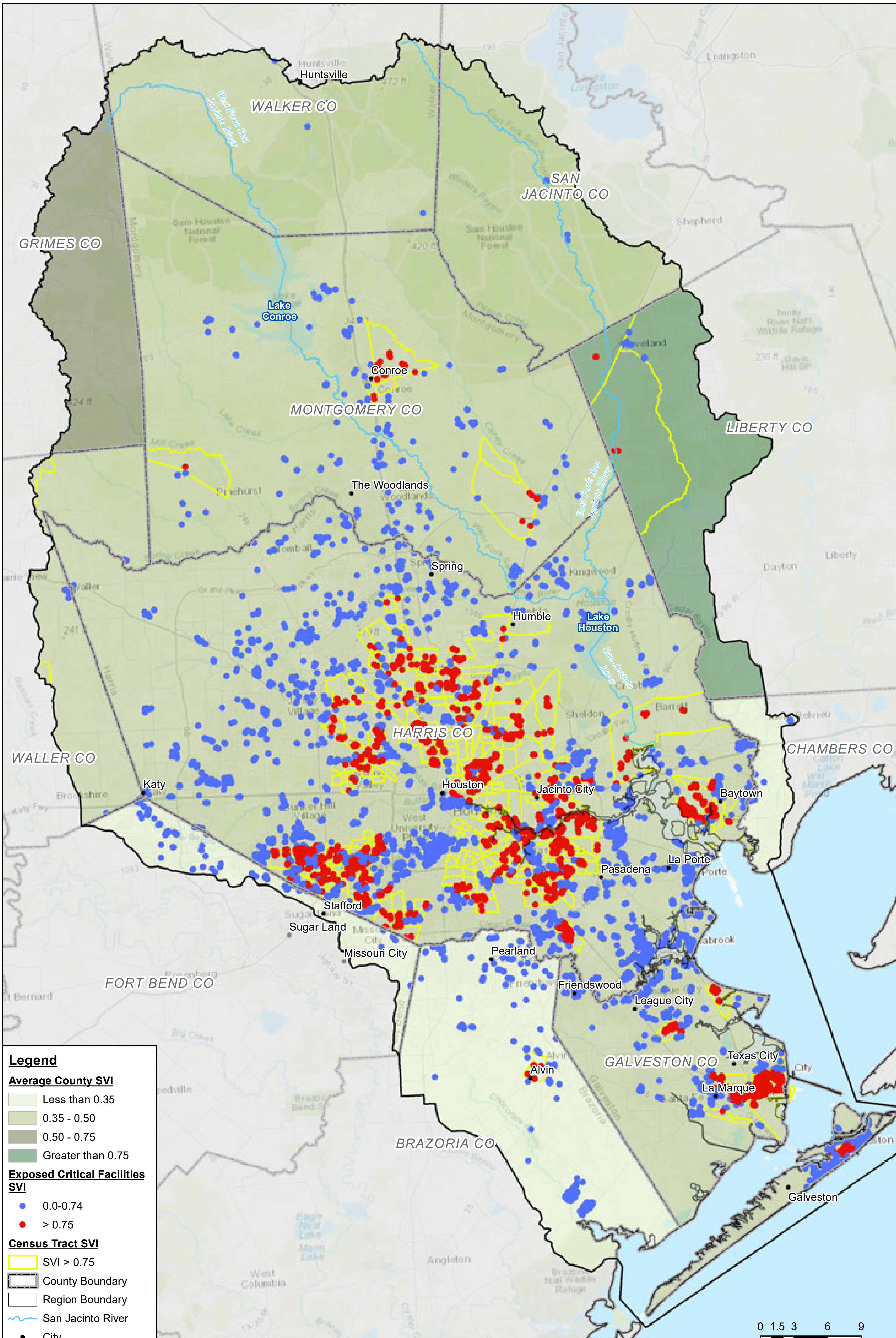

San Jacinto Regional Flood Plan

Future Condition Vulnerability and Critical Infrastructure

MAP 12

Coordinate System: NAD 1983 2011 Texas Centric Mapping System Lambert

APPENDIX 2B-6

TABLE 5: FUTURE CONDITIONS FLOOD EXPOSURE SUMMARY TABLE

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Appendix 2B-6: Table 5 - Future Condition Flood Risk Summary Table

1% Annual Chance Flood Risk														
	RFPG No.	RFPG Name	County	Area in Flood Planning Region (sqmi)	Area in Floodplain (sqmi)	Number of Structures in Floodplain	Residential Structures in Floodplain	Population (daytime)	Population (nighttime)	Population	Roadway Stream Crossings (#)	Roadways Segments (miles)	Agricultural Areas (sqmi)	Critical Facilities (#)
1	6	San Jacinto	Brazoria	368	239	39,724	32,650	86,004	92,612	92,612	516	620	21	484
2	6	San Jacinto	Chambers	54	19	1,326	642	3,166	1,887	3,166	34	29	1	21
3	6	San Jacinto	Fort Bend	98	18	11,122	10,205	29,257	35,258	35,258	140	125	0	75
4	6	San Jacinto	Galveston	350	406	112,174	97,323	233,194	257,594	257,594	762	1,814	10	1,936
5	6	San Jacinto	Grimes	206	31	252	119	115	180	180	111	19	0	0
6	6	San Jacinto	Harris	1,774	752	430,825	374,038	1,714,901	1,560,007	1,714,901	4,498	5,890	15	7,455
7	6	San Jacinto	Liberty	286	117	5,613	3,644	4,157	6,276	6,276	196	227	4	12
8	6	San Jacinto	Montgomery	1,077	345	47,994	39,587	83,001	108,423	108,423	1,236	816	2	261
9	6	San Jacinto	San Jacinto	319	84	1,493	1,344	841	1,989	1,989	154	70	0	0
10	6	San Jacinto	Walker	396	76	928	793	472	1,102	1,102	231	45	0	2
11	6	San Jacinto	Waller	194	39	2,421	1,763	2,191	4,123	4,123	127	72	3	7
Total				**5,123**	**2,125**	**653,872**	**562,108**	**2,157,299**	**2,069,451**	**2,225,624**	**8,005**	**9,726**	**56**	**10,253**

0.2% Annual Chance Flood Risk														
	RFPG No.	RFPG Name	County	Area in Flood Planning Region (sqmi)	Area in Floodplain (sqmi)	Number of Structures in Floodplain	Residential Structures in Floodplain	Population (daytime)	Population (nighttime)	Population	Roadway Stream Crossings (#)	Roadways Segments (miles)	Agricultural Areas (sqmi)	Critical Facilities (#)
1	6	San Jacinto	Brazoria	368	268	50,822	42,063	114,351	120,828	120,959	596	775	23	554
2	6	San Jacinto	Chambers	54	25	2,035	1,022	4,779	3,386	4,779	39	43	1	24
3	6	San Jacinto	Fort Bend	98	28	21,830	20,427	53,869	69,174	69,174	185	234	1	178
4	6	San Jacinto	Galveston	350	421	122,166	106,589	252,683	283,875	283,875	811	1,942	11	2,013
5	6	San Jacinto	Grimes	206	49	752	351	352	670	670	130	40	0	0
6	6	San Jacinto	Harris	1,774	924	599,777	525,312	2,259,872	2,116,997	2,271,891	5,057	7,864	19	9,642
7	6	San Jacinto	Liberty	286	136	7,397	4,816	6,376	8,959	8,959	211	286	5	19
8	6	San Jacinto	Montgomery	1,077	451	80,730	67,231	154,118	185,649	185,649	1,480	1,302	2	463
9	6	San Jacinto	San Jacinto	319	117	2,691	2,384	1,610	3,711	3,711	172	104	0	6
10	6	San Jacinto	Walker	396	116	2,563	2,201	1,946	3,431	3,431	294	110	1	5
11	6	San Jacinto	Waller	194	54	4,349	3,068	5,073	7,604	7,604	134	116	4	18
Total				**5,123**	**2,589**	**895,112**	**775,464**	**2,855,029**	**2,804,284**	**2,960,702**	**9,109**	**12,814**	**66**	**12,922**

Possible Flood Prone Areas												
	RFPG No.	RFPG Name	County	Area (sqmi)	Number of Structures in Flood Prone Area	Residential Structures in in Flood Prone Area	Population	Roadway Stream Crossings (#)	Roadways Segments (miles)	Agricultural Areas (sqmi)	Critical Facilities (#)	Average SVI of features in floodplain or flood prone areas
1	6	San Jacinto	Brazoria	0	0	0	0	0	0	0	0	0.33
2	6	San Jacinto	Chambers	0	0	0	0	0	0	0	0	0.26
3	6	San Jacinto	Fort Bend	0.19	126	123	359	0	2	0	0	0.31
4	6	San Jacinto	Galveston	0	0	0	0	0	0	0	0	0.43
5	6	San Jacinto	Grimes	0	0	0	0	0	0	0	0	0.58
6	6	San Jacinto	Harris	0.70	502	461	1,401	2	8	0	1	0.48
7	6	San Jacinto	Liberty	0	0	0	0	0	0	0	0	0.75
8	6	San Jacinto	Montgomery	0	153	134	316	0	4	0	3	0.38
9	6	San Jacinto	San Jacinto	0.07	28	27	78	0	0	0	0	0.49
10	6	San Jacinto	Walker	0	0	0	0	0	0	0	0	0.40
11	6	San Jacinto	Waller	0.03	0	0	0	0	0	0	0	0.42
Total				**1.25**	**809**	**745**	**2,154**	**2**	**13**	**0**	**4**	**-**

APPENDIX 2B-7
TASK 2B – FUTURE CONDITION FLOOD RISK ANALYSIS TECHNICAL MEMORANDUM

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TECHNICAL MEMORANDUM

TO:	Texas Water Development Board	DATE:	February 23, 2022 April 8, 2022 (revised) May 15, 2022 (revised)
Submitted on Behalf of:	San Jacinto Regional Flood Planning Group		
SUBJECT:	Task 2B – Future Conditions Flood Risk Analysis		

Introduction

For the 2020 – 2023 planning cycle, the Regional Flood Planning Groups (RFPGs) were tasked with performing a future condition flood analysis to determine the potential extent of both the 1-percent (100-year) and 0.2 percent (500-year) annual-chance flood hazard based on a 30-year future forecast period. The estimated flood hazard changes will be used solely for the purpose of estimating the general magnitude of potential future increases in flood risk under the equivalent of a "do-nothing" or "no-action" alternative and within the regional flood planning context will not, in any way, be used for developing new flood hazard maps for any regulatory purposes.

The first step of the task was to identify areas within each Flood Planning Region (FPR) where future condition hydrologic and hydraulic model results and maps are available and to summarize the relevant information for use in determining future flood hazard. In areas where future condition flood hazard data is not available, Exhibit C of the Technical Guidelines for Regional Flood Planning outlines the following four methods for performing future condition flood identification, which are summarized in **Table 1** below.

Table 1: TWDB Future Conditions Flood Hazard Methodology

Method	Description	Explanation
1	Increase water surface elevation based on projected percent population increase (as proxy for development of land areas)	Method 1 involves making certain assumptions about development, and then estimating correlations between impervious cover changes and changes to flood elevations. These results would vary based on a watershed's land use, soil type, and topography. The TWDB acknowledges that population increases do not always lead to impervious cover increases, but this simplified approach can be utilized if desired.
2	Utilize the existing condition 0.2 percent annual chance floodplain as a proxy for the future 1 percent level	Method 2 utilizes existing modeling and mapping to create the future condition 1% annual exceedance flood hazard. However, it does not yield a future 0.2% flood hazard area, so a methodology will need to be determined by the Regional Flood Planning Group on determining the future 0.2% flood hazard area. The TWDB notes that this method may be more appropriate in areas with high growth rates that are categorized as urban or suburban.
3	Combination of methods 1 and 2 or an RFPG-proposed method	Method 3 is a combination of the first two methods, and (as with the other methods), the rational/determination should be well-documented.
4	Request TWDB perform a Desktop Analysis	Method 4 has the TWDB perform a desktop analysis to determine the future condition flood hazard boundaries. This would be primarily utilized in areas where the locations do not have future condition flood hazard data already available.

Future Conditions Flood Risk Considerations

Changes in flood risk are dependent on a variety of factors. The changes in the riverine floodplain boundaries may be influenced by future development, population growth, and future rainfall patterns. Development causes a change in land use and alters existing drainage patterns, which may result in an increase in downstream flow rates and runoff volumes as well as differences in the timing of peak discharges. With the increased flow rates and runoff volumes, water surface elevations and floodplain widths may also increase. However, many municipalities and counties in the region have development retention/detention requirements to reduce and mitigate increases in stormwater runoff. The changes in coastal floodplain boundaries may be due to storm surges, sea level change, subsidence, and coastal erosion.

Increased flow due to future rainfall patterns results in larger changes in water surface elevation and limited changes in inundation extents in areas with steep terrain. Alternatively, the increased flow results in smaller changes in water surface elevations and larger changes in inundation extents in areas with flat terrain. Since varying terrain is common throughout the region, varying results were seen for the floodplain comparisons.

The region was divided into three different zones to represent varying watershed characteristics and different driving factors affecting change in flood hazard to more appropriately estimate the future flood hazard. The zones were designated as northern, southern, and coastal as shown below in **Figure 1**.

The northern zone includes the areas within Montgomery, Grimes, Walker, Waller, Harris, San Jacinto, and Liberty Counties that flow into Lake Houston. This area is characterized by rural development and rolling hill topography which is steeper than the other zones. The Southern Zone includes mostly Harris County and watersheds that drain into the Houston Ship Channel. This zone is characterized by urban development with flat terrain that is mostly influenced by riverine flooding. The Coastal Zone includes the areas that drain into Galveston Bay in Galveston, Brazoria, Fort Bend, Chambers, and southern Harris Counties. This zone is characterized by flat and coastal topography that experiences both riverine as well as coastal storm surge flooding.

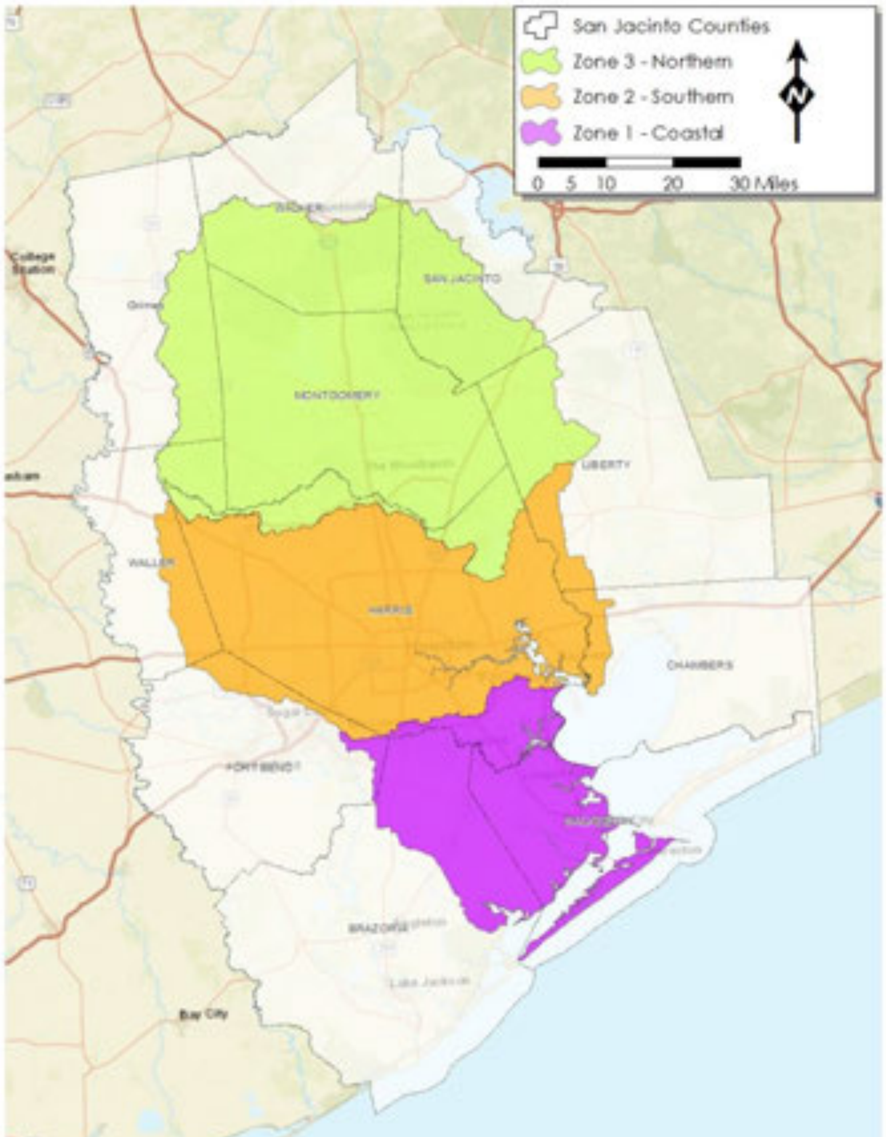

Figure 1: San Jacinto Zone Designations

When developing a predicative assessment for future conditions flood risk, the Texas Water Development Board (TWDB) suggested each region consider several factors which included: increase in population, future rainfall patterns, sea level rise, and subsidence.

Population Increase

The TWDB's Water User Group projects that within the next 30 years, the population in the Water Planning Region H would increase by 3.5 million residents. This would lead to an approximate population increase of 37% between 2020 and 2050. This includes an additional 1.9 million residents in Montgomery, Harris, Galveston, and Brazoria Counties (a 30% increase). Although the boundaries of Region H are not exactly the same as the boundaries of Region 6 of the Regional Flood Planning Groups, the population estimates are an appropriate indication of the changes that the region will see over the next 30 years. **Figure 2** shows the boundaries of Region H in comparison to the boundaries of Region 6.

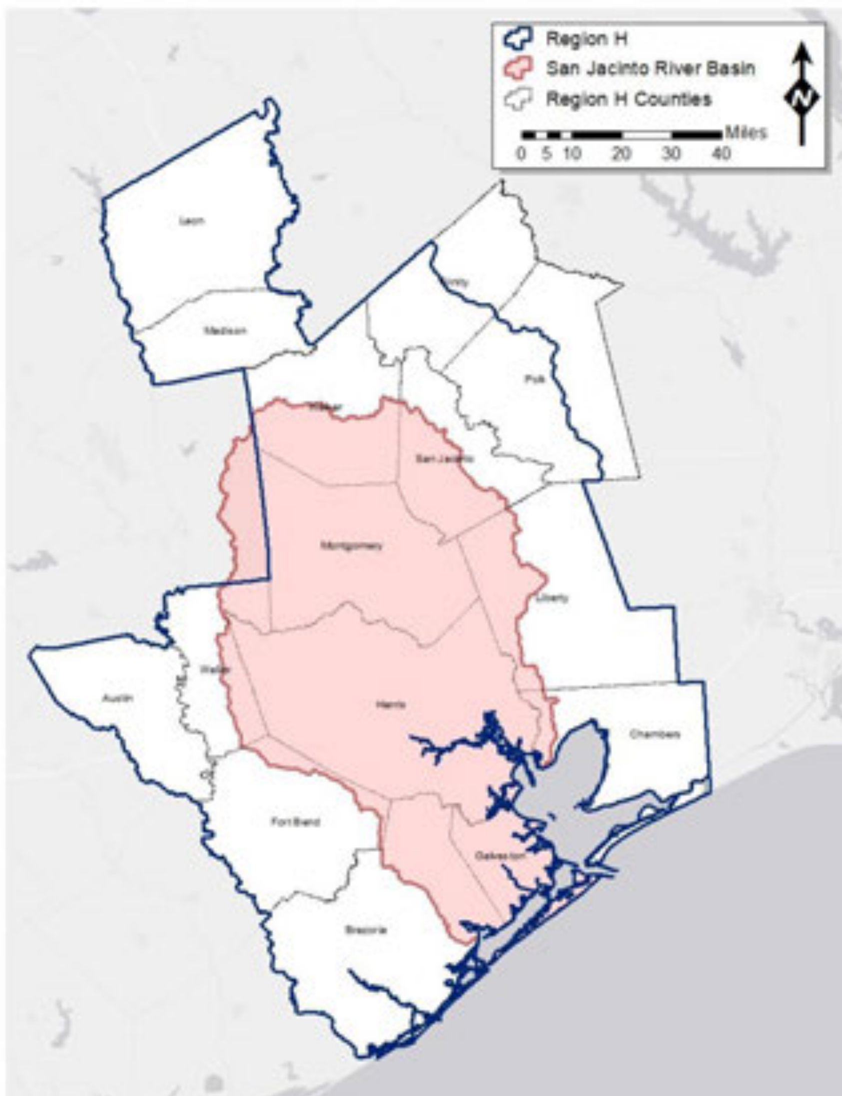

Figure 2: Region H and Region 6 Boundaries

Future Rainfall Patterns

Projected future rainfall patterns can also have an impact on identifying future flood risk. In 2018, the National Oceanic and Atmospheric Administration (NOAA) updated rainfall depths and durations based on an analysis of historical data including the past 20 years. That information was published as NOAA Atlas 14, Volume 11 Precipitation-Frequency Atlas. The Texas coast saw a 10-15% increase in annual precipitation between 1991 and 2012 compared to the average annual precipitation between 1901 and 1960[1].

To aid the RFPGs, the Office of the Texas State Climatologist provided TWDB with guidance on how to incorporate projected future rainfall patterns in their April 16, 2021 report, titled "Climate Change Recommendations for Regional Flood Planning." The report states that 1-day, 100-year rainfall depths increased by approximately 15% between 1960 and 2020. The climatologist coupled historical rainfall data with results from climate models to develop a relationship between extreme rainfall depths and future increases in global temperature. Percent increase in future precipitation was developed for both urbanized and rural watershed conditions. Due to the uncertainty of predicting weather patterns for extreme rainfall events[2], the climatologist provided a minimum and maximum range for estimating future rainfall patterns. The climatologist found even more uncertainty when analyzing rural and large river catchments due to future decreases in soil moisture. This led them to providing a percent decrease as a minimum range. The report did not mention storm events under the 100-year rainfall (for instance, the 10- or 25-year storm events), but this information could be available for analysis during future flood planning phases.

The climatologist recommendations for future percent rainfall patterns are provided in **Table 2**. The table presented below was taken from the climatologist's report and applies to the increase over Atlas 14 runoff volumes across the entire state. In order to be within the range proposed by the climatologist, the averaged maximum for urban and rural areas of 15% was used for modeling efforts to account for the varying types of land use within the San Jacinto watershed.

Table 2: Range of Potential Future Rainfall Patterns

	2050 - 2060	
Location	**Minimum**	**Maximum**
Urban Areas	12%	20%
Rural Areas / River	-5%	10%

Sea Level Rise

Along with a growth in population and future rainfall patterns, sea level rise (SLR) was taken into consideration when estimating future flood hazard boundaries. SLR is an ongoing phenomenon where the relative ocean elevation is increasing and encroaching on coastal areas. Historical SLR has been analyzed by the Texas State Climatologist, Dr. Nielsen-Gammon, and the analysis has shown that the relative SLR increases at approximately 6.59 millimeters per year (0.65 feet in SLR over 30 years) in Galveston Bay at the Pier 21 measurement station.

[1] "Climate Change and Sea-Level Rise Effects for the HSC ECIP Feasibility Study", USACE.

[2] Typically defined as the 100- and 500-year storm events.

Subsidence

Subsidence is the gradual lowering of the ground elevation that can result from changing groundwater levels or increases in sediment loadings. Approximately 250 GPS stations are currently monitoring subsidence within the San Jacinto River Basin, operated by the Harris-Galveston Subsidence District (HGSD), Fort Bend Subsidence District (FBSD), University of Houston, Lone Star Groundwater Conservation District (LSGCD), Brazoria County Groundwater Conservation District (BCGCD), Texas Department of Transportation (TxDOT), and other local entities. The subsidence was examined in the same three zones that were defined earlier: northern, southern, and coastal. Much of the subsidence is observed in the northern and southern zones of the region, as shown in **Figure 3**.

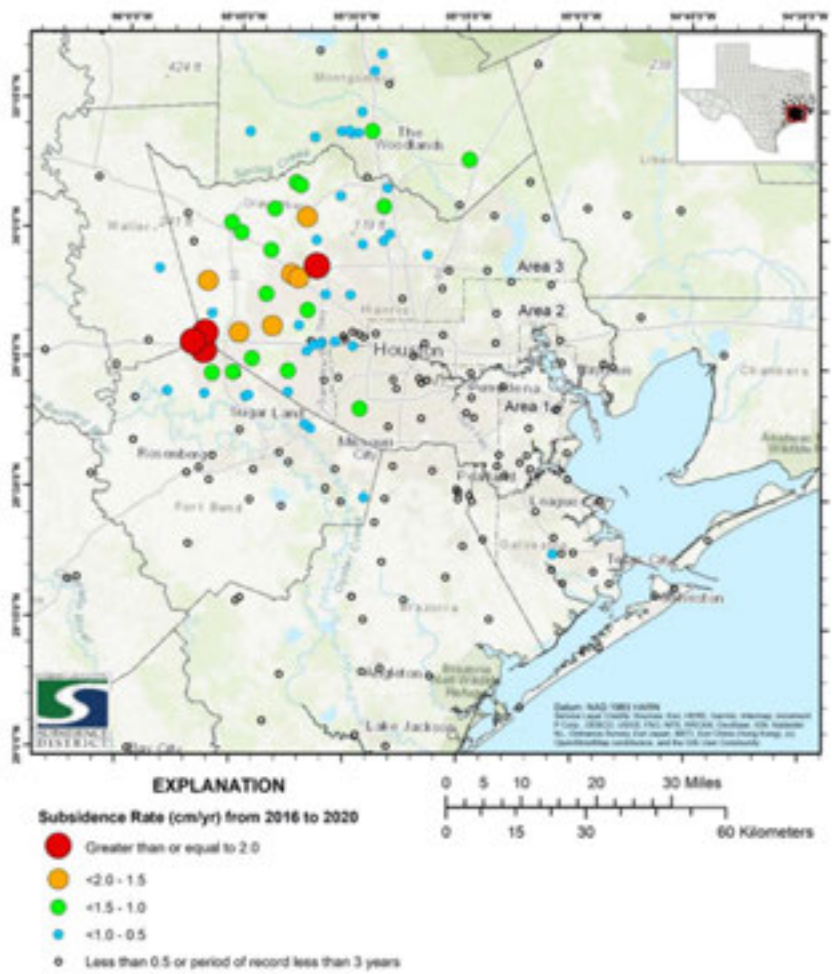

Figure 3: San Jacinto Region Average Subsidence Rates from 2016 to 2020 (HGSD 2021)

Existing Data

Available hydrologic and hydraulic models containing future flood risk data were compiled and analyzed to obtain a better understanding of how future conditions affect future flood risk within Region 6. The models collected included those related to the San Jacinto Regional Watershed Master Drainage Plan (SJRMDP) which were developed in 2020 and the FEMA Effective Modeling within Harris County developed in the early 2000s. Results from these models served as a reference to guide the estimation of how future flood risk considerations impact flood hazard elevations and widths when compared to existing conditions.

San Jacinto Regional Flood Plan

Overview

In 2020, the HCFCD, City of Houston, Montgomery County, and San Jacinto River Authority completed the SJRMDP, a comprehensive plan for all major streams in the upper San Jacinto River basin. The SJRMDP included updated existing conditions hydrologic and hydraulic models for the main streams within the watershed as well as a high-level analysis of future floodplains as the region continues to grow. These models incorporate new software technology, the latest terrain information and Atlas 14 rainfall, and were calibrated to recent storm events. With these enhancements, this plan represents the most up-to-date flood hazard information for the watershed.

Existing Conditions

To understand and identify the existing issues throughout the watershed, a comprehensive hydrologic and hydraulic model was developed for the thirteen major streams. The model incorporated existing available models within Harris County and new models for the remaining streams. The combined comprehensive model was calibrated for several historical storm events including Hurricane Harvey to ensure the analysis provided reasonable results when compared to observed data. The deliverables included models and digital floodplains for the region that were used in project planning efforts.

Future Conditions

The SJRMDP future conditions included changes in land use based on a 50-year population outlook that was accounted for through increased impervious cover in anticipated development areas. The future conditions models reflect anticipated changes in population between 2020 and 2070, which are expected to lead to increases in impervious cover and changes in the timing of basin runoff. While these models were developed for the purpose of high-level planning, they serve as a valuable guide for understanding the potential future flood risk for the basin.

Harris County Flood Control District FEMA Models

Overview

Additional information was analyzed using the HCFCD effective FEMA models that cover Harris County. The models are open-source and can be obtained from HCFCD's website[3]. These steady state HEC-RAS models were developed in the early 2000s by HCFCD and were calibrated to historical storm events. However, the models were developed prior to the release of Atlas 14 rainfall data. HCFCD is in the process of updating the rainfall data and floodplain mapping (referred to as the Harris County Modeling, Assessment and Awareness Project, MAAPnext). The updated modeling and mapping have not been released in time for this round of regional flood planning, but future rounds of regional flood planning should incorporate the results.

[3] https://www.hcfcd.org/Resources/Interactive-Mapping-Tools/Model-and-Map-Management-M3-System

At this time, future rainfall changes beyond Atlas 14 have not been considered. When Atlas 14 was released in 2018, the data that it replaced was developed during the 1960s and 1970s. Additional rainfall updates for the next 30 years were not considered during this stage of the planning cycle.

Existing Conditions

As part of previous efforts, Atlas 14 rainfall had been included in several of the HCFCD models, which provided an approximate representation of what flood elevations may look like with future precipitation. This information was used to inform the future conditions recommended approach for the regional flood plan. The model updates included:

1. Updated rainfall values with Atlas 14 rainfall depths
2. Extrapolated storage-discharge curves as necessary
3. Simulated the existing hydrologic model for the frequency storm events
4. Updated the steady state flow data in HEC-RAS and simulated the updated hydraulic model

Neither routing reach HEC-HMS parameters nor downstream tailwater conditions were updated due to the high-level planning nature of the comparison analysis and the level of detail required for the intended purpose of the analysis. Maintaining the existing routing reach information and tailwater conditions is not expected to significantly affect the conclusions from the water surface elevation profile comparison analysis as it relates to supporting the future flood hazard buffer recommendation.

Future 100-year Flood Hazard Approach

The existing available information was reviewed to identify the approach for the future 100-year flood hazard based on the recommended approaches from the TWDB. Separate approaches for the Northern, Southern, and Coastal Zones are described below.

Northern Zone

Future Flood Hazard Approach

Unique to the nature of the comprehensive analysis, the results of the SJRMDP included future conditions 100-year floodplains for the main rivers for the upper basin. Since the model included a comprehensive model of the area, the rainfall could be easily updated to include an additional 15% over the previously used Atlas 14 rainfall, fully analyzing potential future conditions of both development and rainfall in the region. The 15% value was chosen to be representative of the range of increased rainfall patterns as recommended in the state climatology report to better understand the impacts of additional precipitation in the region. The updated models were simulated for the 100-year storm event and compared to the existing flood hazard layers developed for the RFP.

Comparison to Effective 500-year

From the comparison, the typical observed trend was that the existing 500-year inundation boundaries were close in width and shape to the future 100-year inundation boundaries. **Figure 4** below shows the flood hazard width comparisons for Caney Creek. The rainfall depths that were utilized to develop the existing inundation 500-year boundary are known as TP-40, which is similar in magnitude to the Atlas 14 100-year rainfall amounts, explaining the similarities in the floodplain extents.

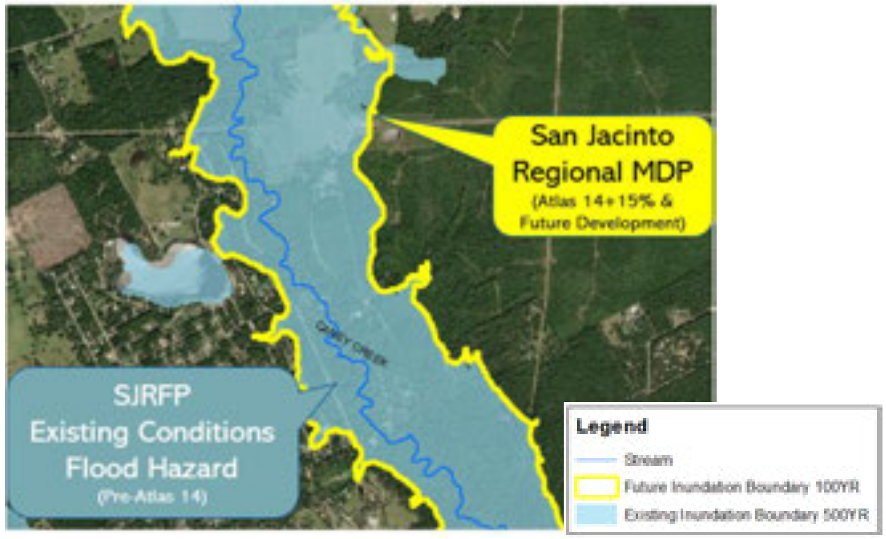

Figure 4: Caney Creek Inundation Boundary Comparison

Although the existing SJRFP 500-year and future SJRMDP 100-year inundation boundaries are similar in shape and width throughout most of the watersheds, there are some areas where the flood hazards showed minor differences, as noted in Peach Creek (shown in **Figure 5)**. Differences can be attributed to changes in topography, model assumptions, and lack of quality existing information. In most cases the differences were minor and showed that the flood hazard boundaries were still comparable and would provide valuable information for the regional flood planning effort. **Appendix 1** shows additional flood hazard width comparisons throughout the San Jacinto River basin.

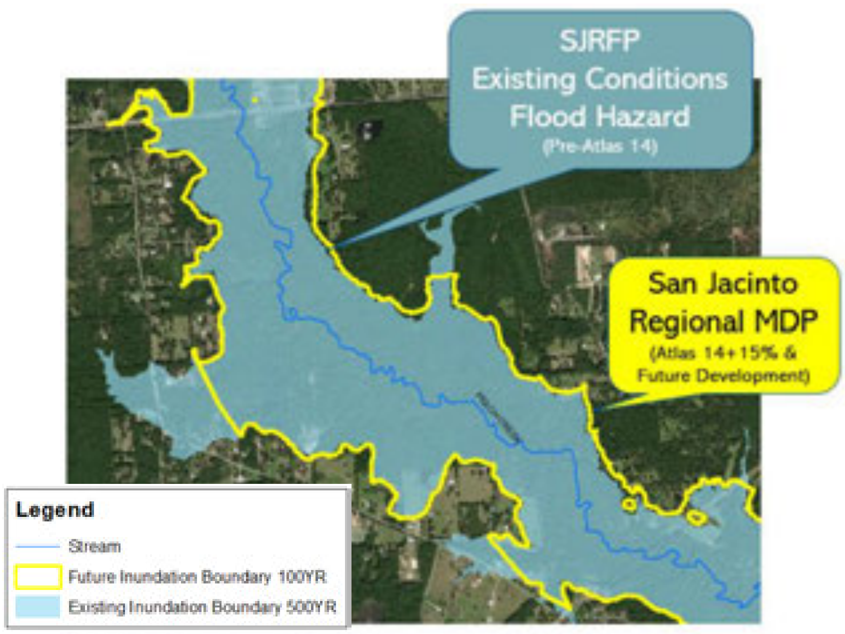

Figure 5: Peach Creek Inundation Boundary Comparison

Southern & Coastal Zones

Future Flood Hazard Approach

The Southern and Coastal Zones have similar topgraphy and channel features and therefore were grouped into one analysis. The available effective Atlas 14 HCFCD models provide an estimated future conditions water surface elevation for the Southern and Coastal Zones based on an increase in rainfall. While the rainfall increase does not include additional increases as shown in the SJRMDP analysis, the models provide a guide for how increased rainfall can increase flooding in the region and can be used to estimate future floodplains.

An analysis of future development was not included for the Southern or Coastal zones due to lack of future floodplain information as well as the high density of development within these regions. While future development may have an impact on runoff, other factors such as increase in rainfall, subsidence, and sea level rise will result in more substantial changes to the floodplain extents. These regions also have high standards of floodplain development and detention criteria which minimize the impacts of future development.

Comparison to Effective 500-year

The effective 500-year water surface elevations (WSELs) were compared with the modeled Atlas 14 100-year water surface elevations for several Harris County watersheds including Greens Bayou, Buffalo Bayou, White Oak Bayou, and Sims Bayou. An example of the comparison for Greens Bayou is shown below in **Figure 6**. **Appendix 2** shows additional plot comparisons throughout Harris County.

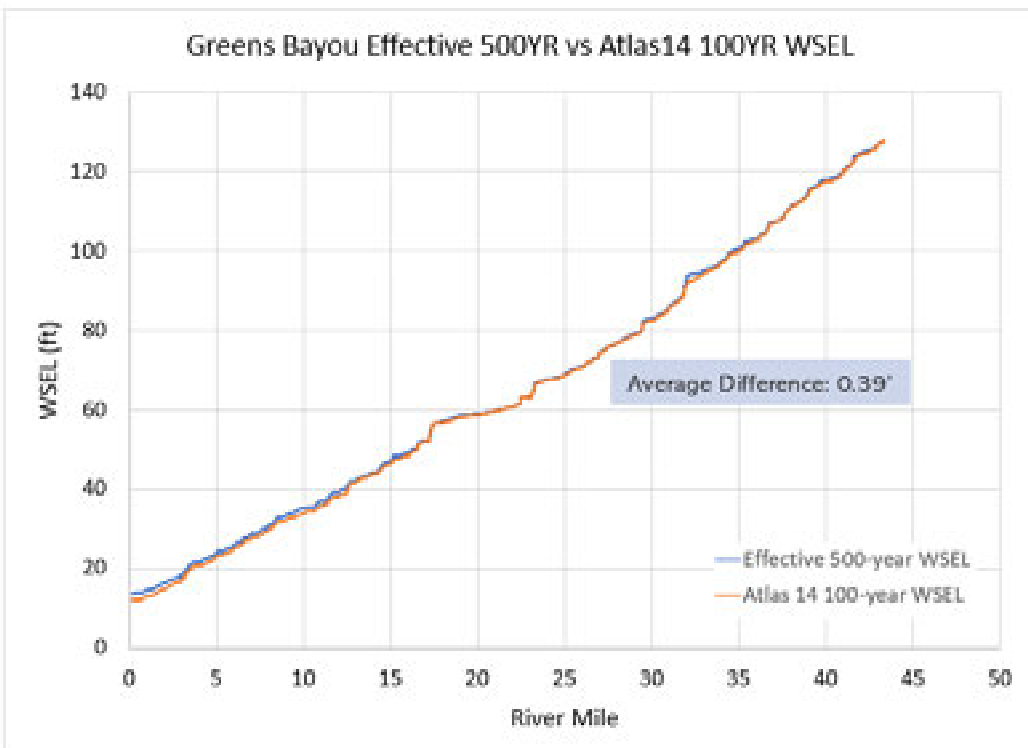

Figure 6: Greens Bayou Water Surface Elevation Comparison

Future 100-year Flood Hazard Conclusion – All Zones

The SJRMDP modeling showed that the anticipated future 100-year flood hazard extents are reasonably consistent with the existing conditions 500-year flood hazard extents for the Northern Zone. This conclusion was also supported by the HCFCD model comparisons between the FEMA existing 500-yr and Atlas 14 100-yr for the Southern and Coastal Zones. While differences exist in flood hazard widths and water surface elevations, they were typically within an acceptable range for the purpose of Task 2B and support the general agreement between the future 100- and 500-year flood hazard comparison. The differences shown in water surface elevations and flood hazard extents are attributed to different modeling approaches and the approximate nature of the comparison analysis.

The comparisons show that the existing 500-year flood hazard area can be used as an appropriate estimate of the future 100-year flood hazard area. However, due to potential land changes caused by subsidance and sea level rise, buffers for those two factors were determined separately and applied to the existing 500-year flood hazard area to create the future 100-year floodplain extents.

Future 500-year Flood Hazard Approach

The existing available information was reviewed to identify the approach for the future 500-year flood hazard based on the recommended approaches from the TWDB. Separate approaches for the Northern, Southern, and Coastal Zones are described below.

Northern Zone

San Jacinto Pre-Atlas 14

The SJRMDP provides a baseline condition for comparing future flood hazard to existing flood hazard. As previously mentioned, the modeling was based on Atlas 14 rainfall. However, the existing flood hazard information compiled as part of the RFP was based on pre-Atlas 14 rainfall depths. To obtain a comparison of future flood hazard areas, the SJRMDP models were simulated with the pre-Atlas 14 rainfall depths based on the Montgomery County Drainage Criteria Manual to understand the difference in inundation boundaries between pre-Atlas 14 rainfall and Atlas 14 rainfall. These comparisons informed the 500-year flood hazard approach and allowed a buffer to be estimated relative to the effective FEMA floodplain.

San Jacinto Future Conditions

Since the model included the latest modeling techniques, the rainfall could be updated to include an additional 15% over the previously used Atlas 14 rainfall. The 15% value was chosen to be representative of the range of increased rainfall patterns as recommended in the state climatology report to better understand the impacts of additional precipitation in the region. The updated models were simulated for the Atlas 14 + 15% 500-year storm event and compared to the existing flood hazard analyzed with the SJRMDP Pre-Atlas 14 rainfall modeling.

Buffers

Since there are not any existing floodplain maps and limited available modeling for events greater than the 500-year storm event to compare with or use as an approximation, future flood hazard boundary was estimated by applying a horizontal buffer based on future development and increases in rainfall to the existing 500-year floodplain boundaries (**Figure 7**). The average difference in flood hazard top width between the existing 500-year and future 500-year was calculated for multiple cross-sections along each evaluated channel and used to inform the boundary used for the Northern Zone.

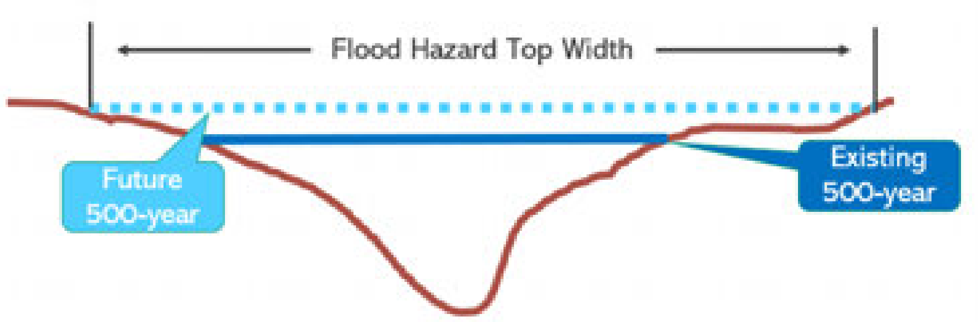

Figure 7: Flood Hazard Top Width

The average difference in flood hazard layer top width within each of the zones was calculated, and then utilized as a 'Development and Rainfall Patterns Buffer' that could be added to the existing 0.2% floodplain. This 'Development and Rainfall Patterns Buffer' would extend the boundaries of the existing floodplain and would therefore act as an appropriate determination for the boundaries of the future conditions 0.2% flood hazard layer. The horizontal buffer is applied to the floodplain as a whole, so the calucated values include an increase on both sides of the channel. For example, a 500 foot buffer would be applied as 250 feet on either side of the channel. The results for the Northern Zone can be seen in **Table 3**. For reference, the average top width of the existing conditions 1% annual chance floodplain of the main stems is also included in the table.

Table 3: Northern Zone 500-Year Top Width Comparison

Channel	Existing Average Width of Floodplain (ft)	Average Difference of Flood Hazard Layer Top Width (ft)
Lake Creek	4,134	343
Peach Creek	2,100	488
Willow Creek	2,761	497
Spring Creek	3,335	565
Caney Creek	3,027	612
Recommended Development and Rainfall Patterns Top Width Buffer		**500**

Southern & Coastal Zones

HCFCD Atlas 14 Simulations

The available effective HCFCD models were simulated with Atlas 14 rainfall to provide an estimated future conditions water surface elevation for the Southern and Coastal zones based on an increase in rainfall. While the rainfall increase does not include additional rainfall increases as shown in the SJRMDP analysis, the models provide a guide for how rainfall can increase flooding in the region and can be used to estimate future floodplains.

An analysis of future development was not included for the Southern or Coastal zones due to lack of future floodplain information as well as the high density of development within these regions. While future development may have an impact on runoff, other factors such as increase in rainfall, subsidence, and sea level rise will have larger impacts. These regions also have higher standards of floodplain development and detention criteria which minimize the impacts of future development.

Buffers

Similar to the Northern Zone, there are no existing floodplain maps and limited available modeling for events greater than the 500-year storm event to compare with or use as an approximation. Therefore, the approach selected to develop the future 500-year flood hazard layer was to estimate the boundary by applying a horizontal buffer to the existing 500-year floodplain boundaries. To inform an appropriate horizontal buffer, the average difference in flood hazard top width between the effective 500-year (Pre-Atlas 14) and the Atlas 14 500-year was calculated for multiple cross-sections along each evaluated channel.

The average difference in flood hazard layer top width within each of the zones was calculated, and then utilized as a 'Development and Rainfall Patterns Buffer' that could be added to the existing 0.2% floodplain. This 'Development and Rainfall Patterns Buffer' would extend the boundaries of the existing floodplain and would therefore act as an appropriate determination for the boundaries of the future conditions 0.2% flood hazard layer. The horizontal buffer is applied to the floodplain as a whole, so the calucated values include an increase on both sides of the channel. For example, a 850 foot buffer would be applied as 425 feet on either side of the channel. The results for the Southern and Coastal Zones can be seen in **Table 4**. For reference, the average top width of the existing conditions 1% annual chance floodplain of the main stems is also included in the table.

Table 4: Southern & Coastal Zone Top 500-Year Width Comparison

Channel	Existing Average Width of Floodplain (ft)	Average Difference of Flood Hazard Layer Top Width (ft)
Greens Bayou	4,502	701
Buffalo Bayou	1,210	817
White Oak Bayou	2,932	843
Sims Bayou	1,399	1,096
Recommended Development and Rainfall Patterns Top Width Buffer		**850**

The flood width boundaries calculated for the southern and coastal zones are much larger than those calculated for the northern zone. This is due to the flat and urbanized nature of the southern and coastal watersheds when compared to the northern zone watersheds.

Minor Tributaries

Upon determining the buffer, an evaluation was done to determine how to apply the buffer across the region. The buffers were generated based on approximate models for the major streams within the Northern, Southern, and Coastal Zones. Minor tributaries to the streams may vary in characteristics which can affect the width of the flood hazard layer. Such characteristics include urbanization, topography, channel improvements, and existing channel capacity. While an overall flood hazard buffer applied to each major stream and minor tributary may not most accurately show the future flood hazard, varying tributary buffers would require substantially more information than is currently available. Therefore, it was determined that the same flood hazard buffer for the main stems would also be applied to the tributaries. During future regional flood plans, reviewing the proposed buffer width along tributaries should be explored further. It would provide the most accurate representation of the future flood hazard boundary if additional information for that analysis becomes available.

Future 500-year Flood Hazard Conclusion – All Zones

The comparisons show that with the addition of a calculated buffer, the existing 500-year flood hazard area can be used as an appropriate estimate of the future 500-year flood hazard area. Buffer factors include a development and rainfall patterns buffer, as well as sea level rise and subsidance buffers. The buffers for all three factors were determined separately and applied to the existing 500-year flood hazard area to create the future 500-year floodplain extents.

Coastal Flood Hazard Analysis

Sea Level Rise

The United States Army Corps of Engineers (USACE) has developed a tool to calculate the approximate sea level rise for a "high", "intermediate", and "low" scenario (**Figure 8**). The rate computed for the "high" scenario builds from the most recent Intergovernmental Panel on Climate Change (IPCC) and modified National Research Council (NRC) projections for a high rate of sea level rise (SLR). In Galveston Bay, the approximate "high" SLR projected by USACE over the next 30 years is 1.6 feet of SLR. The rate computed for the "intermediate" scenario builds from the most recent Intergovernmental Panel on Climate Change (IPCC) and modified National Research Council (NRC) projections for a moderate rate of SLR. In Galveston Bay, the approximate "intermediate" SLR projected by USACE over the next 30 years is 0.85 feet of SLR. The rate computed for the "low" scenario builds from historical rates of SLR to determine the low rate of SLR. In Galveston Bay, the approximate "low" SLR projected by USACE over the next 30 years is 0.6 feet of SLR. The "intermediate" scenario (0.85 feet of SLR) is the recommended estimation of SLR over the next 30 years based on the projections gathered from USACE.

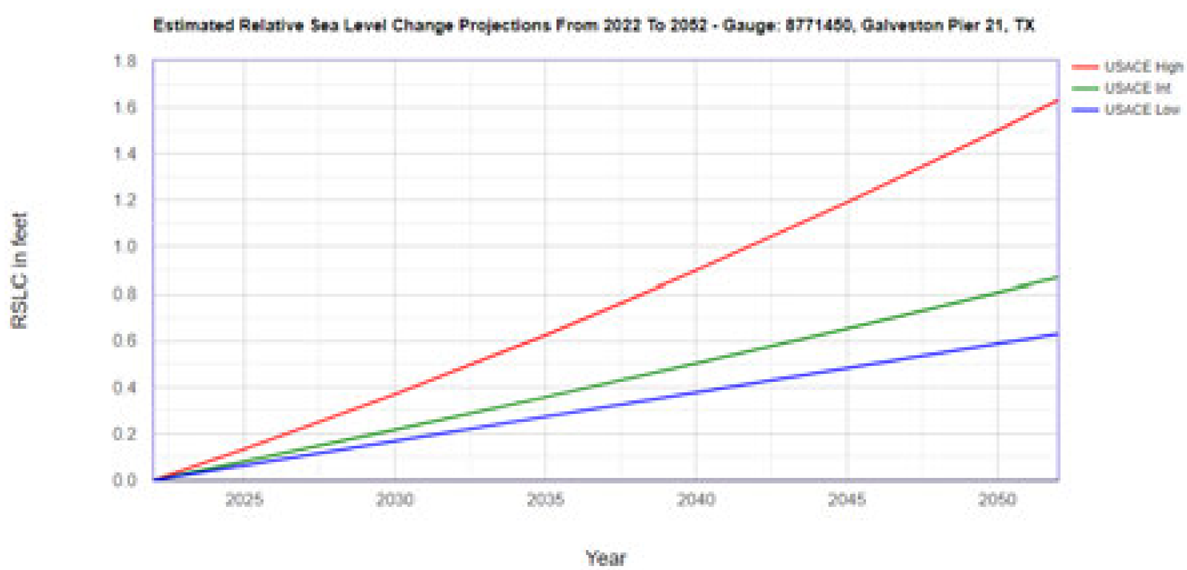

Figure 8: Estimated Sea Level Rise in Galveston Bay from 2022 to 2052 (USACE 2021)

Using the “intermediate” SLR estimate, a horizontal buffer was determined to approximate the influence of SLR on the future condition coastal flood hazard. From the best available terrain data, transects of the coast were cut to determine the average overland slope in the Southern and Coastal Zones. The average overland slope for sea level rise was limited specifically to the coastal areas and does not include overland slopes further inland.

Using best available terrain data, an average slope of 4% was calculated for the coastal zone of the San Jacinto River Basin. The slope, refined to remove the channel bank slopes, was found for each zone, and is detailed in **Table 5** below. The slope was then translated into a horizontal distance for 0.85 feet of rise to determine the recommended buffer distance accounting for sea level rise. Ultimately, the recommended buffer for 0.85 feet of sea level rise was determined to be 315 feet of additional buffer for the Southern Zone and 570 feet for the Coastal Zone to be incorporated in the future conditions 1% and 0.2% flood hazard layer within the coastal zone and applicable portions of the southern zone.

Table 5: Sea Level Rise Buffer Estimate

	San Jacinto River Basin Zone		
	Northern	Southern	Coastal
Estimated Sea Level Rise over 30 years (feet)	N/A	0.85	0.85
Average Overland Slope (%)	N/A	0.27%	0.15%
Estimated Zonal Sea Level Rise Buffer (Feet)	**N/A**	**315**	**570**

Subsidence

Actual ground level subsidence varies spatially. For the purposes of this study, subsidence is adopted as the average for each regulatory subsidence regions defined by the Harris-Galveston Subsidence District (HGSD). Future flood floodplains residing in corresponding subsidence regions are assumed to adopt subsidence projections unique to that region (this projection is subsequently transformed into a horizontal buffer onto the future floodplain). In this study, it is assumed that subsidence projections on a per subsidence region basis experience consistent subsidence rates for both creek bed and flood plain. This is an assumption that airs on the side of conservatism using available data and for informing future flood risk.

For each zone of the San Jacinto River Basin, an average subsidence rate was calculated using historical rates provided by HGSD and was then projected over 30 years to determine an approximate future ground elevation change (HGSD 2021). A similar approach to sea level rise (SLR) was utilized to determine the relationship between the vertical change of subsidence and a horizontal distance that would be incorporated into the total buffer distance. Using best available terrain data, an average slope was determined for each zone of the San Jacinto River Basin using a combination of coastal transects and inland cross sections. The slope was then translated into a horizontal distance to determine the recommended buffer distance accounting for subsidence. **Table 6** provides a summary of the approximate average subsidence rate, estimated subsidence over 30 years, average slopes calculated, and the estimated buffer distance for each zone. The recommended buffer for accounting for future subsidence is 55 feet for the northern zone, 340 feet for the southern zone, and 80 feet for the coastal zone to be incorporated in the future conditions 1% and 0.2% flood hazard layer.

Table 6: San Jacinto River Basin Subsidence Recommendation

	San Jacinto River Basin Zone		
	Northern	Southern	Coastal
Approximate Average Subsidence Rate (cm/yr)	-0.86	-1.10	-0.20
Estimated Subsidence over 30 years (feet)	-0.85	-1.08	-0.19
Average Overland Slope (%)	1.62%	0.32%	0.25%
Estimated Zonal Subsidence Buffer (feet)	**55**	**340**	**80**

Future Flood Hazard Buffer Exceptions

The flood hazard area buffers described above were applied across the region to determine the extents of the future 100- and 500-year floodplains. These buffers were applied to all flood hazard areas except in a few instances where regional, man-made structures influence the flood hazard area. For all areas mentioned, additional analysis should be conducted to understand the implications of future growth in the region.

Within Harris County there are two accredited levee systems in the Spring Creek and the Cypress Creek watersheds. Since these levees were constructed with freeboard, it is anticipated that the future flood hazard areas would remain within the existing. Therefore, the floodplains were clipped to the extent of the existing conditions within the Inverness Forest Levee and Northgate Levee.

Within the planning region, there is one major water supply reservoir and two regional flood control facilities where water surface elevations are strictly controlled by operational gates. (Lake Houston is also a water supply reservoir within the region but water surface elevations during flood events are maintained by the large Amberson spillway rather than operational gates). These gate structures allow storm runoff to pass downstream. The gate operational protocols for each dam are based on maximum allowable upstream water surface elevations rather than volumes and flows. Therefore, within the areas influenced by the Lake Conroe Dam, Addicks Reservoir, and Barker Reservoir, the existing conditions flood hazard areas were used as the future conditions flood hazard areas for both the 1% and 0.2% storm events. Additional analysis should be conducted in future planning cycles to understand the future floodplains within these reservoirs.

Flood Exposure Analysis

An exposure analysis was performed to identify the population and structures in the region that may be affected during the future 1% and 0.2% storm events. ArcGIS was utilized to intersect the future flood hazard layer and the study areas to determine the affected existing development, critical infrastructure, and low water crossings at risk of flooding.

The analysis performed was based on the flood exposure dataset that was created in Task 2A: Existing Condition Flood Risk Analyses. It includes the existing structures that are within the future flood hazard areas. Future development (including population and structures) was not accounted for as part of this analysis due to the complexity and variability associated with predicting future structure locations.

The critical infrastructure that may be impacted and were taken into consideration while analyzing the future flood risk were medical facilities, government buildings, emergency operations centers and shelters, law enforcement facilities, fire stations, schools, nursing homes, airports, railyards, ports, power generating plants, transmission facilities and water/wastewater treatment plants. To facilitate alignment with concurrent GLO and USACE studies, structure types added to the critical infrastructure list include chemical plants, refineries, chemical storage facilities, oil and gas infrastructure and correctional facilities. The full list of critical infrastructure is subject to revision and requires approval from the San Jacinto Regional Flood Planning Group members.

Conclusion

The Region 6 Flood Planning Group and its consultants have developed a procedure for generating potential future 1% and 0.2% flood risk data that generally follows Method 3 (a combination of Methods 1 and 2) of the TWDB's Technical Guidance document. Recommendations were developed for each of the three zones within the San Jacinto FPR to reflect differences in watershed characteristics more appropriately throughout the region.

- The existing 500-year floodplain was selected to serve as a proxy for the future 100-year flood hazard while also accounting for the effects of subsidence and sea level rise.
- For the future 500-year flood hazard, a 500- or 850-foot base buffer plus additional buffers for subsidence and sea level rise, as appropriate, were recommended to be added to the existing 500-year flood hazard boundary.

Table 6 shows the proposed buffer widths that were determined for the future conditions' boundaries. Note that the buffer listed is a total top width buffer and should be divided in half to determine the extension of the future condition flood hazard layer on each side of an associated water body.

Table 7: Future Flood Conditions Flood Hazard Approach

Future Conditions 1% Storm Event

Existing 500-year + Buffer

		Development and Rainfall Patterns Buffer (ft)	Subsidence Buffer (ft)	Sea Level Rise Buffer (ft)	Total Top Width Buffer (ft)
Northern Zone	All	0	55	0	**55**
Southern Zone	Riverine	0	340	0	**340**
	Coastal	0	340	315	**655**
Coastal Zone	Riverine	0	80	0	**80**
	Coastal	0	80	570	**650**

Future Conditions 0.2% Storm Event

Existing 500-year + Buffer

		Development and Rainfall Patterns Buffer (ft)	Subsidence Buffer (ft)	Sea Level Rise Buffer (ft)	Total Top Width Buffer (ft)
Northern Zone	All	500	55	0	**555**
Southern Zone	Riverine	850	340	0	**1,190**
	Coastal	850	340	315	**1,505**
Coastal Zone	Riverine	850	80	0	**930**
	Coastal	850	80	570	**1,500**

This methodology and approach were presented to the Technical Committee on February 3, 2022 and gained consensus and approval by the committee. The RFPG approved the approach on the March 3, 2022. The TWDB accepted the approach on March 23, 2022.

REFERENCES

"Climate Change and Sea-Level Rise Effects for the HSC ECIP Feasibility Study", USACE; https://www.swg.usace.army.mil/Portals/26/docs/Planning/Public%20Notices-Civil%20Works/HSC-ECIP%20FIFR-EIS/App%20C%20%20Att%203%20Climate-SLR%20Effects%20(30Oct2019).pdf?ver=2020-01-21-080804-863

"Climate Change Recommendations for Regional Flood Planning", Texas A&M University; https://climatexas.tamu.edu/files/CliChFlood.pdf

"Measuring Subsidence", Harris-Galveston Subsidence District; https://hgsubsidence.org/science-research/measuring-subsidence/

Sea-Level Change Curve Calculator (Version 2021.12), USACE; https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

Sea Level Rise Viewer, NOAA; https://coast.noaa.gov/slr/

TWDB 2022 Texas State Water Plan, Planning Region H. https://2022.texasstatewaterplan.org/region/H

APPENDICES

Appendix 1: 100-Year Flood Hazard Comparison Maps

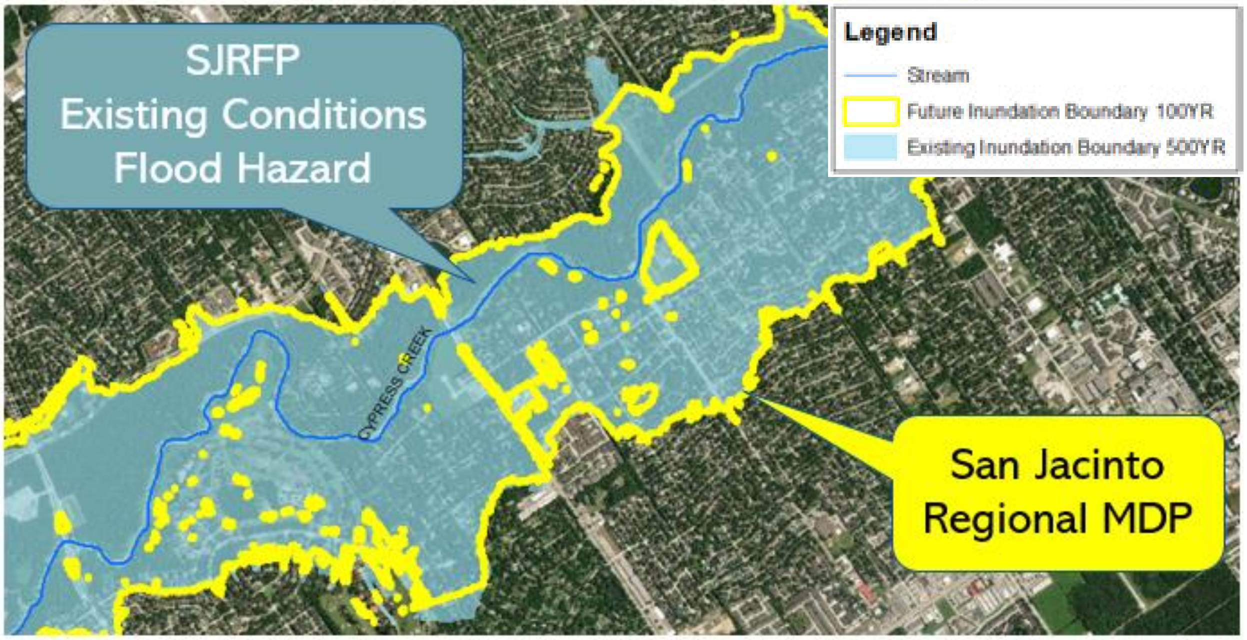

Figure A1-1: Cypress Creek 100-Year Inundation Boundary Comparison

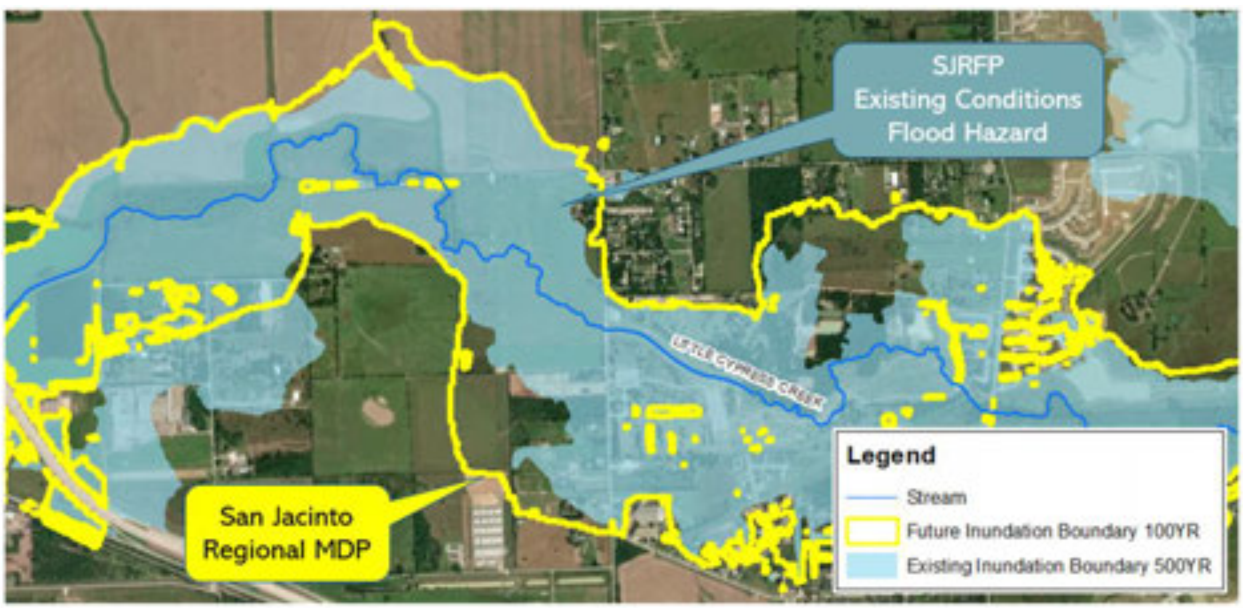

Figure A1-2: Little Cypress Creek 100-Year Inundation Boundary Comparison

Appendix 2: 100-Year Flood Hazard Comparison Graphs

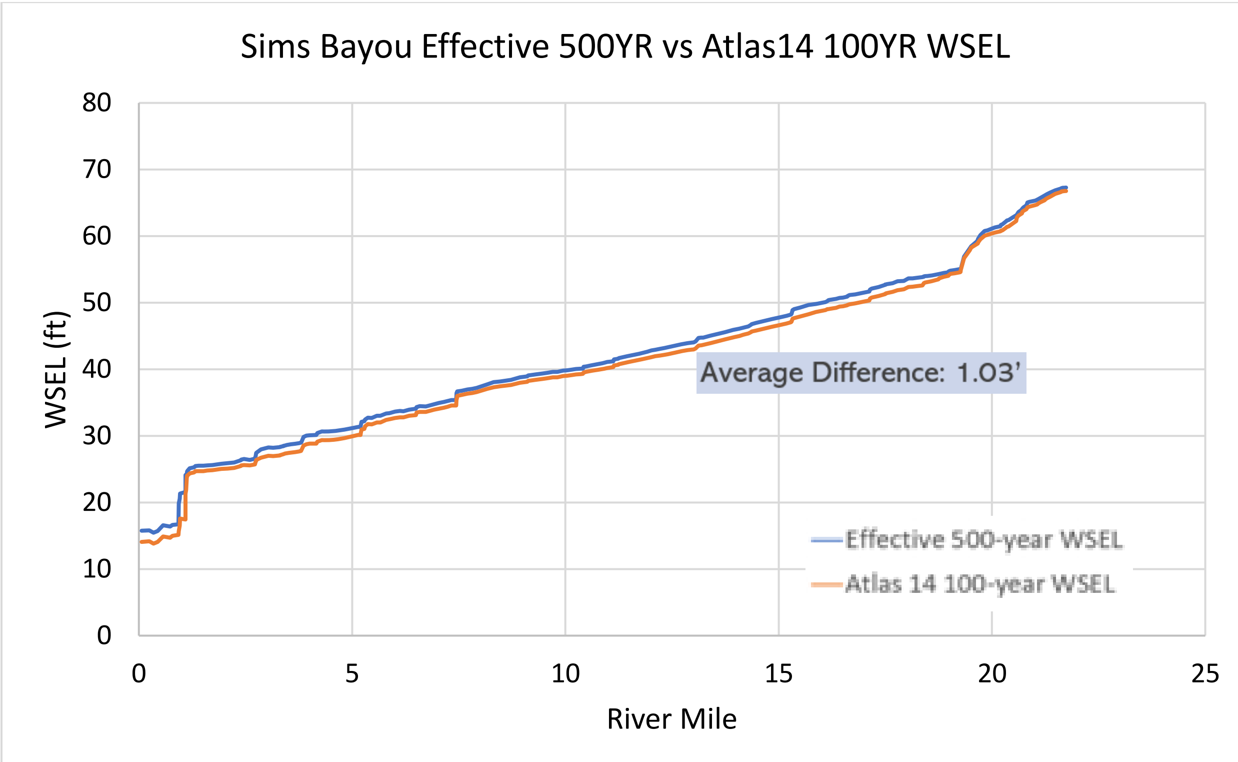

Figure A2-1: Sims Bayou Water Surface Elevation Comparison

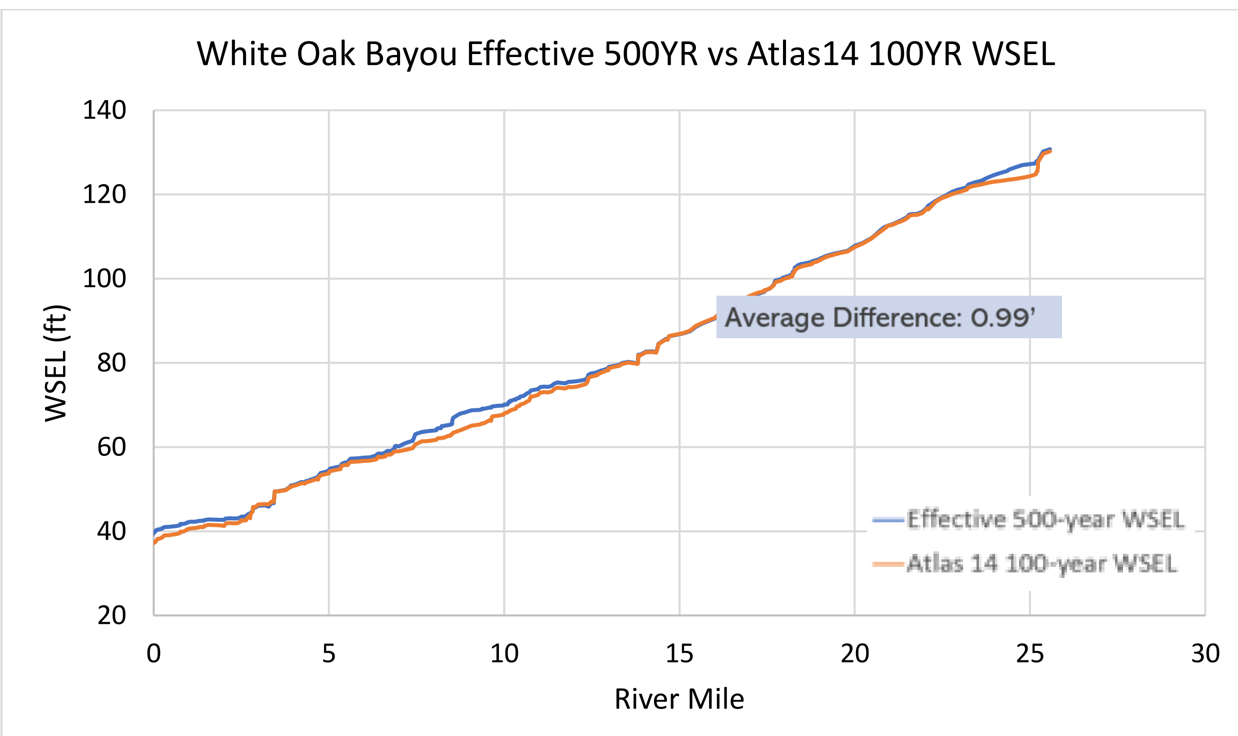

Figure A2-2: White Oak Bayou Water Surface Elevation Comparison

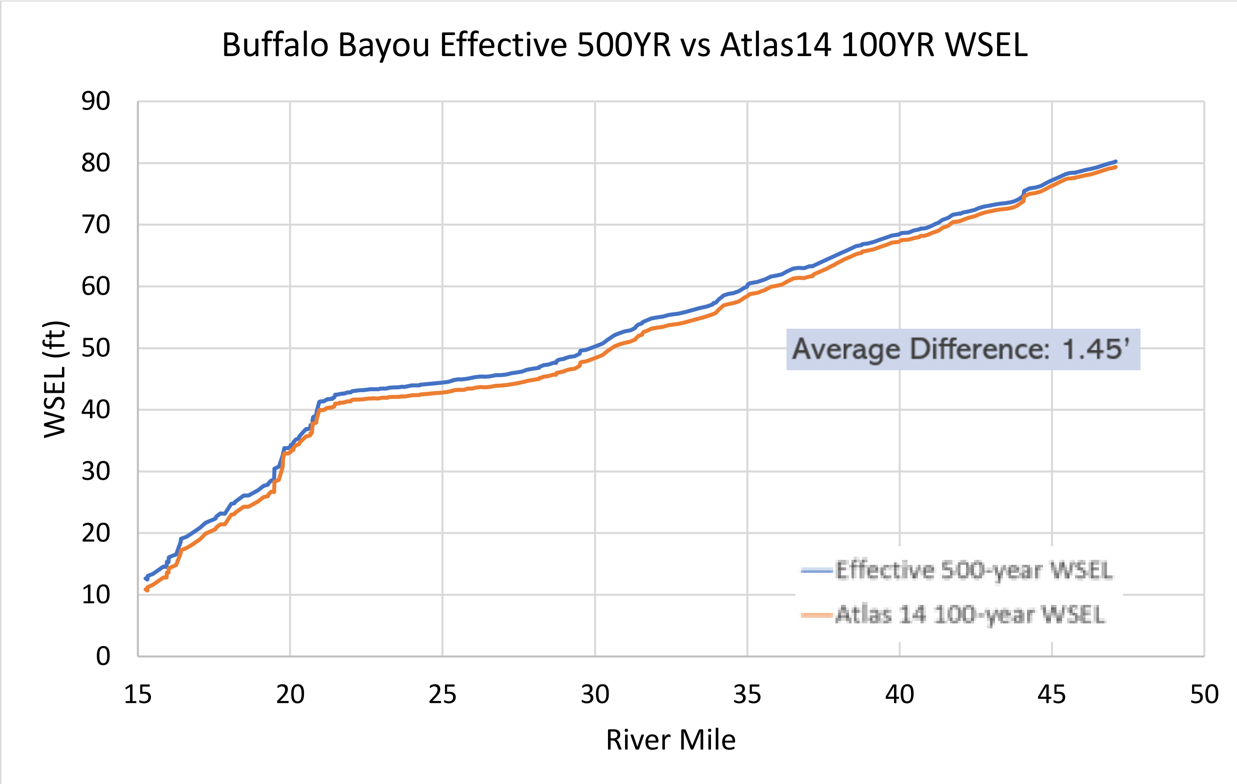

Figure A2-3: Buffalo Bayou Water Surface Elevation Comparison

APPENDIX 2B-8
FUTURE CONDITIONS FLOOD SUMMARY TABLES

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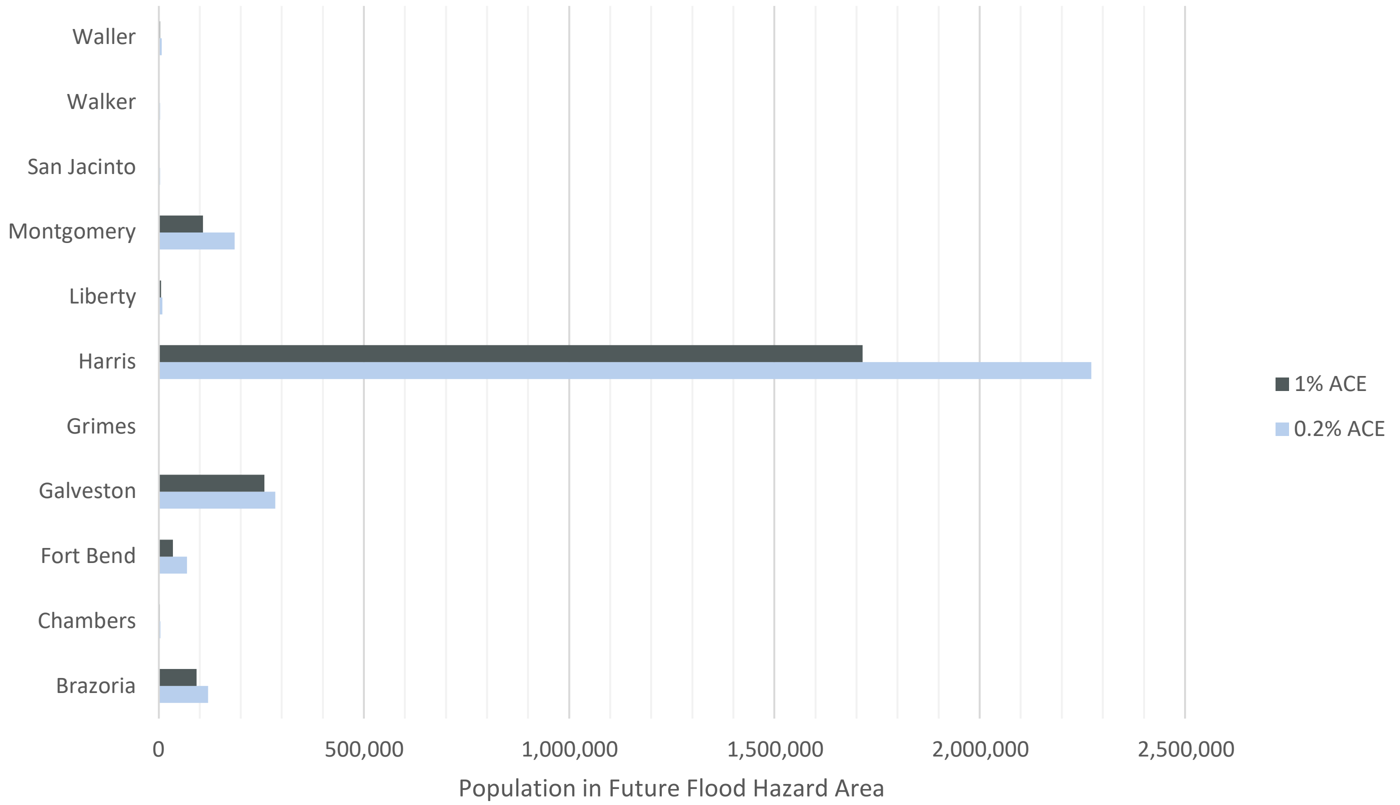
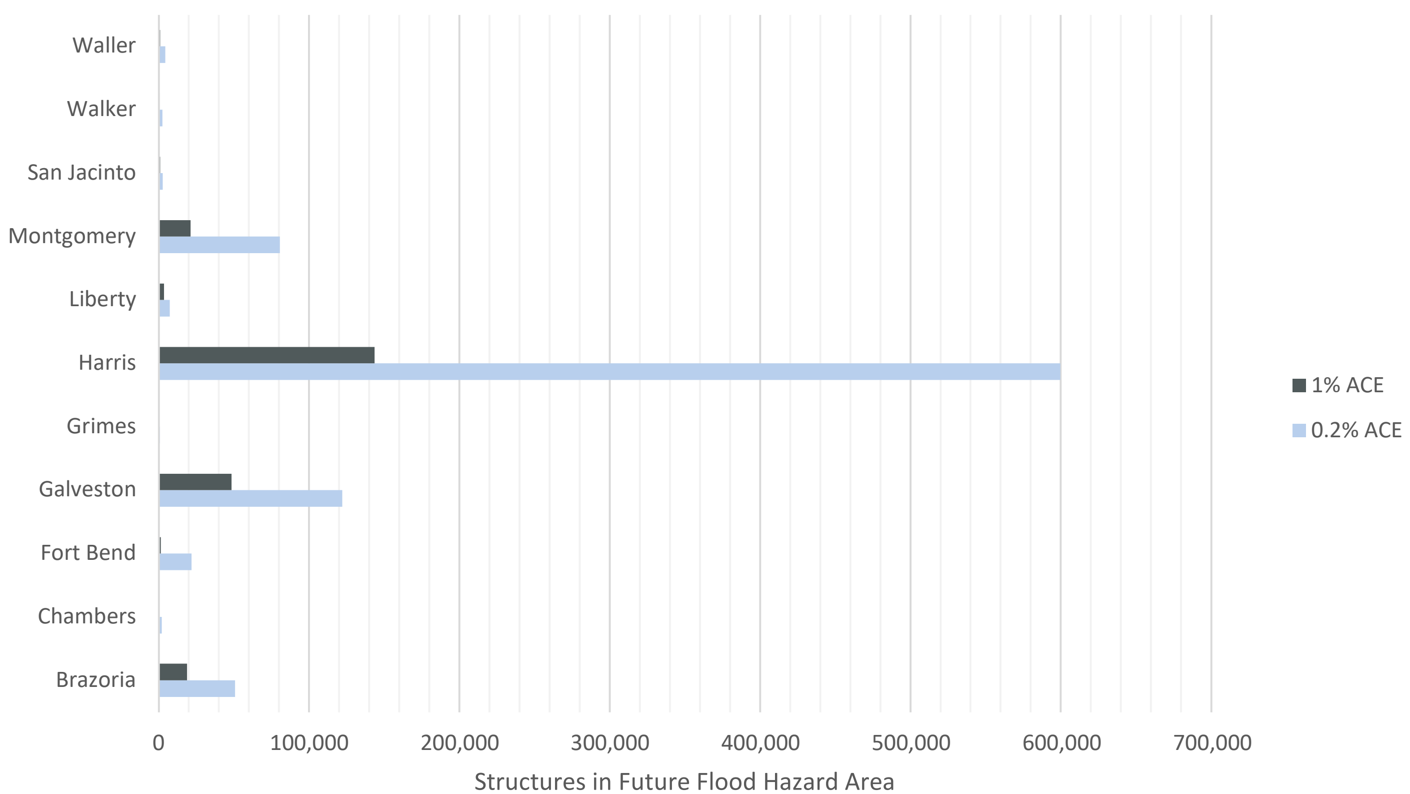
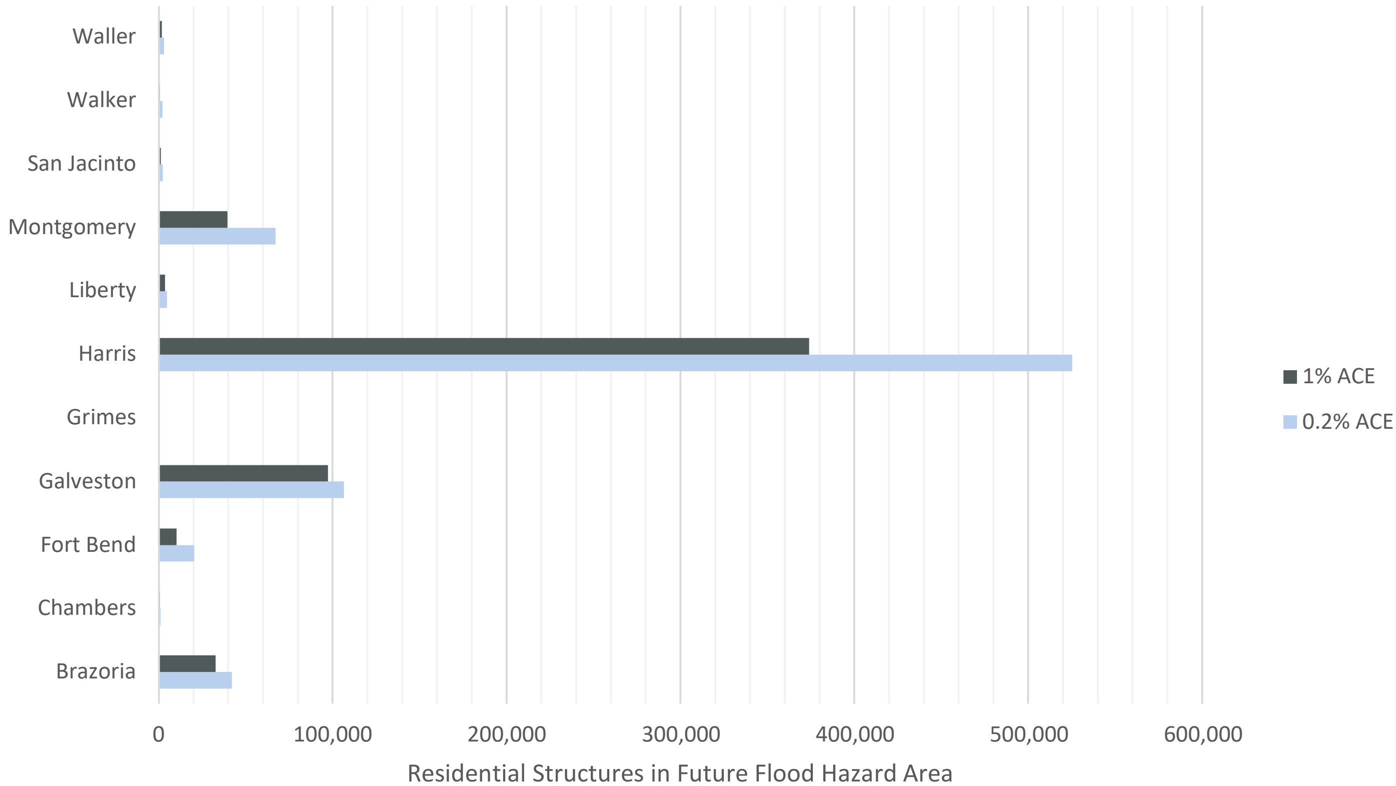
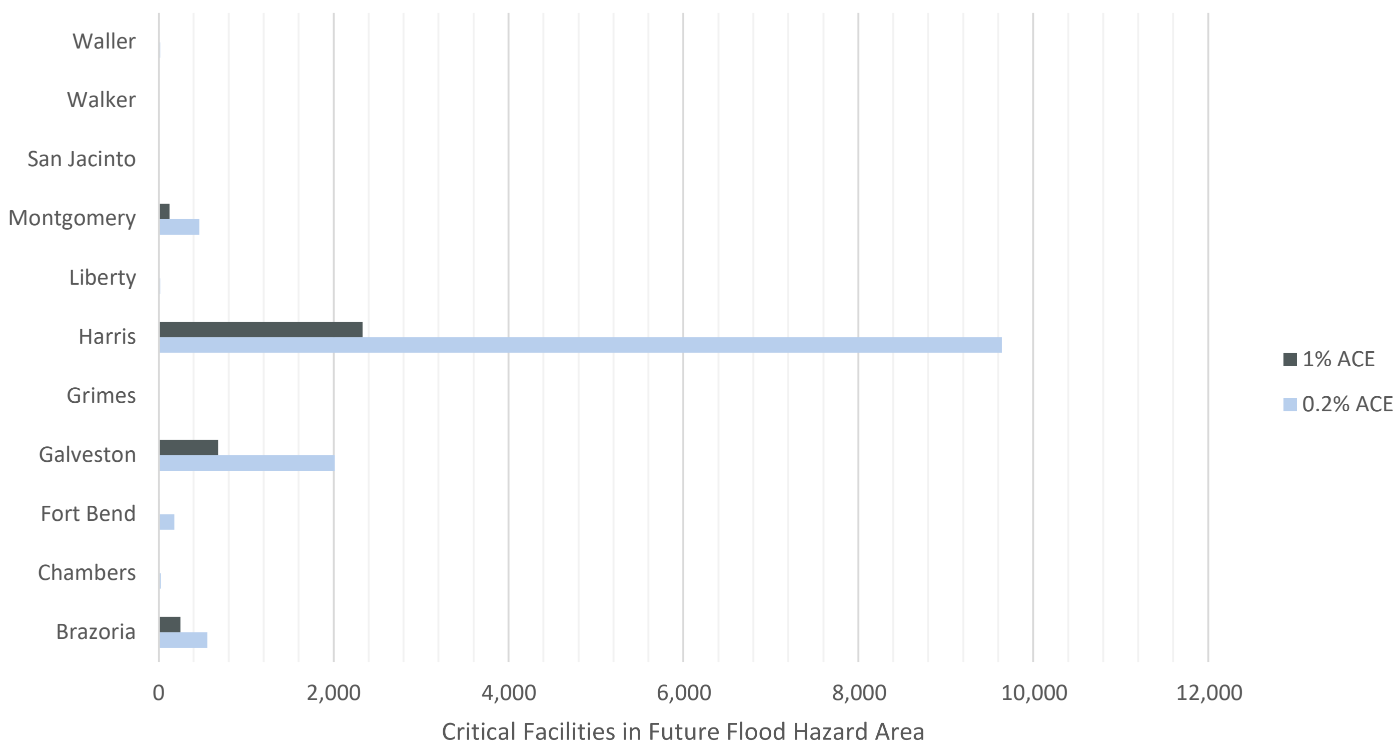

Waller
Walker
San Jacinto
Montgomery
Liberty
Harris
Grimes
Galveston
Fort Bend
Chambers
Brazoria
1% ACE
0.2% ACE
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
Population in Future Flood Hazard Area


Waller
Walker
San Jacinto
Montgomery
Liberty
Harris
Grimes
Galveston
Fort Bend
Chambers
Brazoria
1% ACE
0.2% ACE
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
Structures in Future Flood Hazard Area



Waller
Walker
San Jacinto
Montgomery
Liberty
Harris
Grimes
Galveston
Fort Bend
Chambers
Brazoria
0
100,000
200,000
300,000
400,000
500,000
600,000
Residential Structures in Future Flood Hazard Area
1% ACE
0.2% ACE



Waller
Walker
San Jacinto
Montgomery
Liberty
Harris
Grimes
Galveston
Fort Bend
Chambers
Brazoria
0
2,000
4,000
6,000
8,000
10,000
12,000
Critical Facilities in Future Flood Hazard Area
1% ACE
0.2% ACE