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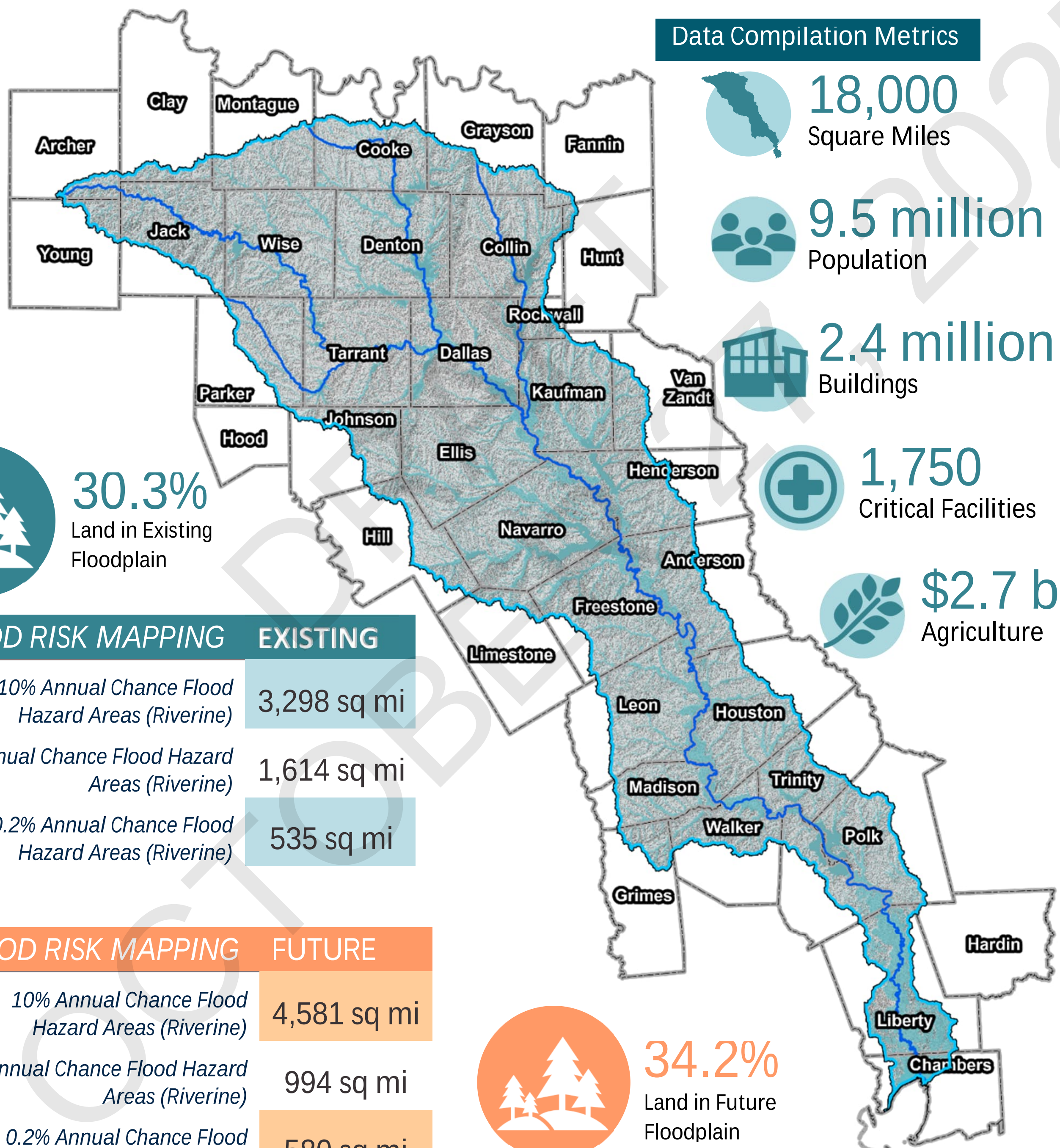
EXISTING & FUTURE FLOOD RISK MAPPING

The existing conditions floodplain quilt was developed using data from FEMA NFHL, Base Level Engineering, Fathom mapping, and other agencies such as USACE and USGS. This data was compiled in accordance with TWDB's data source prioritization hierarchy. The future conditions mapping was estimated as a range between Fathom mapping scenarios 1 and 3, illustrating a zone of potential minimum to maximum future flood mapping extents.



Data Compilation Metrics

18,000 Square Miles

9.5 million Population

2.4 million Buildings

1,750 Critical Facilities

$2.7 billion Agriculture

30.3% Land in Existing Floodplain

FLOOD RISK MAPPING	EXISTING
10% Annual Chance Flood Hazard Areas (Riverine)	3,298 sq mi
1% Annual Chance Flood Hazard Areas (Riverine)	1,614 sq mi
0.2% Annual Chance Flood Hazard Areas (Riverine)	535 sq mi

FLOOD RISK MAPPING	FUTURE
10% Annual Chance Flood Hazard Areas (Riverine)	4,581 sq mi
1% Annual Chance Flood Hazard Areas (Riverine)	994 sq mi
0.2% Annual Chance Flood Hazard Areas (Riverine)	580 sq mi

34.2% Land in Future Floodplain

EXISTING & FUTURE FLOOD EXPOSURE

Flood mapping exposure to development and associated populations focused on buildings (residential, commercial, and critical facilities), roadways segments and crossings, and agricultural areas. Agricultural areas comprised Farming and Ranching. Critical facilities include all public or private assets, systems, and functions vital to the security, governance, public health and safety, economy, or morale of the state or the nation, especially in times of disaster.

EXISTING EXPOSURE

892,139
Population Exposed

7.8% (192,138)
Total Buildings

78.2% (150,268)
Residential Buildings

11.2% (21,469)
Commercial Buildings

2,279
Agricultural Land (Sq mi)

7,096
Roadway Miles

75.4% (1,320)
Critical Facilities

LEVEES & DAMS

People & Property Protected

	People	Property Value
Accredited Levees	400,498	$52.5 billion
Flood-Control Dams	875,587	$82.9 billion

FUTURE EXPOSURE

1,735,291
Population Exposed

15.0% (369,498)
Total Buildings

81.3% (300,487)
Residential Buildings

7.3% (27,027)
Commercial Buildings

2,554
Agricultural Land (Sq mi)

15,111
Roadway Miles

85.4% (1,495)
Critical Facilities

Chapter 2: Flood Risk Analyses

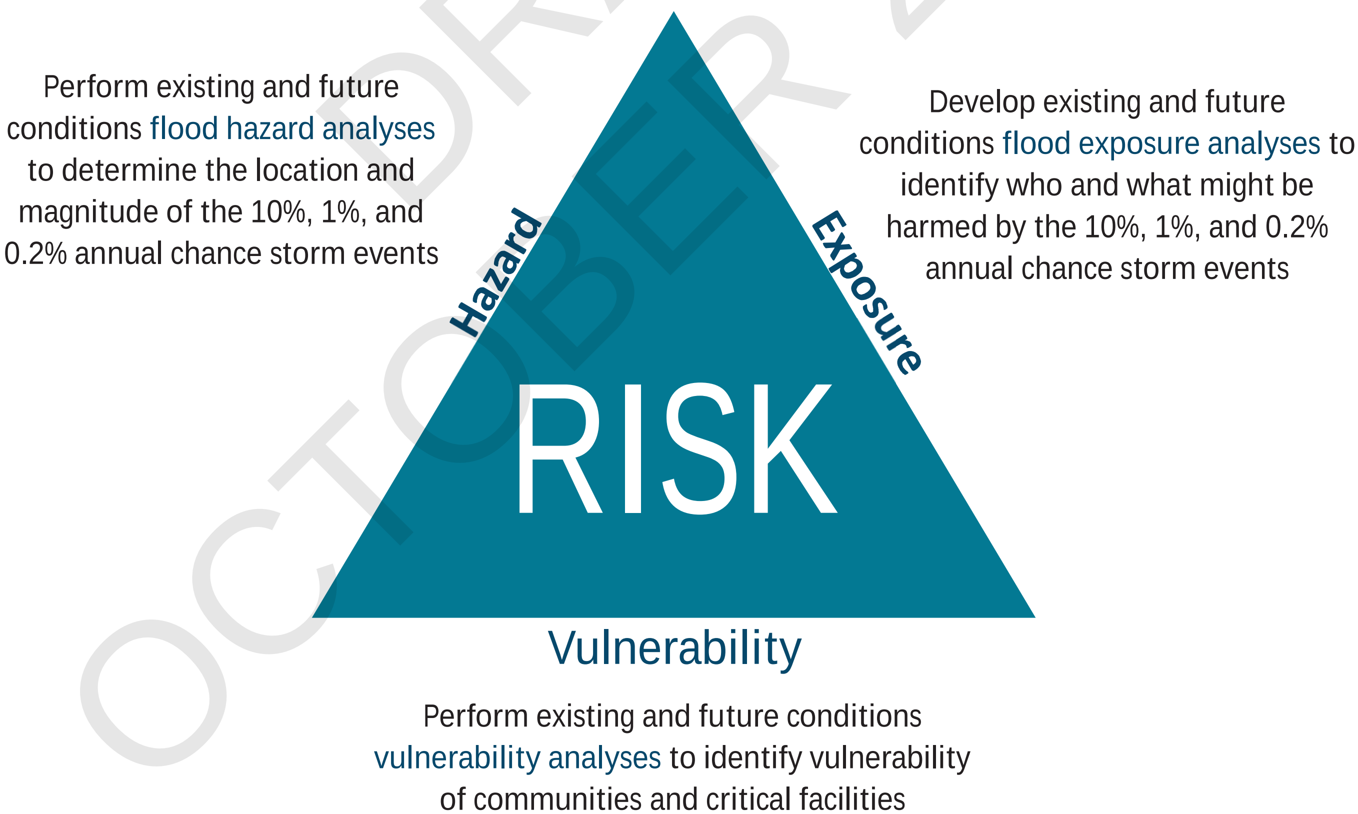
An important aspect of developing a regional flood plan involves providing an accurate assessment of flood risk. This includes a description of flooding, identification of what is at risk, and estimation of the associated impacts. In terms of understanding flood risk and associated impacts, the Trinity Regional Flood Plan assessed flood risk for existing and future conditions.

In this Trinity Regional Flood Plan, the existing and future conditions flood risk assessment focused on the following three components:

1. Flood hazard analyses to determine the location, magnitude, and frequency of flooding
2. Flood exposure analyses to identify who and what might be harmed within the Trinity Region
3. Vulnerability analyses to identify the degree to which communities and critical facilities may be affected by flooding

Figure 2.1: Flood Risk Analyses Triangle Framework shows the risk triangle framework applied to the Trinity Regional Flood Plan flood risk analyses.

Figure 2.1: Flood Risk Analyses Triangle Framework



Source: (TWDB, 2025)

Task 2A – Existing Conditions Flood Risk Analyses

Existing Conditions Flood Hazard Analysis

Sufficiency of Existing Conditions for Planning Purposes

In terms of potential flood hazard analyses, existing conditions refers to the hydrologic and hydraulic conditions that were present at the time the analysis was performed. These conditions include current land use, estimated precipitation data, and constructed drainage-related infrastructure. Existing conditions in relation to the Trinity Region do not consider projected changes in rainfall patterns, future land use/population growth, or planned new/improved infrastructure. Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) Special Flood Hazard Areas (SFHAs) are generally based on existing conditions. The FEMA regulatory SFHA boundaries from these maps form the foundation of the Trinity Region existing conditions flood hazard analysis.

Land Use

Land use is an important factor in determining existing conditions flooding limits. It affects hydrological processes such as evapotranspiration, interception, and infiltration. As urban development (impervious area) is added to a watershed, the hydrologic response is changed, and surface runoff often increases. As demonstrated in *Chapter 1*, most of the urban development occurs in the Upper Basin of the Trinity Region watershed located in Collin, Dallas, Denton, and Tarrant Counties. These four counties are surrounded by heavy agricultural use which extends from the headwaters to the mid-basin area. From the mid basin area, extending to the coast, the existing land use is predominantly forested, interspersed with agriculture. Localized urban development is largely confined within city boundaries and the Extraterritorial Jurisdictions (ETJs). While not as prolific as urban development, cultivated agricultural and grazed land use still quickens the watershed's response time in comparison to natural forested ground cover, which in turn increases flood risk. The rate of development and changes in land use since the initial determination of the flooding limits affects the validity of the analysis for planning purposes. For example, some of FEMA's SFHA within the Trinity Region is based on hydrologic and hydraulic analyses that were performed between the mid-1970s and today. While the 1970s studies are over 50 years old, the flood limits may still be valid due to little change in land use and basin size.

Precipitation

When planning for existing conditions flood risk, assessing potential anomalous flood-causing precipitation is crucial. Precipitation as it relates to flood risk is commonly analyzed in terms of inches of rainfall that occur within a 24-hour duration. In 1973, the FEMA National Flood Insurance Program (NFIP) set the standard for flood hazard areas based on the 1% annual chance storm event, more commonly referred to as the 100-year flood. For the purposes of the State Flood Plan, all risk assessments will be based on this recurrence interval in addition to the 10% annual chance storm event (or 10-year flood) and the 0.2% annual chance storm event (or 500-year flood). A majority of FEMA's SFHA boundaries within the Trinity Region were developed using hypothetical rainfall data from the National Weather Service (NWS) Technical Paper No. 40/NWS Hydro-35 (Hershfield, 1961) or the United States Geological Survey (USGS) Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas (Asquith & Roussel, 2004). Rainfall data was broken down in terms of duration and recurrence interval. In 2019, National Oceanic and Atmospheric Administration (NOAA) developed updated hypothetical rainfall in Texas based on historic rainfall data in its Atlas 14 study. The NOAA Atlas 14 study anticipates significant differences between hypothetical rainfall in the lower portion of the Trinity Region watershed when compared to the 1961/1977 and 2004 rainfall data. *Table 2.1* shows the range of rainfall for each data source.

Table 2.1: Precipitation Data Comparison

Trinity Region Watershed	TP40/Hydro 35 100-year, 24-hour Rainfall (inches)	USGS 2004 100-year, 24-hour Rainfall (inches)	NOAA Atlas 14 100-year, 24-hour Rainfall (inches)
Upper Basin	8.8-10.5	8.5-11.0	8.5-11.0
Middle Basin	10.5-12.0	11.0-12.0	11.0-14.0
Lower Basin	12.0-13.5	12.0-14.0	14.0-18.5

Infrastructure

Drainage-related infrastructure is a key element in determining existing conditions flood risk. Drainage related infrastructure includes, but is not limited to, dams, levees, detention/retention ponds, bridges, culverts, Low Water Crossings (LWCs), tunnels, urban storm drain networks, breakwaters, bulkheads, and revetments. The Trinity Region has eight major flood control reservoirs owned and operated by the United States Army Corps of Engineers (USACE). These include Benbrook Lake, Joe Pool Lake, Grapevine Lake, Ray Roberts Lake, Lewisville Lake, Lavon Lake, Navarro Mills Lake, and Bardwell Lake. In addition to these major reservoirs, the region contains nearly 1,000 Natural Resources Conservation Service (NRCS) minor reservoirs, which control flood waters along the major and minor tributaries. There are 36 accredited levee systems located within the Trinity Region, which account for over 33,000 acres of flood protection.

While flood control infrastructure mitigates existing flood risk, some older drainage-related infrastructure contributes to flooding. Bridges, culverts, and storm drain systems that were designed and constructed before major land use changes and higher standards were implemented can exacerbate flooding by impounding flood water and overtopping during major storm events. The result is increased flood risk to both property and life which is expanded upon in the existing conditions exposure analysis.

Existing Hydrologic and Hydraulic Model Availability

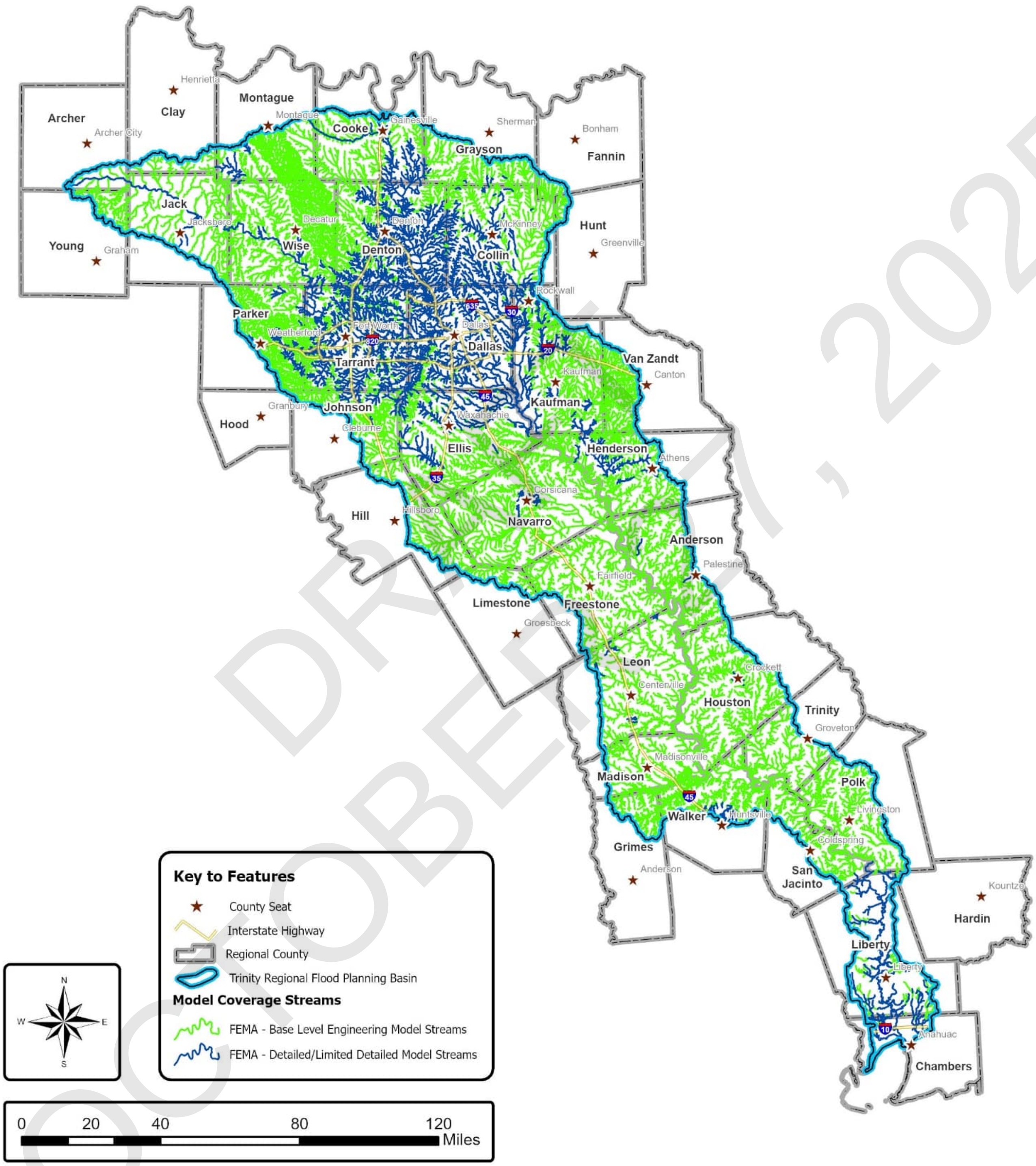
Hydrology and Hydraulic (H&H) modeling is a necessary component in determining how water flows over land. It is a crucial element in developing effective flood planning strategies.

Hydrology is the scientific study of earth's natural water movement with a focus on how rainfall and evaporation affect the amount of flow of water in streams and storm drains. Hydraulics represents the engineering analysis of the flow of water in streams and infrastructure, such as channels, pipes, and other man-made structures.

Applied since the 1970s, H&H uses computer software applications that simulate the flow of rainfall runoff over the land to predict the rise of creek and river water levels and potential flooding, as well as test ways to reduce flooding without constructing projects. H&H modeling simulates flow, frequency, depth, and extent of flooding over land. These models assist with making informed decisions about selecting and implementing flood reduction and restoration projects. H&H modeling also satisfies regulatory requirements and confirms that natural, agricultural, and social resources are not damaged by flooding induced by modifications to creeks, rivers, and channels.

Within the Trinity Region's 13 eight-digit Hydrologic Unit Code (HUC-8) watersheds, hundreds of H&H models have been developed, each calibrated for the specific area and spanning from the late 1970s to the present. All the data output from the various modeling efforts is ultimately incorporated through Geographic Information System (GIS) mapping into the Trinity Region floodplain quilt. *Figure 2.2* shows stream model locations in the Trinity Region.

Figure 2.2: Existing Conditions Model Availability



Regional Data Collection and Current Mitigation Projects

A regional online data collection website was created as an outreach tool to work closely with regional entities (counties, municipalities, state and federal agencies, or political subdivisions with flood related authorities) to gather local flood-risk information. When asked what flood mitigation activities, strategies, or projects are currently in progress or proposed, survey respondents indicated significant interest in participating in the NFIP, establishing and maintaining floodplain management ordinances, and making improvements to existing roadways and water crossings. *Figure 2.3* summarizes the responses received regarding the types and counts of in-progress flood projects.

Per the survey responses, two projects were identified as "in-progress" with dedicated funding in place: (Each project is summarized in *Table 2.2*.)

1. The College Street Drainage Improvements in the City of Waxahachie within Ellis County focuses on the building of local storm drainage systems and a tunnel. Due to holes that appeared in the parking lots of businesses on College Street in 2019, the old infrastructure was deemed outdated and no longer serving its intended purpose. The drainage improvements are expected to alleviate the flooding with right-sized infrastructure.
2. Lynchburg Creek Flood Mitigation Project in the City of Corinth in Denton County is improving and/or building regional dams, reservoirs, detention, and retention basins. The Lynchburg sub-basin is in the central and eastern portion of the city and contains most of the drainage problems in the city. The area is about 2.2 square miles and has mixed development with significant undeveloped land. The westernmost reach is in the Amity Village neighborhood. Flooding in this basin has gotten progressively worse over time. Infrastructure improvements are anticipated to address concerns in this area.

Throughout the flood planning region, multiple projects are in various stages of a project lifecycle. As weather and development patterns change, current mitigation projects must consider and address the changing risks associated with future disasters. Communities that invest in forward-looking projects are expected to experience fewer flood-related impacts and are more likely to recover quickly after severe flooding events. Projects completed with the consideration of future conditions will minimize new structures from being located within the future floodplain and reduce losses to life and property over time.

Figure 2.3: Types of Flood Mitigation Strategies or Projects Currently in Progress or Proposed

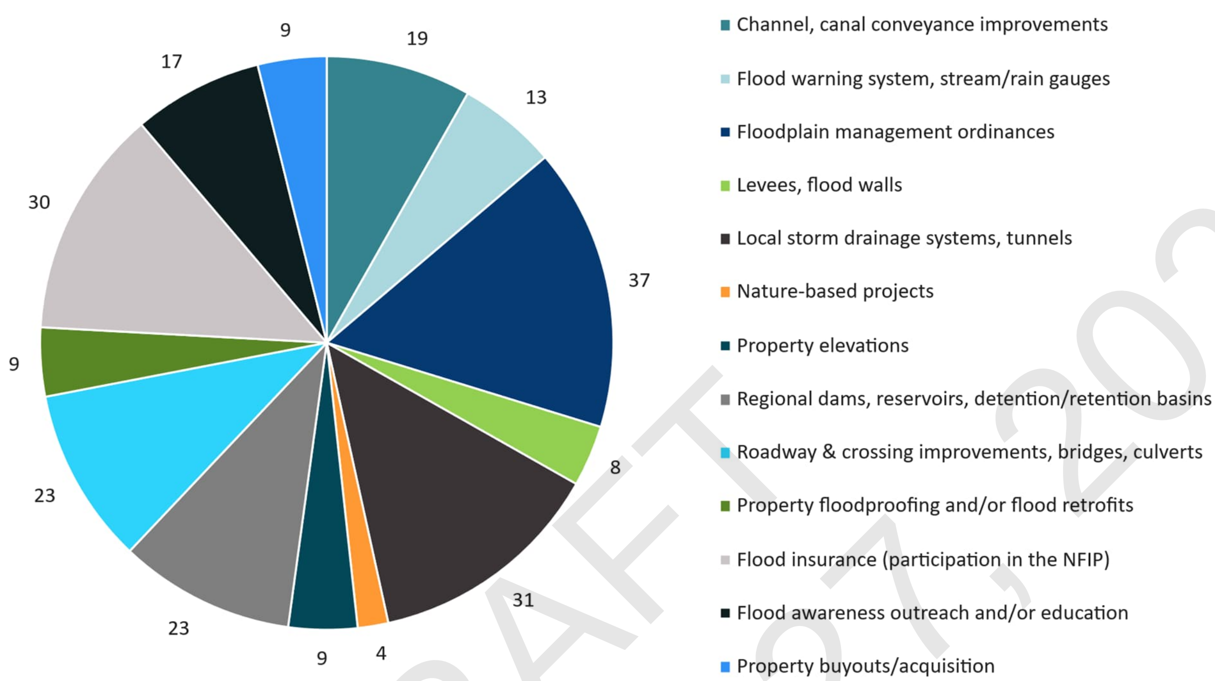


Table 2.2: Projects In-Progress with Dedicated Funding

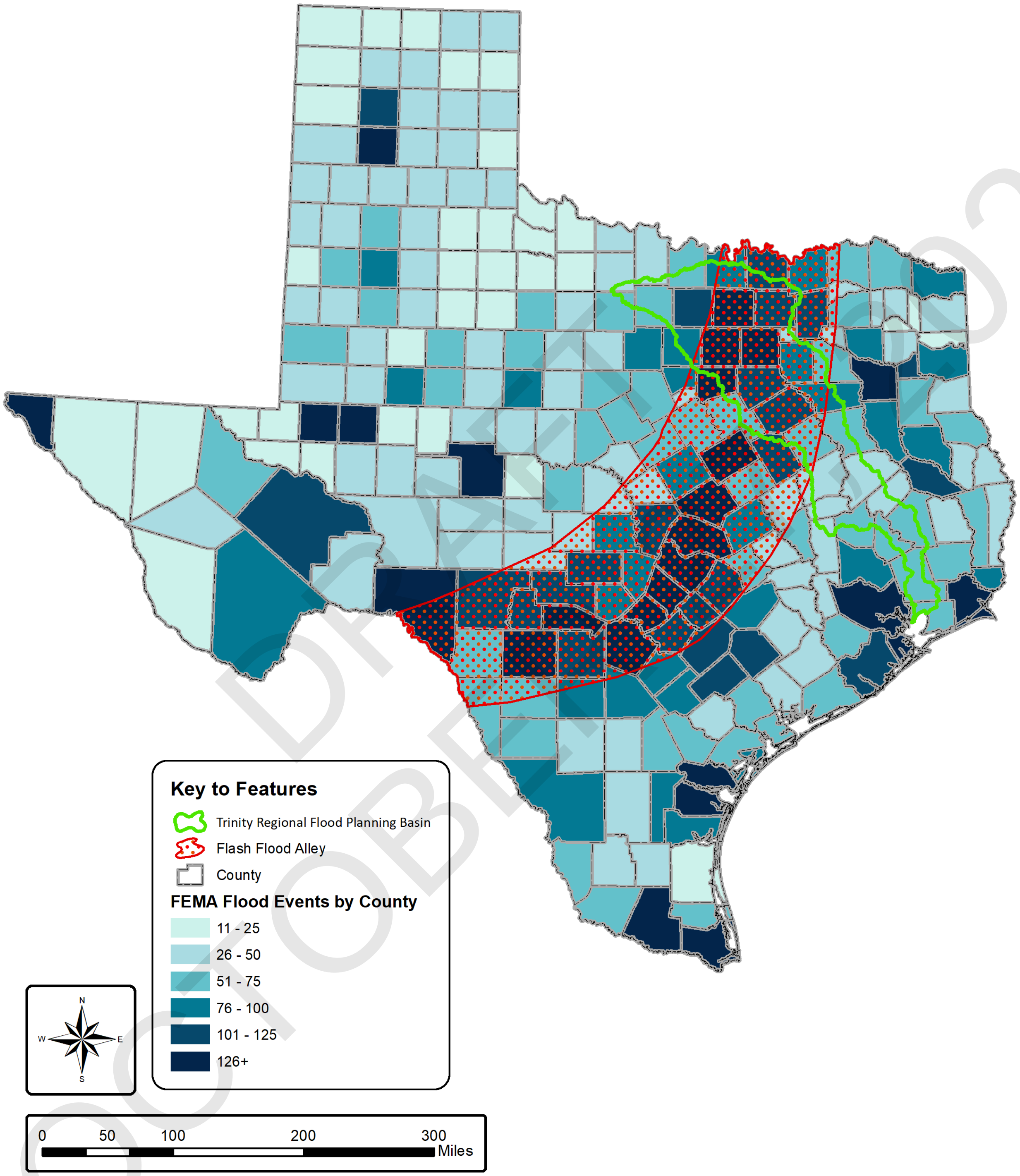
Project Name	College Street Drainage Improvements	Lynchburg Creek Flood Mitigation Project
Description	Local storm drainage systems, tunnels	Regional dams, reservoirs, detention, retention basins
Communities	City of Waxahachie, Ellis County	City of Corinth, Denton County
Project Status	In progress	In progress
Project Cost	$2,600,000	$3,000,000
Dedicated Funding for Construction (Yes/No)	Yes	Yes
Source of Funding	Not Identified	FEMA Grant
Expected Year of Completion	6/1/2022	6/30/2023

Chapter 1 of this regional flood plan provides additional information on both proposed and ongoing mitigation projects.

Best Available Existing Flood Hazard Data

Flooding within the Trinity Region is mostly riverine (based on the Region's location, availability of flood mapping data, and historical data) with some coastal influence in Chambers and Liberty counties in the south, where they are directly (and frequently) affected by hurricane storms from the Gulf. Hurricanes typically fade and downgrade to tropical storms or tropical depressions as they move inland away from the coast. Riverine flooding often occurs from general rainfall and thunderstorm floods. Flash floods are common from these rainfall events, which can occur within a few minutes or hours of excessive rainfall, exposing valuable public and private properties to flood risk. A portion of the region lies within Texas' flash flood alley. *Figure 2.4* shows reported and documented flood events by county, as well as location band of the flash flood alley.

Figure 2.4: Major Documented Storm Events and Flash Flood Alley (1950 through 2025)



Source: Storm Events Database by County (NOAA, 2025)

Even though riverine and coastal-based flooding are the dominant types of flooding in the Trinity Region, urban flooding data was evaluated for inclusion in the existing conditions floodplain quilt where available. Urban flooding (off-floodplain, pluvial, or surface flooding) occurs when intense local precipitation runs off impermeable surfaces such as paved streets, sidewalks, and structures. This overwhelms local drainage systems and causes overflows in small waterways. This flooding may enter buildings and properties, which often occurs in locations such as historic downtown areas and residential neighborhoods that predate floodplain maps. Communities have made significant progress in mitigating upland flooding. However, the importance of flood infrastructure, ongoing operations, and mitigation activities continue to be paramount. Flood Mitigation Projects (FMPs) are discussed in *Chapter 4*.

Existing flood hazard mapping estimation is based on the use of current land use and precipitation data to estimate hydrologic condition parameters and discharges. Data is then used to simulate Water Surface Elevations (WSEs) to create existing floodplain mapping extents.

The most current existing flood hazard mapping data from multiple sources was compiled by the Texas Water Development Board (TWDB) to create a comprehensive, single, coherent, continuous set of best available existing floodplain data for the Trinity Region. Mapping data was compiled and included the 10%, 1%, and 0.2% annual chance floodplain data. The existing floodplain quilt data was then updated with data obtained from FEMA, USACE, USGS, and local communities where available. The main data sources comprising the existing floodplain data for the Trinity Region are described below.

Regulatory Federal Emergency Management Agency Floodplain Data

FEMA maps flood zones on their FIRMs, which forms the basis of regulatory floodplain management for communities and mandatory flood insurance requirements for structures in the mapped SFHA floodplains. The regulatory FEMA floodplain data used in the Trinity Regional Flood Plan ranged from digital FEMA floodplain datasets from those that were already effective and have become available for NFIP regulatory use, to those that are at the Letter of Final Determination stage and are pending, with six months to become effective. FEMA's preliminary datasets issued for public review, and in due process, were also utilized, including Letter of Map Revision (LOMR) data that has become effective as of May 2025.

10% Annual Chance Storm Event Floodplains

Floodplain data developed for the Trinity Region includes the 10%, 1%, and 0.2% annual chance mapping to describe the flood hazards and perform the exposure and vulnerability analyses. The 10% annual chance storm event has a ten percent chance of being equaled or exceeded in any given year, and it has an average recurrence interval of 10 years. This type of storm event occurs frequently, particularly in the flash-flood alley areas within the region. Although it is not a regulatory FEMA dataset, the 10-year flood mapping data was recently developed to enhance local ownership of flood risk communication and management. The introduction of the Base Level Engineering (BLE) process and studies has facilitated the development and utilization of the 10-year flood risk dataset.

1% Annual Chance Storm Event Floodplains

On FIRMs, FEMA maps both the 1 percent and 0.2 percent annual chance storm event floodplains. The 1 percent annual chance storm event has a one percent chance of being equaled or exceeded in any given year, and it has an average recurrence interval of 100 years. Also referred to as the SFHA, or 100-year flood, this boundary is mapped as a high-risk flood area subject to a one percent or greater annual chance of shallow flooding in any given year, where shallow flooding is usually in the form of ponding or sheet flow with average depths between one and three feet. Along the coast, these high-risk areas are associated with velocity wave action. In the Trinity Region, coastal wave action only affects Chambers County. The areas may also be susceptible to erosion, deposition, and mudflow. It is sometimes referred to as the "Base Flood" and is the national standard used by the NFIP and other federal agencies for the purposes of regulating development and requiring the purchase of flood insurance.

0.2% Annual Chance Storm Event Floodplains

The 0.2 percent annual chance storm event has a 0.2 percent (or 1-in-500 chance) of occurring in any given year and is also referred to as the 500-year flood or Non-Special Flood Hazard Areas (NSFHAs). The 500-year flood refers to areas of moderate flood risk that are not considered to be in immediate danger from flooding caused by overflowing rivers; areas in the 100-year flood with average depths less than one foot or drainage areas less than one square mile; or areas protected by levees from the 100-year flood.

For the remainder of this report, the 10%, 1%, and 0.2% annual chance flood events are respectively also referred to as the 10-year, 100-year, and 500-year floods.

Other Floodplain Data

Where only paper-based FEMA data was available, digitally converted FIRMs from First American Flood Data Services (FAFDS) was utilized. FEMA and TWDB's BLE study data, which are model-backed HUC-8 wide and countywide level studies, was leveraged to revise the existing conditions floodplain quilt.

TWDB provided modeled flood data from the 2025 Cursory Fathom Data to be used where applicable. Fathom was developed by a research group at the University of Bristol in England. The Fathom model has been peer reviewed and compares reasonably well to FEMA flood data. The Fathom model is a two-dimensional (2D) hydraulic framework developed at a national scale using 30-meter Digital Elevation Models (DEMs). The results have been mapped on 10-foot

LiDAR for Texas to create statewide flood depth rasters for fluvial, pluvial, and coastal mapping for the 10-year, 100-year, and 500-year and other frequencies. The fluvial, pluvial, and coastal flood polygons from the Cursory Fathom Data for the Trinity Region served as a supplemental dataset for inclusion in the existing flood boundaries where data was not available or the approximate study extents were abruptly truncated as a limit of study.

Flood-Prone Areas

The Trinity Region developed an online data collection website to gather local flood-risk information. The website included a web mapping application that enabled entities to document other possible flood-prone areas not previously identified as mapped flood hazard areas. These included areas of historic flooding events, roads that frequently overtopped, past flood claim hot spots, and local knowledge obtained from outreach activities and public meetings.

The Trinity Regional Flood Planning Group (RFPG) gathered data related to areas subject to inundation from dams and levees. Dam breach inundation areas have been included where data was publicly available. Additionally, data submitted to the Trinity RFPG through the online GIS-based data collection tool has been incorporated. Cities, counties, entities with flood control responsibilities, and the general public had the opportunity to submit data to the Trinity RFPG.

Existing Conditions Flood Quilt

The Trinity RFPG skillfully weaved together the existing conditions flood data into a comprehensive flood data quilt. The various data sources received were compiled according to TWDB's ranking hierarchy as shown in *Table 2.3*. The data ranking was based on the quality and coverage extent relative to other datasets.

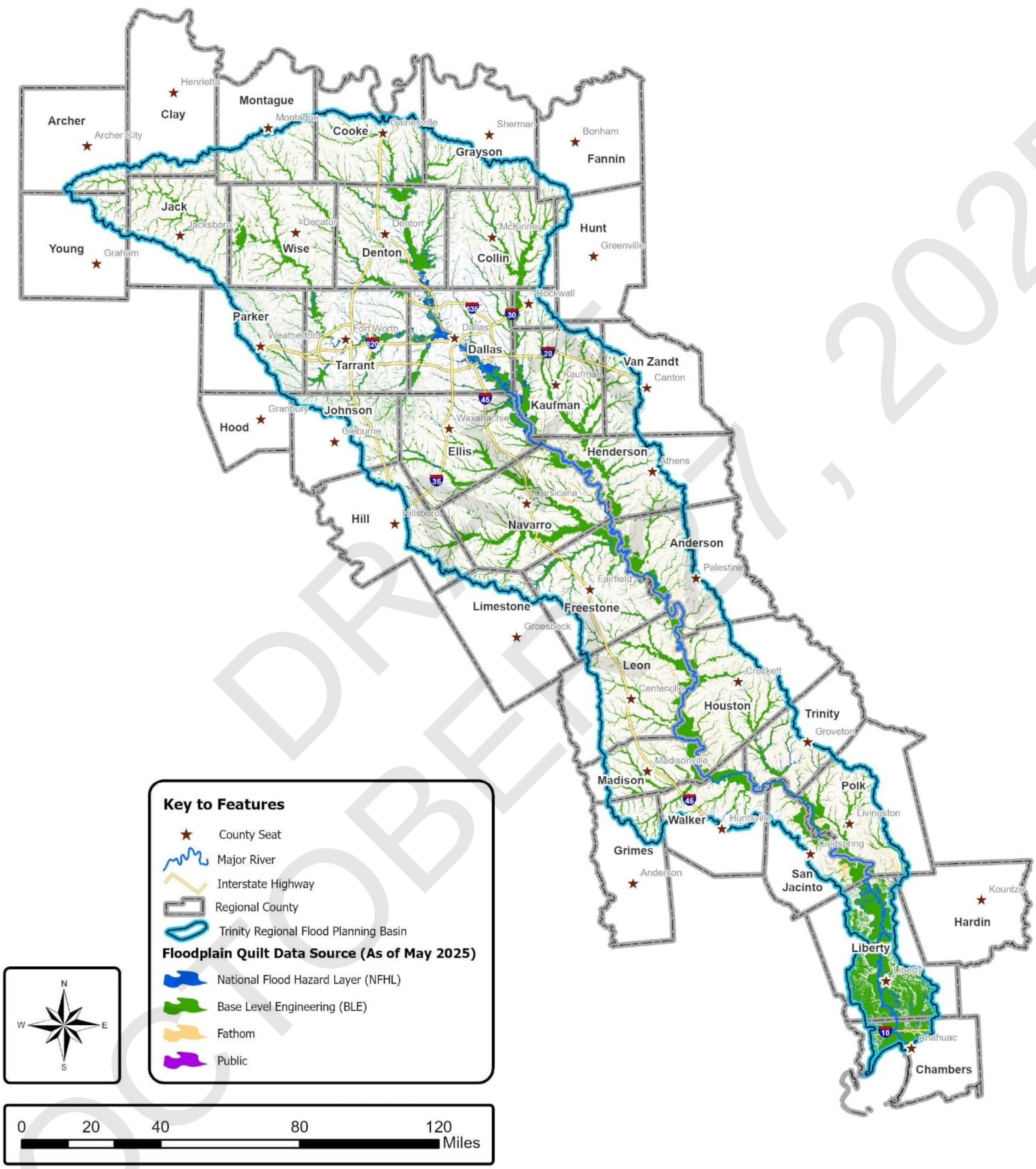
Figure 2.5 shows the floodplain data sources by location developed for the Trinity Region. A larger version of this map is included in *Appendix B*.

Table 2.3: Floodplain Quilt Data Hierarchy and Sources

Ranking	Data Category	Source
1	NFHL Pending (Detailed and Approximate Studies)	FEMA
2	NFHL Preliminary (Detailed and Approximate Studies)	FEMA
3	NFHL Effective (Detailed Study Only)	FEMA
4	BLE	FEMA
4.5	Cursory Fathom Data	FEMA
5	NFHL Effective (Approximate Study Only)	FEMA
6	Digitized Effective FIRMs	CoreLogic FAFDS
	Other Potential Data Sources	USACE or Other Federal Data (0.5 to 4.5 Ranking)
		Regional or Local Community Data (0.5 to 6.5 Ranking)

Source: TWDB Technical Guidelines for Regional Flood Planning

Figure 2.5: Existing Conditions Floodplain Quilt Data Sources



The compiled existing conditions floodplain quilt data for the Trinity Region is included in the submittal GIS database layer named "ExFldHazard". *Figure 2.6* shows a GIS coverage map of the comprehensive existing floodplain data compiled for the Trinity Region showing the 100-year and 500-year floods. Larger detailed maps are included in *Appendix B*.

The total floodplain area for each county is also shown in *Figure 2.7* and *Table 2.4.*

When this compiled existing floodplain quilt was shown to the public at an in-person meeting, the following disclaimer note was used:

> *"The floodplain quilt is a compilation of data from multiple sources and is intended to approximate the extent of existing flood risk in the Trinity Region. This data layer is for planning purposes only and is not to be used for any regulatory activities. For regulatory floodplain maps, contact your local floodplain administrator or visit the FEMA Map Service Center."*

Overall, the Trinity Region covers a total land area of approximately 18,000 square miles with about 22 percent (4,000 square miles) in the existing conditions floodplain. It is notable that Chambers County contains a significant proportion of floodplain area, attributable to its Gulf Coast location along Trinity Bay and East Bay, as well as its relatively flat topography. The County experiences both inundated coastal flooding, as well as riverine flooding from the Trinity River. Hardin and Hood counties exhibit small floodplain area percentages, as they have less than one percent of their land areas located in the Trinity Region.

Figure 2.6: Existing Conditions Floodplain Quilt

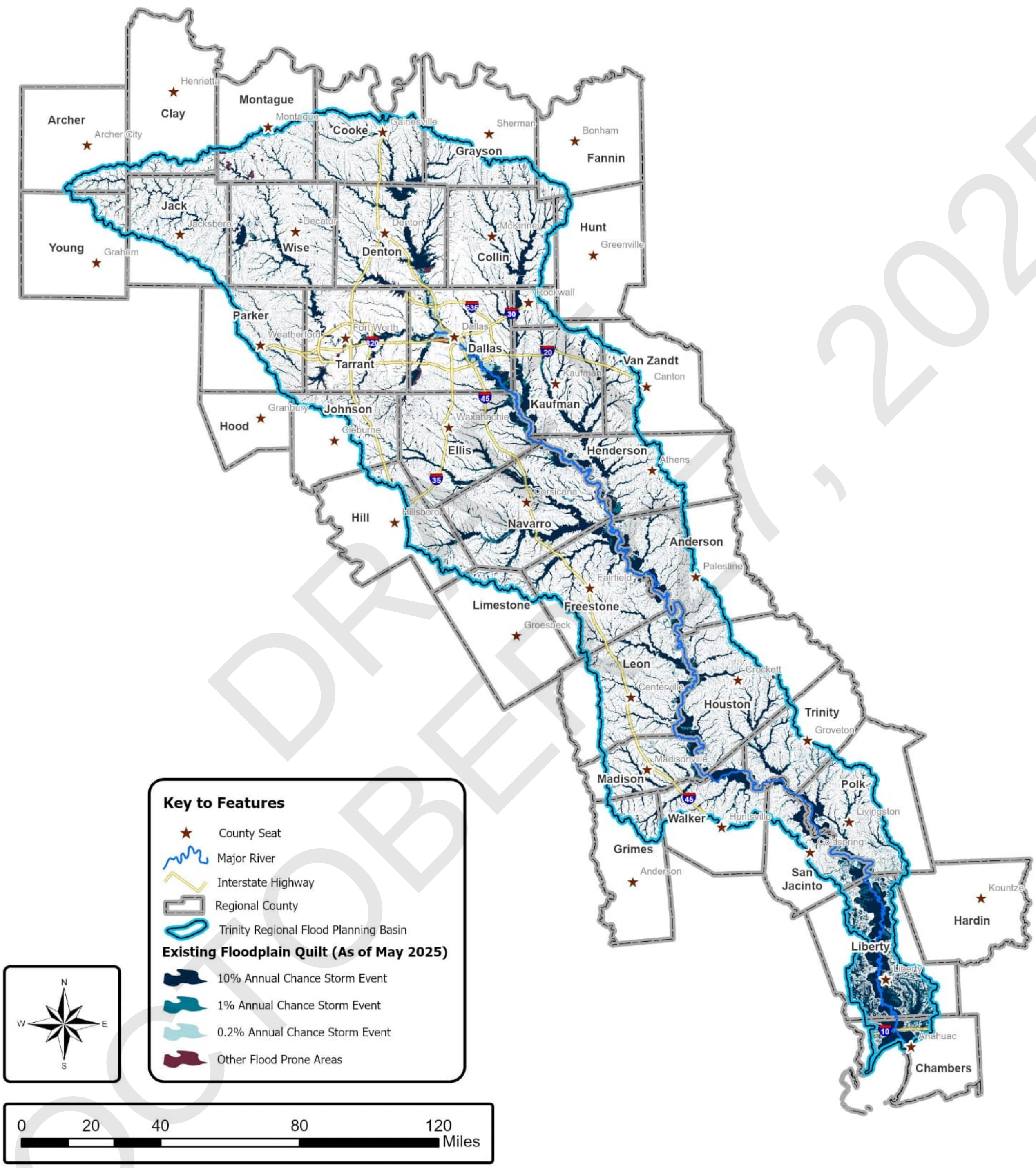


Figure 2.7: Existing Conditions Flood Hazard Areas (in sq mi) by County

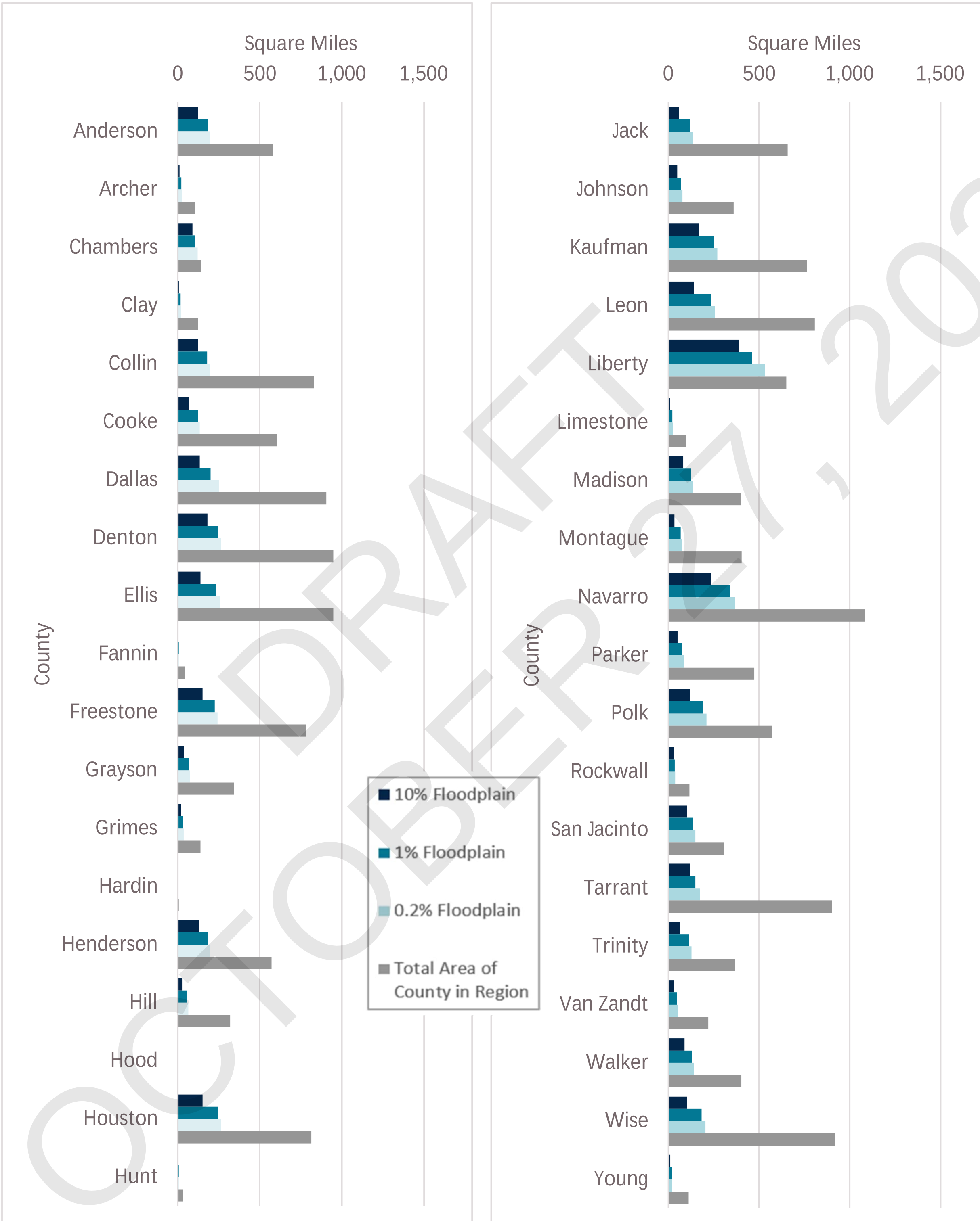


Table 2.4: Existing Conditions Flood Hazard Flood Type and Areas by County

County	10% Annual Chance Flood Risk		1% Annual Chance Flood Risk		0.2% Annual Chance Flood Risk	
	Area in Riverine Flood Type (square miles)	Area in Coastal Flood Type (square miles)	Area in Riverine Flood Type (square miles)	Area in Coastal Flood Type (square miles)	Area in Riverine Flood Type (square miles)	Area in Coastal Flood Type (square miles)
Anderson	124.8	-	57.4	-	13.2	-
Archer	11.8	-	10.8	-	2.6	-
Chambers	39.0	50.6	7.5	6.5	9.3	8.8
Clay	7.6	-	10.1	-	2.1	-
Collin	123.1	-	57.3	-	17.2	-
Cooke	69.3	-	54.6	-	10.6	-
Dallas	133.7	-	65.9	-	51.4	-
Denton	180.8	-	63.5	-	20.1	-
Ellis	139.2	-	92.9	-	24.3	-
Fannin	3.2	-	2.8	-	0.9	-
Freestone	151.5	-	74.1	-	16.3	-
Grayson	38.2	-	27.7	-	8.0	-
Grimes	20.2	-	12.2	-	3.2	-
Hardin	0.9	-	1.3	-	0.9	-
Henderson	132.8	-	52.3	-	13.0	-
Hill	26.3	-	29.9	-	9.1	-
Hood	0.2	-	-	-	-	-
Houston	151.7	-	94.2	-	19.4	-
Hunt	3.5	-	2.6	-	0.6	-
Jack	57.2	-	65.0	-	15.5	-
Johnson	48.8	-	20.6	-	8.8	-
Kaufman	170.9	-	80.9	-	17.7	-
Leon	140.7	-	94.9	-	21.1	-
Liberty	388.4	-	72.9	-	72.9	-
Limestone	9.8	-	12.1	-	2.6	-
Madison	82.6	-	43.0	-	9.9	-
Montague	33.8	-	34.2	-	8.2	-
Navarro	234.1	-	105.3	-	29.1	-
Parker	51.0	-	25.8	-	11.2	-
Polk	119.8	-	72.5	-	17.6	-
Rockwall	29.4	-	6.3	-	1.8	-
San Jacinto	103.1	-	34.3	-	11.1	-
Tarrant	122.6	-	26.5	-	24.3	-
Trinity	62.9	-	51.8	-	12.6	-
Van Zandt	31.6	-	15.5	-	5.0	-
Walker	89.8	-	41.0	-	10.2	-

County	10% Annual Chance Flood Risk		1% Annual Chance Flood Risk		0.2% Annual Chance Flood Risk	
	Area in Riverine Flood Type (square miles)	Area in Coastal Flood Type (square miles)	Area in Riverine Flood Type (square miles)	Area in Coastal Flood Type (square miles)	Area in Riverine Flood Type (square miles)	Area in Coastal Flood Type (square miles)
Wise	103.1	-	79.6	-	22.5	-
Young	124.8	-	8.0	-	2.3	-

**The 1% flood hazard does not incorporate the 10% flood hazard to avoid overlapping polygons*

**The 0.2% flood hazard does not incorporate the 1% flood hazard to avoid overlapping polygons*

Flood Data Gaps

Once the best available comprehensive existing flood data was complied, data gaps were assessed to identify any remaining areas where flood inundation boundary mapping was missing, lacked modeling and/or mapping, used outdated modeling and/or mapping, or recently had more accurate topographic data produced since the last map update. Other contributing engineering factors considered to identify data gaps included modeling technology, significant land use and/or impervious area change, change in flood control structures, channel configuration (including erosion and sedimentation) changes, as well as rainfall pattern changes, which altered peak discharges. Within the Trinity Region, the average age of the effective FIRMs of the study watersheds is 12 years. Among the counties without new Digital FIRMs, Clay and Madison Counties have the oldest FEMA effective maps, dated 1991. Within the modernized counties, the FIRM effective dates range from 2008 to 2024, with Collin County having the latest date of 2024. As of 2025, all communities in the Trinity Region have modernized FEMA digital county-wide effective FIRMs except for Clay, Freestone, Madison, and Trinity counties and their respective incorporated communities. FEMA recently published preliminary Digital FIRM products for Freestone and Trinity Counties in 2024. With recently completed BLE flood data, the non-modernized county maps have the potential to be eligible for FEMA's Paper Reduction projects and become modernized.

The Trinity RFPG attempted to determine the validation status (whether a stream model was new or updated) of the associated H&H models supporting the mapped floodplains using the contributing engineering factors listed earlier. For example, Chambers, Liberty, Polk, San Jacinto, and Walker counties, located in the southern portion of the Trinity Region, were greatly affected by NOAA Atlas 14 precipitation updates which showed higher rainfall events, invalidating their effective FEMA NFHL floodplain information contained within the floodplain quilt. Because of this, these counties are reported as data gaps. Model-backed (H&H) detailed stream study flood data varied in age and conformance to current technologies, even for modernized county-wide FIRMs. In the urban areas, a large percentage of the H&H model data is outdated (HEC-2 or not in digital format), with only a few models revised recently (HEC-RAS, XPSWMM, etc.) and in digital format.

The gap areas data is included in the "Fld_Map_Gaps" GIS database layer. *Figure 2.8* shows the locations of identified existing flood data gaps. Additional detailed data gap maps are provided in *Appendix B*. While areas were identified within the floodplain quilt as data gaps with outdated information, the compiled existing floodplain quilt still comprised the best available floodplain datasets for the Trinity Region and was used for the flood risk analysis in the Trinity Regional Flood Plan. It is the goal of this plan to further evaluate these data gaps for inclusion as potentially feasible Flood Management Evaluations (FMEs). See *Chapter 4*.

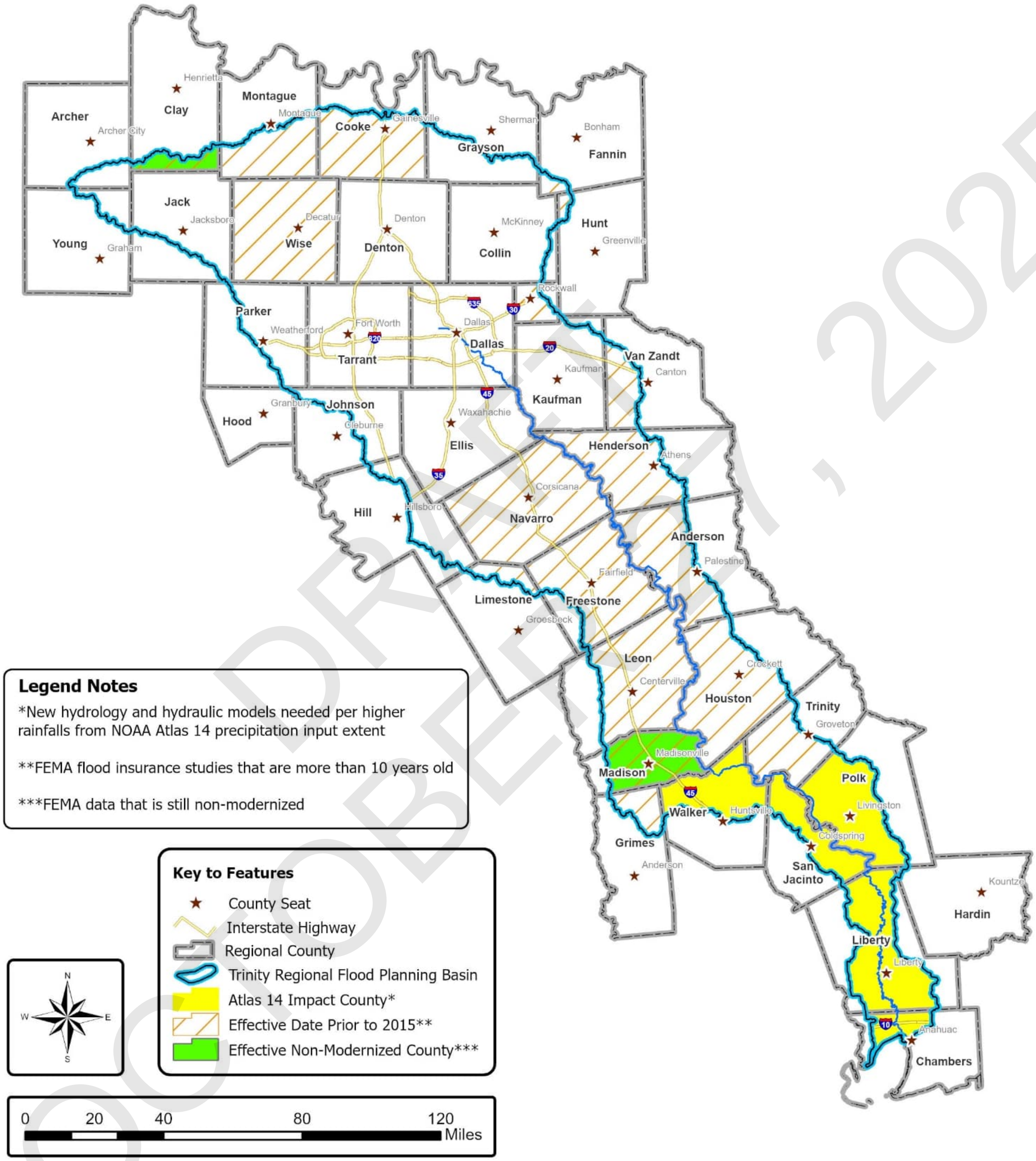
Existing Conditions Flood Exposure Analysis

Flooding is a common occurrence within the Trinity Region (See *Figure 2.4*). Flooding can become a significant hazard when it inundates the built environment and causes direct damage to buildings, critical facilities, crops, or significant injuries and sometimes death to people. Flooding frequency and intensity have been increasing in recent years, often necessitating state and federal relief, which has risen to record levels. The existing conditions flood risk exposure analysis leveraged the compiled existing conditions 10-year, 100-year, and 500-year floods in the Trinity Region to determine existing flooding exposure to buildings, critical facilities, and agriculture. Results from the flood exposure analysis were utilized to estimate the impact to socially vulnerable populations or communities discussed later in this chapter.

Existing Development within the Floodplain

A regionwide inventory of buildings, population, critical facilities, utilities, and agriculture was conducted to assess who and what was at-risk within the Trinity Regional Flood Plan. Existing development data leveraged for the Trinity Regional Flood Plan came from several data sources. The Homeland Infrastructure Foundation Level Data (HIFLD) and data from TWDB were the sources of critical facilities data. The Texas Department of Transportation (TxDOT) bridge inventory and roadway data was also used. The TWDB provided building data in February 2025 with associated population and Social Vulnerability Index (SVI) estimates, which were confirmed and updated where additional information was available.

Figure 2.8: Existing Conditions Floodplain Quilt Data Gaps



The TWDB building dataset was built on available Light Detection and Ranging (LiDAR) information (2010 to 2021), Microsoft Artificial Intelligence Version 2 data, and 2021 Open Street Map (OSM) buildings. The 2019 LandScan USA dataset from Oak Ridge National Laboratory (ORNL) was utilized to estimate population per building, for both day and night. The 2025 Texas Flood Social Vulnerability Index (TX F-SVI) was applied to the building and critical asset data.

The 2024 USGS National Land Cover Database (NLD) provided data for agricultural areas. Bridge and roadway asset inventory data came from the 2025 TxDOT dataset. Communities and invested entities within the Trinity Region also provided data via the online GIS-based data collection tool developed for the Trinity Region.

Results of the detailed analyses of exposure to development within the existing floodplain are presented later in this chapter.

Impact of Levees and Dams on Existing Flood Exposure

Flood exposure is the identification of what is at risk due to extreme flooding. This refers to the people, buildings, businesses, infrastructure systems, and associated functions that could be lost to a flood hazard. Exposure also refers to the economic value of assets subjected to the flood hazard. This section discusses flood exposure due to levees and dams in the Trinity Region.

Levees in the Trinity Region

The USACE National Levee Database (NLD) identifies an estimated 78 levee systems within the Trinity Region. Approximately 78 percent of the levee systems are maintained and owned by local entities. The remainder are overseen by USACE or another federal or state agency. These levees are built parallel to rivers, streams, creeks, lakes, and their tributaries. They are also built along the coast to provide protection from certain levels of flooding. An estimated 30 of the levee systems in the Trinity Region are located along the Trinity River mainstem and 8 systems are located along the West Fork Trinity River. The remaining are scattered throughout the Trinity Region.

Levees can be breached during flood events due to overtopping, toe scour, seepage/piping, and foundation instability. The resulting torrent can quickly inundate a large area behind the failed levee with little or no warning, thereby exposing them to extreme flooding effects and consequences.

Levee accreditation is FEMA's recognition that a levee is reasonably certain to contain the base (1 percent annual chance storm event) regulatory flood. To help communities understand the flood risk behind levee structures, FEMA applies levee accreditation information on FIRMs to show the locations with reduced risks from the regulatory flood event. Approximately 36 of the levee systems in the Trinity Region are accredited. See *Figure 2.9* for location of the levees and their FEMA accreditation status in the Trinity Region.

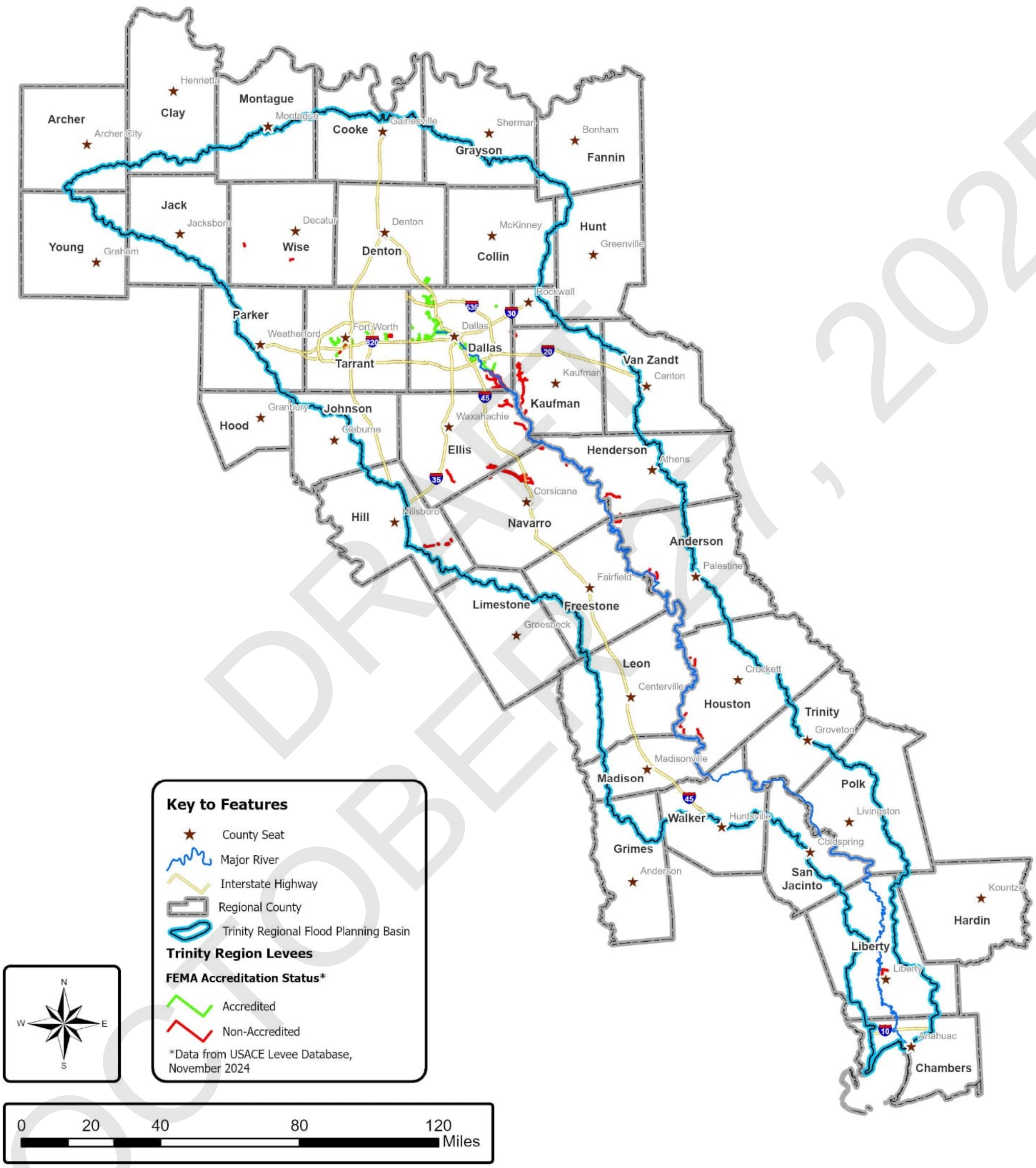
On FIRMs, FEMA shows areas mapped behind accredited levees as "Areas with Reduced Risk Due to Levee". These accredited levees protect several thousands of structures and people as well as several billion dollars of property from flood damage. When the levee is not accredited, the embankments are categorized as hydraulically significant structures and the area behind the landward side of the levee is not considered to be protected from any flood event, and consequently, exposed to flooding.

While the Trinty Region boasts 36 accredited levee systems, an estimated 42 non-accredited levee systems are located throughout the region. Non-accredited levee systems are those that do not meet all of the levee certification requirements and subsequent accreditation from FEMA. When non-accredited levee systems are shown on a FEMA map, a special note is attached to indicate that the levee system has not been accredited and therefore not shown as providing protection form the 1-percent annual chance flood.

USACE leveed-area floodplain data and FEMA's "Areas with Reduced Risk Due to Levee" datasets were incorporated into the existing floodplain quilt dataset for the Trinity Region as "Other Floodprone Areas".

Areas behind the accredited levees are considered to protected from flooding and therefore have a reduced flood risk due to the levees. Areas behind non-accredited levees have minimal protection and remain exposed to flood risks.

Figure 2.9: Levees and Federal Emergency Management Agency Accreditation Status



Levee Protection and Exposure Assessment

There are more than 13,000 people who live and work behind the non-accredited levees in the Trinity Region. See *Table 2.5* and *Table 2.6* for levee protection and exposure by county respectively. The exposure summary was estimated by overlaying the leveed areas within the Trinity Region's existing floodplain quilt with building and population data. The exposure assessments include structure and population counts behind the non-accredited levees.

As shown in *Table 2.5* and *Table 2.6*, Dallas County has significant population and properties protected by levees. In contrast, Liberty County has the most exposure due to the presence of non-accredited levees.

Dams in the Trinity Region

In the Trinity Region, dams and their associated reservoirs are used for water supply, recreation, navigation, electric generation, irrigation, and flood control. According to the USACE National Inventory of Dams, NRCS dams inventory, and Texas Commission on Environmental Quality (TCEQ), there are over 1,800 dams in the Trinity Region and most of these dams are used for flood control, water supply, recreation, or agriculture. Most dams are owned by local and private entities.

Dam-controlled reservoirs with flood storage capacities impound floodwaters and either release floodwaters in controlled amounts downstream or store or divert water for other uses. As such, areas lying adjacent or downstream of dams are exposed to severe flooding and its associated consequences when a dam breaks or fails.

Dams suffer the same failure modes as levees. A dam failure causes an uncontrolled release of impounded water to adjacent or downstream areas. The recent dam failure of Lake Dunlap along the Guadalupe River, downstream of New Braunfels, is a good example; on May 14, 2019, the spillway unexpectedly collapsed due to structural defects. Homeowners experienced flooding with the resultant fear of decline in their property values. Because the area was an attraction for fishing, boating, and other recreational activities, the area experienced significant economic losses after the dam failure.

On average, the dams located in the Trinity Region are 62 years old, with 76 percent having been built before 1975. Typically, the dams that are owned and operated by large entities are well-maintained. However, dams owned and operated by smaller entities or private landowners are more likely to need inspections and/or rehabilitation as funding for such activities is often more costly than the property owners can afford.

Areas downstream of flood-controlled dams are considered to protected from flooding and therefore have a reduced flood risk due to the dams. Areas downstream of other dams have minimal protection and remain exposed to flood risks.

Table 2.5: Accredited Levee Protection by County

County	Number of Levees	Buildings Affected	Population Affected	Economic Value
Anderson	-	-	-	-
Archer	-	-	-	-
Chambers	-	-	-	-
Clay	-	-	-	-
Collin	-	-	-	-
Cooke	-	-	-	-
Dallas	22	23,626	378,951	$47,490,213,172
Denton	2	1,332	9,253	$2,070,619,327
Ellis	-	-	-	-
Fannin	-	-	-	-
Freestone	-	-	-	-
Grayson	-	-	-	-
Grimes	-	-	-	-
Hardin	-	-	-	-
Henderson	-	-	-	-
Hill	-	-	-	-
Hood	-	-	-	-
Houston	-	-	-	-
Hunt	-	-	-	-
Jack	-	-	-	-
Johnson	-	-	-	-
Kaufman	1	26	28	$7,219,355
Leon	-	-	-	-
Liberty	-	-	-	-
Limestone	-	-	-	-
Madison	-	-	-	-
Montague	-	-	-	-
Navarro	-	-	-	-
Parker	-	-	-	-
Polk	-	-	-	-
Rockwall	-	-	-	-
San Jacinto	-	-	-	-
Tarrant	13	5,791	21,519	$4,938,332,204
Trinity	-	-	-	-
Van Zandt	-	-	-	-
Walker	-	-	-	-
Wise	-	-	-	-
Young	-	-	-	-

Table 2.6: Non-Accredited Levee Exposure by County

County	Number of Levees	Buildings Affected	Population Affected	Economic Value
Anderson	2	4	-	$75,484,749
Archer	-	-	-	-
Chambers	-	-	-	-
Clay	-	-	-	-
Collin	-	-	-	-
Cooke	1	17	-	$4,177,493
Dallas	6	717	1,224	$114,750,958
Denton	-	-	-	-
Ellis	8	65	73	$3,004,500
Fannin	-	-	-	-
Freestone	-	-	-	-
Grayson	-	-	-	-
Grimes	-	-	-	-
Hardin	-	-	-	-
Henderson	3	42	32	$95,152,172
Hill	4	2	6	$11,270,010
Hood	-	-	-	-
Houston	4	53	76	$0
Hunt	-	-	-	-
Jack	-	-	-	-
Johnson	-	-	-	-
Kaufman	8	55	77	$289,109,575
Leon	-	-	-	-
Liberty	1	1,839	6,601	$854,230,796
Limestone	-	-	-	-
Madison	-	-	-	-
Montague	-	-	-	-
Navarro	9	15	48	$117,757,142
Parker	-	-	-	-
Polk	-	-	-	-
Rockwall	-	-	-	-
San Jacinto	-	-	-	-
Tarrant	3	78	29	$95,751,231
Trinity	-	-	-	-
Van Zandt	-	-	-	-
Walker	-	-	-	-
Wise	2	36	23	$40,710,151
Young	-	-	-	-

While FEMA does not show downstream dam inundation extents on maps, such data may be available as non-regulatory products in some of its flood risk studies. TCEQ requires dam inundation mapping for certain dams. Recently, USACE developed dam inundation mapping for six high-hazard dams in the Trinity Region. The dam inundation areas from the National Hydrography Dataset (NHD) were incorporated into the existing floodplain quilt for the Trinity Region as "Other Floodprone Areas". These "Other Floodprone Areas" do not have the same probability of occurrence as the 100-year and 500-year floods.

Dam Flowage Easement

Flowage easements are perpetual rights typical of a government agency, such as the USACE. The dam flowage easements grant them the right to essentially flood privately owned land to properly operate a reservoir. Flowage easements also grant entities the right to prohibit construction of, or maintenance to, any improvement(s) for human habitation, and the right to approve any other structures constructed on such property. The purpose of establishing these lines is to protect personal property in the event of a flood since they are flood prone. These boundaries, therefore, assist in estimating buildings and population affected in areas subject to dam inundation within the Trinity Region. FEMA identifies these flowage easements lying along reservoirs on its FIRMs. *Figure 2.10* shows a typical dam and associated flowage easement on a FEMA FIRM.

Dam Protection and Exposure Assessment

For the purposes of the Trinity Region dam exposure analysis, areas subject to flooding from dams were overlaid on buildings, critical facilities, and population to estimate the associated hazard potential. The available USACE dam risk assessment data was also leveraged where available. *Figure 2.11* shows locations of dams in the Trinity Region. There are over 300,000 people living in these exposure areas. These areas are mostly located around dams with no Emergency Action Plans. In populated areas, residents may not be aware of this risk, especially when flooding occurs. See *Table 2.7*, and *Table 2.8* for dam protection and exposure by county respectively. According to *Table 2.7*, high dam exposures are prevalent in Collin, Denton, Ellis, and Tarrant counties, with a few scattered exposures throughout the region.

It must be emphasized that the State of Texas does not regulate development in high hazard areas immediately adjacent to or downstream of dams. While flooding from high precipitation or dam failure impacts dams, human activity must also be considered when analyzing the risks posed by dams. In Texas, the hazard classification of dams is based on the potential for loss of life and economic loss in the area downstream of the dam, not on its structural safety. Thus, dams that may be of very sound construction are labeled "high hazard" if failure could result in catastrophic loss of life. In other words, the term "high hazard" applies if people have settled in the potential inundation zone. The “high hazard” designation does not imply structural weakness or an unsafe dam (TCEQ, 2006).

Many developers are purchasing property with small livestock dams and developing property around lakes and downstream of the dams, creating additional risk. Continued growth in rural areas will result in changes to hazard classifications of dams that current residents may not be aware of.

Figure 2.10: Flowage Easement Area on Federal Emergency Management Agency Flood Insurance Rate Maps

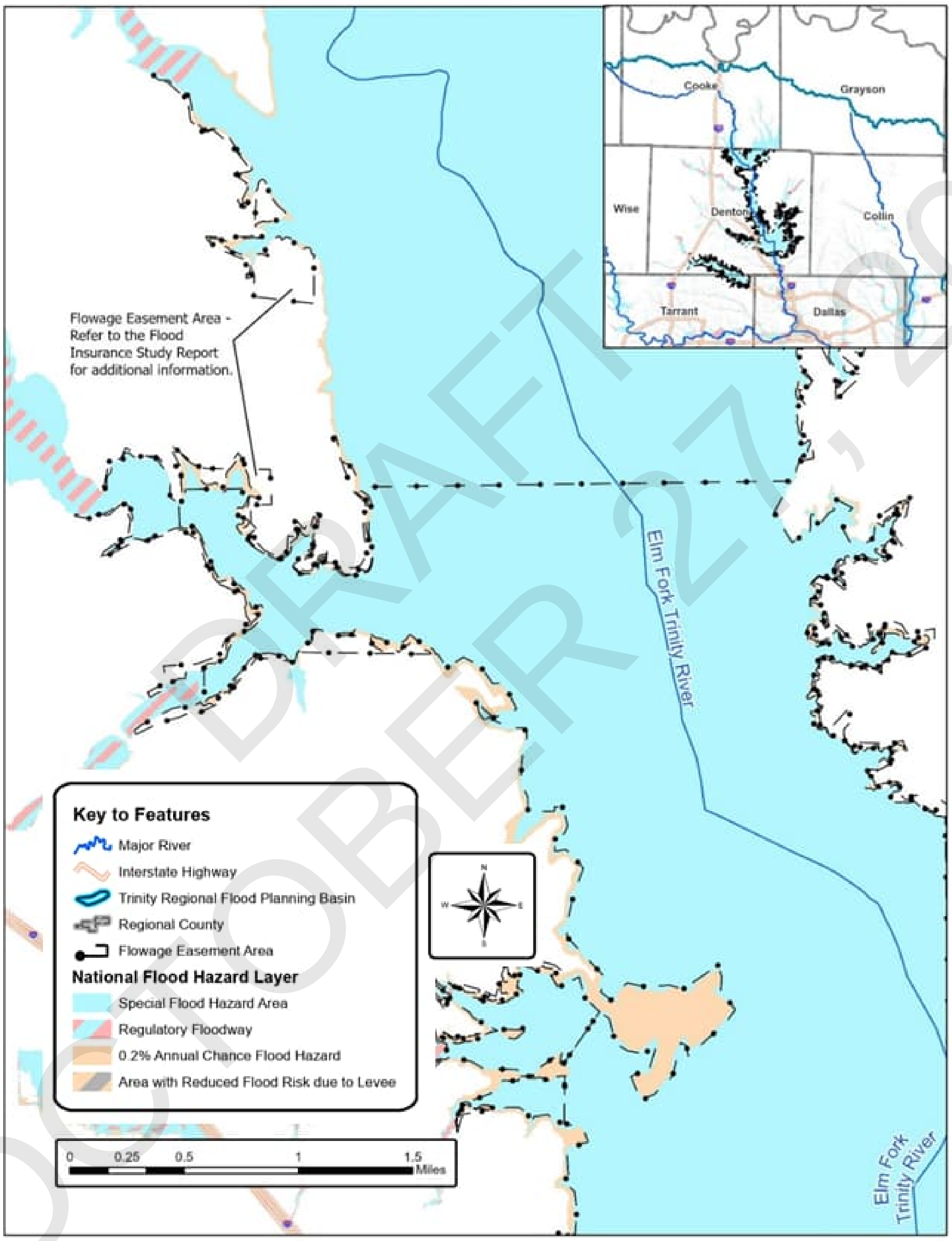


Figure 2.11: Dams in the Trinity Region

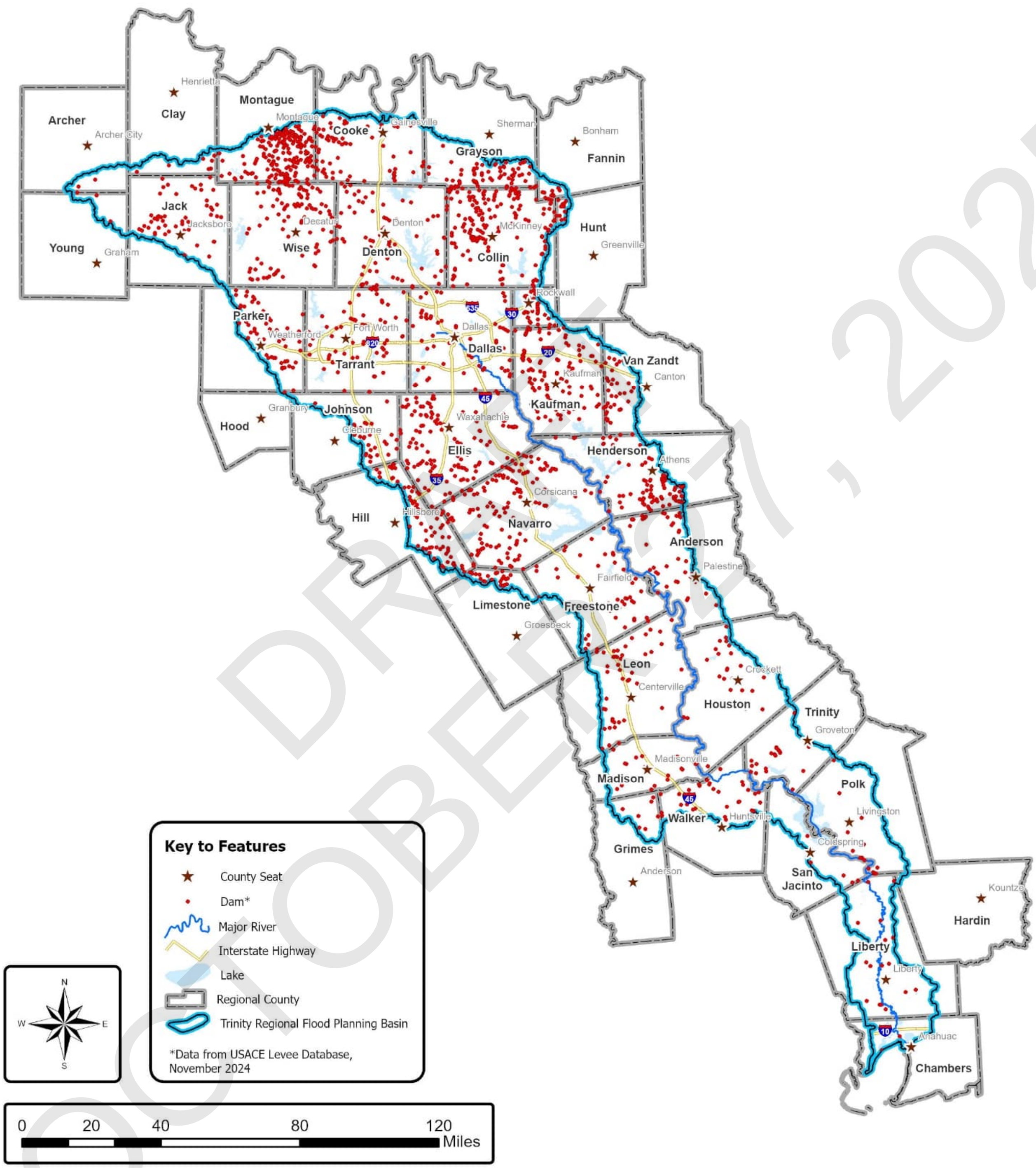


Table 2.7: Flood Control Dam Protection by County

County	Dams	Buildings Affected	Population Affected	Economic Value
Anderson	-	-	-	-
Archer	-	-	-	-
Chambers	-	-	-	-
Clay	-	-	-	-
Collin*	1	7,476	22,256	$426,384,000
Cooke	-	-	-	-
Dallas	-	-	-	-
Denton*	2	47,082	385,364	$29,593,309,184
Ellis*	1	4,831	10,610	$405,447,008
Fannin	-	-	-	-
Freestone	-	-	-	-
Grayson	-	-	-	-
Grimes	-	-	-	-
Hardin	-	-	-	-
Henderson	-	-	-	-
Hill	-	-	-	-
Hood	-	-	-	-
Houston	-	-	-	-
Hunt	-	-	-	-
Jack	-	-	-	-
Johnson	-	-	-	-
Kaufman	-	-	-	-
Leon	-	-	-	-
Liberty	-	-	-	-
Limestone	-	-	-	-
Madison	-	-	-	-
Montague	-	-	-	-
Navarro*	1	5,578	16,594	$486,287,008
Parker	-	-	-	-
Polk	-	-	-	-
Rockwall	-	-	-	-
San Jacinto	-	-	-	-
Tarrant*	2	96,917	440,763	$51,923,197,952
Trinity	-	-	-	-
Van Zandt	-	-	-	-
Walker	-	-	-	-
Wise	-	-	-	-
Young	-	-	-	-

**Includes data from the USACE Dam Risk Assessment (data as of August 2025)*

Table 2.8: Other Dam Exposure by County

County	Dams	Buildings Affected	Population Affected	Economic Value
Anderson	40	18	-	$1,796,693,765
Archer	3	-	-	$15,825,470
Chambers	3	84	17	$7,157,100
Clay	7	-	-	-
Collin*	164	150	560	$3,751,373,534
Cooke	68	88	26	$712,014,583
Dallas	63	156	2127	$8,424,993,387
Denton*	73	318	801	$4,629,172,572
Ellis*	122	74	43	$8,880,410
Fannin	10	2	-	$31,257,090
Freestone	47	127	17	$907,232,541
Grayson	64	28	2	$882,138,222
Grimes	7	-	-	$1,279,860
Hardin	-	-	-	$7,912,802
Henderson	85	231	157	$2,392,402,035
Hill	72	11	11	$295,086,060
Hood	-	-	-	-
Houston	25	63	-	$7,299,840
Hunt	11	1	-	$49,502,860
Jack	51	6	2	$2,619,985
Johnson	38	28	36	$0
Kaufman	108	161	166	$1,386,811,160
Leon	44	4	4	$2,055,084
Liberty	16	307	314	$6,265,163,480
Limestone	24	3	2	$420,310
Madison	20	3	2	$397,468,060
Montague	187	86	81	$3,758,666
Navarro*	117	499	55	$1,306,313,850
Parker	63	274	348	$932,263,455
Polk	19	98	156	$336,120,161
Rockwall	32	81	262	$628,305,555
San Jacinto	6	104	104	$807,358,140
Tarrant*	70	1131	2,607	$6,098,780,721
Trinity	22	143	191	$296,851,025
Van Zandt	33	2	-	$123,210,699
Walker	34	57	42	$775,815,472
Wise	99	666	881	$1,320,522,839
Young	2	-	-	$9,093,540

**Includes data from the USACE Dam Risk Assessment (data as of August 2025)*

Existing Conditions Flood Exposure

To assist with flood risk analysis, TWDB has provided statewide coverage of building footprints along with improvement value, land use, population estimate, and SVI data. This dataset formed the basis for determining existing development within the existing conditions floodplains in the Trinity Region. According to this database, approximately three million buildings are located within the counties intersected by the Trinity Region. Approximately 60,000 buildings in the Trinity Region are partially or completely within the 100-year floodplain. *Table 2.9* summarizes existing development in existing conditions floodplains. Note that these estimates are based on a GIS analysis that accounts for the area of impact without necessarily considering the finished floor elevations of structures.

Table 2.9: Existing Development Exposure (Total Structure Count) in Existing Conditions Floodplain Quilt

County	Number of Structures within Existing Conditions Floodplains*	County	Number of Structures within Existing Conditions Floodplains*
Anderson	950	Jack	405
Archer	2	Johnson	5,839
Chambers	8,109	Kaufman	3,878
Clay	30	Leon	948
Collin	8,968	Liberty	21,649
Cooke	2,232	Limestone	104
Dallas	47,188	Madison	668
Denton	9,990	Montague	632
Ellis	5,224	Navarro	2,706
Fannin	275	Parker	3,832
Freestone	810	Polk	5,105
Grayson	701	Rockwall	1,155
Grimes	173	San Jacinto	3,517
Hardin	58	Tarrant	28,091
Henderson	3,145	Trinity	1,689
Hill	208	Van Zandt	676

County	Number of Structures within Existing Conditions Floodplains*		County	Number of Structures within Existing Conditions Floodplains*
Hood	2		Walker	2,299
Houston	1,175		Wise	2,603
Hunt	39		Young	13

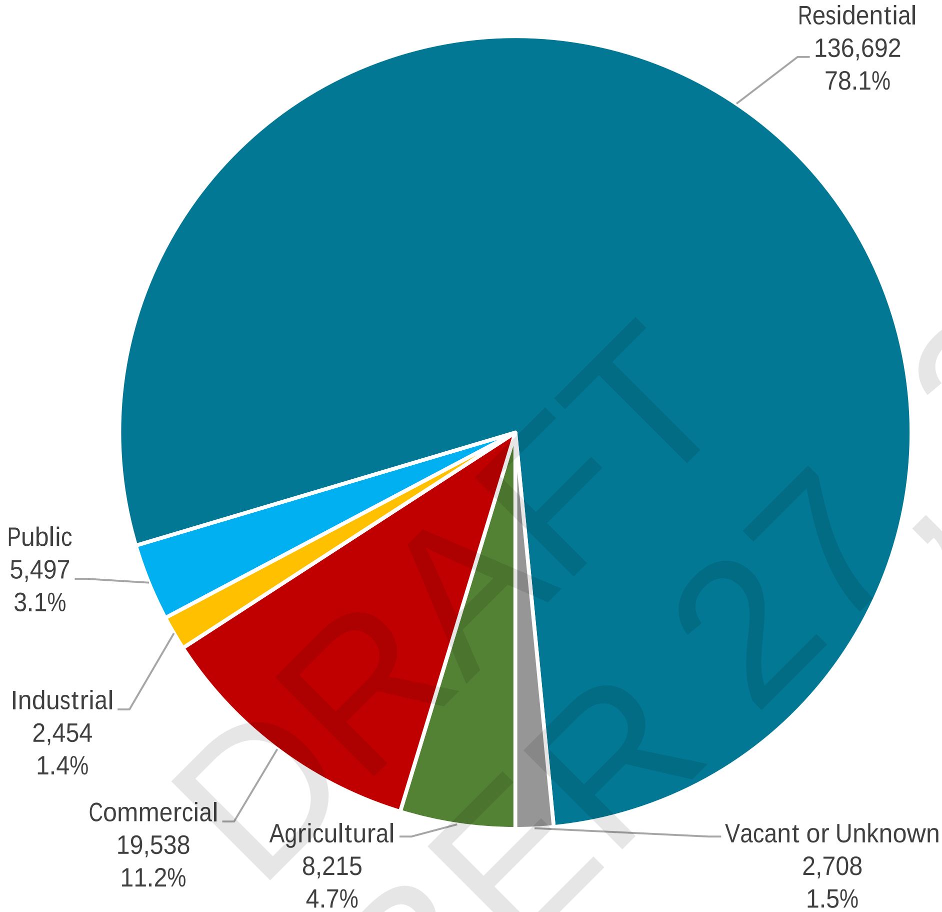
*This is the exposure in the combined total 10%, 1%, and 0.2% existing floodplain extents

The sections that follow discuss and summarize the results of the existing conditions flood exposure to existing development. The existing conditions flood exposure analysis considered buildings, population, public infrastructure, critical facilities, roadway segments and crossings, and agricultural areas exposed to the compiled existing conditions floodplain quilt. This section excludes flood exposure associated with levees and dams. The 10-year, 100-year, and 500-year mapping extents are represented in the Trinity Region existing conditions floodplain quilt.

Regional building data collected for the Trinity Region were classified into three main categories: residential, non-residential, and critical facilities. Approximately seven percent of buildings within the Trinity Region are located within the existing floodplain, as shown in *Figure 2.12*. Of those, an estimated 78 percent are residential, and 11 percent are commercial. Buildings classified as vacant are structures for which the building type and/or use could not be determined.

Figure 2.13 illustrates graphically by county the total exposure structure (residential, non-residential, and critical facilities) count in the existing conditions floodplain quilt.

Figure 2.12: Building Type Exposure Distribution in the Existing Conditions Floodplain Quilt



Residential Properties

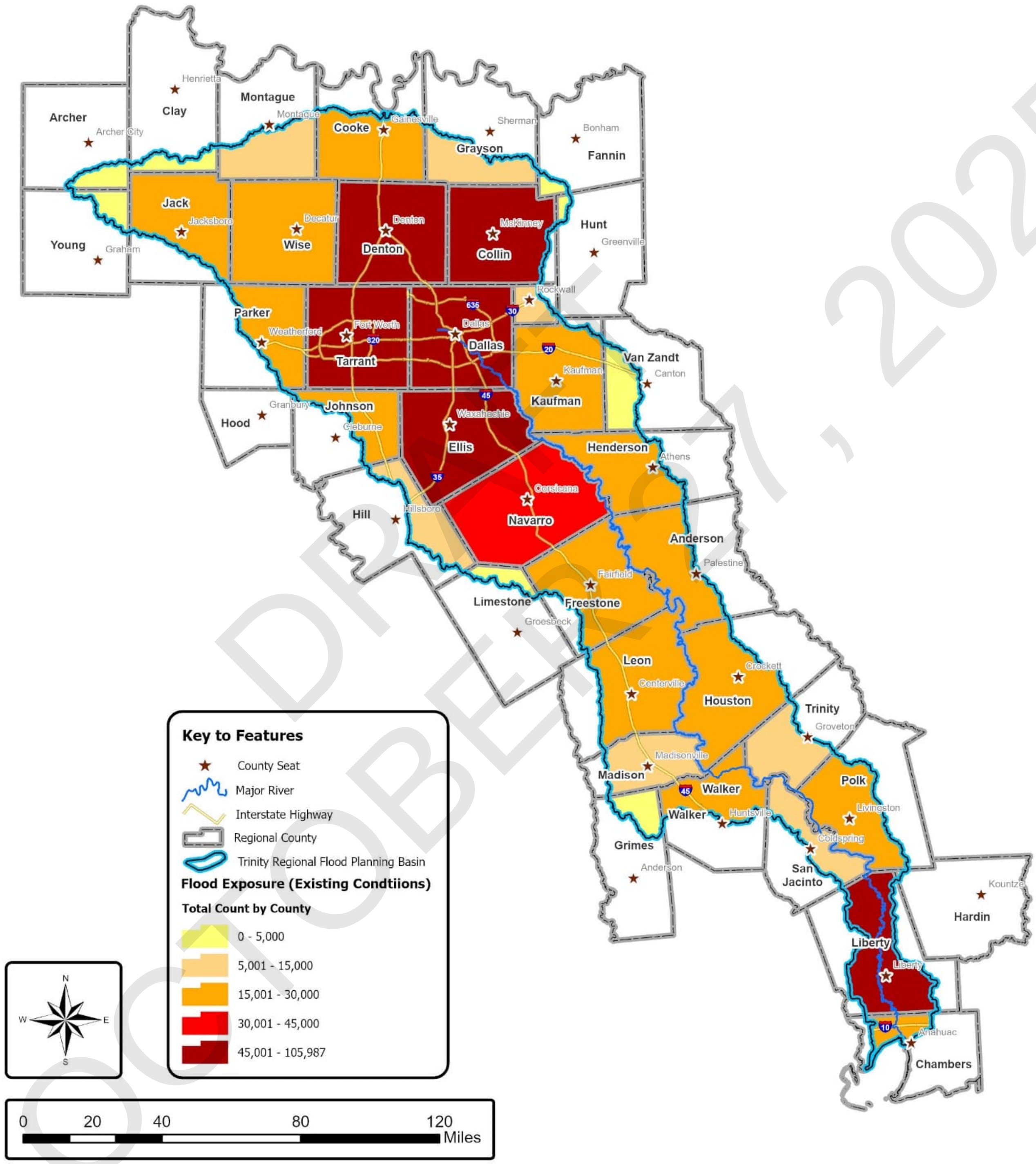
Residential structure data used in the Trinity Regional Flood Plan include single-family homes, town homes, mobile homes, as well as multi-family residences such as apartments and condominiums. Over two million residential building footprints have been gathered for the Trinity Region and an estimated seven percent of these buildings have been found to be exposed to flooding. An associated population of over 661,000 is estimated as being at risk to flooding.

Figure 2.13 and *Figure 2.15* shows the total estimated number of residential structures by county exposed to the existing floodplain quilt. Dallas, Denton, and Tarrant counties (all in the Upper Subregion) and the coastal Liberty County (in the Lower Subregion) have the highest number of residential buildings in the existing floodplain. Archer, Clay, Hardin, Hill, Hood, Hunt, Leon, Limestone, and Young counties show very little residential building exposure because only very small portions of these counties are in the Trinity Region, most of which are their respective unincorporated areas.

Residential Population Totals by County

Population data (day and night) attributed to the residential buildings has been used to summarize countywide residential population exposed to the existing conditions floodplain quilt. Adhering to the TWDB guidance, the RFPG has assigned the greater of the day or night population attributes for the building population exposure estimates. *Figure 2.14* shows a representation of the total population located within flood risk across the entire region graphically. As shown in *Figure 2.14*, high population exposures occur in the Dallas-Fort Worth-Arlington area, Collin, Dallas, Denton, and Tarrant counties in the Upper Subregion, as well as coastal Liberty County in the Lower Subregion. It must be noted that because the population count is the greater of the day or night numbers, this assumes the worst possible scenario where the maximum number of people present are exposed to the existing conditions floodplain quilt.

Figure 2.13: Existing Development (Total Count of Buildings, Agricultural Land, and Infrastructure) Exposure in Existing Conditions Floodplain Quilt by County



Non-Residential Properties

Non-Residential inventory data included agricultural, commercial, industrial, and public buildings. Over 406,000 non-residential building footprints were gathered for the Trinity Region, and an estimated 25 percent of these buildings are exposed to flooding. An associated population of over 52,000 is estimated as being at risk of flooding. *Figure 2.16* shows the total estimated number of non-residential structures by county exposed to the existing conditions floodplain quilt.

Ellis County (in the Upper Subregion) and coastal Chambers County (in the Lower Subregion) have the highest number of agricultural buildings in the existing floodplain. Collin, Dallas, Denton, and Tarrant counties (in the Upper Subregion) showed the highest number of commercial buildings in the existing conditions floodplain. Archer, Clay, Hardin, Hill, Hood, Hunt, Limestone, and Young counties show very little residential building exposure because only a very small portion of these counties are in the Trinity Region, most of which are their respective unincorporated areas.

Critical Facilities and Public Infrastructure

A critical facility provides services and functions essential to a community, especially during and after a disaster. Critical infrastructure includes all public or private assets, systems, and functions vital to the security, governance, public health and safety, economy, or morale of the state or the nation (TWDB Flood Planning Frequently Asked Questions, 2021). Critical facilities data gathered for the Trinity Region included fire stations, hospitals, nursing homes, police stations, emergency shelters, schools (kindergarten through 12th grade), government facilities, military installations, water and wastewater treatment facilities, TCEQ wastewater outfalls, water supply systems (well sites), and Superfund sites. Lifeline utility systems data, such as petrol storage tanks, power generating plants, as well as natural gas and electric transmission lines, were collected for exposure analysis. Critical facilities data was from TWDB, TCEQ, Railroad Commission (RRC) of Texas, HIFLD, as well as data from Trinity Region area communities.

The existing floodplain quilt was overlaid on the data gathered for critical facilities to estimate the flood exposures. *Figure 2.17* shows the total counts of exposed critical facilities to the existing conditions floodplain quilt in the Trinity Region.

Figure 2.14: Population at Risk in Existing Conditions Flood Hazard by County

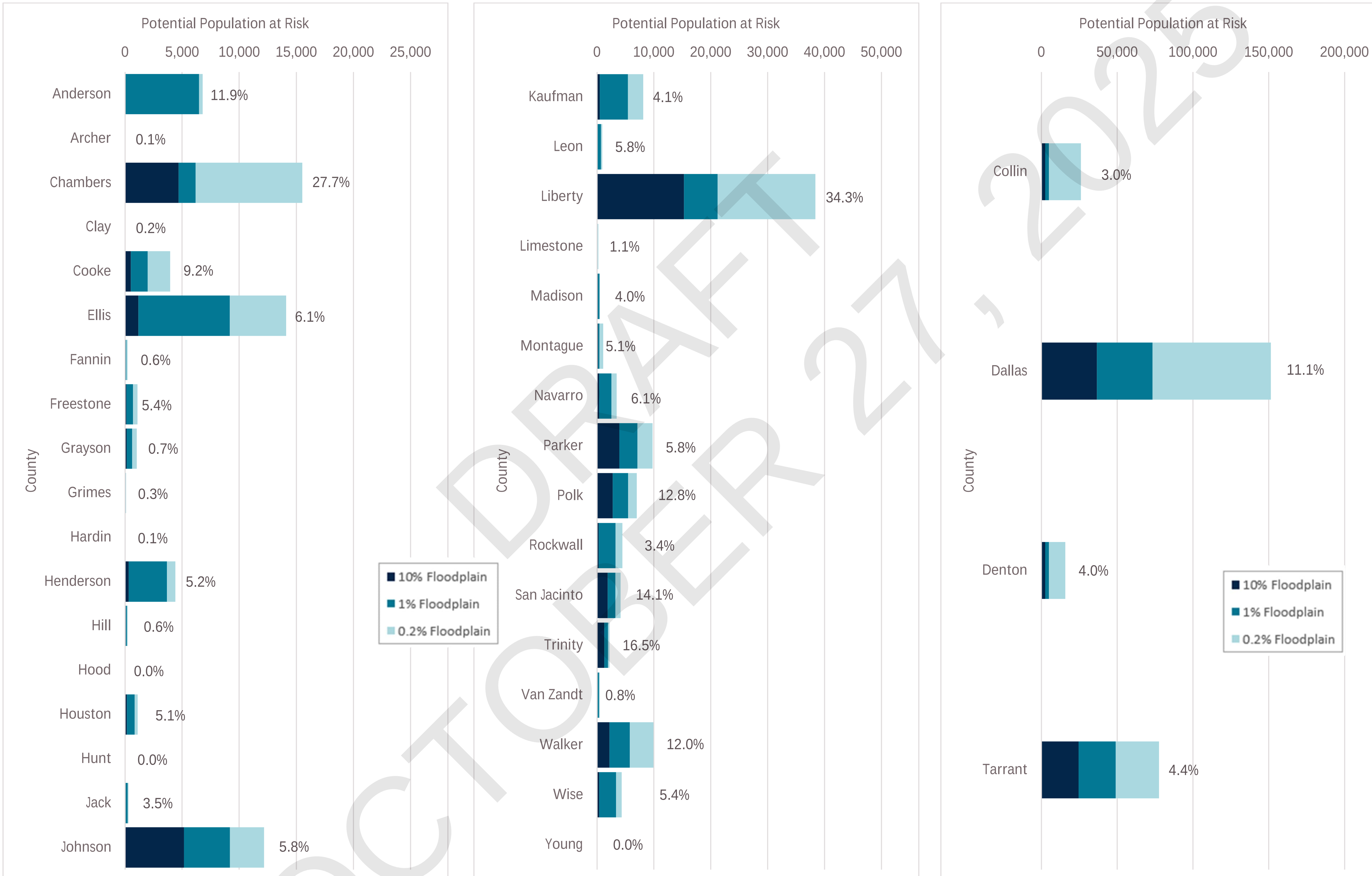


Figure 2.15: Residential Structure Counts in Existing Conditions Floodplain Quilt by County

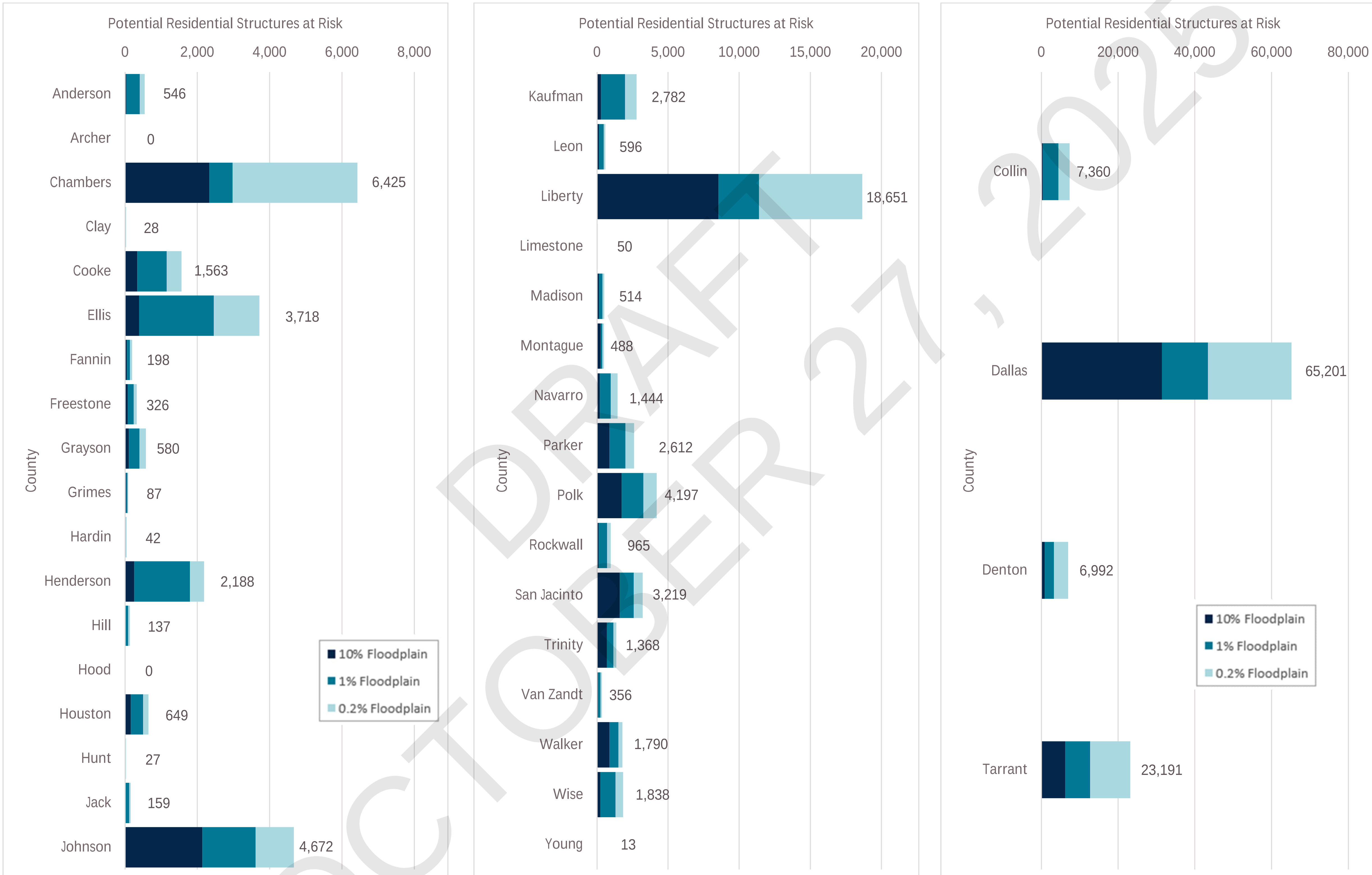


Figure 2.16: Non-Residential Structure Counts in Existing Conditions Floodplain Quilt by County

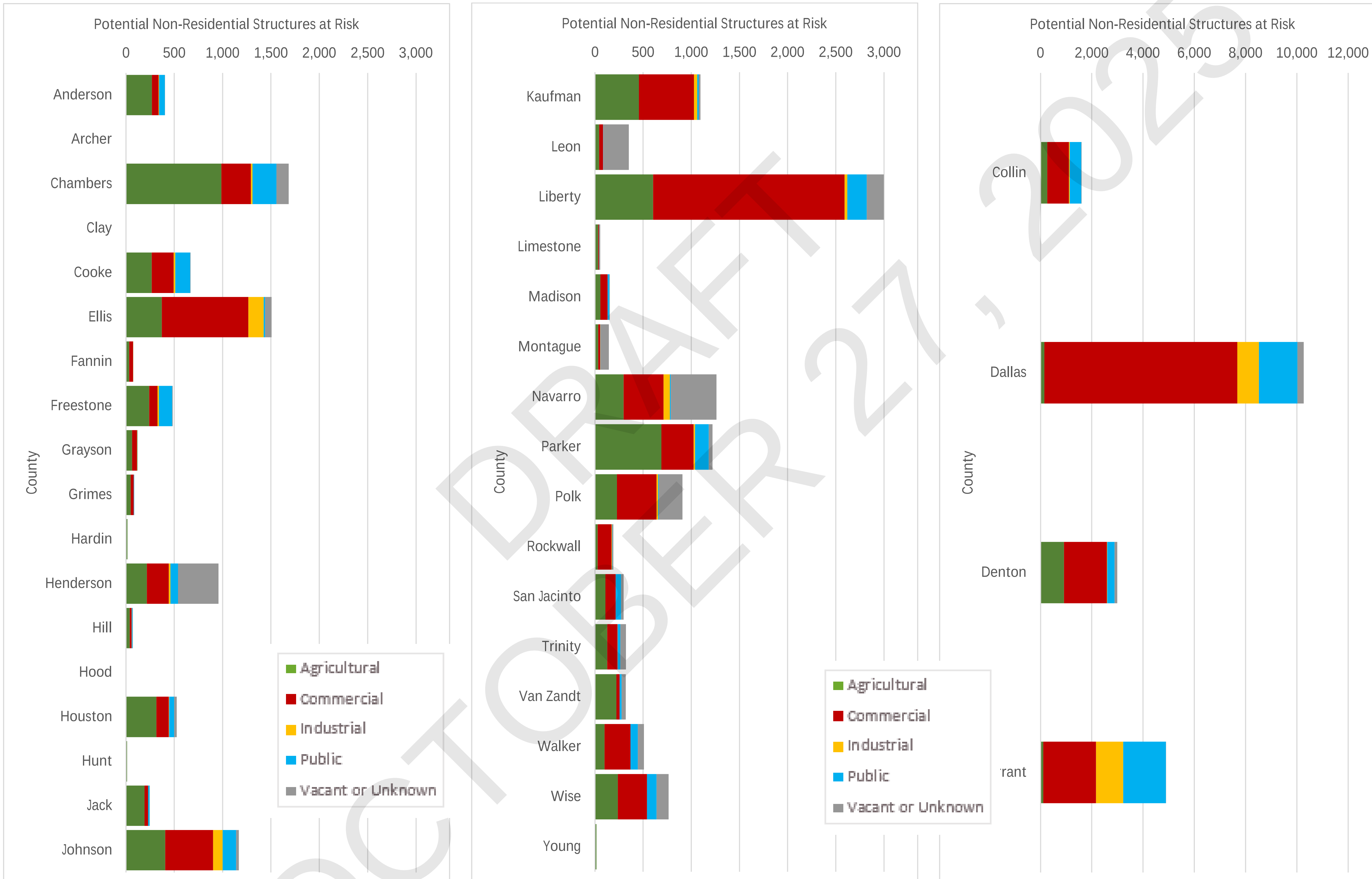
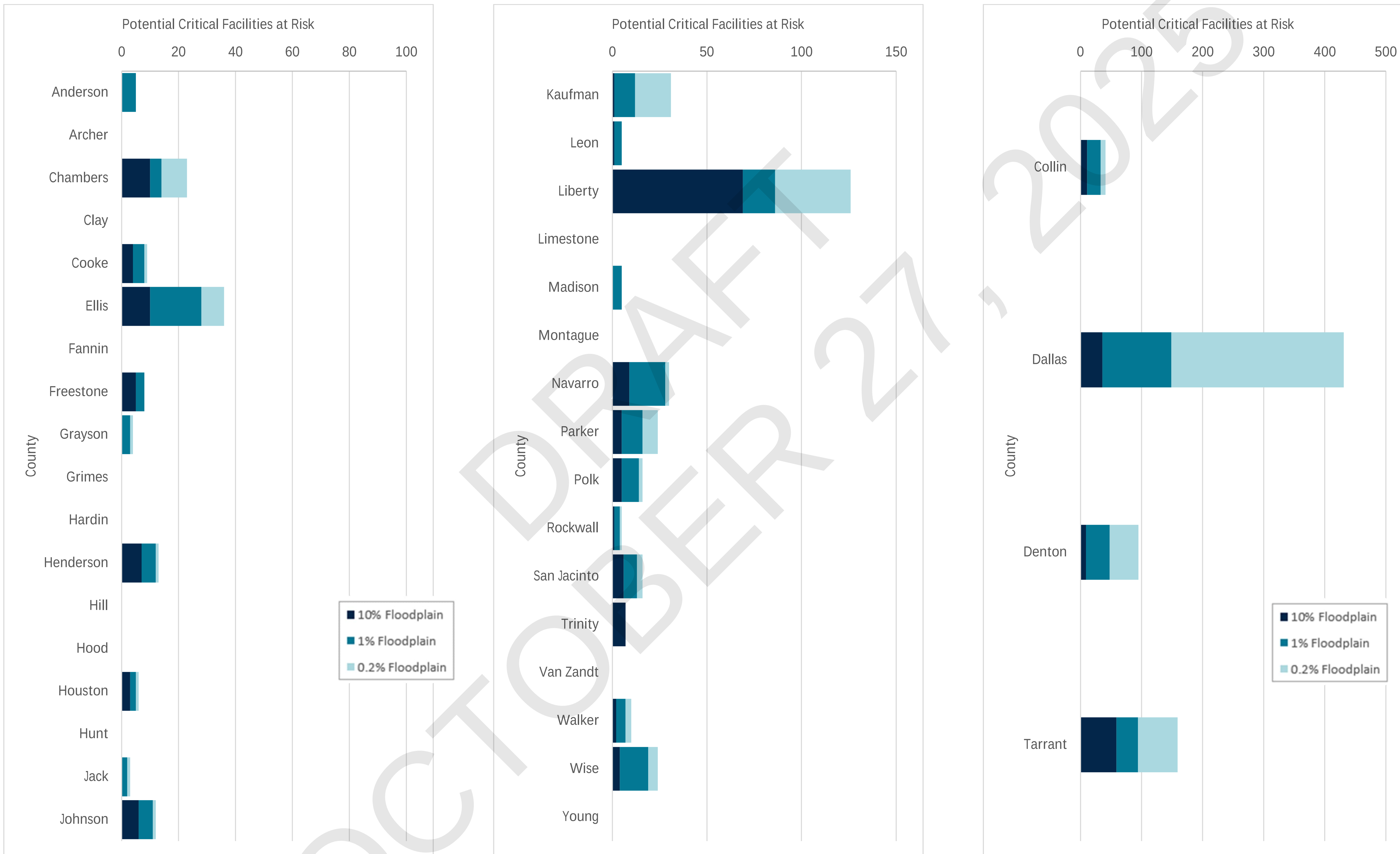


Figure 2.17: Critical Facilities Counts in Existing Conditions Floodplain Quilt by County



Over 10,000 critical facilities were identified for the Trinity Region and an estimated 10 percent of these facilities are exposed to flooding in the 100-year floodplain.

The Trinity Region's Upper Subregion counties have the most critical exposure counts to the existing floodplain quilt, with the Dallas/Fort Worth (DFW) area counties having the highest exposures of people and structures. Archer, Clay, Hardin, Hood, and Hunt counties showed very little to no exposure of critical facilities to the existing floodplain quilt.

Roadway Crossings and Roadway Segments

Transportation line data (roadways) from TxDOT was used to estimate roadway stream crossings at-risk of flooding. A combination of available flood depth information from BLE and Fathom data, as well as bridge deck elevation from LIDAR data, was used to estimate flood exposure of roadway bridges at stream crossings. LWC data, provided by Trinity Region area communities and the TWDB, was also used to identify exposed road and railway crossings. The Tarrant Regional Water District (TRWD) also provided information on bridges that are inundated during flood events.

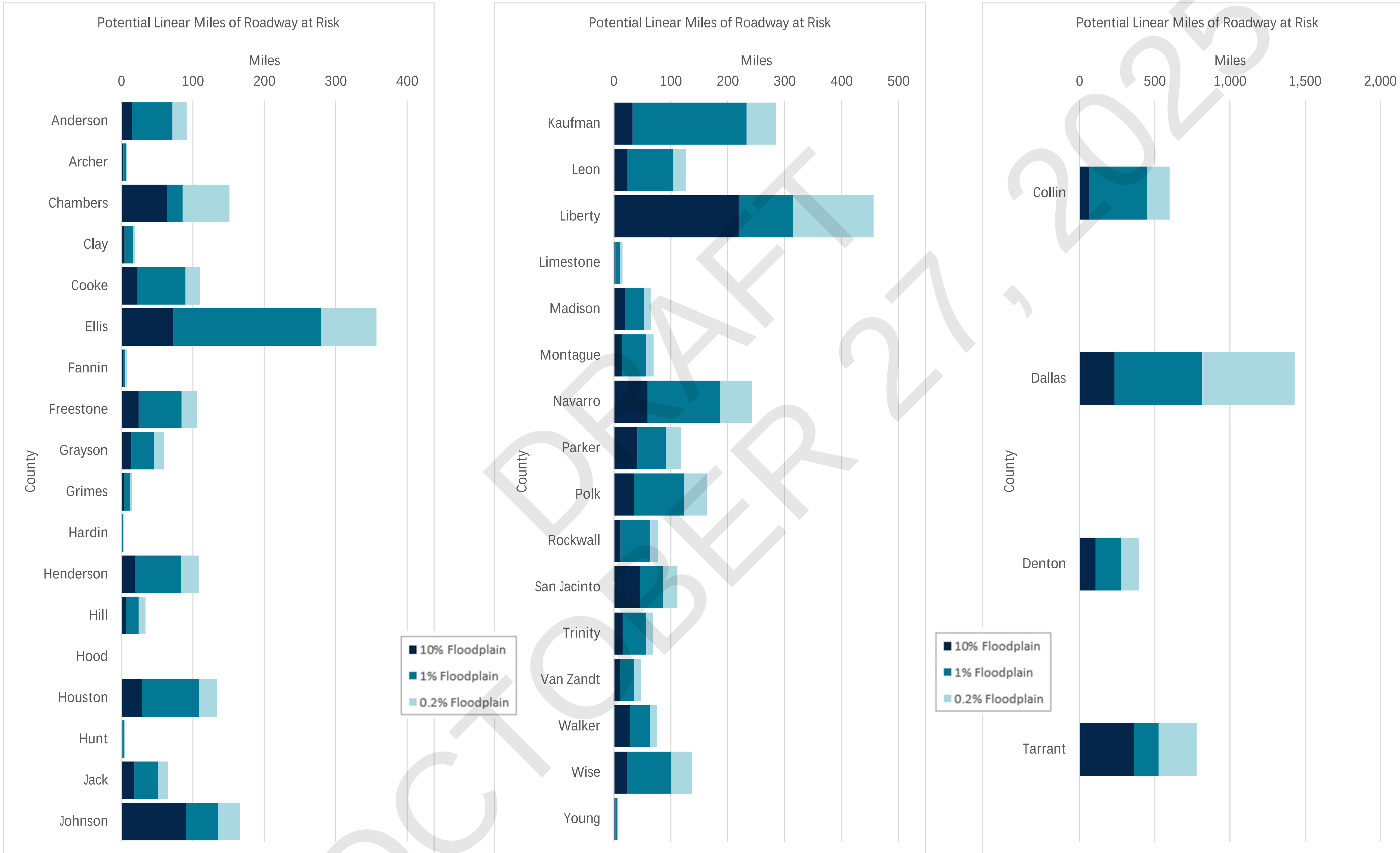
There are approximately 1,700 LWCs in the Trinity Region and several bridges are inundated by flooding in the Trinity Region. *Table 2.10* shows the LWC exposure totals per county. *Figure 2.18* shows the miles of road segment exposed to the existing floodplains. The highest mileage exposures are seen in Dallas and Tarrant counties in the Upper Subregion and in the coastal Chambers County in the Lower Subregion.

Table 2.10: Exposed Bridge and Low Water Crossings in Existing Conditions Floodplain Quilt

County	Number of LWCs	County	Number of LWCs	County	Number of LWCs
Anderson	5	Houston	19	Navarro	55
Collin	58	Jack	3	Parker	26
Cooke	34	Johnson	271	Polk	3
Dallas	427	Kaufman	19	Rockwall	17
Denton	95	Leon	13	Tarrant	475
Ellis	60	Liberty	4	Trinity	1
Freestone	3	Limestone	3	Van Zandt	2
Grayson	1	Madison	2	Walker	4
Henderson	10	Montague	4	Wise	17

*This tables lists only counties with identified and documented LWC in the Trinity Region

Figure 2.18: Linear Miles of Roadway at Risk in Existing Conditions Floodplain Quilt



Agricultural Area and Crop Values

Crop and livestock data used in the Trinity Region was obtained from the 2024 USGS Annual National Land Cover Database. In the Trinity Region, increasing population continues to have a significant influence on the continued loss of working lands, changing ownership sizes, and land values. This occurs particularly within or adjacent to urban centers like DFW in the Upper Subregion. Large sections of the Lower Subregion are facing similar challenges because of development in the neighboring Houston-Galveston area. (Texas A&M Natural Resources Institute, 2020). *Figure 2.19* shows the distribution of Farming (crops) and Ranching (livestock) areas in the Trinity Region.

Crops and livestock exposed to flooding (dollar exposure from production) are documented in *Table 2.11*, which summarizes estimated exposure values in dollars to the existing floodplain quilt by county. The 2022 USDA NASS Census of Agriculture profile data was leveraged to show the value of crops and livestock exposed to flooding. The 2022 Census of Agriculture data in dollars was used to calculate crop and livestock production value density per county. The county value is divided by the total crop and livestock land area of the county to find its dollar value density as shown below.

$$AgValueDen_{Co} = \frac{AgValue_{Co}}{AgArea_{Co}}$$

$AgValueDen_{co}$ is the crop and livestock value density calculated at the county level (in dollars per square mile; $AgValue_{co}$ is the is the total crop and livestock production value of the county, as reported in the 2017 Census of Agriculture (in dollars); and $AgArea_{co}$ is the total crop and livestock production area of the county (in square miles).

Each county's crop and livestock value losses were then calculated as the product of the crop and livestock production value density per county and the associated crop and livestock areas exposed to flooding from the existing conditions floodplain. *Table 2.11* shows the value of crop and livestock (production) areas in dollars and potential agricultural losses to the existing floodplain quilt in the Trinity Region. Denton, Ellis, Hill, Houston, Kaufman, Leon, Limestone, Navarro, and Van Zandt counties have high agricultural exposure values. Even though Madison County showed large agriculture areas (a little more than Anderson County) per *Figure 2.19*. There was no data available from the 2017 USDA crop and livestock production summaries. *Figure 2.20* shows the exposed agricultural areas in square miles.

Figure 2.19: Agricultural Land Distribution in the Trinity Region

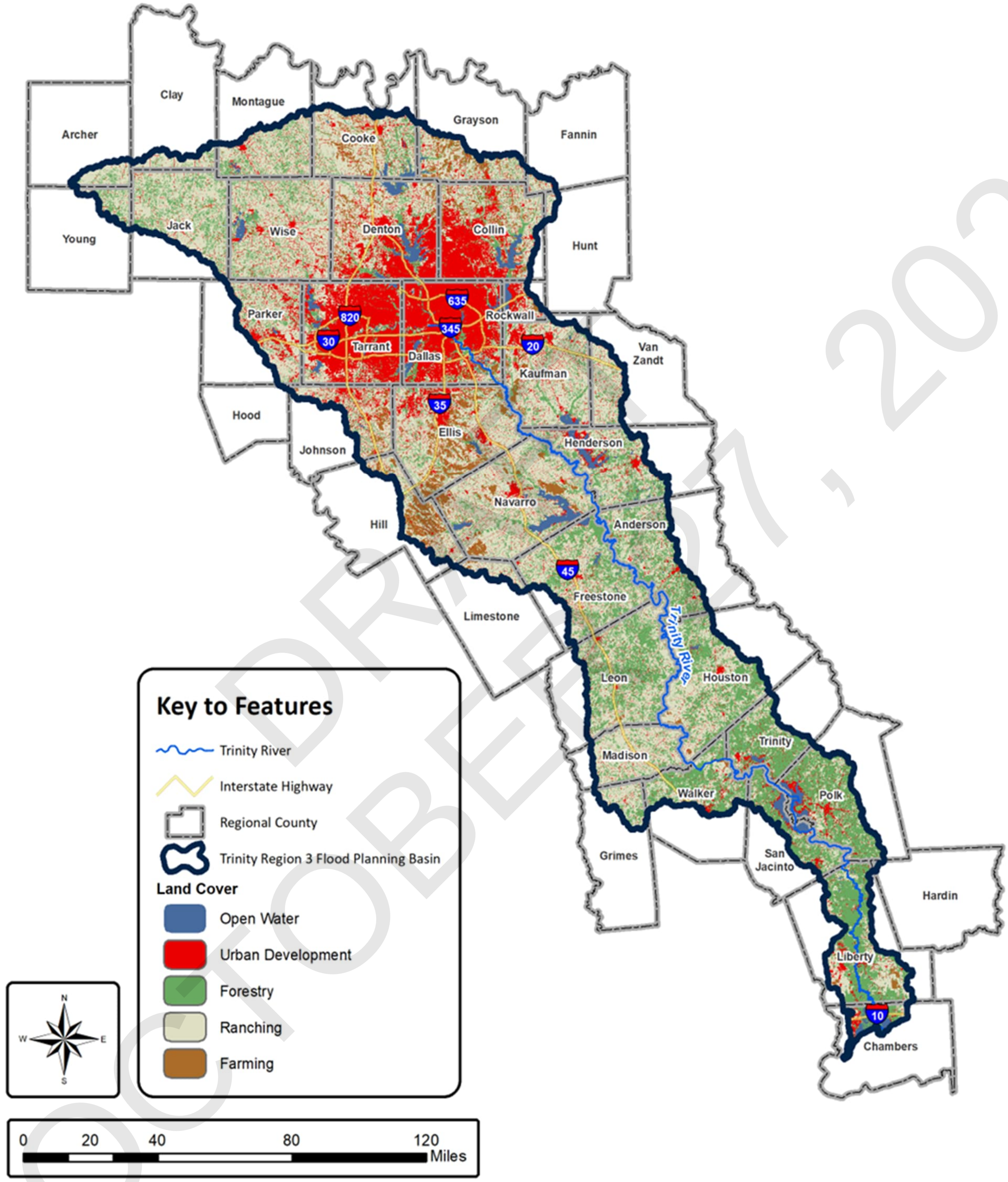


Table 2.11: Crop (Farming) and Livestock (Ranching) Inventory in the Trinity Region

County	$ Inventory Total Agriculture*	$ Inventory Crop	$ Inventory Livestock
Anderson	$190,138,000	$24,811,000	$165,327,000
Archer	$116,409,000	$8,344,000	$108,065,000
Chambers	$53,224,000	$39,530,000	$13,694,000
Clay	$80,929,000	$5,441,000	$75,488,000
Collin	$98,779,000	$45,111,000	$53,668,000
Cooke	$109,451,000	$19,860,000	$89,591,000
Dallas	$32,680,000	$24,837,000	$7,843,000
Denton	$135,467,000	$25,217,000	$110,250,000
Ellis	$78,344,000	$50,972,000	$27,372,000
Fannin	$103,695,000	$55,953,000	$47,742,000
Freestone	$122,796,000	$6,737,000	$116,059,000
Grayson	$87,097,000	$48,035,000	$39,062,000
Grimes	$83,236,000	$15,847,000	$67,389,000
Hardin	$4,637,000	$1,753,000	$2,884,000
Henderson	$44,194,000	$10,380,000	$33,814,000
Hill	$129,942,000	$95,298,000	$34,644,000
Hood	$22,551,000	$12,953,000	$9,598,000
Houston	$89,987,000	$12,464,000	$77,523,000
Hunt	$82,418,000	$40,205,000	$42,213,000
Jack	$42,816,000	$2,022,000	$40,794,000
Johnson	$65,995,000	$25,113,000	$40,882,000
Kaufman	$49,372,000	$10,815,000	$38,557,000
Leon	$233,518,000	$8,819,000	$224,699,000
Liberty	$40,698,000	$16,379,000	$24,319,000
Limestone	$95,645,000	$11,047,000	$84,598,000
Madison**	-	-	-
Montague	$62,059,000	$11,903,000	$50,156,000
Navarro	$64,962,000	$22,173,000	$42,789,000
Parker	$68,496,000	$8,531,000	$59,965,000
Polk	$10,892,000	$5,423,000	$5,469,000
Rockwall	$5,361,000	$3,055,000	$2,306,000
San Jacinto	$9,206,000	$3,535,000	$5,671,000
Tarrant	$24,327,000	$9,059,000	$15,268,000
Trinity	$8,237,000	$2,127,000	$6,110,000
Van Zandt	$168,285,000	$75,291,000	$92,994,000
Walker	$25,399,000	$7,847,000	$17,552,000
Wise	$58,945,000	$14,755,000	$44,190,000
Young	$29,820,000	$5,008,000	$24,812,000

**Total Agricultural Value of county, including land area outside of Trinity Region*
***USDA NASS Census of Agriculture Values were unavailable for Madison County*

Table 2.12: Potential Crop (Farming) Losses in Existing Conditions Floodplain Quilt

County	$ Inventory Crop*	$ Losses in Existing 10-Year**	$ Losses in Existing 100-Year**	$ Losses in Existing 500-Year**
Anderson	$24,811,000	$24,053,012.55	$425,935.85	$8,802.03
Archer	$8,344,000	$460,764.24	$445,939.74	$146,077.15
Chambers	$39,530,000	$22,873,801.11	$1,430,869.14	$10,661,773.46
Clay	$5,441,000	$24,857.76	$292,040.84	$89,670.68
Collin	$45,111,000	$3,087,431.06	$1,933,491.61	$705,435.65
Cooke	$19,860,000	$1,662,33.67	$1,109,717.82	$283,505.10
Dallas	$24,837,000	$10,309,929.55	$962,596.98	$1,297,370.31
Denton	$25,217,000	$1,961,788.81	$1,344,499.75	$333,497.28
Ellis	$50,972,000	$6,650,019.44	$3,654,488.34	$1,140,776.63
Fannin	$55,953,000	$242,123.93	$1,683,390.52	$539,152.38
Freestone	$6,737,000	$1,669,810.13	$1,302,838.28	$8,262.40
Grayson	$48,035,000	$901,229.34	$1,911,221.62	$644,916.42
Grimes	$15,847,000	-	-	-
Hardin	$1,753,000	-	-	-
Henderson	$10,380,000	$8,744,018.34	$237,010.48	$111,904.50
Hill	$95,298,000	$3,730,556.75	$5,833,743.74	$2,554,168.47
Hood	$12,953,000	$3,742,067.91	$582,993.47	$385,685.73
Houston	$12,464,000	$9,566,830.76	$384,047.55	$195,306.90
Hunt	$40,205,000	$51,456.45	$345,818.91	$110,124.82
Jack	$2,022,000	$263,470.02	$172,558.25	$70,181.46
Johnson	$25,113,000	$1,642,889.17	$903,331.18	$484,614.67
Kaufman	$10,815,000	$5,347,626.41	$1,106,450.36	$79,739.62
Leon	$8,819,000	$1,840,191.35	$375,559.63	$124,839.05
Liberty	$16,379,000	$9,547,430.15	$3,291,168.96	$2,783,655.98
Limestone	$11,047,000	$1,009,702.94	$945,329.13	$242,146.61
Madison***	-	-	-	-
Montague	$11,903,000	$2,132,264.59	$1,206,328.52	$516,747.31
Navarro	$22,173,000	$2,817,439.92	$1,885,678.90	$815,336.38
Parker	$8,531,000	$1,274,959.11	$655,554.99	$376,814.06
Polk	$5,423,000	$2,177,872.08	$191,227.79	$42,134.48
Rockwall	$3,055,000	$156,718.68	$115,463.57	$39,257.89
San Jacinto	$3,535,000	$3,523,619.45	$2,000.51	$0.00
Tarrant	$9,059,000	$857,734.43	$295,831.12	$275,327.19
Trinity	$2,127,000	$2,114,795.12	$130.12	$531.47
Van Zandt	$75,291,000	$780,547.30	$583,728.95	$157,064.48
Walker	$7,847,000	$7,763,136.53	$5,458.80	$2,946.94
Wise	$14,755,000	$3,258,312.68	$1,701,657.85	$606,222.13
Young	$5,008,000	$57,526.42	$115,283.09	$75,400.20

**Total Agricultural Value of county, including land area outside of Trinity Region*

***Total Agricultural Losses only within Trinity Region*

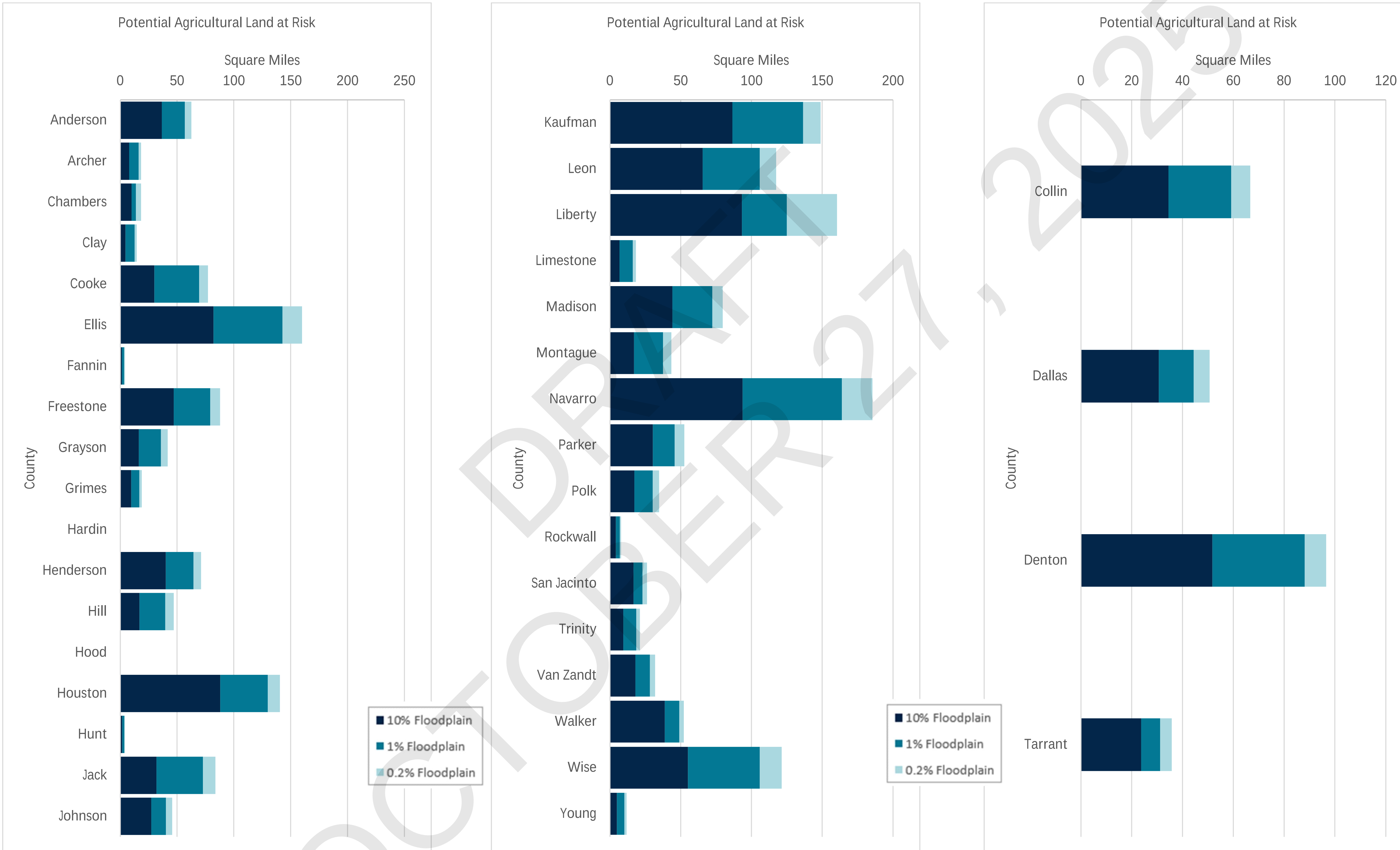
****USDA/NASS Crop and Livestock Values were unavailable for Madison County*

Table 2.13: Potential Livestock (Ranching) Losses in Existing Conditions Floodplain Quilt

County	$ Inventory Livestock*	$ Losses in Existing 10-Year**	$ Losses in Existing 100-Year**	$ Losses in Existing 500-Year**
Anderson	$165,327,000	$20,912,135.55	$13,045,878.89	$3,685,420.68
Archer	$108,065,000	$9,619,554.20	$10,381,964.38	$2,574,460.44
Chambers	$13,694,000	$5,930,675.15	$2,390,748.69	$2,721,751.05
Clay	$75,488,000	$3,517,799.16	$6,015,792.44	$1,291,180.31
Collin	$53,668,000	$5,500,732.37	$4,029,986.21	$1,185,589.50
Cooke	$89,591,000	$5,611,918.04	$8,141,050.13	$1,540,109.00
Dallas	$7,843,000	$1,736,752.71	$1,032,971.79	$416,850.47
Denton	$110,250,000	$13,131,728.56	$9,217,518.60	$2,156,942.11
Ellis	$27,372,000	$3,139,634.69	$2,562,867.35	$703,495.96
Fannin	$47,742,000	$2,565,848.36	$2,979,276.80	$1,000,297.74
Freestone	$116,059,000	$13,094,101.21	$8,953,239.21	$2,396,056.29
Grayson	$39,062,000	$2,994,143.39	$3,273,390.85	$1,000,289.01
Grimes	$67,389,000	$6,950,346.46	$5,166,860.33	$1,461,309.78
Hardin	$2,884,000	$10,641.47	$361,044.17	$496,502.51
Henderson	$33,814,000	$3,962,841.02	$2,883,328.71	$810,640.66
Hill	$34,644,000	$2,580,021.77	$3,283,359.74	$943,608.84
Hood	$9,598,000	$471,439.74	$91,481.07	$72,569.37
Houston	$77,523,000	$14,971,112.52	$7,546,633.44	$1,911,029.58
Hunt	$42,213,000	$3,165,721.10	$3,236,294.05	$744,339.35
Jack	$40,794,000	$2,777,144.87	$3,634,161.36	$955,990.81
Johnson	$40,882,000	$5,179,066.81	$2,391,101.33	$986,212.05
Kaufman	$38,557,000	$5,493,544.18	$3,705,642.08	$967,901.40
Leon	$224,699,000	$35,805,429.35	$22,147,960.51	$6,381,300.00
Liberty	$24,319,000	$11,246,831.52	$3,809,871.91	$4,382,310.51
Limestone	$84,598,000	$7,147,048.87	$10,079,132.28	$2,319,753.71
Madison***	-	-	-	-
Montague	$50,156,000	$3,015,501.20	$3,751,190.81	$1,044,568.62
Navarro	$42,789,000	$5,190,548.75	$3,935,306.89	$1,159,297.87
Parker	$59,965,000	$6,034,492.61	$3,063,176.79	$1,369,077.17
Polk	$5,469,000	$840,497.53	$631,208.91	$219,722.74
Rockwall	$2,306,000	$227,948.20	$146,963.90	$47,469.92
San Jacinto	$5,671,000	$1,579,477.62	$651,655.62	$334,349.54
Tarrant	$15,268,000	$2,306,226.98	$731,752.71	$442,679.95
Trinity	$6,110,000	$655,710.07	$680,857.22	$194,932.71
Van Zandt	$92,994,000	$9,940,421.66	$5,664,669.37	$2,010,168.46
Walker	$17,552,000	$4,525,558.53	$1,323,761.89	$411,793.21
Wise	$44,190,000	$3,610,530.99	$3,425,734.25	$1,029,450.72
Young	$24,812,000	$1,638,101.25	$1,753,867.54	$536,331.47

**Total Agricultural Value of county, including land area outside of Trinity Region*
***Total Agricultural Losses only within Trinity Region*
****USDA/NASS Crop and Livestock Values were unavailable for Madison County*

Figure 2.20: Agricultural Land Exposure (in sq mi) in Existing Conditions Floodplain Quilt



Expected Loss of Function

Severe flooding can cause a loss of function for a community's residential and critical infrastructure, which has an impact on the socio-economic systems supported by them. These impacts may include disruptions to life, business, and public services. Some public services are essential to a community during and after a flood event. Flood inundation depth and duration are typically considered the best flood characteristics in predicting expected functionality losses. Inundated structures and critical facilities are often not functional during the flood event and through the recovery process. Closure length is dependent on the severity of damage to the structure, interrupted access, and lingering health hazards.

Inundated Structures and Flood Losses

FEMA's HAZUS 6.1 Program was used to generate quantitative estimates of expected loss of functions for counties in the Trinity Region using the 100-year flood depth from the existing conditions flood quilt. Note that the HAZUS analysis assumes that a flood event covers the entire county or river basin. The HAZUS analysis is also based on the default inventory data and future similar assessments will benefit from updated inventory data. The total exposure value of buildings in the Trinity Region is $1.4 trillion. HAZUS estimates the total direct and indirect losses for the 100-year flood to be $30.2 billion and $53.9 billion, respectively. Direct losses account for building, content, and inventory losses, while indirect losses include relocation, capital, wages, and rental income losses. The total loss is estimated at $84.1 billion or six percent of the total exposure value of buildings in the Trinity Region. *Table 2.14* summarizes direct economic losses (direct, indirect, and total building losses) by county in the Trinity Region. Liberty County is anticipated to have the highest loss ratio. The HAZUS analysis predicts that approximately 344,046 tons of debris will be generated from finishes (drywall, flooring, insulation, etc.), structures (framing, walls, exterior cladding, wood, brick, etc.), and foundation weight (concrete slab, concrete block, or other foundation) from a 100-year flood. *Table 2.15* summarizes HAZUS' estimated debris generation by county in the Trinity Region. Dallas County is estimated to generate the highest amounts of debris and would account for approximately 35 percent of the total debris generated in the Trinity Region.

HAZUS predicts that an estimated 887,208 million people would be displaced during a 100-year flood and approximately 218,360 people would require short-term shelter. *Table 2.16* summarizes HAZUS' estimated displacement and shelter requirements by county in the Trinity Region. Dallas and Denton counties are estimated to account for 79 percent of the displaced population, and 65 percent of the people requiring short-term shelter.

Table 2.14: Direct Economic (Direct, Indirect, and Total Building) Losses by County

County	Inventory Value ($ million	Direct Loss ($ million)	Indirect Loss ($ million)	Total Loss ($ million)	Total Loss Ratio (%)
Anderson	$11,552	$375.176	$307.052	$682.228	5.91%
Archer	$1,938	$16.741	$18.709	$35.45	1.83%
Chambers	$12,017	$625.239	$1025.893	$1651.132	13.74%
Clay	$2,247	$15.816	$30.654	$46.47	2.07%
Collin	$183,753	$2,834.07	$4952.784	$7,786.85	4.24%
Cooke	$12,152	$371.592	$446.994	$818.586	6.74%
Dallas	$388,422	$8,290.61	$16,316.95	$24,607.56	6.34%
Denton	$158,034	$3,844.46	$5968.899	$9,813.36	6.21%
Ellis	$32,183	$540.577	$944.612	$1485.189	4.61%
Fannin	$6,146	$57.265	$109.921	$167.186	2.72%
Freestone	$6,124	$95.596	$114.216	$209.812	3.43%
Grayson	$25,585	$424.579	$727.082	$1151.661	4.50%
Grimes	$4,411	$91.645	$247.14	$338.785	7.68%
Hardin	$10,373	$347.315	$648.758	$996.073	9.60%
Henderson	$13,865	$242.737	$606.602	$849.339	6.13%
Hill	$6,825	$80.958	$219.849	$300.807	4.41%
Hood	$11,886	$531.958	$549.378	$1081.336	9.10%
Houston	$4,980	$85.611	$149.142	$234.753	4.71%
Hunt	$16,944	$194.845	$441.63	$636.475	3.76%
Jack	$1,941	$29.858	$34.637	$64.495	3.32%
Johnson	$28,544	$541.068	$823.935	$1365.003	4.78%
Kaufman	$24,219	$495.573	$719.175	$1214.748	5.02%
Leon	$4,165	$46.258	$82.219	$128.477	3.08%
Liberty	$10,264	$535.236	$1600.505	$2135.741	20.81%
Limestone	$5,927	$69.847	$128.097	$197.944	3.34%
Madison	$3,040	$38.505	$81.669	$120.174	3.95%
Montague	$5,283	$55.041	$79.461	$134.502	2.55%
Navarro	$11,580	$583.651	$510.903	$1094.554	9.45%
Parker	$24,695	$553.302	$583.665	$1136.967	4.60%
Polk	$7,637	$267.857	$421.743	$689.6	9.03%
Rockwall	$17,865	$211.481	$339.178	$550.659	3.08%
San Jacinto	$4,113	$145.644	$218.241	$363.885	8.85%
Tarrant	$317,254	$6820.174	$13120.437	$19940.611	6.29%
Trinity	$ 4,016	$70.642	$102.377	$173.019	4.31%
Van Zandt	$10,164	$200.836	$366.216	$567.052	5.58%
Walker	$10,146	$157.186	$247.758	$404.944	3.99%
Wise	$12,312	$214.403	$428.114	$642.517	5.22%
Young	$5,604	148.738	213.801	362.539	6.47%

Table 2.15: Social Impacts - Debris Generation by County

County	Finishes (tons)	Structures (tons)	Foundations (tons)	Total (tons)
Anderson	3,649	255	429	4,333
Archer	369	24	56	449
Chambers	7,208	1400	2,236	10,844
Clay	616	60	137	812
Collin	7,571	718	987	9,275
Cooke	3,093	730	1,024	4,847
Dallas	103,729	11,716	14,049	129,494
Denton	7,506	715	814	9,035
Ellis	3,641	769	931	5,341
Fannin	652	109	246	1,007
Freestone	630	73	148	850
Grayson	5,924	775	1,306	8,004
Grimes	850	224	505	1,578
Hardin	5,332	785	1,613	7,730
Henderson	3,117	630	1,312	5,059
Hill	785	209	391	1,385
Hood	4,502	1,049	1,491	7,042
Houston	987	90	196	1,272
Hunt	2,003	324	745	3,072
Jack	534	105	160	798
Johnson	3,267	521	1,094	4,882
Kaufman	2,934	608	1,330	4,872
Leon	1,399	263	577	2,239
Liberty	7,315	1,342	2,990	11,648
Limestone	853	120	245	1,218
Madison	672	59	132	863
Montague	1,081	219	423	1,723
Navarro	2,547	516	974	4,036
Parker	3,295	912	1,625	5,832
Polk	1,836	513	885	3,233
Rockwall	371	8	11	390
San Jacinto	1,271	266	478	2,015
Tarrant	56,138	8,193	7,896	72,227
Trinity	2,925	831	1,803	5,559
Van Zandt	1,195	225	518	1,939
Walker	994	231	440	1,664
Wise	1,890	698	1,403	3,991
Young	2,316	458	714	3,488

Table 2.16: Social Impacts - Displacement and Shelter Requirements by County

County	Number of Displaced People	Number of People Needing Short-Term Shelter
Anderson	4,090	1,299
Archer	456	131
Chambers	16,732	2,019
Clay	364	66
Collin	99,367	16,965
Cooke	4,189	803
Dallas	281,064	84,462
Denton	95,292	16,573
Ellis	13,248	3,048
Fannin	1,579	478
Freestone	870	396
Grayson	8,171	2,866
Grimes	2,748	793
Hardin	12,517	2,535
Henderson	5,671	2,847
Hill	1,923	488
Hood	8,019	1,721
Houston	1,455	698
Hunt	5,961	2,113
Jack	498	143
Johnson	15,588	4,507
Kaufman	14,899	3,476
Leon	892	330
Liberty	32,385	4,997
Limestone	1,312	444
Madison	626	310
Montague	900	244
Navarro	4,691	1,581
Parker	10,066	3,183
Polk	4,516	1,608
Rockwall	6,908	1,078
San Jacinto	4,576	1,400
Tarrant	210,159	48,638
Trinity	1,271	439
Van Zandt	3,440	1,627
Walker	5,264	2,313
Wise	3,876	1,343
Young	1,625	398

Transportation

HAZUS estimates the total highway bridge damage to be $1.1 million in the Trinity Region for a 100-year flood. An average damage of 0.25 percent for a 100-year flood is estimated for the highway bridges in the Trinity Region. Other than the nine bridges identified by TRWD, none of the highway bridges are estimated to be non-functional according to the HAZUS results. *Table 2.17* summarizes HAZUS' estimated highway bridge damage by county in the Trinity Region. The highest damages are estimated for Collin and Dallas counties.

Health and Human Services

The HAZUS analysis does not predict any losses to small, medium, and large hospitals in the Trinity Region for the 100-year flood. There are no predicted losses to the number of available beds, no building or content losses are predicted, and none of the hospitals are expected to be non-functional based on the results of the HAZUS analysis.

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 2,391 public water supply wells in the Trinity Region with 127 in the 100-year floodplain. Therefore, five percent of the public water supply wells in the Trinity Region are potentially exposed to flood risk. The HAZUS analysis predicts damage to one potable water facility in Henderson County, Johnson County, and Kaufman County. The potable water facility in Johnson County is projected to sustain approximately 23 percent damage, resulting in a loss of operational functionality during the 100-year flood event.

Water Treatment

Failure of water 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 (Arrighi, Tarani, Vicario, & Castelli, 2017). Floods have the potential to impact operations at water treatment facilities resulting in poorer potable water quality. HAZUS predicts that one potable water system in Johnson County will be non-functional due to damages from a 100-year flood. The potable water facility is estimated to sustain an average damage of 23 percent and a total loss of $6.8 million.

Table 2.17: Highway Bridge Damages by County

County	Number of Highway Bridges	Average Damage (%)	Total Loss ($)
Anderson	1	0.25%	$3,000
Archer	2	0.25%	$8,000
Chambers	0	0.00%	-
Clay	2	0.25%	$14,000
Collin	0	0.00%	-
Cooke	1	0.25%	$1,000
Dallas	32	0.30%	$528,000
Denton	0	0.00%	-
Ellis	0	0.00%	-
Fannin	1	0.25%	$2,000
Freestone	3	0.25%	$10,000
Grayson	1	0.25%	$7,000
Grimes	1	0.25%	$6,000
Hardin	6	0.25%	$28,000
Henderson	1	0.50%	$12,000
Hill	5	0.25%	$50,000
Hood	0	0.00%	-
Houston	4	0.50%	$14,000
Hunt	2	2.75%	$43,000
Jack	1	0.50%	$1,000
Johnson	0	0.00%	-
Kaufman	3	0.25%	$28,000
Leon	0	0.00%	-
Liberty	2	0.25%	$29,000
Limestone	4	0.25%	$26,000
Madison	0	0.00%	-
Montague	0	0.00%	-
Navarro	6	0.25%	$11,000
Parker	0	0.00%	-
Polk	10	0.28%	$82,000
Rockwall	0	0.00%	-
San Jacinto	2	0.25%	$4,000
Tarrant	24	0.25%	$162,000
Trinity	1	0.25%	$2,000
Van Zandt	5	0.25%	$22,000
Walker	0	0.00%	-
Wise	0	0.00%	-
Young	2	0.25%	$6,000

Utilities

The HAZUS analysis estimates damages to potable water and wastewater treatment facilities amounting to $10 million and $3.3 billion, respectively. The average predicted damage to the water facilities is approximately 17 percent. HAZUS estimates 61 of the 155 wastewater facilities are predicted to be non-operational due to damage from a 100-year flood. *Table 2.18* summarizes HAZUS' predicted wastewater facility losses by county in the Trinity Region. The highest losses are predicted for Chambers, Clay, Henderson, Montague, Navarro, Polk, and San Jacinto counties where average damages are 27 percent and most facilities in these counties are projected to be non-functional.

While the HAZUS analysis estimates no losses to communication systems in the Trinity Region for a 100-year flood, it is expected that localized areas may experience temporary loss or interruption of internet, TV, or Phone services during or following a flood event. Predicted utility losses at the county level for the Trinity Region are summarized in *Table 2.19*.

Energy Generation

The HAZUS analysis estimates no losses to oil systems, natural gas, and electric power systems in the Trinity Region. Despite the zero estimated energy generation losses, it is expected that localized areas may experience temporary loss of energy delivery services during or following a flood event.

Emergency Services

Flooding has the potential to cause disruption to emergency services by causing delays in response times. The HAZUS analysis for the Trinity Region quantifies damages and expected loss of use associated with essential facilities including emergency operation centers, fire stations, hospitals, schools, and police stations. For the 100-year flood event, the HAZUS analysis estimates total building and content damages amounting to $71.5 million and $403.8 million, respectively. Two emergency operation centers in Dallas County are estimated to be non-functional. A total of 8 fire stations are estimated to be non-functional in the event of a 100-year flood.

Total building and content damages to fire stations are predicted at $3.4 million and $10.5 million, respectively. Total building and content damages to police stations are estimated at $3.7 million and $7.3 million, respectively. *Table 2.20* summarizes HAZUS estimated losses to emergency services by county in the Trinity Region for a 100-year flood.

Table 2.18: Wastewater Facility Losses by County

County	Number of Wastewater Facilities	Average Damage (%)	Total Loss ($)	Number of Non-Functional Facilities
Anderson	1	9.10%	$11,212	0
Archer	1	5.60%	$6,967	0
Chambers	5	36.20%	$223,717	5
Clay	2	35.00%	$86,626	2
Collin	16	16.80%	$333,026	7
Cooke	5	16.40%	$101,723	2
Dallas	3	21.60%	$80,129	2
Denton	14	9.70%	$168,734	2
Ellis	6	17.70%	$131,077	2
Fannin	4	18.00%	$89,311	1
Freestone	5	11.80%	$72,704	1
Grayson	8	15.50%	$153,773	3
Grimes	2	14.30%	$35,368	1
Hardin	6	17.40%	$128,961	2
Henderson	6	22.70%	$168,536	3
Hill	7	18.40%	$159,230	5
Hood	2	20.60%	$51,060	1
Houston	2	8.00%	$19,813	0
Hunt	5	12.00%	$74,040	1
Jack	0	0.00%	-	0
Johnson	8	12.50%	$123,664	3
Kaufman	1	9.50%	$11,781	0
Leon	7	19.40%	$167,856	3
Liberty	3	14.60%	$54,376	1
Limestone	1	8.30%	$10,321	0
Madison	1	10.00%	$12,350	0
Montague	2	22.70%	$56,245	1
Navarro	5	25.60%	$158,475	4
Parker	3	19.60%	$72,889	1
Polk	2	25.70%	$63,620	2
Rockwall	5	17.40%	$107,861	2
San Jacinto	3	24.60%	$91,402	2
Tarrant	1	10.00%	$12,350	0
Trinity	1	5.20%	$6,485	0
Van Zandt	4	14.70%	$72,704	1
Walker	4	14.20%	$70,117	0
Wise	4	15.90%	$78,854	1
Young	0	0.00%	-	0

Table 2.19: Utility Losses by County

County	Potable Water ($ million)	Wastewater ($ million)	Oil Systems ($ million)	Natural Gas ($ million)	Electric Power ($ million)	Communication ($ million)	Total ($ million)
Anderson	-	$11.21	-	-	-	-	$11.21
Archer	-	$6.97	-	-	-	-	$6.97
Chambers	-	$223.72	$0.04	-	-	-	$223.76
Clay	-	$86.63	-	-	-	-	$86.63
Collin	-	$333.03	-	-	-	-	$333.03
Cooke	-	$101.72	-	-	-	-	$101.72
Dallas	-	$80.13	-	-	-	-	$80.13
Denton	-	$168.73	-	-	-	-	$168.73
Ellis	-	$131.08	-	-	-	-	$131.08
Fannin	-	$89.31	-	-	-	-	$89.31
Freestone	-	$72.70	-	-	-	-	$72.70
Grayson	-	$153.77	-	-	-	-	$153.77
Grimes	-	$35.37	-	-	-	-	$35.37
Hardin	-	$128.96	-	-	-	-	$128.96
Henderson	$1.14	$168.54	-	-	-	-	$169.68
Hill	-	$159.23	-	-	-	-	$159.23
Hood	-	$51.06	-	-	-	-	$51.06
Houston	-	$19.81	-	-	-	-	$19.81
Hunt	-	$74.04	-	-	-	-	$74.04
Jack	-	-	-	-	-	-	-
Johnson	$6.80	$123.66	-	-	-	-	$130.47
Kaufman	$2.02	$11.78	-	-	-	-	$13.80
Leon	-	$167.86	-	-	-	-	$167.86
Liberty	-	$54.38	-	-	-	-	$54.38
Limestone	-	$10.32	-	-	-	-	$10.32
Madison	-	$12.35	-	$0.02	-	-	$12.37
Montague	-	$56.24	-		-	-	$56.24
Navarro	-	$158.48	-		-	-	$158.48
Parker	-	$72.89	-		-	-	$72.89
Polk	-	$63.62	-	$0.23	-	-	$63.85
Rockwall	-	$107.86	-	-	-	-	$107.86
San Jacinto	-	$91.40	-	-	-	-	$91.40
Tarrant	-	$12.35	$0.03	-	-	-	$12.38
Trinity	-	$6.48	-	-	-	-	$6.48
Van Zandt	-	$72.70	-	-	-	-	$72.70
Walker	-	$70.12	-	-	-	-	$70.12
Wise	-	$78.85	-	-	-	-	$78.85
Young	-	-	-	-	-	-	-

Table 2.20: Emergency Services Losses by County

County	Emergency Operation Centers			Fire Stations			Police Stations			Schools		
	Building Damage ($ thousand)	Content Damage ($ thousand)	Non-Functional	Building Damage ($ thousand)	Content Damage ($ thousand)	Non-Functional	Building Damage ($ thousand)	Content Damage ($ thousand)	Non-Functional	Building Damage ($ thousand)	Content Damage ($ thousand)	Non-Functional
Anderson	0	0	0	222	1,284	2	0	0	0	0	0	0
Chambers	0	0	0	117	298	0	0	0	0	432	2,334	1
Collin	2	0	0	88	151	0	135	231	0	5,328	28,900	7
Cooke	0	0	0	55	107	0	176	302	0	0	0	0
Dallas	1,432	5,612	2	777	2,191	1	1,651	3,295	2	32,891	212,888	25
Denton	0	0	0	154	938	1	0	0	0	4,033	22,658	5
Grayson	0	0	0	0	0	0	353	605	0	0	0	0
Fannin	0	0	0	0	0	0	0	0	0	627	3,437	1
Freestone	0	0	0	52	94	0	0	0	0	0	0	0
Grimes	86	148	0	0	0	0	0	0	0	263	1,423	1
Hardin	0	0	0	0	0	0	107	183	0	0	0	0
Henderson	0	0	0	43	74	0	196	405	1	0	0	0
Hill	0	0	0	0	0	0	266	922	1	0	0	0
Hood	0	0	0	0	0	0	0	0	0	53	287	1
Hunt	0	0	0	0	0	0	0	0	0	421	2,275	1
Johnson	0	0	0	37	63	0	0	0	0	2,343	12,653	2
Leon	0	0	0	48	82	0	0	0	0	0	0	0

County	Emergency Operation Centers			Fire Stations			Police Stations			Schools		
	Building Damage ($ thousand)	Content Damage ($ thousand)	Non-Functional	Building Damage ($ thousand)	Content Damage ($ thousand)	Non-Functional	Building Damage ($ thousand)	Content Damage ($ thousand)	Non-Functional	Building Damage ($ thousand)	Content Damage ($ thousand)	Non-Functional
Liberty	141	242	0	336	775	1	322	558	1	2,012	12,853	3
Navarro	0	0	0	65	111	0	0	0	0	0	0	0
Parker	0	0	0	0	0	0	0	0	0	327	1,766	1
Rockwall	0	0	0	38	65	0	0	0	0	3,776	20,391	3
San Jacinto	0	0	0	70	197	0	0	0	0	0	0	0
Tarrant	0	0	0	957	2,331	1	462	791	0	10,256	58,104	26
Walker	0	0	0	129	344	0	0	0	0	0	0	0
Wise	0	0	0	188	1,296	2	0	0	0	5	26	1
Young	0	0	0	41	70	0	0	0	0	0	0	0

Note: Only counties for which the HAZUS analysis reported losses are summarized.

Existing Conditions Vulnerability Analysis

Vulnerability is an assessment of the potential negative impact of the flood hazard to communities and a description of the impacts. The existing conditions vulnerability analysis uses the 2025 flood-specific SVI for Texas (TX F-SVI) developed by TWDB. The TX F-SVI calculates the SVI at the census tract level within a specified county using 18 sociable factors including poverty, housing, ethnicity, and vehicle access. It then groups them into six related dimensions of vulnerabilities: Socio-economic, Place and Status, Socio-Cultural, Rurality, Infrastructure, and Socio-Demographic. *Figure 2.21* shows the TX F-SVI dimensions used for SVI calculation. Each census tract receives a separate ranking for each of the six dimensions, as well as an overall ranking.

Vulnerabilities of Structures, Agricultural Areas, Bridges, Low Water Crossings, and Critical Facilities

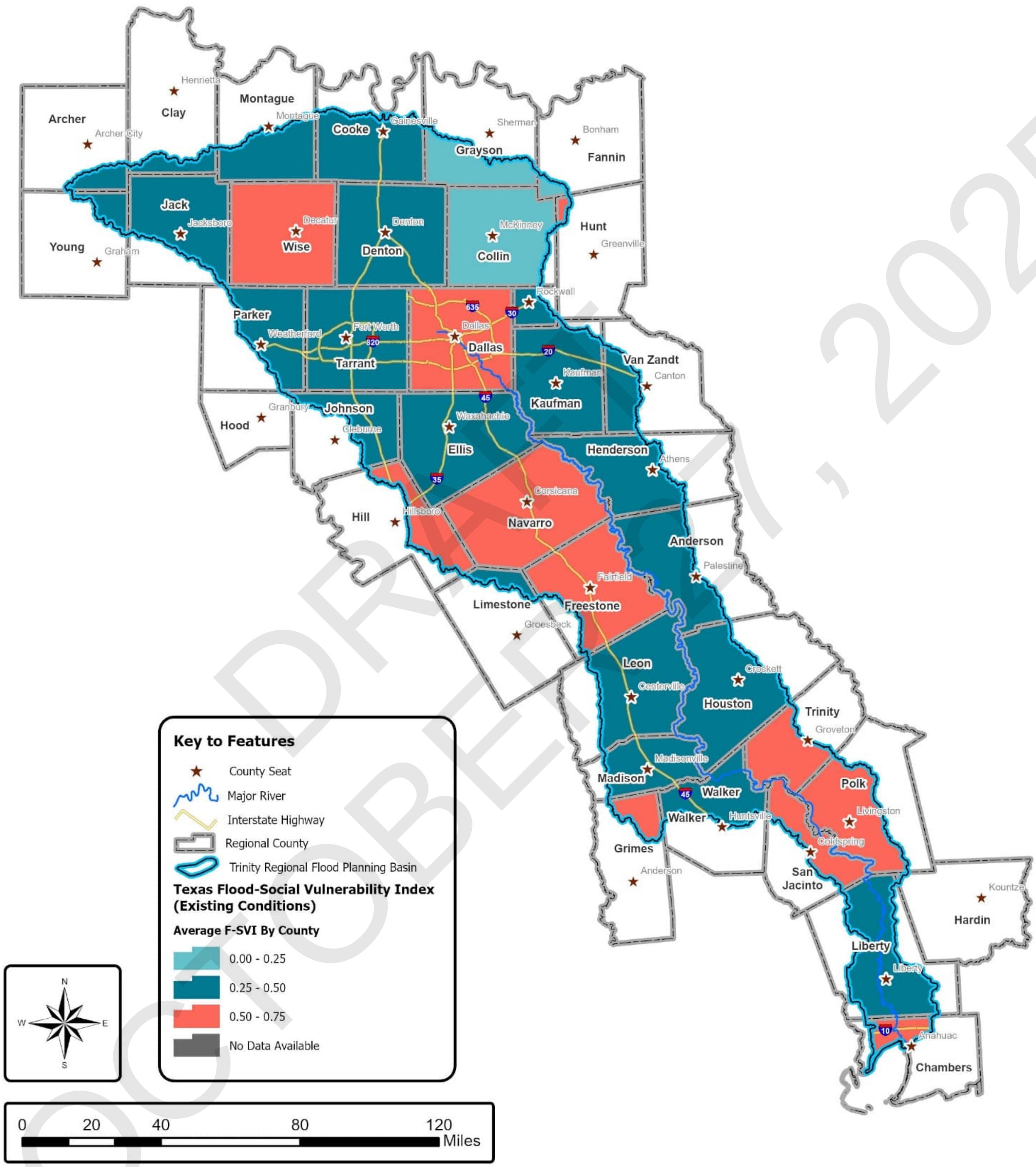
The 2025 TX F-SVI data was overlaid with the Trinity Region's exposed buildings, critical facilities, bridges, roadway and railway stream crossings, LWCs, and agricultural areas. The SVI values for all the buildings, critical facilities, agricultural areas, bridges, and LWCs exposed to the existing conditions floodplain quilt are summarized by county averages and shown in *Figure 2.22*.

Figure 2.21: TX-F-SVI Dimensions of Vulnerabilities

DIMENSION	**VARIABLE**
Socio-Economic	Income
	Poverty
	Unemployment
	Housing Value
	Employment Type
Place and Status	Environmental Risk Factors
	Migration
	Renters
Socio-Cultural	Language
	Minority
Rurality	Rural-Urban
	Mobile Homes
Infrastrucure	Housing Age
	Access to phone/internet
	No Vehicle
Socio-Demographic	Age
	Disability
	Single Parent Household

Source: TWDB (TWDB TX F-SVI, 2025)

Figure 2.22: Existing Conditions Exposure and Social Vulnerability Index by County



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 (TWDB TX F-SVI, 2025). 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 (TWDB TX F-SVI, 2025).

Figure 2.22 shows Collin and Grayson counties as being the least vulnerable with respect to the existing exposure of buildings, critical facilities, agricultural areas, bridges, and LWCs. TWDB considers a threshold of 0.75 as an indicator for highly vulnerable areas. At the county level, none of the counties reached this threshold. *Figure 2.23* shows the countywide average distribution of SVI with regards to the exposed buildings, critical facilities, agricultural areas, bridges, and LWCs in the Trinity Region. Chambers, Dallas, Freestone, Grimes, Hill, Hunt, Navarro, Polk, San Jacinto, Trinity, and Wise counties had the largest SVI countywide values. Large, detailed maps for the vulnerability assessment are shown in *Appendix B*.

Resiliency of Communities

Community resilience is a measure of the sustained ability of a community to prepare for anticipated natural hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions. It refers to the ability of a community to survive and thrive when confronted by external stresses, such as natural or human-caused disasters like floods. A community resilience score is inversely proportional to a community's risk.

FEMA's 2025 Resilience Analysis and Planning Tool (RAPT) was leveraged to assess the resilience readiness of communities in the Trinity Region. RAPT uses 22 commonly used community resilience indicators from peer-reviewed published methodologies, infrastructure, and hazard data that inform strategies for preparedness, response, and recovery. Example indicators include median household income, disability (percent of population with disabilities), hospital capacity (number of hospitals per 10,000 people), and NFIP policy penetration rates. *Table 2.21* illustrates a summary community resilience indicator used by RAPT. The data is aggregated at the census tract and county levels and then aggregated into bins for visualization using all the indicators combined. *Figure 2.24* shows the resiliency ratings of the counties in the Trinity Region. Community resilience is a consequence reduction risk component, and a community resilience score is inversely proportional to a community's risk. A higher community resilience score results in a lower risk index score.

Figure 2.23: Texas Flood-Social Vulnerability Index Averages by County

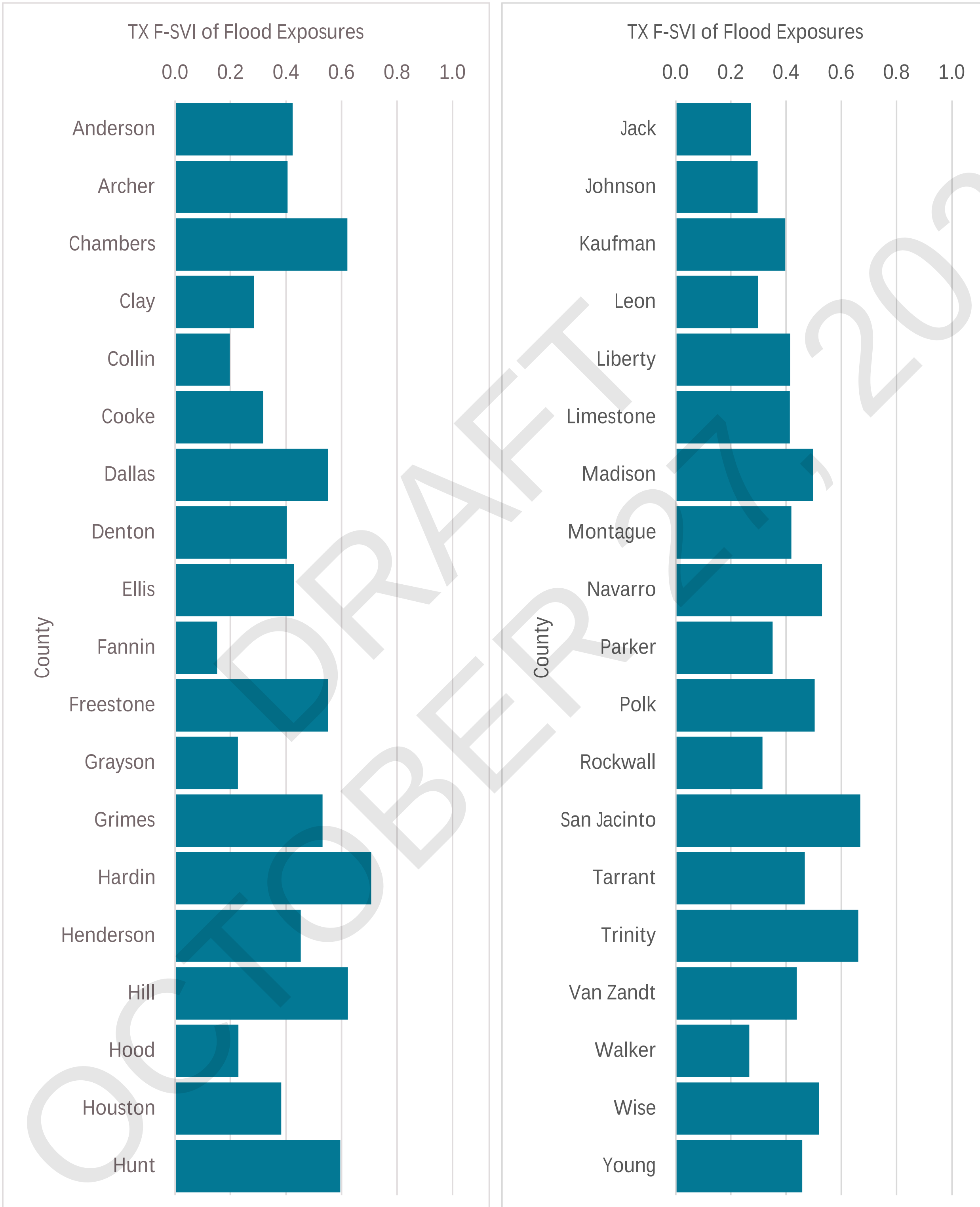
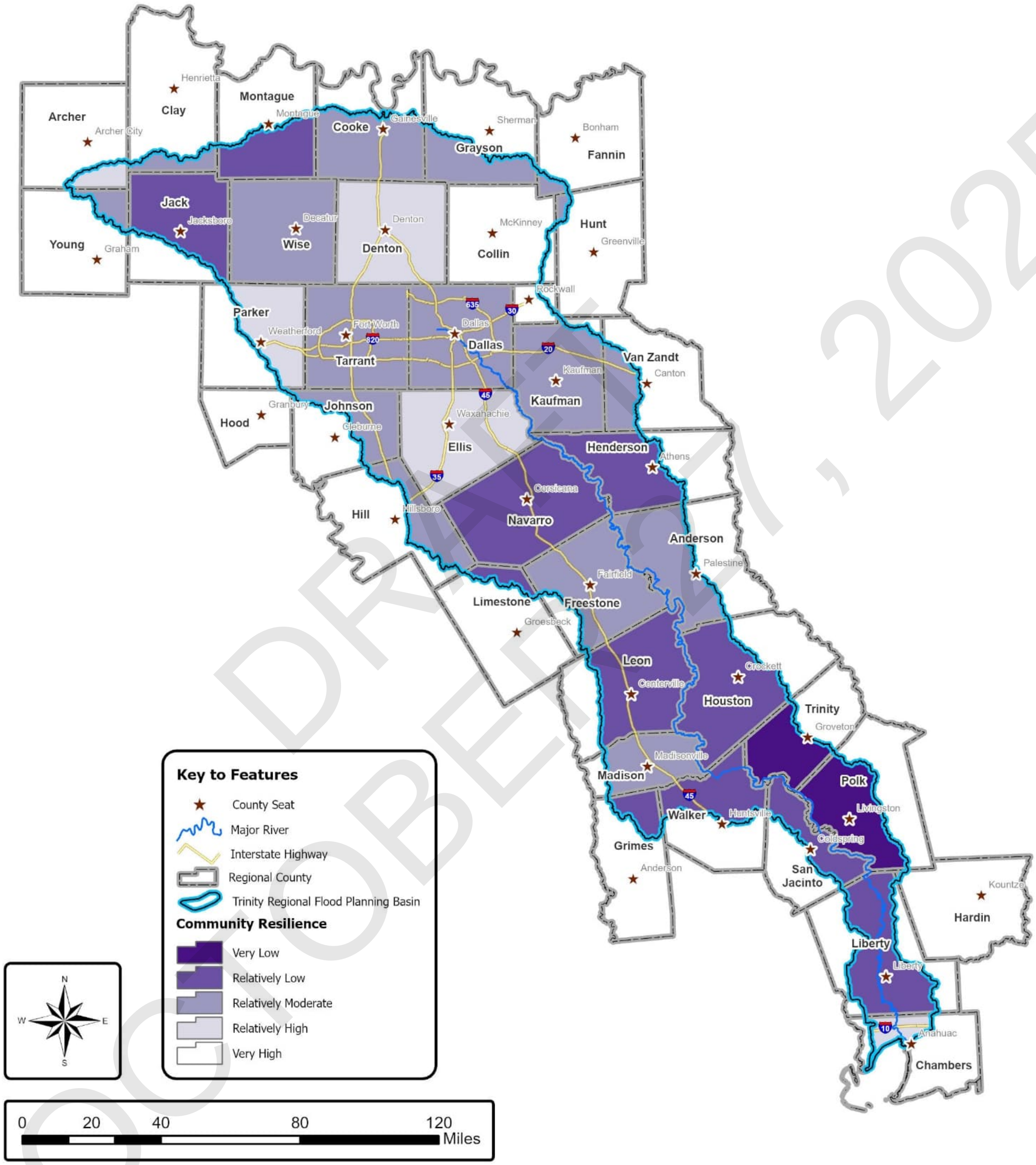


Table 2.21: Commonly Used Resilience Analysis and Planning Tool Indicators and Datasets

Population-Focused Indicators	Community-Focused Indicators	Infrastructure Data	Hazard Data
• % Population without Health Insurance • % Population Unemployed • % Population without a High School Education • % Population with a Disability • % Population without Access to a Vehicle • % Population with Home Ownership • % Population over 65 • % Population Single-Parent Households • % Population with Limited English Proficiency • Median Household Income • Gini Index: Income Inequality • At-risk electricity-dependent Medicare beneficiaries • Tribal Populations • Households without Internet Subscriptions • Power-dependent Devices for Medicare beneficiaries	• Connection to Civic/Social Organizations • Hospital Capacity • Medical Professional Capacity • Affiliation with a Religion • Presence of Mobile Homes • Public School Capacity • Population Change • Hotel/Motel Capacity • Rental Property Capacity • NFIP policy penetration rates (residential) • National Flood Insurance Program policy penetration rates (residential)	• Nursing Homes • Hospitals • Urgent Care Facilities • Public Health Depts. • Fire Stations • Emergency Medical Services (EMS) stations • Local Law Enforcement locations • 911 Service Area Boundaries • Mobile Home Parks • Places of Worship • Public Schools • Private Schools • Colleges and Universities • Prison Boundaries • Transmission Lines • Electric Power Plants • Solid Waste Landfills • Wastewater Treatment Plants • Pharmacies (Rx Open) • Dialysis Centers • High Hazard Dams	• Flood Hazard Zones • Tornado Paths • Tropical Storms • Seismic Hazards • Wildfire • Current Watches/Warnings • Hurricane Outlook: Atlantic • Severe Weather Outlook • Excessive Rainfall Outlook • River Flood Outlook

Figure 2.24 shows that Rockwall County has the highest resiliency rating in the Trinity Region. Leon, Polk, and Trinity counties show the lowest overall resiliency readings. In general, the Trinity Region Upper Subregion shows relatively higher resiliency ratings than the Middle and Lower Subregions.

Figure 2.24: Resiliency Rating by County



Summary of Existing Conditions Flood Exposure and Vulnerability Analyses

Based on exceedance probability for a period of years, and not just one year, there is a 26 percent chance that a 100-year flood will occur over the next 30 years. There are over 140,000 buildings in the Trinity Region that have greater than a 26 percent chance of being severely affected by flooding over the next 30 years. This represents 2.2 percent of all buildings in the region.

While population estimates are valuable for defining the general severity of flood exposure, as documented in the upcoming Existing Conditions Flood Exposure section, such aggregated measures inform only how many people are exposed, but not who. Disaggregating the exposed populations according to SVI helps inform who lives in the floodplain and where. Questions about flood risk, exposure, vulnerability, and resilience are fundamentally questions of where. Hence for the Trinity Region, spatial autocorrelation techniques using the values from the existing flood exposure and social vulnerability were used to map to map and identify hotspots (most vulnerable areas).

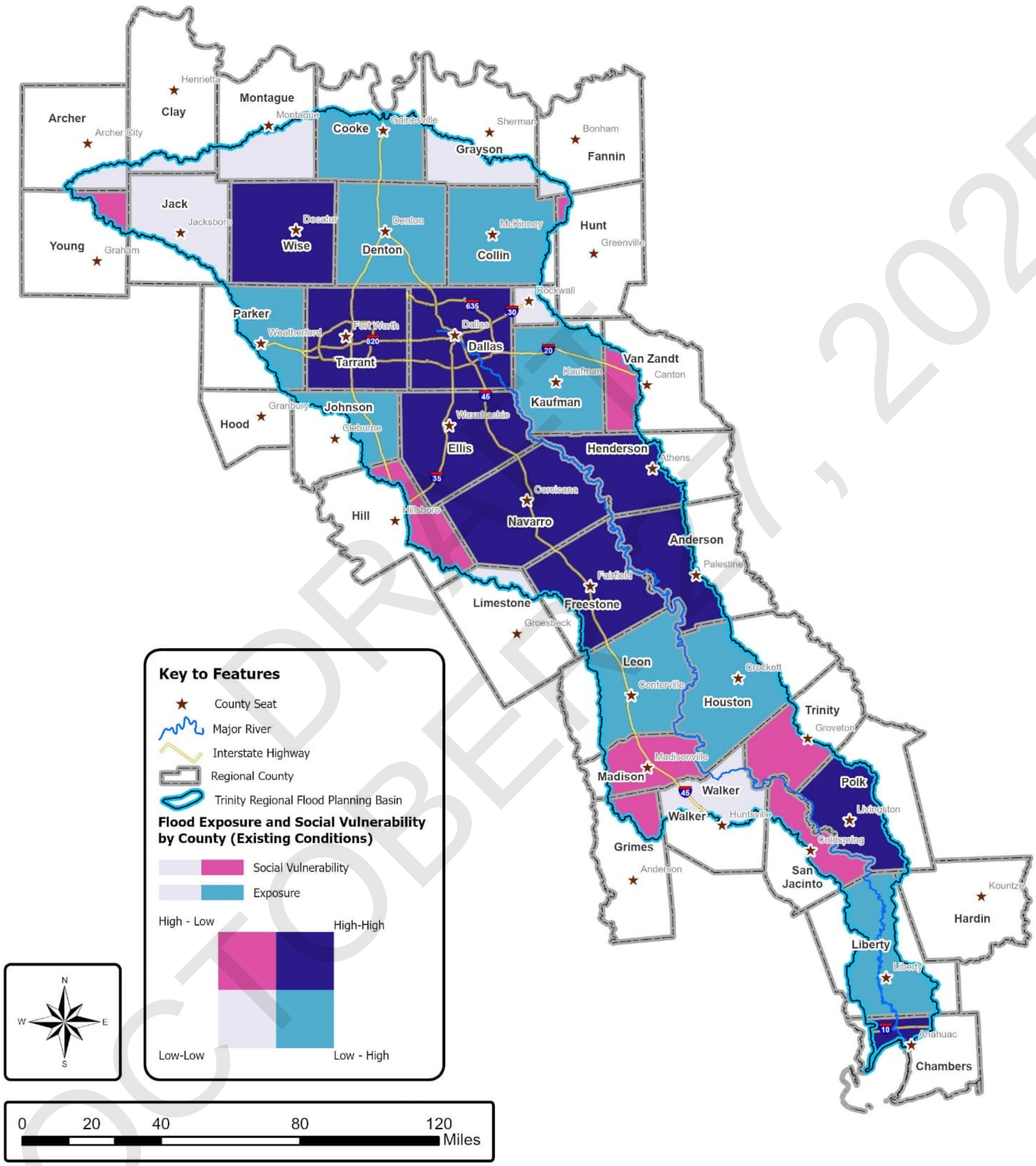
As shown in *Figure 2.25*, the High-High (HH) hotspots (purple) are counties with higher-than-average flood exposure and are surrounded by areas with higher-than-average social vulnerability. The majority occur in the upper region (Dallas, Ellis, Henderson, Navarro, Tarrant, and Wise counties). There are also two hotspots in the middle region (Anderson and Freestone counties) and two in the lower region (Chambers and Polk counties). These HH counties are home to approximately 5.5 million (ESRI, 2025) people.

The High-Low (HL) counties are in pink, representing counties with high social vulnerability with neighboring low flood exposure. These areas are mostly in the upper region (Hill, Hunt, Van Zant, and Young counties), and then two in the middle region (Madison and Trinity counties), and one in the lower region (San Jacinto). In total the HL clusters are populated by approximately 290,800 people. Extreme flood events have the probability of high adverse impacts due to the high population susceptibility.

The Low-High (LH) counties in blue represent counties with low social vulnerability and high flood exposure, and are home to approximately 3 million people. The areas are interspersed throughout the region .

The Low-Low (LL) counties are the least in the Trinity Region and are mostly in the upper and middle the regions. These LL counties are Archer, Clay, Fannin, Grayson, Jack, Limestone, Montague, Rockwall, and Walker counties. These counties have the lowest levels of flood exposure and social vulnerability and require less attention from the perspective of flood vulnerability.

Figure 2.25: Existing Conditions Flood Exposure and Social Vulnerability Index by County



A larger version of *Figure 2.25*, as well as a more detailed exposure and vulnerability relationship at the census tract level, is shown in *Appendix B*.

The hotspot area can be used to help identify and justify priority locations for interventions like FMPs that can mitigate both physical and social aspects of flood vulnerability (Tate, Asif, Emrich, & Sampson, 2021). FMPs are discussed in *Chapter 4*. For example, LH areas (Low vulnerability and High exposure) can become areas where exposure reduction projects like levees, detention basins, and other natural based solutions can be prioritized. If an FMP goal is to optimize both reduction in physical risk and address socially vulnerable populations, then areas can be prioritized.

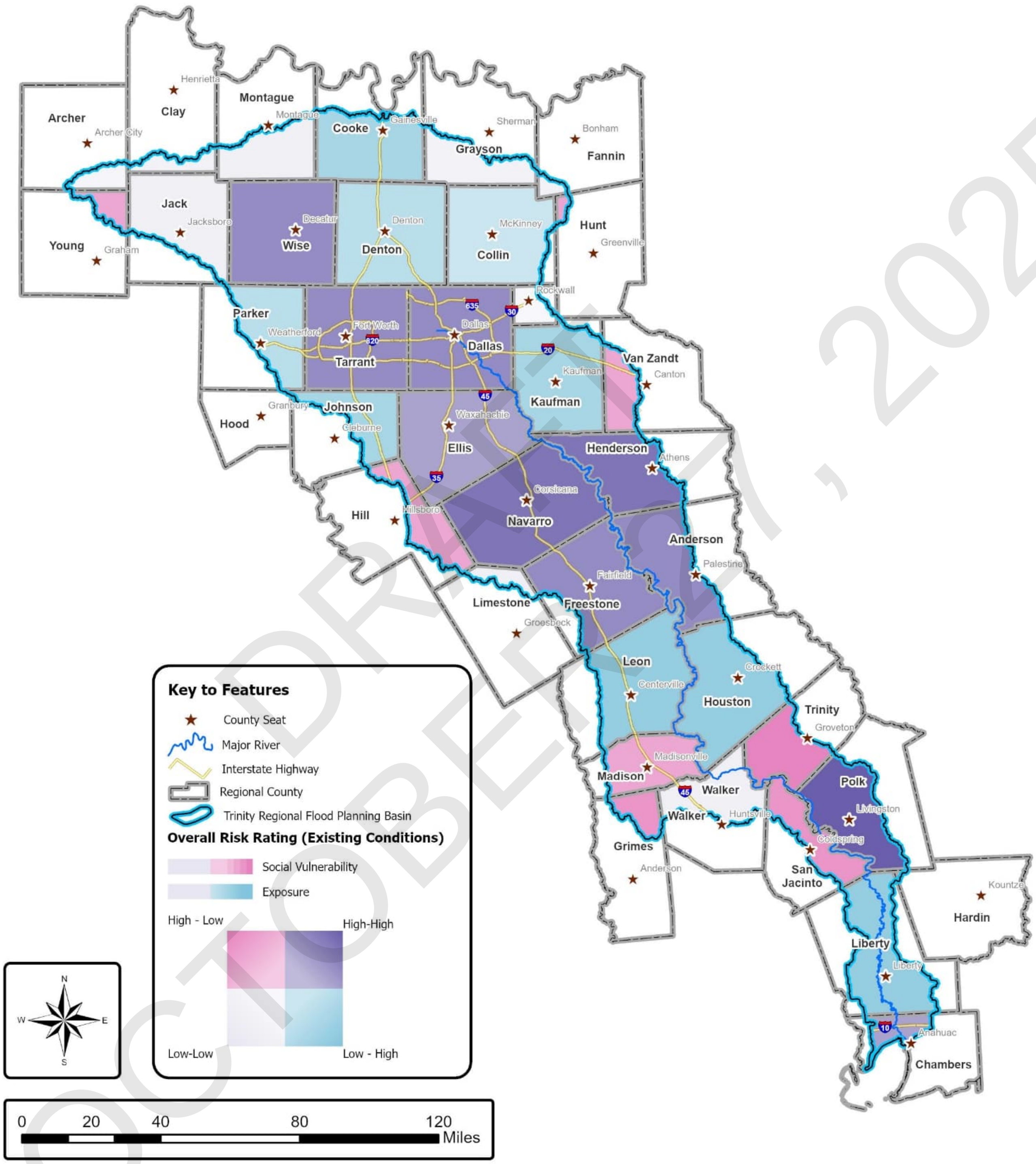
While the product of exposure and vulnerability paints a picture of risk in an area, weighing this against resilience helps to map an overall risk rating for a community. The bivariate map in *Figure 2.26* that shows exposure and vulnerability is weighted against the resiliency factors discussed previously in the Resiliency of Communities section. This results in trivariate choropleth map with varying color intensities to maps and display the overall ratings by county.

As shown in *Figure 2.26*, with the addition of the third variable (resiliency), counties like Henderson, Houston, Leon, and Navarro counties are now in a slightly lower risk rating than Dallas, Freestone, Hill, Kaufman, and Liberty counties. In the previous *Figure 2.25*, the counties all used to be in the same High Exposure and High vulnerability category (HH). A more detailed-level, larger map of the overall risk rating based on census tract levels for the Trinity Region is shown in *Appendix B*. Higher intensity colors show higher risk levels within the same category. For example, Hill, Hunt, Madison, Van Zandt, and Young counties now show a lower risk rating than Grimes, San Jacinto, and Trinity counties, even though they all fit in the High-Low category.

The existing flood risk, exposure, and vulnerability for the Trinity Basin are summarized in *TWDB-Required Table 3*. The TWDB *Table 3* provides the results per county of the existing flood exposure and vulnerability analysis as outlined in the Technical Guidelines for Regional Flood Planning. This table is included in *Appendix A*.

A geodatabase with applicable layers, as well as associated *TWDB-Required Maps 1* through *22* are provided in *Appendix B* as digital data. *Table 2*, included in *Appendix B*, 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 located on the web at www.twdb.texas.gov/flood/planning/planningdocu/2023/index.asp.

Figure 2.26: Overall Risk Rating by County



Task 2B – Future Conditions Flood Risk Analyses

Future Conditions Flood Hazard Analysis

The future flood risk assessment begins by estimating the increased extent of the future flood hazard. The future flood risk mapping extent is commonly determined under fully developed watershed conditions, which is the anticipated condition of the watershed after the watershed has undergone ultimate land use development. The determination of the general magnitude of potential increases in the Trinity Region's future 10%, 1% and 0.2% annual chance storm events are based on a "do-nothing" or "no-action" scenario of approximately 30 years of continued development and population growth under current development trends and patterns, and existing flood regulations and policies.

Future Conditions Based on "No Action" Scenario

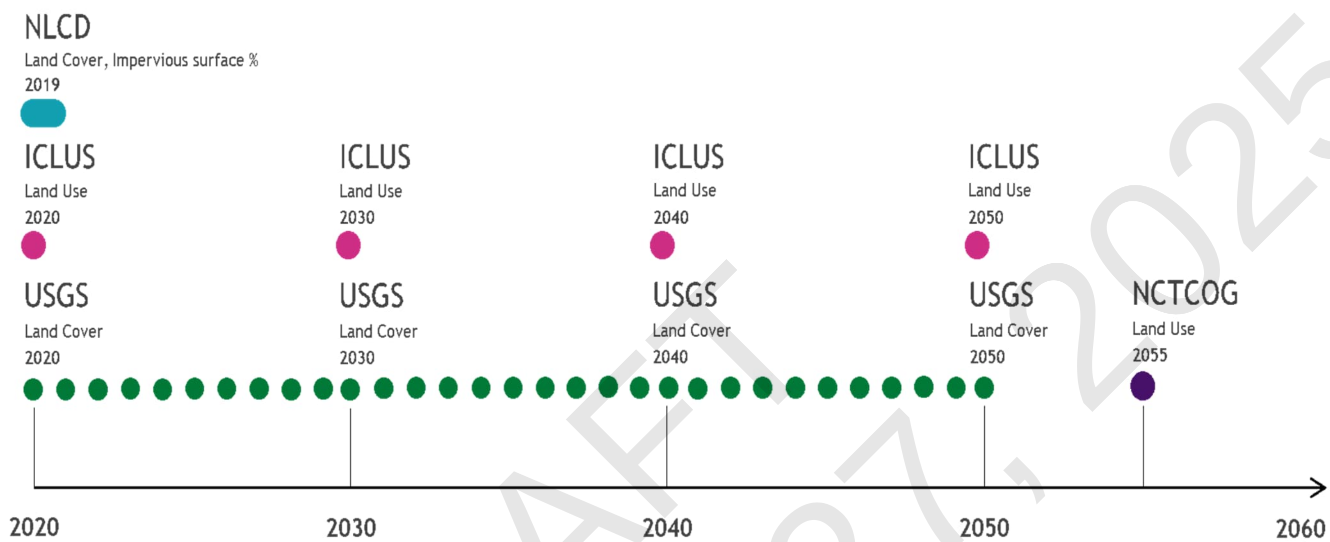
Land Use and Development Trends

Land use and land cover (LULC) data provides a valuable method for determining the current and future extents of various land types in a floodplain. The LULC datasets are typically derived from the results of classifying satellite images. For the Trinity Region, the open-sourced datasets of current LULC conditions and future projections can be retrieved from the National Land Cover Dataset (NLCD), Environmental Protection Agency (EPA) Integrated Climate and Land Use Scenarios (ICLUS) land use projections, USGS conterminous United States land cover projections, and North Central Texas Council of Governments (NCTCOG) land use projection as shown in the *Figure 2.27*.

In advanced hydrodynamic flood models, LULC data is a critical input. It is used to define key physical characteristics of the landscape that directly influence flood behavior, such as the surface roughness of a floodplain (defined by a Manning's n coefficient) and the amount of impervious cover, which affects urban drainage and infiltration assumptions for pluvial (rainfall-driven) flooding. As land cover changes over time due to development and other factors, so do these characteristics, which in turn alters the evolution of a flood wave over the land.

The NLCD provides the latest LULC dataset (2019) for the Trinity Region, which is considered a credible data source with a 30-meter spatial resolution. The current LULC condition can also be estimated based on the projections from the ICLUS and USGS datasets for 2020, which can be consistently compared with the respective projections for 2050. The ICLUS dataset provides decadal land use projections (years 2020, 2030, 2040, and 2050) at a 90-meter spatial resolution, while USGS provides annual land cover projections (every year from 2020 to 2100) at a 250-meter spatial resolution. The NCTCOG also provides a localized land use projection for North Central Texas for the year of 2055. The following sections will include detailed descriptions for each dataset and show how the datasets can be used to investigate future LULC changes in the Trinity Region.

Figure 2.27: Summary of the Current and Future Land Use and Land Cover Datasets



Future Land Use and Land Cover Conditions

Future land use conditions are available from three LULC datasets:

- EPA ICLUS land use projections
- USGS conterminous United States land cover projections
- NCTCOG land use projection

Recent statewide future flood mapping efforts undertaken for the Texas Water Development Board (TWDB) have utilized these datasets to model future conditions. In the "Year 2060 Floodplain Maps for Texas" project, the USGS Conterminous United States Land Cover Projections have identified the LULC dataset as the most appropriate future land use conditions. This dataset provides projections covering the entire state for the target year of 2060, and its underlying scenarios align with the project's specific climate targets. While the EPA ICLUS dataset has also been considered, the USGS dataset's land cover categories and associated temperature targets more closely match for the statewide modeling framework.

The ICLUS is based on the EPA demographic and spatial allocation models to produce land use changes according to different scenarios. The dataset includes land use classifications of the contiguous United States at a spatial resolution of 90 meters. A demographic model generates population estimates that are distributed by a spatial allocation model (SERGoM v3) (Bierwagen, Theobald, Pyke, & Morefield, 2010) into housing density (HD) across the landscape. In the initial version (v1), land-use outputs were developed for the four main

Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (A1, A2, B1, and B2) and a baseline. The land use outputs are available for each scenario by decade from 2010 to 2100.

Two of the new Shared Socioeconomic Pathways (SSPs) (SSP2 and SSP5) and two Representative Concentration Pathways (RCPs) (RCP 4.5 and RCP 8.5) were added in the recent version (v2). (United States EPA, 2016). The details of the selected pathways are shown below:

- SSP2 is a "middle-of-the-road" projection, where social, economic, and technological trends do not shift markedly from historical patterns, resulting in a United States population of 455 million people by 2100. Domestic migration trends remain largely consistent with the recent past.
- SSP5 describes a rapidly growing and flourishing global economy that remains heavily dependent on fossil fuels, and a United States population that exceeds 730 million by 2100. ICLUS v2.1 land use projections under SSP5 result in a considerably larger expansion of developed lands relative to SSP2.
- RCP4.5 assumes that global greenhouse gas emissions increase into the latter part of the century, before leveling off and eventually stabilizing by 2100 because of various climate change policies.
- RCP8.5 assumes that global greenhouse gas emissions increase through the year 2100.

Figure 2.28 and *Figure 2.29* illustrate the land use conditions of the Trinity Region based on the ICLUS dataset of the years of 2020 and 2060.

Another LULC projection dataset for the contiguous United States is produced by USGS. The year 1992 was used by USGS as the baseline for the landscape modeling while other datasets such as NLCD, USGS Land Cover Trends, and USDA's Census of Agriculture were used to guide the recreation of historical land cover information for the 1992 to 2005 period. The forecasting scenarios of land use (FORE-SCE) model were used to produce landscape projections for the 2006 to 2100 period as future projection. The FORE-SCE model also considers four IPCC SRES scenarios (A1/A1B, A2, B1, and B2) corresponding to the four storylines (Shukla, et al., 2019). The details of each storyline are shown below:

- The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. As one of A1 scenario family, A1B is selected in the USGS land cover model to represent balanced use across fossil and non-fossil energy sources.
- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita

economic growth and technological change are more fragmented and slower than in other storylines.

- It is important to note how future LULC data is applied in complex hydrodynamic models. In the statewide 2060 study, the future land use data was used to explicitly model changes to floodplain friction and to adjust pluvial (local rainfall) runoff based on increased urbanization. However, the study did not use the LULC data to model the impacts of urbanization on upstream fluvial (river) runoff. This was because the climate models used to generate future river flow scenarios assumed a static global land use configuration from the year 2005. This highlights a key limitation and an area of complexity in integrating multiple future projection datasets.

Figure 2.28: Integrated Climate and Land Use Scenarios Land Use Projections of 2020

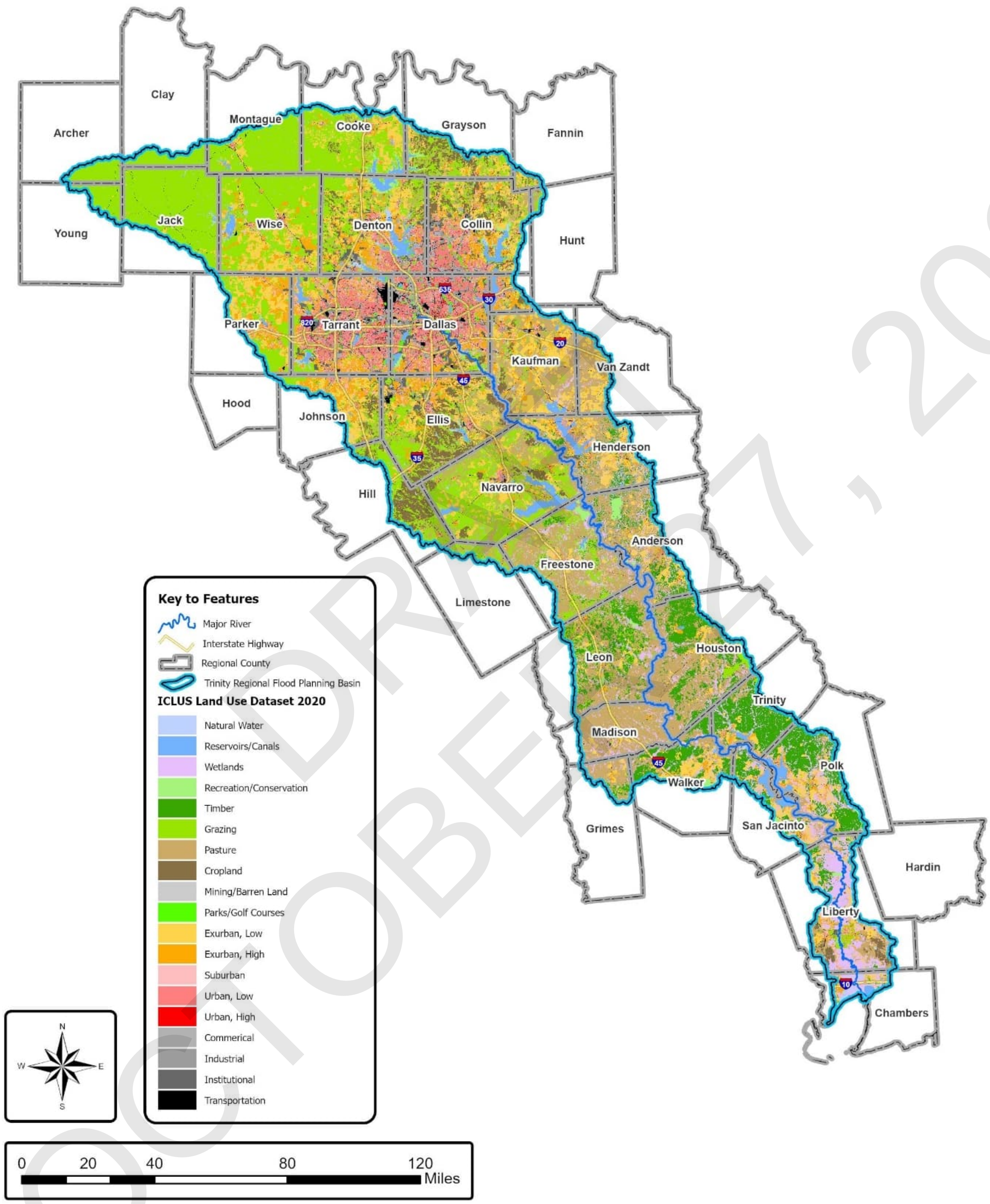
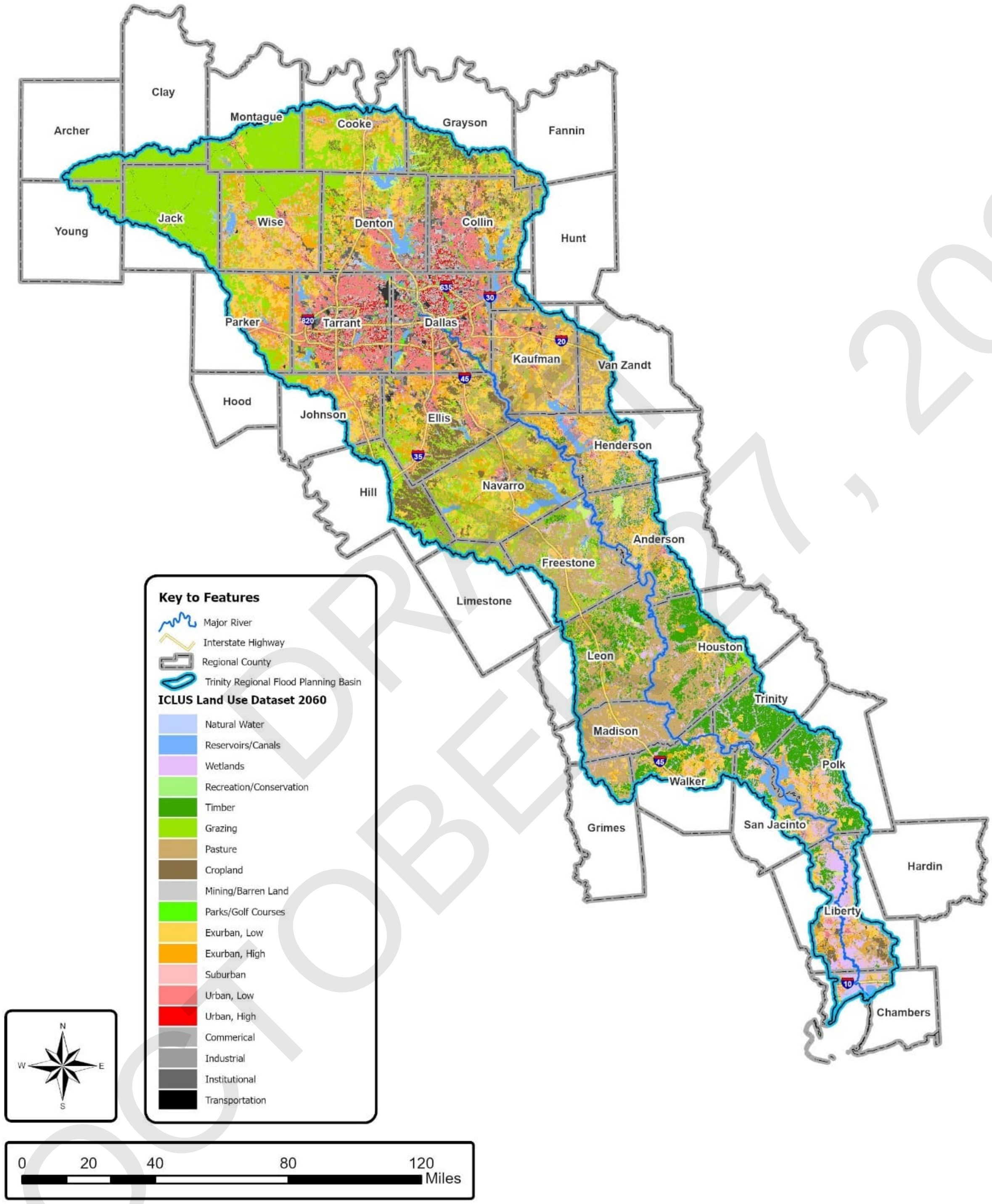


Figure 2.29: Integrated Climate and Land Use Scenarios Land Use Projections of 2060



- The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

This USGS LULC projection dataset has been used for a wide variety of studies, including topics of regional weather and climate, landscape change on biodiversity, and water quality (Sohl, 2018). *Figure 2.30* and *Figure 2.31* illustrate the land cover conditions of Trinity Region from the USGS dataset for the years of 2020 and 2060.

From both the LULC projections from ICLUS and USGS datasets, rapid land development is found to occur in the Upper Subregion from 2020 to 2060, indicated by increased coverage of the "Suburban", "Urban Low" and "Urban High" (*Figure 2.30*) and "Developed" (*Figure 2.31*) areas in the DFW metroplex and its suburbs. Rapid land use changes will increase the flood risks for the communities in this region if no proactive flood planning and mitigation measures are taken. On the contrary, areas in the Trinity Region do not show significant changes in future land use. The comparative analysis between the LULC data suggests that further studies (for example, hydrologic/hydraulic analyses) should be conducted to provide more detailed information related to impacts from changes of LULC.

Recent statewide modeling efforts quantify this relationship by explicitly modeling the effects of urbanization on flood behavior. In these models, future land use changes impact flooding in two main ways: by altering the floodplain's surface roughness and by changing how rainfall runs off the land in urban areas. For example, the Fathom model accounts for the protection provided by urban drainage systems by reducing the amount of rainfall that produces pluvial flooding. This is done by assuming that drainage systems in urbanized areas are designed to handle a specific level of storm (for example, a 1-in-5-year rainfall event), and rainfall below this level is removed by the system. This modeled standard of protection varies based on the level of development and whether the region is flat and poorly drained or steeper and better-drained. While the overall impact of future land use and subsidence is generally less than that of future climate change, these factors are responsible for localized changes and the redistribution of flood waters. It is also noted that while new drainage systems may reduce flooding from smaller, more frequent storms, the increase in impervious surfaces (like pavement) means that infiltration is assumed to be zero, which can potentially worsen flooding during extreme events that exceed the drainage system's capacity.

For the Upper Subregion, the NCTCOG collects the future land use planning data from individual cities (for example., Arlington, Dallas, Plano, etc.) and integrates it into a regional future land use planning dataset (as shown by the land use conditions of 2055 in *Figure 2.32*). This dataset provides a future land use condition scenario for the Upper Subregion and will be compared with the datasets from ICLUS and USGS for future flood risk analyses. In summary, the current and future projection of land cover and land use datasets suggest that the upper basin will experience rapid urban development with significant land use changes. It is highly recommended for communities to consider land use planning and projections in the future flood mitigation and planning to help communities mitigate their current and future vulnerability to floods.

Figure 2.30: United States Geological Survey 2020 Land Cover

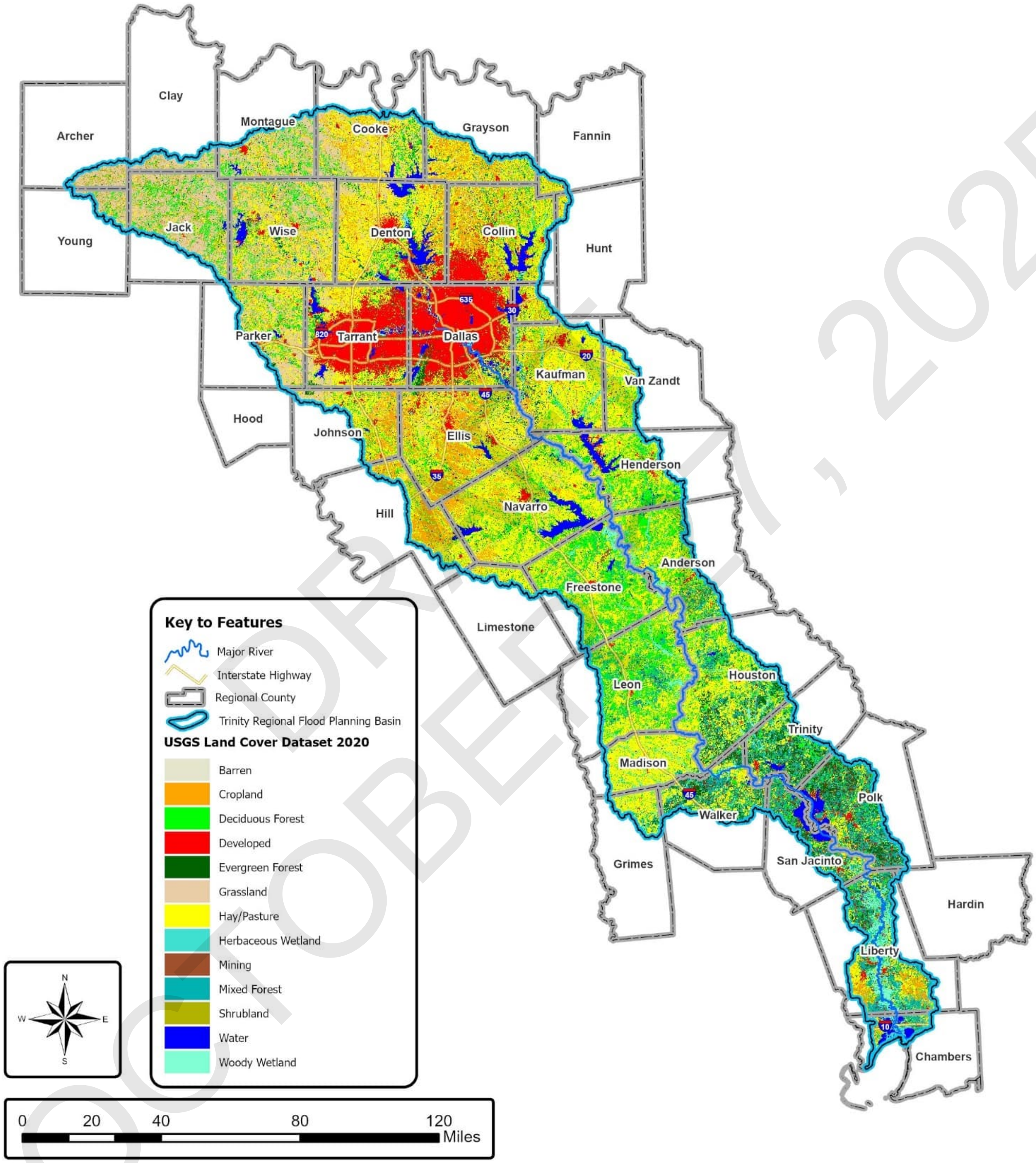


Figure 2.31: United States Geological Survey 2060 Land Cover Projection

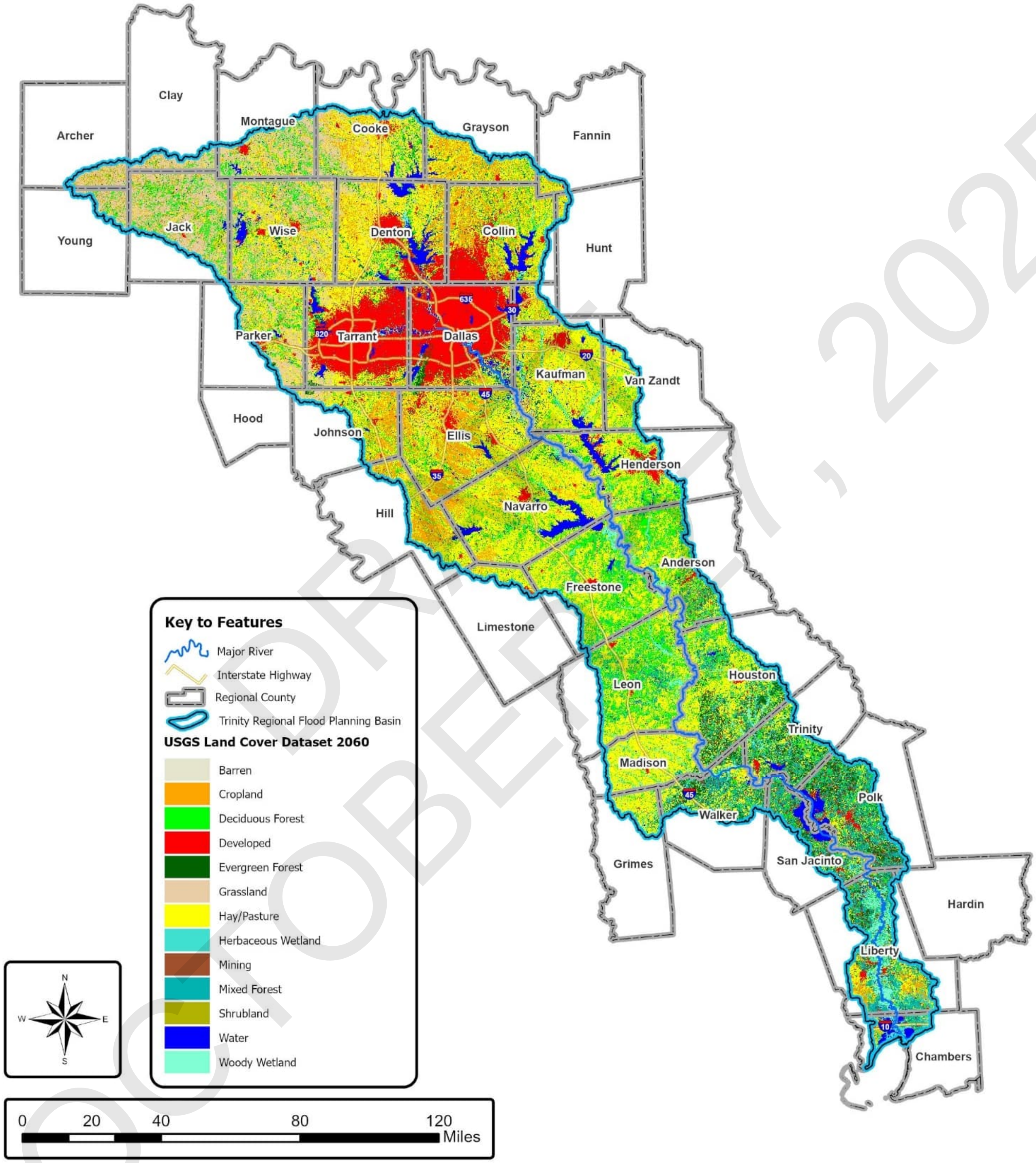
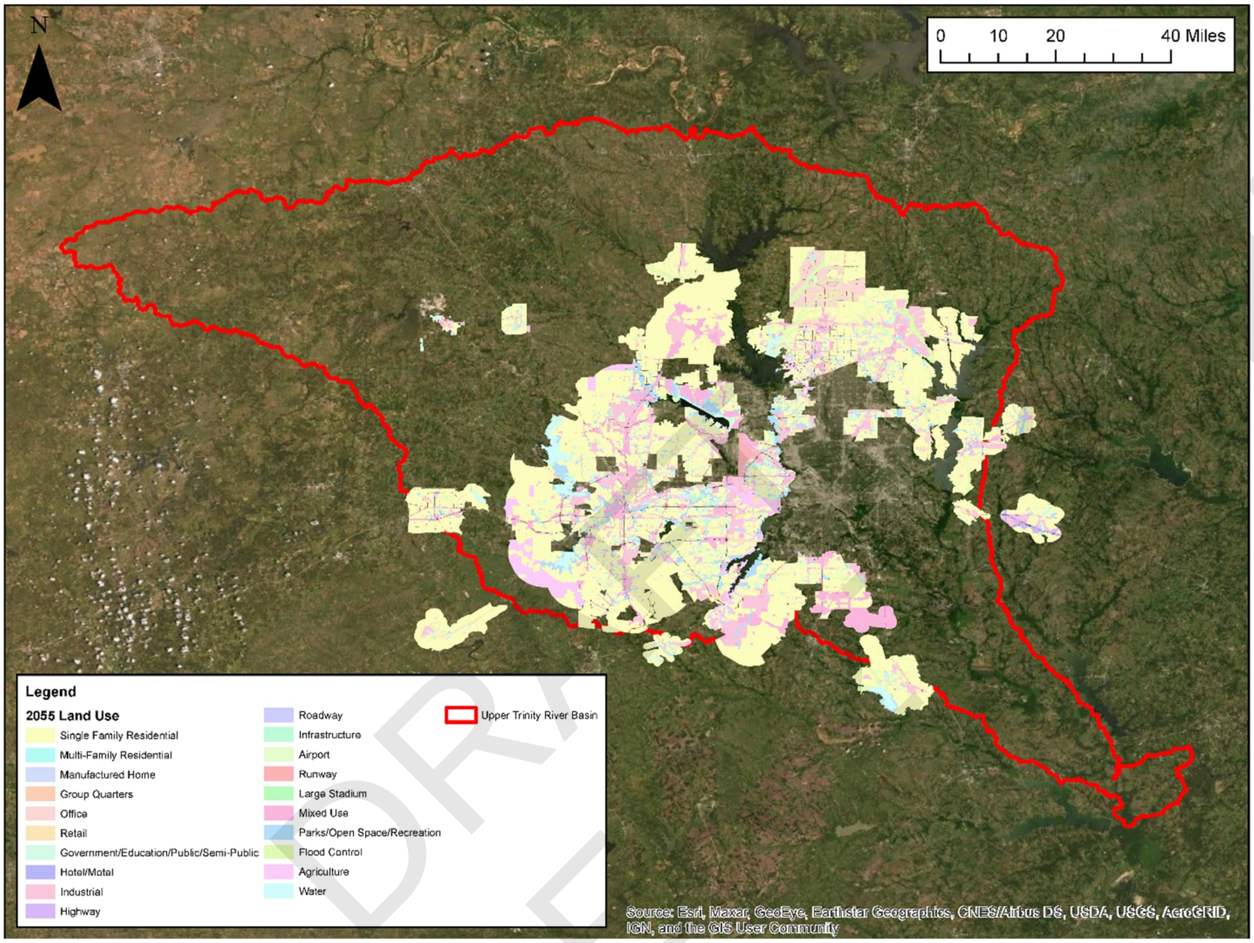


Figure 2.32: North Central Texas Council of Governments Land Use Projection in 2055



It is noted that the future land use and urbanization projections for 2060 are included in the Fathom 2060 future conditions floodplain modeling in this second cycle of the regional flood plan.

Population Growth

According to World Bank, 2.2 billion people, or around 29 percent of the world population, live in areas that experience various levels of inundation during 100-year floods (Rentschler & Salhab, 2020). FEMA estimates that 13 million Americans live within a 100-year flood zone. Recent research argues that the real number is about 41 million (Wing, et al., 2018). On one hand, the future flood conditions will significantly affect the people exposed to flood risks, leading to higher flood vulnerability over the areas with rapid population growth in the United States (Swain, et al., 2020).

On the other hand, the population dynamics, which show how and why populations change in structure and size over time, also has important interrelationships with the changes of land cover and land use, as well as water demands for all uses (National Academies of Science, Engineering, and Medicine, 1994). Rapid population growth results in expansion of urban and industrial lands, and depletion of wetlands, floodplains, and waterbodies, which can potentially impact the flood dynamics (Rahman, Tharzhiansyah, Rizky, & Vita, 2021). Identifying future growth, composition, and distribution of a population is crucial for flood planning.

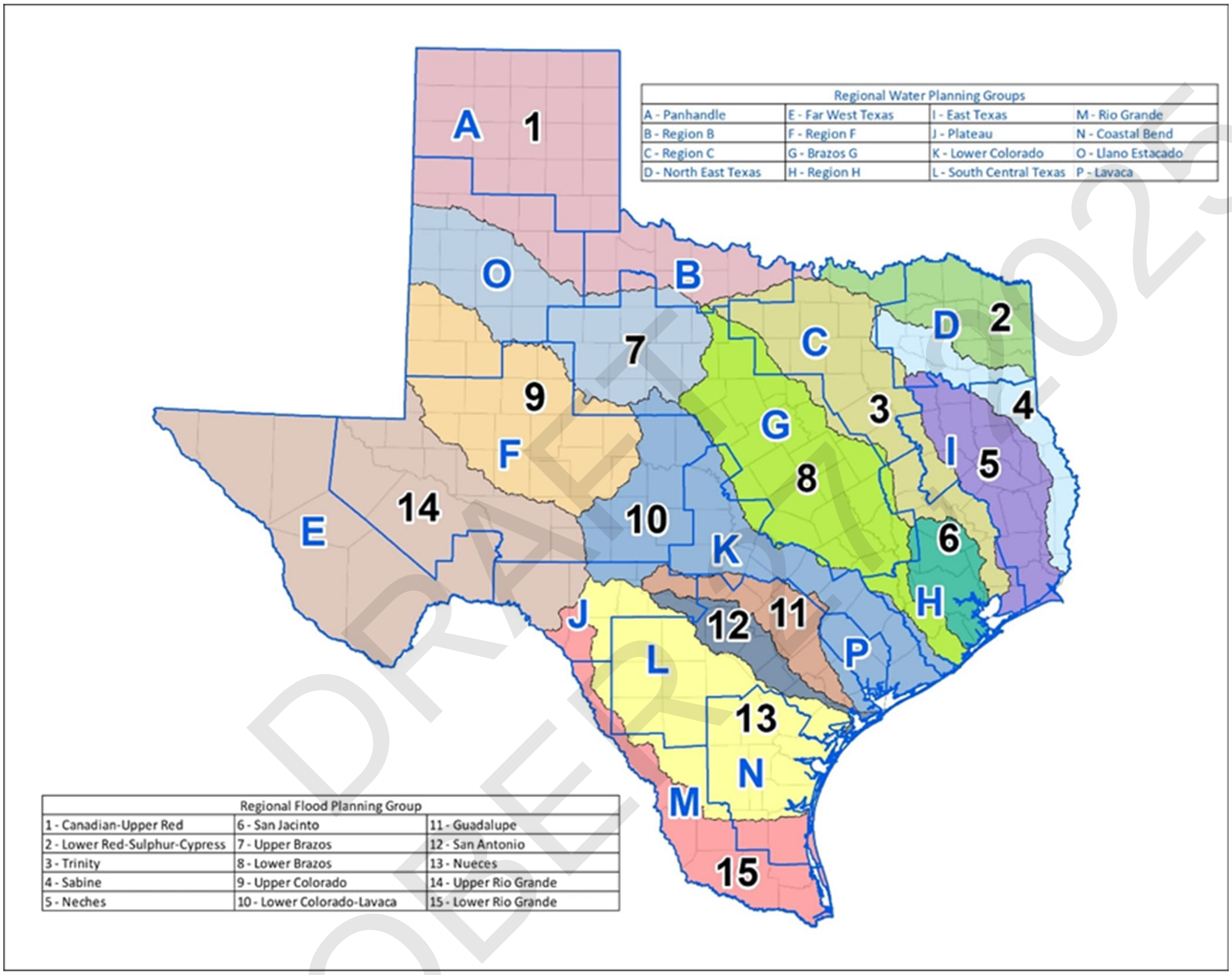
The population in Texas is expected to increase 42 percent between 2020 and 2060, from 29.7 million to 42.3 million people (ESRI, 2025). The projection was made based on a standard demographic methodology known as a cohort-component model, which uses different cohorts (combinations of age, gender, and racial-ethnic groups) and components of cohort change (birth, survival, and migration rates) to estimate future population at a county level. The Texas State Data Center provided the TWDB with the initial 30-year population projections for each county. The TWDB then extended these 30-year projections to the State Water Plan's 50-year planning horizon. In the State Water Plan, the state is divided into 16 Regional Water Planning Groups (RWPGs) (*Figure 2.33*). Rapid population growth (over 35 percent) between 2020 and 2060 is expected to occur within Regions C (which includes the Dallas-Fort Worth metropolitan area) and H (which includes the Houston metropolitan area) as shown in *Table 2.22*. It is noted that the majority of Region C and portions of Region H are contained in the Trinity Region (*Figure 2.33*).

Table 2.22: Decadal Population Growth for Regions C and H Water Planning Areas from 2020 to 2060

Regional Water Planning Group	2020	2030	2040	2050	2060	Percent Growth from 2020 to 2060
C	7,638,000	8,858,000	10,150,000	11,534,000	13,052,000	71%
H	7,325,000	8,208,000	9,025,000	9,868,000	10,766,000	47%

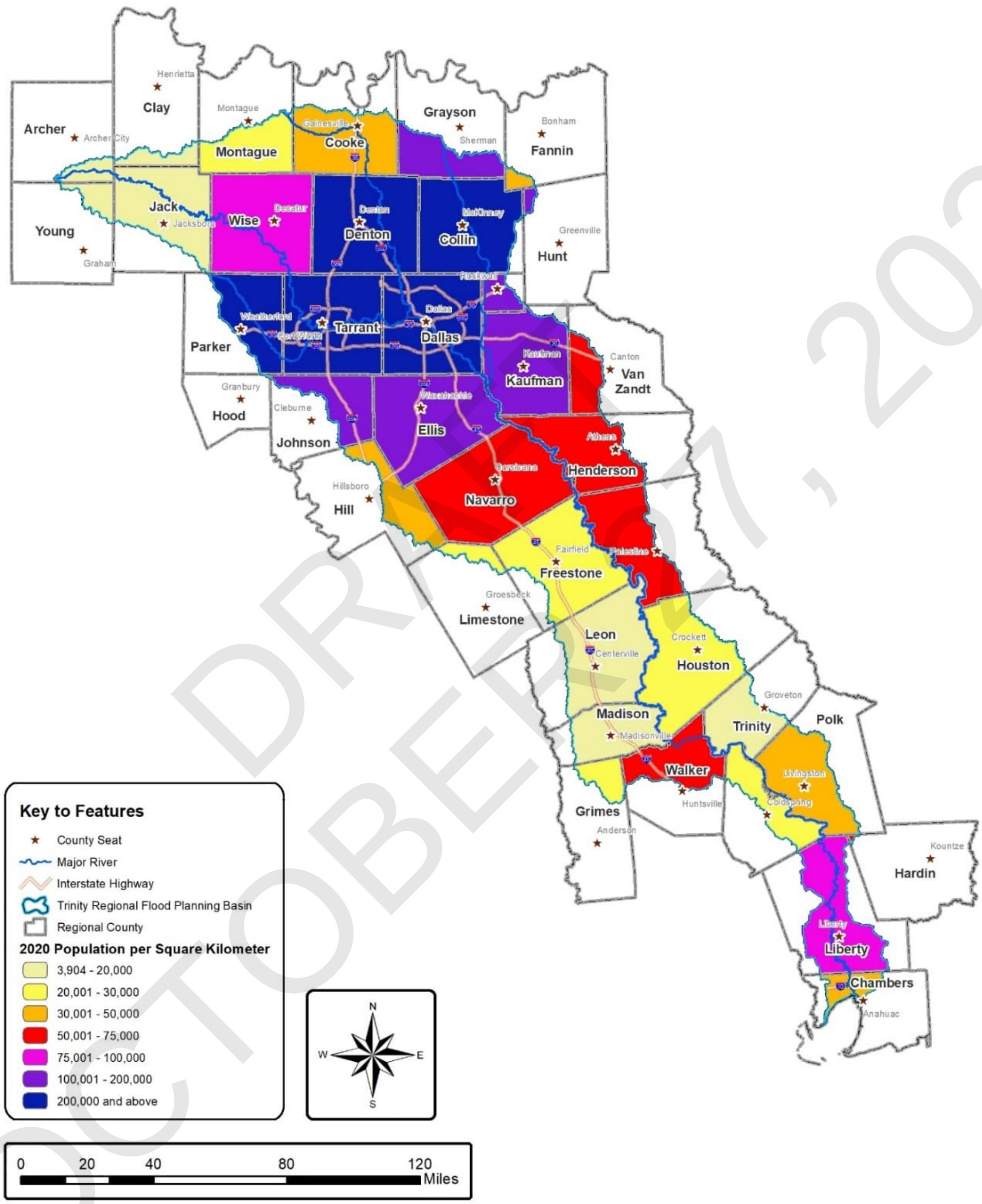
The population of the Trinity Region was estimated to be 8.6 million in 2025 (ESRI, 2025), where higher population density is present in the Trinity Region's upper reaches (*Figure 2.34*). As an example, the projected population for each county in Region C and Region H in the Trinity Region is listed in *Table 2.23*. Kaufman County and Rockwall County are projected to more than double their current population by 2060 as shown in *Table 2.23*. The counties with over one million population, such as Collin, Dallas, and Tarrant counties, will also have rapid growth (over 40 percent) by 2060. Not only will the population growth demand for significantly increased water supply but also will change regional land cover and land use conditions that could alter the floodplain and increase flood risks in these areas.

Figure 2.33: Texas Water Development Board Regional Water Planning Areas and the Trinity Region



Source: TWDB, 2016

Figure 2.34: Population Density of the Trinity River in 2020



Source: TWDB County Population Projections in Texas: 2020-2070 population projections by county (ESRI, 2025)

Table 2.23: Decadal Population Growth for all Trinity Region Flood Planning Counties from 2020 to 2060

Region	County	2020	2030	2040	2050	2060	Percent Growth (from 2020 to 2060)
I	Anderson	61,016	63,017	63,746	63,746	63,746	4%
B	Archer	9,409	9,845	9,960	9,960	9,960	6%
B	Clay	42,162	50,543	59,210	68,541	11,503	3%
H	Chambers	11,154	11,503	11,503	11,503	78,516	86%
C	Collin	1,050,506	1,239,303	1,497,921	1,807,279	2,093,720	99%
C	Cooke	40,903	44,035	46,984	52,427	62,905	54%
C	Dallas	2,587,960	2,871,662	3,180,529	3,429,783	3,627,334	40%
C	Denton	891,063	1,115,119	1,329,551	1,584,015	2,113,136	137%
C	Ellis	191,638	241,778	280,745	360,584	479,939	150%
C	Fannin	38,330	43,084	52,891	69,328	101,706	165%
C	Freestone	20,437	21,077	22,947	31,142	44,475	118%
C	Grayson	135,311	149,527	159,610	178,907	337,120	149%
I	Grimes	29,441	32,179	34,258	36,454	38,277	30%
I	Hardin	59,477	63,986	67,194	69,560	71,410	20%
C	Henderson	92,383	99,236	106,681	116,100	142,441	54%
G	Hill	37,828	40,277	41,935	43,643	44,937	19%
G	Hood	61,316	71,099	78,111	84,147	88,785	45%
I	Houston	24,151	24,260	24,260	24,260	24,260	0%
D	Hunt	104,894	130,351	164,886	207,929	271,952	159%
C	Jack	9,751	10,409	10,817	11,033	11,190	15%
G	Johnson	173,835	200,573	228,160	258,414	291,047	67%
C	Kaufman	146,389	195,107	242,354	306,833	423,277	189%
H	Leon	18,211	19,536	20,603	22,071	23,340	28%
H	Liberty	86,303	97,227	107,618	118,048	128,028	48%
G	Limestone	25,136	26,615	27,817	29,134	30,206	20%
H	Madison	14,753	15,817	16,786	17,872	18,886	28%
B	Montague	20,507	21,260	21,600	21,979	22,223	8%
C	Navarro	52,505	59,556	65,958	74,213	83,221	59%
C	Parker	201,491	260,194	276,979	360,125	472,097	134%
H	Polk	51,870	57,943	62,722	66,796	70,120	35%
C	Rockwall	119,410	160,315	213,619	246,938	291,850	144%
H	San Jacinto	29,610	32,627	34,996	37,614	39,789	34%
C	Tarrant	2,004,609	2,279,113	2,580,325	2,799,127	2,978034	49%
H	Trinity	16,502	17,847	17,981	17,473	18,283	11%
D	Van Zandt	58,455	64,146	68,496	72,817	76,407	31%
H	Walker	71,800	75,243	77,724	80,050	81,859	14%

Region	County	2020	2030	2040	2050	2060	Percent Growth (from 2020 to 2060)
C	Wise	79,882	95,086	110,343	135,797	162,282	103%
G	Young	19,336	20,400	21,166	21,972	22,579	17%

Note: Regions C and H cover most areas in the Trinity Region; and they are the most populated water planning regions in Texas

Consequently, an integrated assessment of linkage between population dynamics and future flood planning is highly recommended for the Trinity Region.

Sea Level Change

Global Mean Sea Level (MSL) has risen by about 0.2 meters (or eight inches) at a rate of 1.7 millimeters per year since reliable record keeping began in 1880 (Church & White, A 20th Century Acceleration in Global Sea-Level Rise, 2006). Research shows that rising sea levels can affect coastal regions in many ways including shoreline erosion, loss of land, tidal flooding, and saltwater intrusion into groundwater (Anthoff, Nicholls, Tol, & Vafeidis, 2006), (Nicholls & Tol, Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century, 2006), (Nicholls & Cazenave, Sea-Level Rise and Its Impact on Coastal Zones, 2010), (Church & White, Sea-Level Rise from the Late 19th to the Early 21st Century, 2011). The contributions to sea level rise come primarily from two factors related to global warming — increases in water mass from melting ice and glaciers, and thermal expansion of seawater (Church & White, A 20th Century Acceleration in Global Sea-Level Rise, 2006) (Nicholls & Cazenave, Sea-Level Rise and Its Impact on Coastal Zones, 2010) (Church & White, Sea-Level Rise from the Late 19th to the Early 21st Century, 2011).

The rapid changes observed in polar regions suggest that the ice sheets melt faster than previously anticipated due to global warming (Masson-Delmotte, et al., 2021) , and many studies show that the sea level is projected to rise another 0.3 to 1.8 meters (one to four feet) by 2100 as global warming continues (Rahmstorf, 2007), (Vermeer & Rahmstorf, 2009), (Jevrejeva, Moore, & Grinsted, 2010), (Nicholls & Cazenave, Sea-Level Rise and Its Impact on Coastal Zones, 2010), (Walsh, et al., 2014). Climate-induced sea level rise will affect a large fraction of the cities located along the coastline by the end of the 21st century (Church, et al., 2013). Meanwhile, high-tide flooding is increasingly common due to years of sea level increases. High tide flooding occurs when tides reach anywhere from 0.53 to 0.61 meters (1.75 to two feet) above the daily average high tide and inundate low-lying streets (NOAA, 2021). Being one of the largest coastal communities in the world, the Houston-Galveston region is highly susceptible to coastal and inland flooding from hurricanes (storm surge and rainfall), high tides, and other extreme storms. Because the Trinity River drains into Galveston Bay, the change of sea level inevitably affects the riverine hydraulics and ecology of the watershed. Thus, the sea level rise near the outlet of the Trinity River must be evaluated by analyzing the

MSL measured at tide gauges to help us understand sea level trends and potential hydrodynamic changes to the Trinity River.

Because sea level rise varies around the globe, relative sea level measured locally provides more insights to engineering practices in coastal resilience and flood mitigation for the study area. Five NOAA tide gauges located along the Gulf Coast and near the Trinity River outlet were identified to provide water elevation records: Sabine Pass (8770570), Galveston Pier 21 (8771450), Galveston Pleasure Pier (8771510), Freeport (8772440), and Freeport (8772447) (*Figure 2.35*). All five gauges have monthly data and have more than 50 years of records available from NOAA (2013a); in particular, the Galveston Pier 21 gauge has the longest time series, data ranging from January of 1904 to September of 2025. *Table 2.24* summarizes location and period of record for each gauge. Available tidal records are referenced to MSL vertical datum.

Figure 2.35: Locations of the Five Selected National Oceanic and Atmospheric Administration Tide Gauges

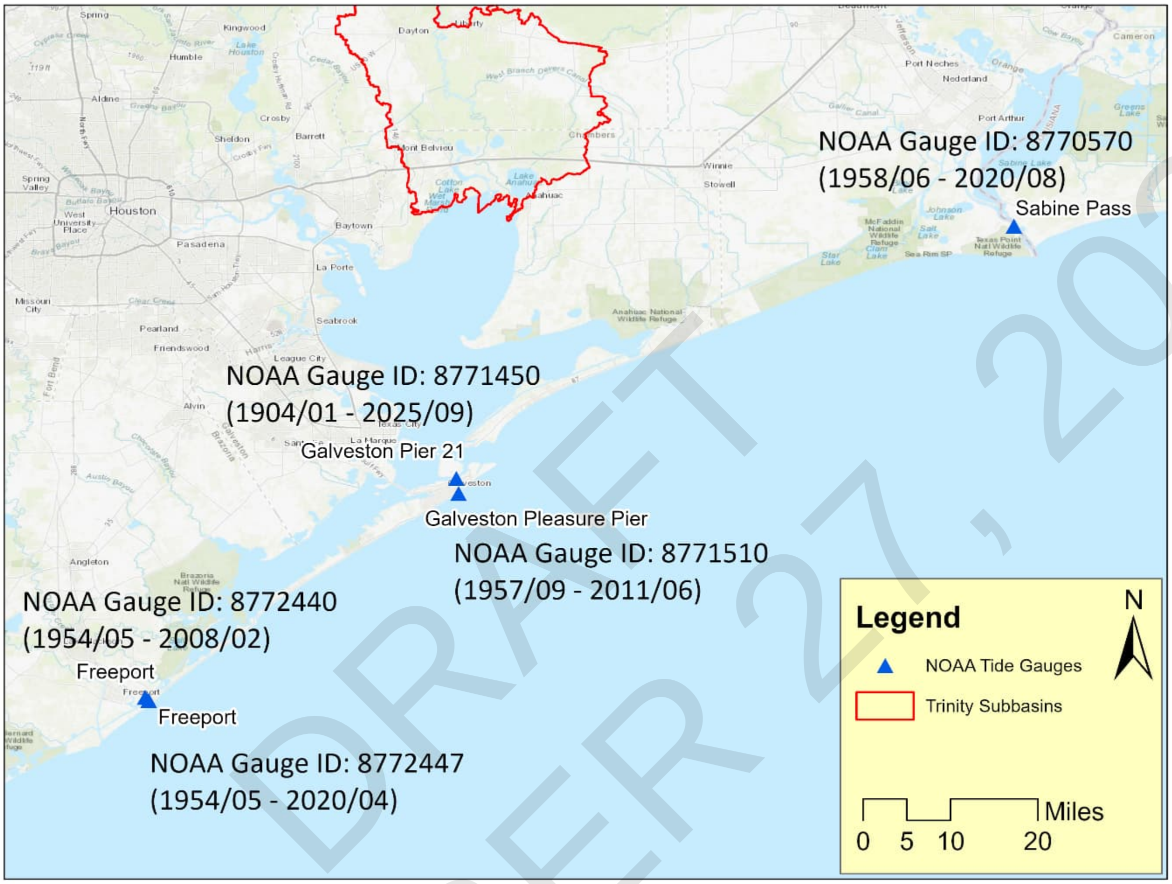


Table 2.24: Tide Gauges Along the Gulf Coast

Gauge ID	Gauge Name	Latitude & Longitude Coordinates	Data Availability Period
8770570	Sabine Pass	29.7284, -93.8701	1958/06 – 2020/08
8771450	Galveston Pier 21	29.3100, -94.7933	1904/01 – 2025/09
8771510	Galveston Pleasure Pier	29.2853, -94.7894	1957/09 – 2011/06
8772440	Freeport	28.9483, -95.3083	1954/05 – 2008/02
8772447	Freeport	28.9433, -95.3025	1954/05 – 2020/04

To examine the trend of MSL along the Galveston Gulf Coast, historical data from the five selected tide gauges is plotted together with a fitted regression line as shown in *Figure 2.36*. All five gauges show a similar rise in MSL trend between 1980 and 2021. The slope (0.0068) of the regression equation implies the rate (6.8 millimeter per year) of the relative sea level rise for these five locations. As previously noted, the Galveston Pier 21 gauge has the longest time series data and is located closest to the outlet of the Trinity River Estuary. Linear regression is used to simply demonstrate an average change rate of the sea level to date based on available data. The linear trendline of the Galveston Pier 21 gauge is similar to the other four nearby tide gauges, as shown in *Figure 2.37*.

The trend analysis shows that the MSL at the Galveston Pier 21 gauge has risen 0.113 meter (0.371 feet) between 1904 and 2025. If the trend continues at the current rate (6.6 millimeters per year), the MSL at the Galveston Pier 21 gauge in 2060 will result in an additional MSL increase of 0.23 meter (0.754 feet), or a total increase of 0.344 meter (1.129 feet) since 1904.

Figure 2.36: Plot of the Mean Sea Level at the Five Tide Gauges

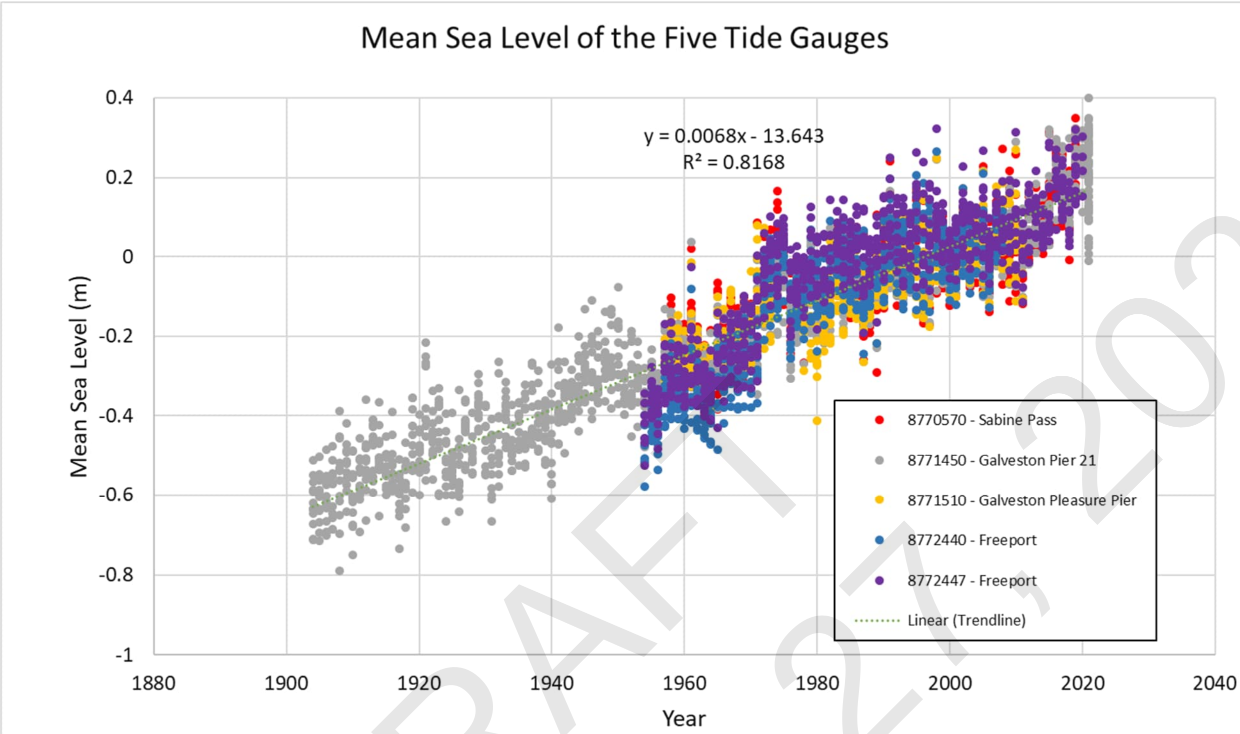
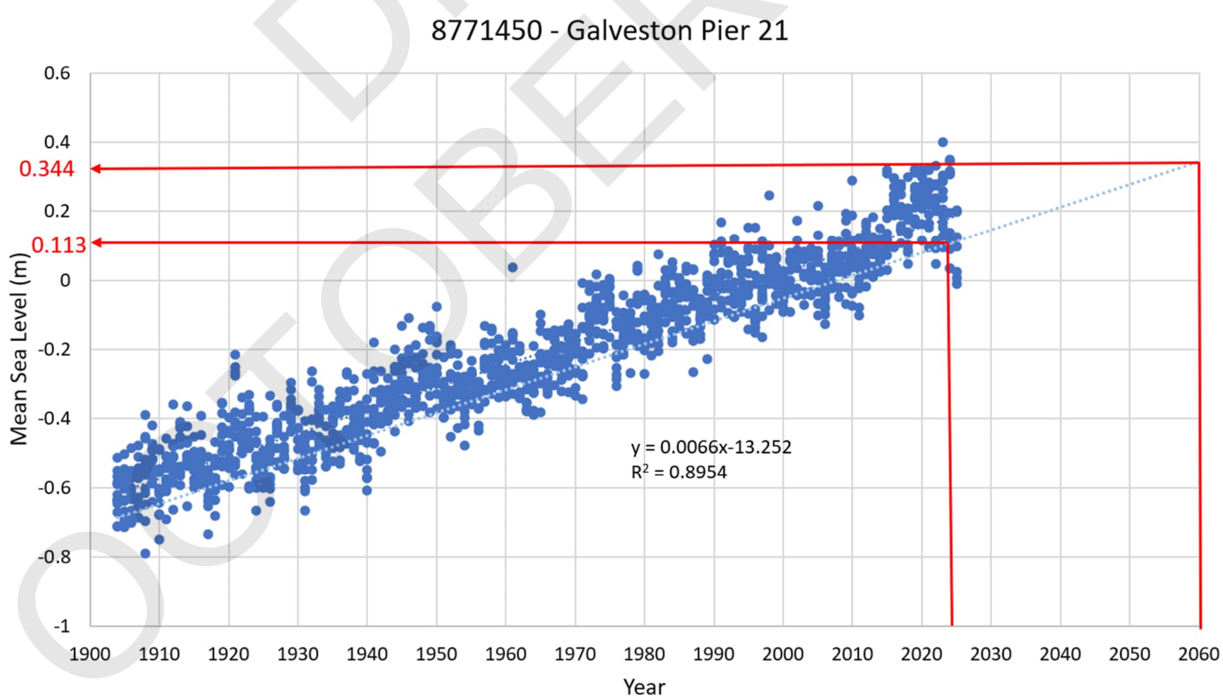


Figure 2.37: Plot of the Mean Sea Level at Gauge: 8771450, Galveston Pier 21, TX



To account for the uncertainty from the expected ice melting volume and ocean temperatures, researchers and engineers from the NOAA and USACE have made predictions based on ranges from low to high (Huber & White, 2017). The governing equations for calculating the sea level change are shown below:

Global Sea Level Change: $E(t) = 0.0017t + bt^2$

In the above equation, *t* refers to the number of years starting in 1992 (NOAA considers 1992 as the center year of the NOAA National Tidal Datum Epoch (NTDE) ranging from 1983–2001), 0.0017 is the global sea level rise rate (1.7 millimeters per year) and *b* is a constant parameter.

Relative (Regional) Sea Level Change: $E(t) = Mt + bt^2$

In the above equation, *M* is the combination of the global sea level rise rate (1.7 millimeters per year) plus the local Vertical Land Movement (VLM). *M* can be obtained from NOAA's Sea Level trends website (NOAA, 2022) and NOAA Technical Report NOS CO-OPS 65 (Zervas, Gill, & Sweet, 2013).

To visualize different sea level scenarios for any NOAA tide gauge, the data from an online Sea Level Change Curve Calculator (USACE, 2022) can be used. This online tool was developed under the USACE Comprehensive Evaluation of Projects with respect to Sea Level Change in support of vulnerability assessments for USACE coastal projects. The USACE Sea Level Change Curve Calculator includes the datasets from four studies, namely: the NOAA Technical Report OAR CPO-1 titled Global Sea Level Rise Scenarios for the United States National Climate Assessment (Parris, et al., 2012), the USACE Incorporating Sea Level Changes in Civil Works Programs (Department of the Army, 2013), the Region Sea Level Scenarios for Coastal Risk Management Report by the Coastal Assessment Regional Scenario Working (Hall, et al., 2016), and the United States Global Change Research Program 2017 (Wuebbles, et al., 2017). Different parameters of *b* were utilized to represent different sea level scenarios among the four studies.

The NOAA 2017's extreme scenario forecasts a sea level rise of 1.11 meters (3.642 feet) in 2050. Under the extreme scenario, an increase of 0.78 meters (2.560 feet) sea level would be expected to occur from 2020 to 2050. The delta values of the estimated sea levels between 2020 to 2050 (*Table 2.25*) from various scenarios indicate that the estimated sea level in 2050 range from 0.19 meters to 0.78 meters.

NOAA released an updated tool – the NOAA Sea Level Rise Calculator in 2022, which integrates the findings of the 2022 NOAA National Ocean Service Technical Report, Global and Regional Sea Level Rise Scenarios for the United States (Sweet et al., 2022). This study incorporates the latest advances in satellite altimetry, ice-sheet mass balance measurements, global climate models (CMIP6), and refined regional and vertical land motion estimates. Furthermore, this study redefines the baseline approach (2005-2020) and updates scenario categories (Low, Intermediate-Low, Intermediate, Intermediate-High, and High) to better reflect the accelerated pace of global sea-level rise. The report provides revised global mean and regional relative sea level projections through 2150, offering scenario-based data for both probabilistic and deterministic applications. The calculator can be used to visualize and compare different sea level rise scenarios at specific NOAA tide gauges.

Figure 2.38 through *Figure 2.42* show the ranges of estimated relative sea level change at the Galveston Pier 21 gauge from (Parris, et al., 2012), (Huber & White, 2017), (Department of the Army, 2013), and (Hall, et al., 2016) and (Sweet et al., 2022) for the period of 1992–2060 (Note: (Huber & White, 2017) only shows a ranger from 2000 to 2050). As summarized in *Table 2.25*, three studies unanimously show the lowest projected sea level is approximately 0.43 meter (1.41 feet) by 2060 (Parris, et al., 2012), (Department of the Army, 2013), (Hall, et al., 2016), and their results are consistent with the historical records by assuming that the sea level rises at the current rate of 6.6 millimeters per year. In other words, the lowest sea level rise scenarios conducted by (Parris, et al., 2012), (Department of the Army, 2013), (Hall, et al., 2016), all produce a rate (6.3 millimeters per year) similar to the average rise rate (6.6 millimeters per year) from 1904 to 2021 at Galveston Pier 21.

However, the NOAA 2022 study reports a slightly higher sea level rise value (0.6m) (1.969ft) for the lowest scenario by 2060 due to the inclusion of updated global climate projections and recognition of accelerating trends in ocean thermal expansion and ice-sheet loss. The updated NOAA scenarios account for both global mean sea-level acceleration and local subsidence at Galveston leading to higher projected values compared to the earlier models that assumed a near linear trend.

Figure 2.38: Estimated Relative Sea Level Change Projections – Gauge: 8771450, Galveston Pier 21, TX (Parris, et al., 2012)

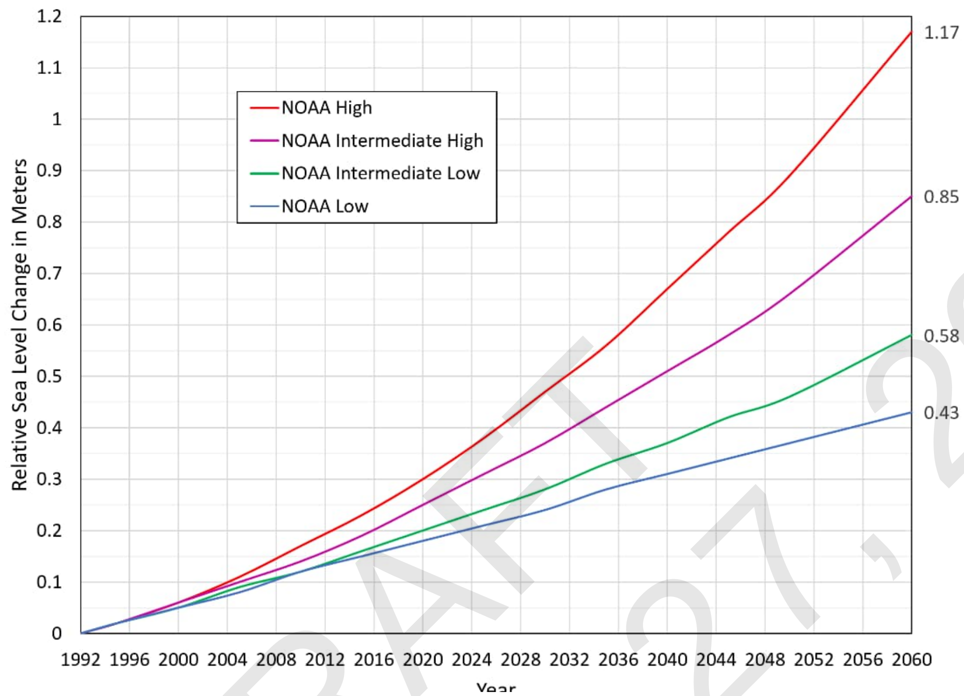


Figure 2.39: Estimated Relative Sea Level Change Projections – Gauge: 8771450, Galveston Pier 21, TX (Department of the Army, 2013)

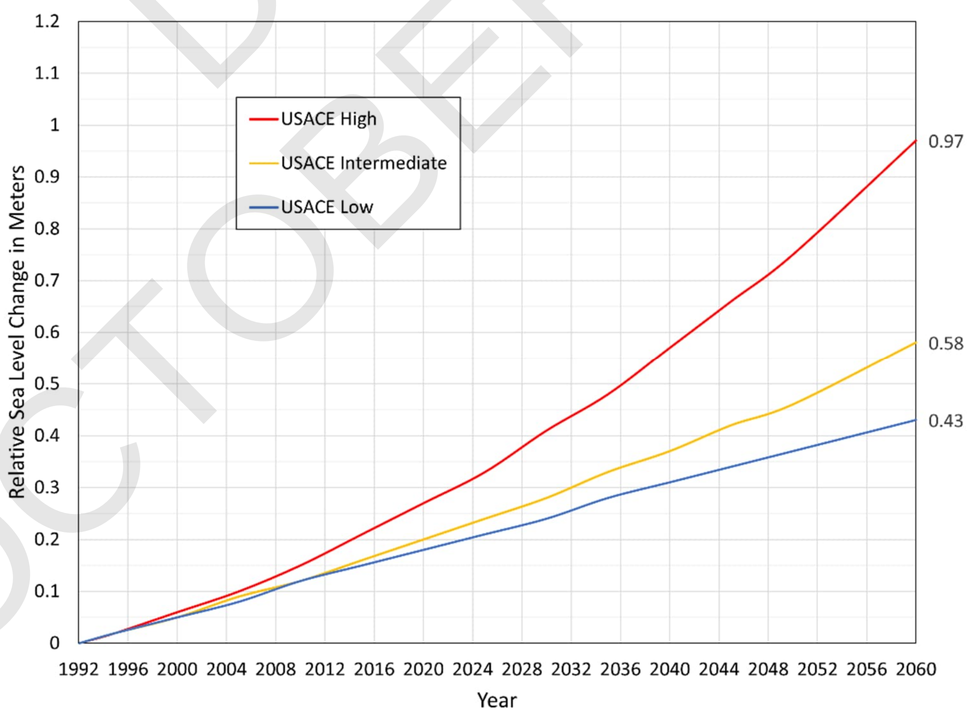


Figure 2.40: Estimated Relative Sea Level Change Projections – Gauge: 8771450, Galveston Pier 21, TX (Hall, et al., 2016)

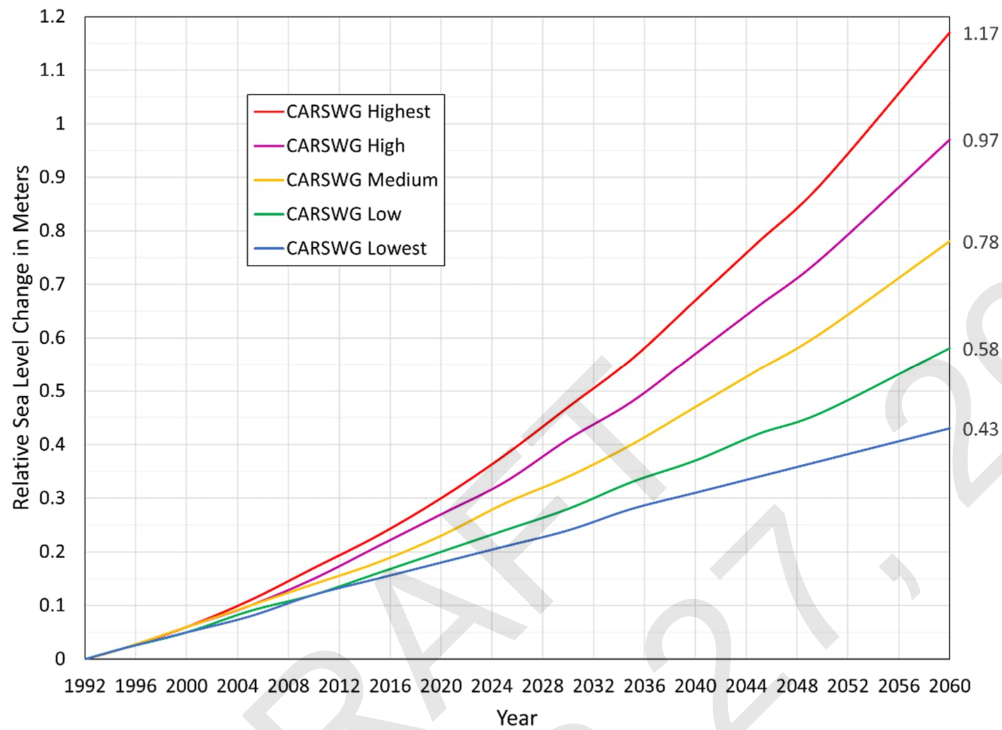


Figure 2.41: Estimated Relative Sea Level Change Projections - Gauge: 8771450, Galveston Pier 21, TX (Huber & White, 2017)

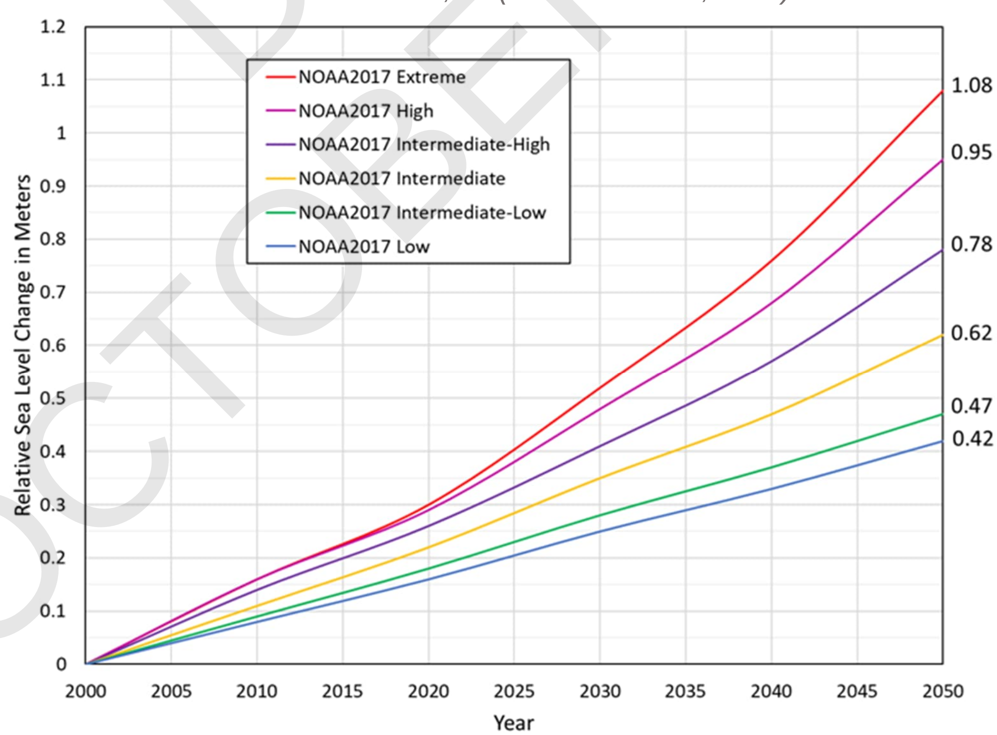


Figure 2.42: Estimated Relative Sea Level Change Projections - Gauge: 8771450, Galveston Pier 21, TX (Huber & White, 2017)

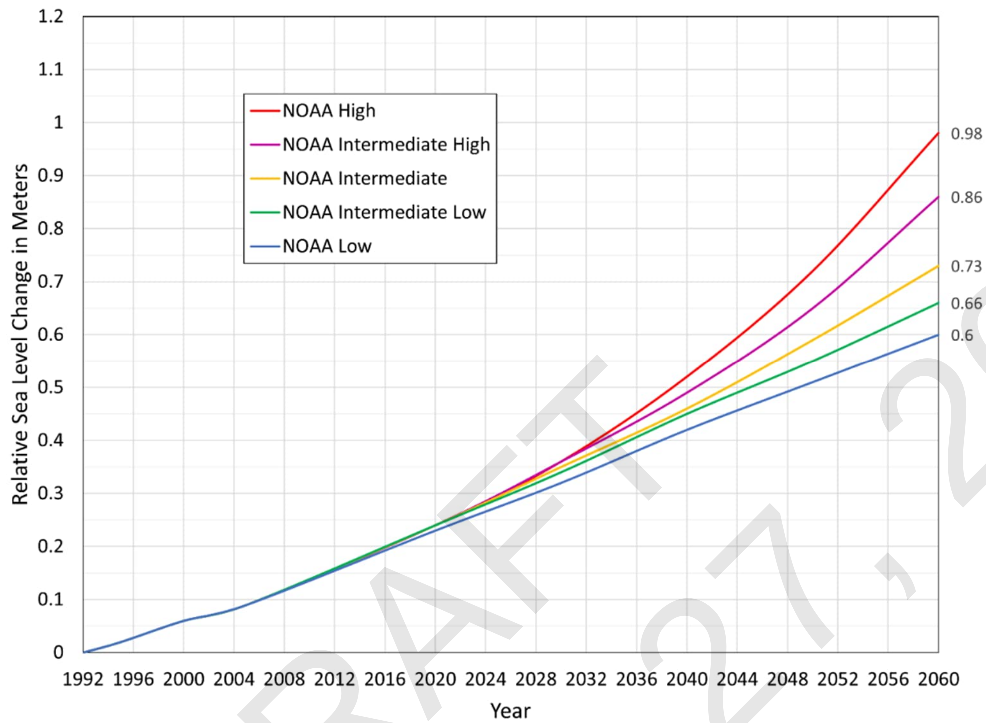


Table 2.25: Estimated Relative Sea Level in Meters for 2020, 2050, and 2060 from Various Studies

Study	2020		2050		2060		Delta (Δ) Between 2020 and 2060	
	Lowest (m)	Highest (m)	Lowest (m)	Highest (m)	Lowest (m)	Highest (m)	Lowest (Δ)	Highest (Δ)
NOAA 2012	0.18	0.30	0.37	0.89	0.43	1.17	0.25	0.87
USACE 2013	0.18	0.27	0.37	0.75	0.43	0.97	0.25	0.70
CARSWG 2016	0.18	0.30	0.37	0.89	0.43	1.17	0.25	0.87
NOAA 2017*	0.16	0.30	0.42	1.08	N/A	N/A	N/A	N/A
NOAA 2022	0.23	0.24	0.51	0.72	0.6	0.98	0.37	0.74

**Note:* (Huber & White, 2017) *projects relative sea level changes from 2000 and other three studies* (Parris, et al., 2012)*;* (Department of the Army, 2013)*; and* (Hall, et al., 2016) *project relative sea level changes from 1992.*

More recent statewide modeling efforts provide additional context by using the latest global projections. The 2025 Fathom report on future floodplains uses the IPCC's Regional Sixth Assessment Report (AR6) sea level projections, which represent a synthesis of numerous models simulating the primary drivers of sea level rise. According to that study, a 2°C global warming level by 2060 is associated with a projected sea level rise of approximately 0.2 meters (with a likely range of 0.17-0.26 m) relative to a 2005 baseline. This projection is roughly equivalent to the Intermediate-Low scenarios from the 2017 and 2022 NOAA reports. The Fathom study modeled three future climate scenarios for 2060 (representing the 17th, 50th, and 83rd percentiles of possible outcomes), which show a sea level rise along the Texas coast ranging from approximately 0.2 m to 0.7 m.

The RFPG performed a GIS exercise applying increased sea level from both low and high scenarios to the study area, as a demonstration of the potential land that would be inundated. *Figure 2.43* shows the flooded area (blue) in the Trinity Region caused by a rise of 0.25 meters (Lowest Scenarios from (Parris, et al., 2012), (Department of the Army, 2013), and (Hall, et al., 2016) studies) and 0.87 meters (Highest Scenario from(Hall, et al., 2016) respectively by 2060. While the additional area inundated by sea level rise is limited to the outlet of the Trinity River, the impacts from sea level rise on the Trinity Region cannot be neglected. For more information, Sea Level Rise Viewer from NOAA (https://coast.noaa.gov/slr/) can be utilized to visualize the sea level rise along with potential coastal flooding impact areas and relative depths. The RFPG recommends continued monitoring of the local sea level through the tide gauges and/or buoys along the coastline for future flood mitigation and planning.

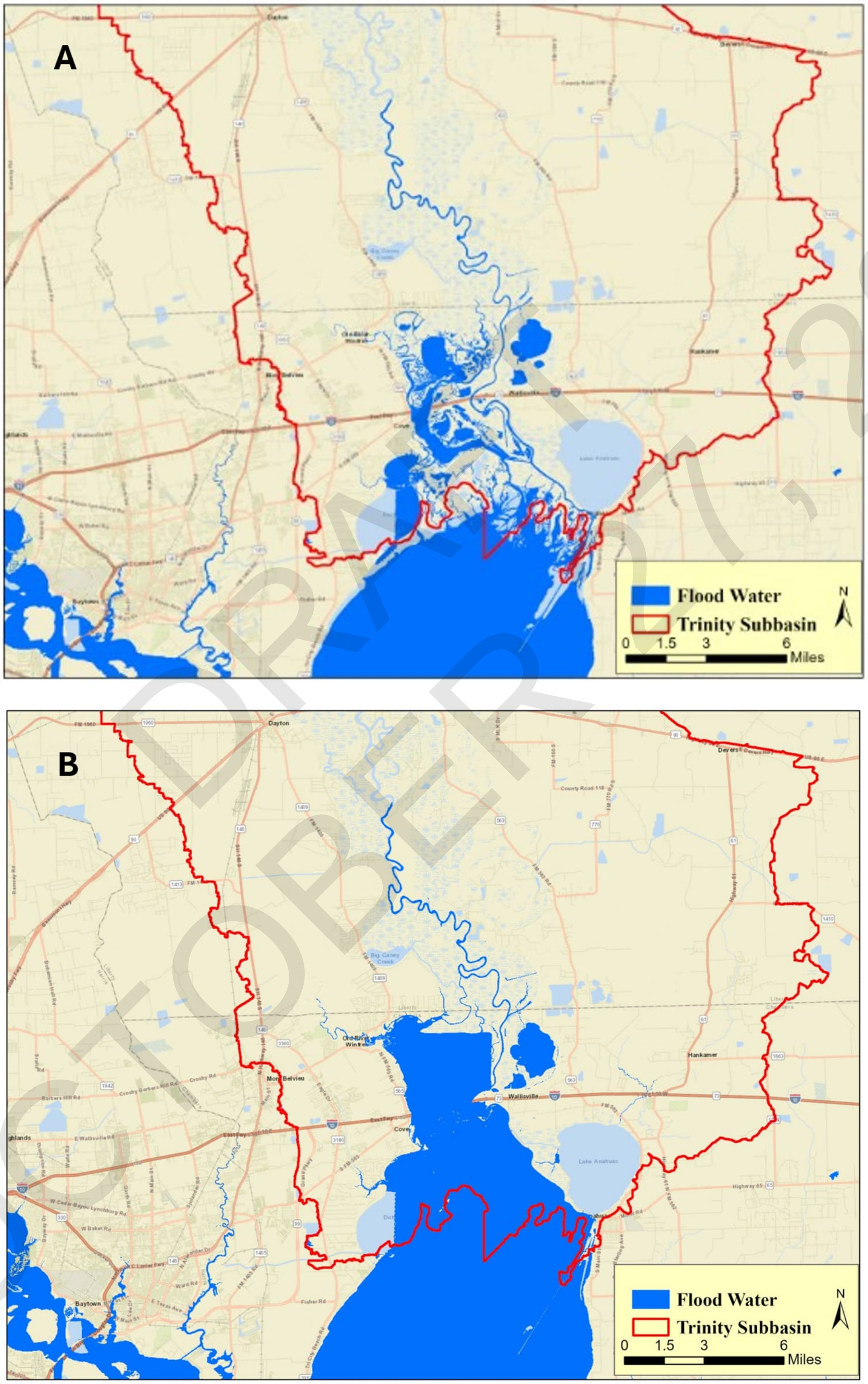
Land Subsidence

Land subsidence, as a sudden sinking or a gradual settling of the Earth's surface on account of the subsurface movement of earth materials, is regarded as a worldwide problem leading to numerous adverse impacts on infrastructure and the environment (Galloway, Jones, & Ingebritsen, Land Subsidence in the United States, 1999). The natural and human-induced causes of land subsidence include tectonic motion; aquifer-system compaction associated with groundwater, soil, and gas withdrawals; underground mining; etc. ((Galloway, Jones, & Ingebritsen, Land Subsidence in the United States, 1999); (Xue, Zhang, Ye, Wu, & Li, 2005); (Braun & Ramage, 2020); (Herrera-García, et al., 2021)). During the past century, land subsidence caused by the groundwater depletion occurred at approximately 200 locations in 34 countries (Herrera-García, et al., 2021).

In the United States, more than 17,000 square miles in 45 states have been directly affected by land subsidence (Galloway, Jones, & Ingebritsen, Land Subsidence in the United States, 1999).

Land subsidence is of particular concern, especially in flat coastal areas such as the Houston-Galveston Region, since land subsidence in conjunction with the sea level rise would exacerbate the severity of flooding in the neighboring watersheds (Galloway & Coplin, Managing Coastal Subsidence, 1999).

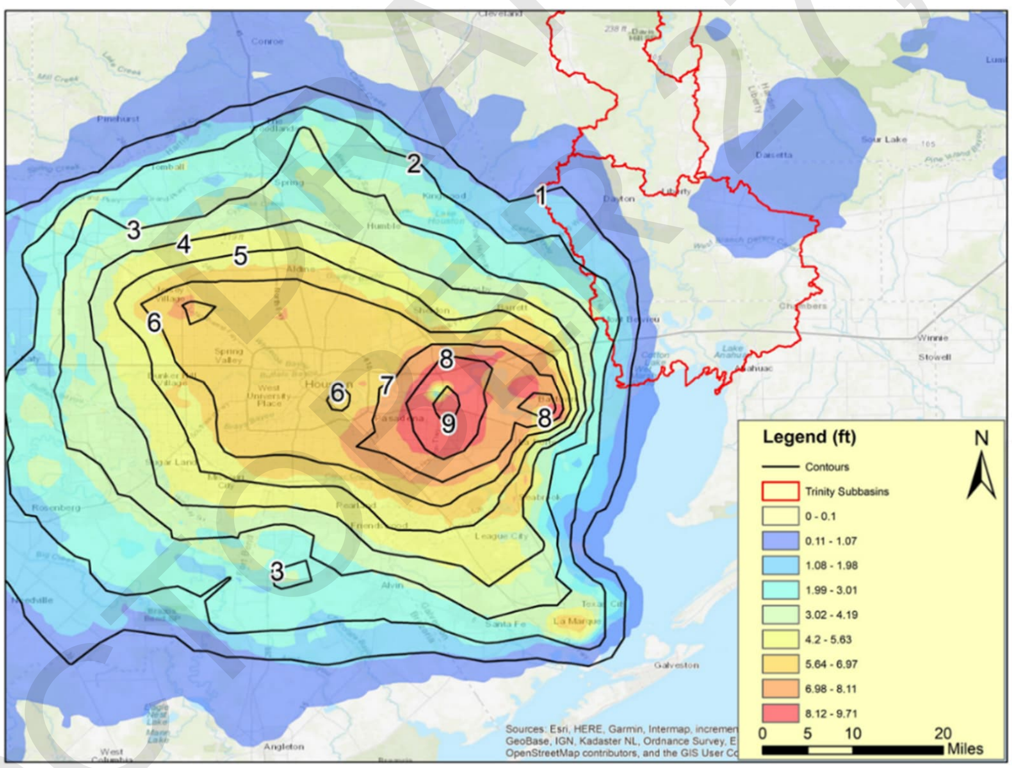
Figure 2.43: Potentially Impacted Area in the Trinity Region Caused by the Increase of (A) 0.25 Meter Sea Level Rise, (B) 0.87 Meter Sea Level Rise by 2060



According to a report produced by the USGS, land subsidence in the Houston-Galveston region continues to occur throughout the 20th century (Stork & Sneed, 2002). Two additional studies by (Kasmarek & Johnson, 2013) and (Liu, Li, Fasullo, & Galloway, 2020) have been completed for investigating the land subsidence in the Houston-Galveston region. Given that the downstream portion of the Trinity River is close to the Houston region, the expansion of land subsidence impacts the H&H of the watershed. Thus, potential impact needs to be understood for the area subject to land subsidence in the Trinity Region.

(Kasmarek & Johnson, 2013) simulated and measured land subsidence between 1900s to 2000 for the Houston-Galveston region. To better illustrate the land subsidence conditions in the Trinity Region, the boundary of the Trinity River is overlaid with the simulated land subsidence data as shown in *Figure 2.44*. The highest land subsidence (9.7 feet) areas can be found in southeastern Harris County.

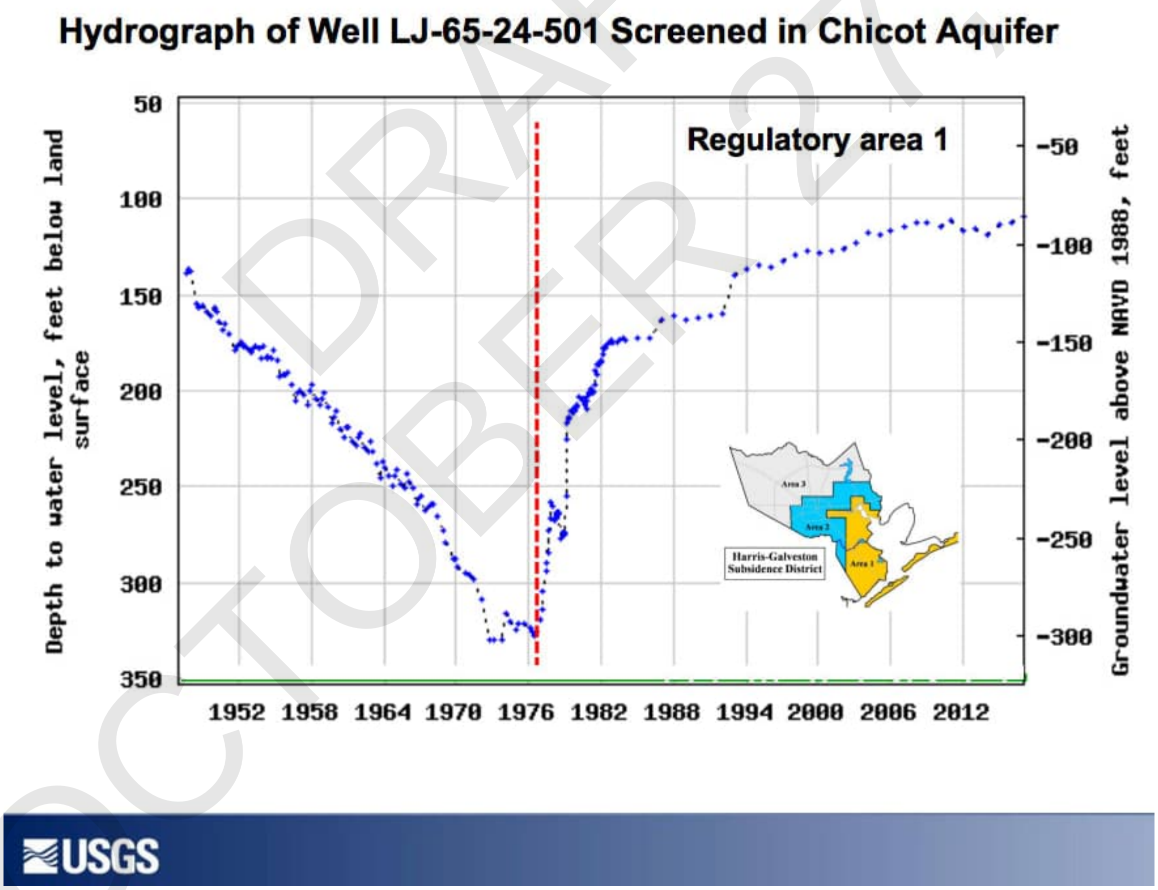
Figure 2.44: Land Subsidence Simulated by the Houston Area Groundwater Model
(Liu, Li, Fasullo, & Galloway, 2020)



Since the 1970s, several subsidence regulatory entities (Harris-Galveston Coastal Subsidence District, Fort Bend Subsidence District, Lone Star Groundwater Conservation District, and Brazoria County Groundwater Conservation District) have established various policies to manage groundwater pumping activities and enforce groundwater regulations. The well monitoring data from USGS shows that groundwater levels in the region rose significantly once subsidence districts were established, thereby mitigating subsidence issues in the region (Texas Living Water Project, 2017).

Figure 2.44 shows that when the Harris-Galveston Coastal Subsidence District was created around 1976 (red line), groundwater levels in the Chicot Aquifer rose substantially and have remained relatively constant since 2006, suggesting that the rate of land subsidence should not change significantly compared to the current condition. In other words, the future impact of land subsidence to the Trinity Region in 2060 is anticipated to remain the same as 2020 (*Figure 2.45*). The current regional flood plan did not consider land subsidence in determining future flood risk due to its insignificant changes as observed and projected. While the area impacted by land subsidence is considered minimal for the Trinity Region, the Trinity RFPG supports long-term monitoring and management of the groundwater resources for future planning cycles.

Figure 2.45: Chicot Aquifer Hydrograph



Source: USGS Presentation: Connecting Groundwater level altitudes, Compaction and Growth

Recent flood mapping efforts by the Texas Water Development Board have incorporated updated land subsidence data to better reflect future conditions in the Trinity Region. Specifically, two complementary datasets have been integrated into the modeling workflow: the 2022 NOAA vertical land-motion dataset and the GPS measurements from the Harris-Galveston Subsidence District collected between 2018 and 2022. Using ordinary kriging these data points have been interpolated into a continuous 30-meter resolution raster surface representing subsidence rates for the baseline year 2022. To project the subsidence through 2060, a linear accumulation factor of 38 is applied and the resulting surface has been resampled to a finer 3-meter grid resolution. This high-resolution subsidence model provides an improved representation of elevation changes due to land subsidence and can be integrated into the Trinity regional flood planning analysis to enhance the accuracy of future flood risk assessments.

Changes in Floodplain

Future rainfall patterns are also considered regarding potential impacts to the floodplains in this plan. To aid the regional planning groups, the Office of the Texas State Climatologist has provided TWDB with guidance on how to incorporate future rainfall in its April 16, 2021, report, titled “Climate Change Recommendations for Regional Flood Planning.” (Nielsen-Gammon & Jorgensen, 2021) The report states that 24-hour, 100-year rainfall amounts increased by approximately 15 percent between 1960 and 2020. The climatologist couple historic rainfall data with results from climate models to develop a relationship between extreme rainfall amounts and future increases in global temperature. Percent increase in future precipitation has been developed for both urbanized and rural watershed conditions. Due to the uncertainty of predicting weather patterns for extreme rainfall events, the climatologist provides a minimum and maximum range for estimating future rainfall increases. The climatologist has found more uncertainty when analyzing rural and large river catchments due to future decreases in soil moisture. This uncertainty results in the climatologist developing a range of future rainfall increases as shown in *Table 2.26*.

Table 2.26: Trinity Region Range of Potential Future Rainfall Increase 2021-2060

Location	Range - Minimum	Range - Maximum	Range - Minimum	Range - Maximum
	2021		2050 - 2060	
Urban Areas	5%	12%	12%	20%
Rural Areas/River	-2%	5%	-5%	10%

Sedimentation and Major Geomorphic Changes

Anticipated Impacts of Sedimentation in Flood Control Structures

Flood control structures prevent floodwaters from inundating vast amounts of land and property. Hydraulic works (levees, flood walls, dams, river diversions, etc.) represent the single, most important form of human adaptation to the flood hazard. In the Trinity Region, the most prominent flood control structures at a regional scale are levees, dams, and their associated reservoirs. In general, reservoirs are the flood control facilities that are most susceptible to the impacts of sediment deposition over time within this watershed. While sedimentation in reservoirs has a directly measurable impact and is typically accounted for in the design, the plan needs to recognize the reduction in conveyance capacities due to sedimentation in channels, and floodplain fringes, and ultimately bays and estuaries.

Historically, reservoirs have been designed with relatively large storage capacities to offset sediment deposition and achieve the desired reservoir life. In general, reservoir design includes a sedimentation pool, commonly known as "dead storage", which is a portion of its storage capacity that is essentially set aside for sediment deposition during the design life of the structure. It could be argued that the operation of the reservoir for authorized purposes, such as municipal water supply, flood control, hydropower generation, and recreation, is not significantly impacted if sediment accumulation does not exceed the dead storage capacity. However, large flood events can carry relatively large loads of sediment that can be deposited in portions of the reservoir that are outside of the designated dead storage areas. Thus, provisions need to be taken for sediment management to achieve a sustainable long-term use of the facility.

Within the framework of this regional flood plan for the Trinity Region, the loss of flood storage is considered the primary impact of sedimentation in terms of increasing future flood risk. Reservoir flood operations can be severely impacted by the time 50 percent of the sedimentation volume has been filled with sediment, but operational issues may arise even when smaller percentages of flood storage are lost. The intent of this section is to provide a high-level assessment of the expected loss of flood storage capacity due to sedimentation in the region's flood control facilities and determine if these losses would result in a significant increase to flooding risks. Data for this assessment is obtained from Natural Resources Conservation Service (NRCS) historical documents, TWDB volumetric and sedimentation surveys, and recent NRCS basis of design reports. The assessment is subdivided into two main groups: major reservoirs and NRCS floodwater retarding structures.

It is recognized, however, that sediment transport within a river system is a complex phenomenon with substantial geographic and temporal variability. The assessment and information provided in this section are based on a series of simplifying assumptions and are only intended to serve as a general indicator of the potential impacts of sedimentation in future flood risk at a regional scale within a 30-year planning horizon.

Major Reservoirs Assessment

The TWDB recognizes 34 major lakes and reservoirs within the Trinity Region. A body of water that contains at least 5,000 acre-feet of storage capacity at its normal operating level is considered a major reservoir, according to TWDB. Some of the operators of these reservoirs include the USACE, TRWD, Trinity River Authority (TRA), and local municipalities. These facilities may serve multiple purposes including municipal water supply, irrigation, flood control, and/or recreation. Not all reservoirs are designed with flood control capacity. Six of these reservoirs were selected for this high-level assessment as a representative sample for the watershed (see *Figure 2.46*).

Design and Operation of Multipurpose Reservoirs

The design and operation of reservoirs includes allocating volumes of reservoir storage (typically referred to as "pools") for each purpose. There are three broad categories of pools (: flood control, conservation (also referred to as multi-purpose), and sediment (also referred to as inactive or dead storage)as depicted in *Figure 2.47*. Each reservoir is designed with specific capacity limits for each pool.

Figure 2.46: Locations of Major Reservoirs Analyzed

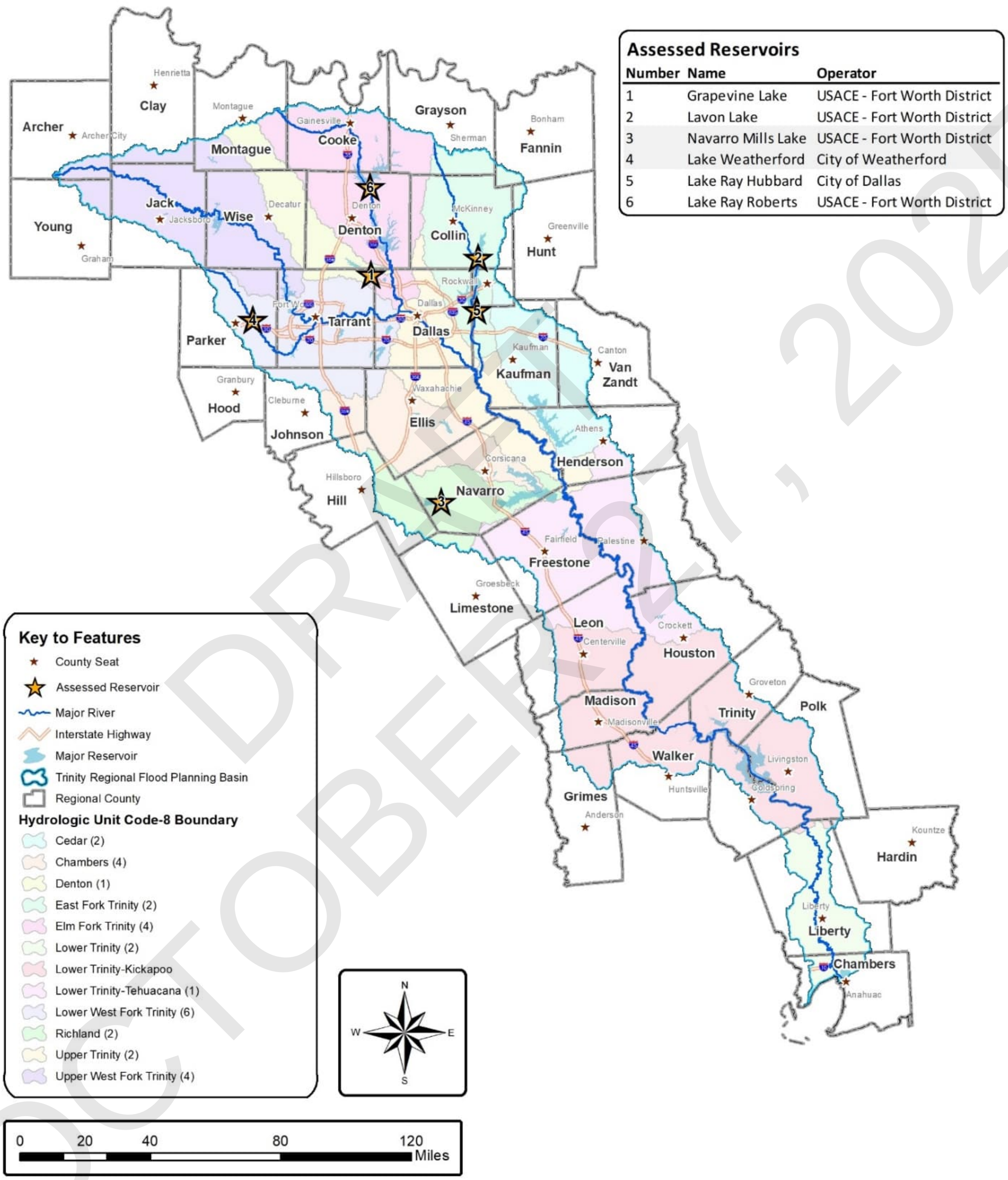
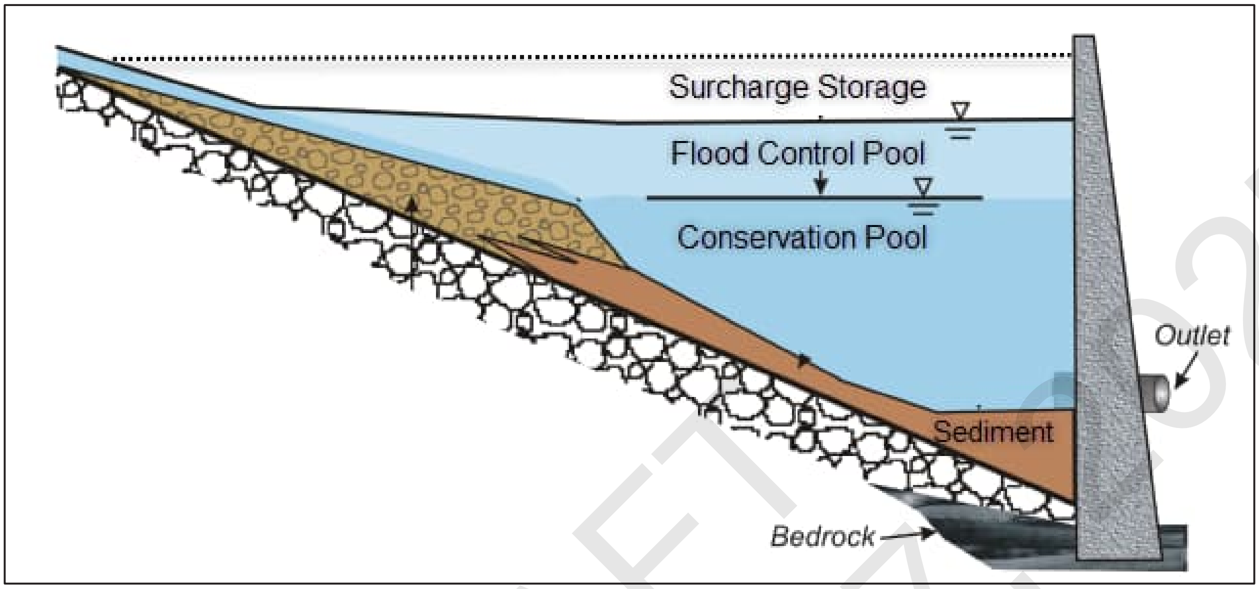


Figure 2.47: Typical Multipurpose Reservoir Design



Source: Modified from https://acwi.gov/sos/faqs_2017-05-30.pdf

The conservation pool is generally the largest layer, with the greatest capacity. The top of the conservation pool is typically varied based on seasonal patterns. Reservoir operators attempt to maintain this pool at the highest possible level. On top of the conservation pool is the zone reserved for flood control, which is also influenced by seasonal variations. Major reservoirs that provide flood control benefits are designed to capture upstream runoff, store it, and then release it at a controlled rate to minimize the flooding downstream.

Sediment Deposition

The amount of sediment accumulation in a reservoir depends on the sediment yield to the reservoir and the trap efficiency. Trap efficiency is the amount (percentage) of the sediment delivered to a reservoir that remains in it. How the accumulated sediment is distributed within the reservoir pools depends on the character of the inflowing sediment, the operation of the reservoir, detention time, and other factors. The incoming sediment that is deposited under water is called “submerged sediment”. The sediment deposited above the conservation pool elevation is referred to as “aerated sediment” (United States Soil Conservation Service, 1983).

The distinction between submerged and aerated sediment is important in determining the capacity that each will displace within a reservoir. The high-level assessment presented in the following sections assumes that 80 percent of the incoming sediment will be submerged and 20 percent aerated. This assumption is based on guidelines established on the Soil Conservation Service (SCS) National Engineering Handbook, Section 3 (United States Soil Conservation Service, 1983) and a study performed by (Strand & Pemberton, 1987) for 11 reservoirs in the US

Great Plains region. In this study, the reported percent of aerated sediment deposited in the flood control pool for Lavon Lake is approximately 20 percent, and this same value has been adopted for all other reservoirs included in this assessment. Due to the complexity in determining the trap efficiency for each reservoir, a conservative assumption of 100 percent trap efficiency was has been adopted for the purposes of this assessment. A 100 percent trap efficiency indicates that all sediment delivered to a given reservoir remains in it, and no sedimentation management practices are being implemented.

Flood Control Capacity Loss Assessment

The TWDB in conjunction with the USACE-Fort Worth District, TRWD, and TRA, has developed Volumetric and Sedimentation Surveys for several major reservoirs within the Trinity Region (Texas Water Development Board, 1993-2020). Six reservoirs are identified as a representative sample of all the major reservoirs in the watershed for this high-level assessment (see *Figure 2.46*).

In the sedimentation surveys, a range of values is provided for the annual sedimentation rates of each reservoir. The reported high and low annual sedimentation rate estimates are reflected in *Table 2.27*. These sedimentation rates are generally determined based on a comparison of storage capacity from volumetric surveys over time. In addition to the TWDB Volumetric and Sedimentation Surveys, the TWDB's Water Data for Texas website and the USACE – Fort Worth District website is used to collect pertinent reservoir data. The flood control storage volume is not provided as part of the TWDB surveys; however, those volumes are collected from multiple sources including data sheets from the USACE – Fort Worth District website (USACE, 2021), interpolation of rating curves from TRWD, and original reservoir/dam design documents from Freese and Nichols, Inc. (FNI).

The objective of this assessment is to estimate the potential loss of flood control storage capacity for the selected reservoirs over a 30-year planning horizon. Sediment accumulation is calculated from the year of the latest volumetric survey for each reservoir until year 2053. The percent of reservoir capacity lost from the conservation and flood pools by year 2053 is determined using both the high and low annual sedimentation rates. This calculation assumes that the annual sedimentation rate remains constant over time and that, as stated in the previous section, 80 percent of the annual sediment load is deposited in the conservation pool and 20 percent in the flood control pool. A conservative 100 percent trap efficiency assumption is adopted for this assessment. This assessment also assumes that the conservation storage includes any additional volume designated as dead pool storage.

Table 2.27: Estimate of Flood Control Storage Capacity Remaining by 2053 – Representative Reservoirs

Reservoir Name	Reservoir Operator	Drainage Area (square miles)	Conservation Storage (acre-feet)	Flood Control Storage (acre-feet)	Annual Sedimentation Rate (acre-feet/year)		Remaining Flood Control Capacity by 2053 (%)	
					Low	High	Low	High
Lavon Lake	USACE – Fort Worth District	770	409,360	338,840	1,212	1,310	97.1%	96.9%
Lake Ray Roberts	USACE – Fort Worth District	692	788,490	276,110	180	483	99.4%	98.5%
Navarro Mills Lake	USACE – Fort Worth District	320	49,827	149,403	124	124	99.3%	99.3%
Lake Weatherford	City of Weatherford	109	17,812	11,188	37	37	97.1%	97.1%
Grapevine Lake	USACE – Fort Worth District	695	163,064	235,136	392	426	98.6%	98.5%
Lake Ray Hubbard	City of Dallas	1,074	439,559	44,224	719	1,097	88.0%	81.6%

A summary of analyzed results is presented in *Table 2.27* and *Figure 2.48*. Detailed calculations are provided in *Table 2.28*. Analyzed results suggest that, overall, sedimentation will have a minor impact in the flood control function of the major reservoirs in the Trinity Region, as nearly all reservoirs resulted in over 90 percent of their flood control storage capacity is still available by the end of the 30-year planning horizon.

Changes to Sediment Dynamics and Culvert Sedimentation

Sediment transport is a fundamental function of stream systems. However, changes in sediment dynamics can affect flood risk. These changes are often interrelated with hydrologic changes, the presence of man-made structures, or local disturbances to channel geomorphology. Upstream channel change/erosion can account for as much as 90 percent of sediment yield volumes. When sediment yields increase, the resulting excess sediment typically has one of three fates:

1. Sediment can be redeposited downstream within the channel or floodplain. This reduces flood capacity in locations where the stream no longer has the sediment transport capacity to move the sediment through the system. This can happen in locations where the channel has become overly wide as a result of historic channel downcutting and widening.
2. Sediment can be transported and stored within reservoirs or retention/detention ponds. This can reduce flood storage if not properly addressed by maintenance (as discussed in previous sections). This then becomes a maintenance responsibility for the owner of the reservoir.
3. Sediment is effectively transported out of the watershed over time.

Sedimentation within culverts or stormwater infrastructure is also a common source of increased local flood risk. Culvert designs are typically based on maximum expected flood events. However, culvert designs have traditionally not considered lower-level flood events or sediment transport. As such, many culverts are oversized for more frequent storm events. Flows entering culverts spread out laterally, increasing the channel width and decreasing the channel depth. This reduces the stream power through the culvert. The result is a loss in sediment transport capacity and deposition within the culvert. As deposition continues, culverts lose capacity. This can cause increased flood risks as water stacks up behind filled in culverts and road crossings. This phenomenon is often not accounted for in flood risk analysis.

The two primary solutions to local sedimentation at culverts and road crossings include: ongoing monitoring and maintenance by the owner of the culvert to remove sediment deposits and considering sediment transport and stream geomorphology during culvert design.

One example of culverts that accounts for sediment transport is tiered culverts or staged culverts. These have shown to be considerably more effective at reducing sedimentation, while still maintaining flood capacity, than the traditional practice of oversizing culverts. A tiered culvert set-up has a primary culvert that accommodates more frequent flow events and maintains the stream channels width-depth ratio and sediment transport capacity. Adjacent culverts are placed at higher flow elevations and become activated during larger flood events. This allows flood capacity to be maintained while reducing sedimentation within culverts. An example of a staged culvert is shown in *Figure 2.48*.

Figure 2.48 Staged or Tiered Culvert Design Used in North Texas with Multiple Culvert Sizes and Flow Elevations

Source: David Rivera, Freese & Nichols

Natural Resources Conservation Service Floodwater Retarding Structures

The NRCS, formerly known as the SCS, has a long history of designing and building dams and reservoirs with the primary purpose of serving rural/agricultural areas. Based on a combination of data from the (USACE, 2024) and the Texas State Soil and Water Conservation Board's (TSSWCB) Local Dams Inventory (Texas State Soil and Water Conservation Board, 2021), 986 NRCS dams are located within the Trinity Region (see *Figure 2.50*), most of which were designed and built during the early 1950s and 1960s. These dams are one of the elements that comprise what is known as a Watershed Work Plan (WWP), developed by the NRCS. The typical goals of a WWP are to improve agricultural practices, apply land treatment practices that will reduce upland erosion, and implement structural measures to reduce flood damage and provide for sediment control.

The WWPs refer to their dams and reservoirs as “Floodwater Retarding Structures”. Their intent is to reduce flood-related damage to both private property and agricultural crops. Reduction of floodplain scour and capturing excess sediment is also a typical goal for these facilities. A section of a typical floodwater retarding structure is shown in *Figure 2.51*. It is important to note that the design of these structures includes a sediment pool and a sediment reserve. Thus, sedimentation may be considered to have an adverse impact to the structure’s flood control performance only when the sediment pool capacity has been depleted and sediment starts to accumulate in the detention pool. However, as stated earlier, large flood events may carry relatively large loads of sediment that can be deposited in portions of the reservoir that are outside of the designated sediment pool, which results in some loss of detention storage prior to filling the entire sediment pool.

Figure 2.49: Estimate of Flood Control Storage Capacity Remaining by 2053 – Representative Reservoirs

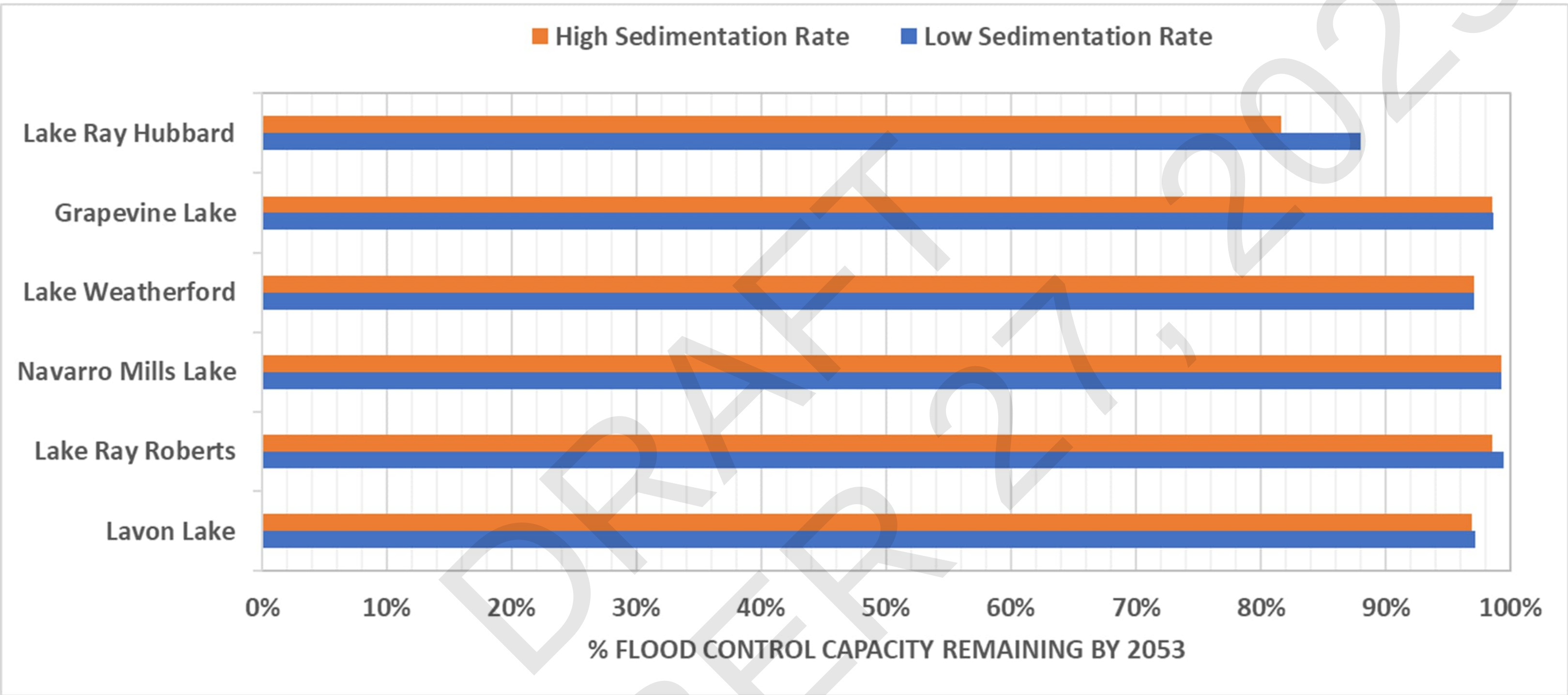
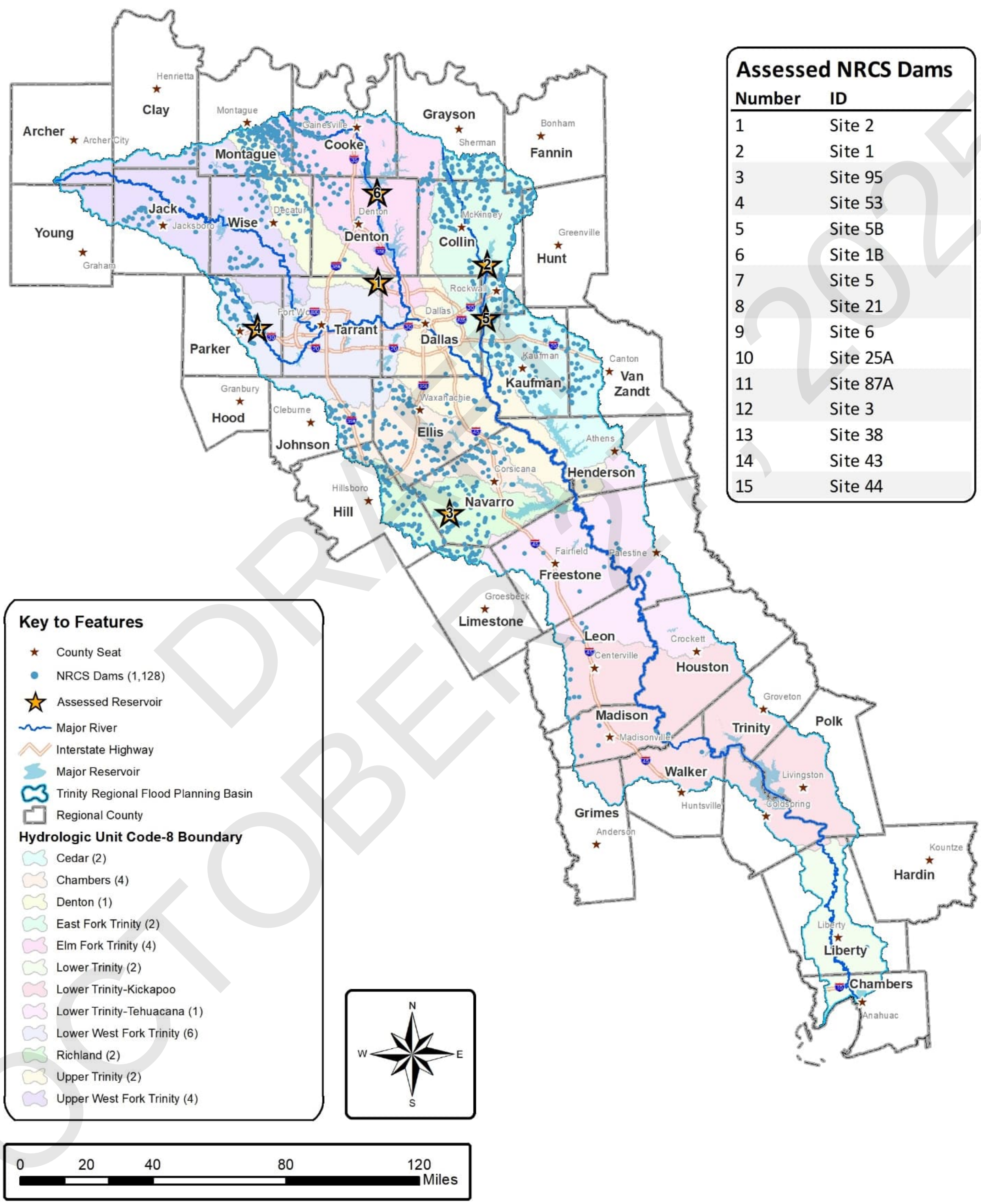


Table 2.28: Estimated Loss of Conservation Pool and Flood Control Pool Capacity due to Sedimentation – Detailed Calculations

Reservoir Name	Reservoir Operator	Drainage Area (square miles)	Survey Year	Years to 2053	Conservation Storage (acre-feet)	Flood Control Storage (acre-feet)	Annual Sedimentation Rate (acre-feet/year)		Average Annual Sedimentation Rate (acre-feet/year)	Capacity Lost from Conservation Pool by 2053 (%)		Capacity Lost from Flood Control Pool by 2053 (%)		Average Capacity Lost from Flood Control Pool by 2053 (%)	Remaining Flood Control Capacity by 2053 (%)	
							Low	High		Low	High	Low	High		Low	High
Lavon Lake	USACE – Fort Worth District	770	2013	40	409,360	338,840	1,212	1,310	1,261	9.5%	10.2%	2.9%	3.1%	3.0%	97.1%	96.9%
Lake Ray Roberts	USACE – Fort Worth District	692	2010	43	788,490	276,110	180	483	332	0.8%	2.1%	0.6%	1.5%	1.0%	99.4%	98.5%
Navarro Mills Lake	USACE – Fort Worth District	320	2009	44	49,827	149,403	124	124	124	8.8%	8.8%	0.7%	0.7%	0.7%	99.3%	99.3%
Lake Weatherford	City of Weatherford	109	2009	44	17,812	11,188	37	37	37	7.3%	7.3%	2.9%	2.9%	2.9%	97.1%	97.1%
Grapevine Lake	USACE – Fort Worth District	695	2012	41	163,064	235,136	392	426	409	7.9%	8.6%	1.4%	1.5%	1.4%	98.6%	98.5%
Lake Ray Hubbard	City of Dallas	1,074	2016	37	439,559	44,224	719	1,097	908	4.8%	7.4%	12.0%	18.4%	15.2%	88.0%	81.6%

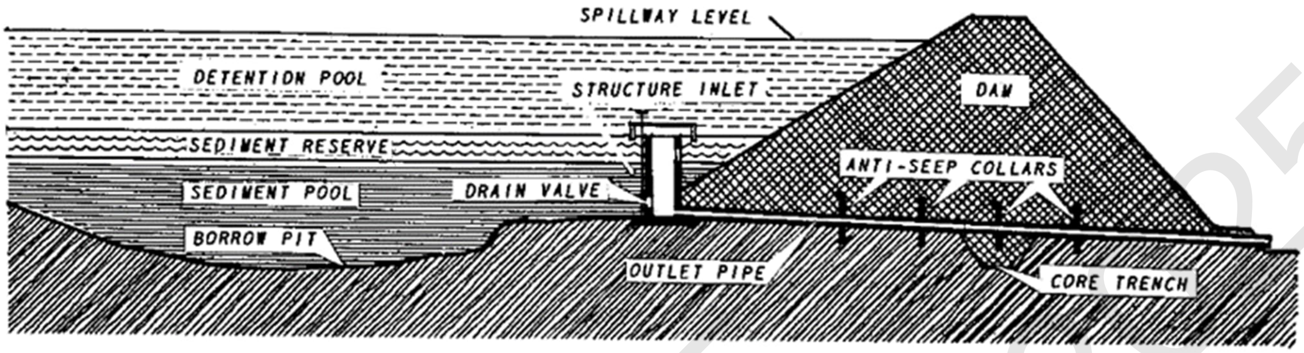
Figure 2.50: Locations of Natural Resources Conservation Service Dams



Assessed NRCS Dams

Number	ID
1	Site 2
2	Site 1
3	Site 95
4	Site 53
5	Site 5B
6	Site 1B
7	Site 5
8	Site 21
9	Site 6
10	Site 25A
11	Site 87A
12	Site 3
13	Site 38
14	Site 43
15	Site 44

Figure 2.51: Section of a Typical Natural Resources Conservation Service Floodwater Retarding Structure



Source: Big Sandy Creek WWP, SCS, 1955 (USDOA, 1955)

Flood Storage Loss Assessment

A high-level assessment of the loss of flood storage capacity due to sedimentation in the region's NRCS facilities was conducted as part of this regional flood plan. A total of 30 WWPs were reviewed for this plan. The watershed areas included in these WWPs are scattered throughout the Trinity Region and represent areas that are within 10 of its 12 sub-basins. No WWPs were available for floodwater retarding structures located within the Lower Trinity-Kickapoo and Lower Trinity sub-basins. WWPs can be downloaded from the following NRCS website: www.nrcs.usda.gov/wps/portal/nrcs/detail/tx/programs/planning/wpfp/?cid=stelprdb1186445.

The WWPs include relevant data about each of the floodwater retarding structures, including sedimentation pool storage, detention storage, drainage area, and the year the facility was built. Most WWPs include a "Sedimentation Investigation" section or similar that provides an average annual rate per area of sediment deposition into the floodwater retarding structures. This data was used to perform approximate calculations of the time it would take to fill the sedimentation pool and the time it would take to fill a given percentage of the detention or flood control storage. For the purposes of this high-level assessment, it is assumed that the performance of the structure in terms of reducing flooding risk begins to be significantly affected once 15 percent of the flood control pool is lost due to sedimentation.

Given the large number of NRCS floodwater retarding structures in the region and other limitations, the assessment was limited to 15 representative structures. At least one structure was included in each Trinity Region sub-basin (see *Figure 2.50*). Structures that were analyzed by FNI in 2021 (four sites) were also included to supplement the assessment (Freese and Nichols, Inc., 2021).

Based on the sedimentation rates reported in the above-mentioned references, an average rate is calculated for each structure except for those that were analyzed by FNI in 2021. In these four cases, the sedimentation rate calculated as part of those investigations is adopted for this analysis. To calculate the time it would take to fill 100 percent of the sediment pool and 15 percent of the flood control pool, the RFPG assumes that 80 percent of the annual sediment deposition occur within the sediment pool and 20 percent within the flood pool. Once the sediment pool fills, the entire sediment accumulation occurs within the flood pool. A conservative 100 percent trap efficiency assumption is adopted for this assessment. The results of these calculations are presented graphically in *Figure 2.52* and summarized in *Table 2.29*. Further details on the data used and calculations are presented in *Table 2.30*.

Figure 2.52 shows a series of bar graphs representing each site. The first point on the bar represents the year the structure was built. The segment between the first and second points represents the time it would take to fill the sedimentation pool. At that point, the facility would no longer perform its sediment control purpose as designed. The segment between the second and third points represents the additional time it would take to fill 15 percent of the flood control pool. This point represents a conservative assumption of when flood control benefits may be significantly reduced due to loss of storage capacity. The red dashed line that marks year 2053 depicts the long-term planning horizon for this first regional flood plan. Based on these calculations, flood control operations would not be significantly affected for most of the selected sites within the next 30 years. Ten sites would still have residual capacity in their sedimentation pool to continue accumulating sediment beyond 2053. In some instances, the bars extend beyond the limits of the time axis, indicating extensive time frames to reach the set storage losses.

Figure 2.52: Estimate of Time to Lose Sediment Pool and Flood Control Pool Capacity due to Sedimentation – Representative National Resources Conservation Services Structures

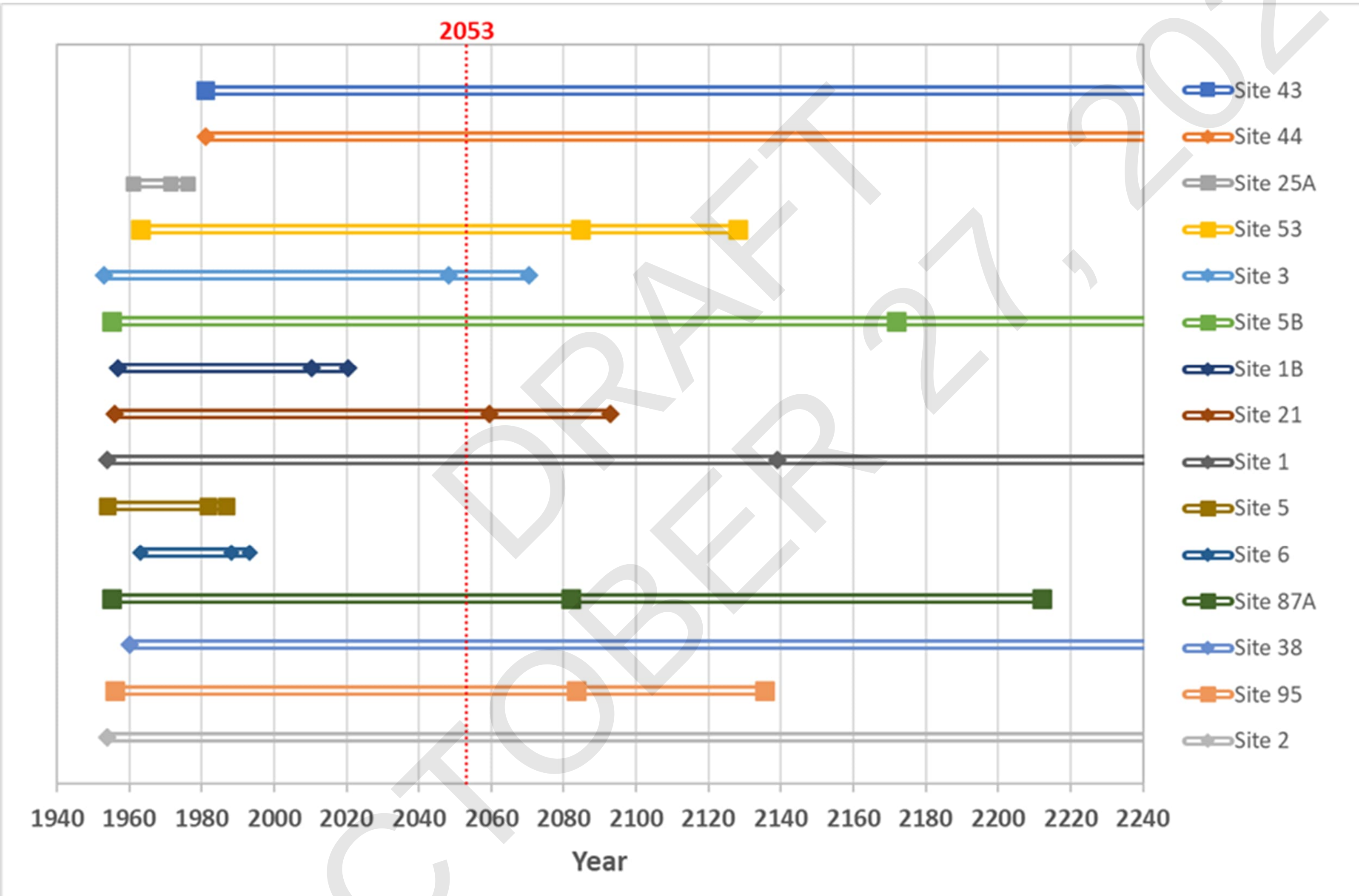


Table 2.29: Estimate of Time to Lose Sediment Pool and Flood Control Pool Capacity due to Sedimentation – Representative Natural Resources Conservation Service Structures

Trinity Region Sub-basin	Creek	NRCS Dam ID	Average or *FNI 2021 Sedimentation Rate (ac-ft/yr)	Year Built	Estimated Year Sediment Pool is Filled	Estimated Year Flood Pool is Filled 15%
Upper West Fork Trinity	Blue Creek	Site 43	0.07*	1981	3963	5242
Upper West Fork Trinity	Blue Creek	Site 44	0.09*	1981	3050	3660
Denton Creek	Denton Creek	Site 25A	12.42	1961	1971	1976
Elm Fork Trinity	Clear Creek	Site 53	2.50	1963	2085	2128
East Fork Trinity	Buffalo Creek	Site 3	2.26*	1953	2048	2070
East Fork Trinity	Buffalo Creek	Site 5B	1.77*	1955	2172	2245
East Fork Trinity	Rutherford Branch	Site 1B	4.10	1957	2010	2020
Lower West Fork Trinity	Clear Fork	Site 21	1.79	1956	2059	2093
Upper Trinity	Turkey Creek	Site 1	0.80	1954	2139	2291
Upper Trinity	Grays Creek	Site 5	13.92	1954	1982	1987
Upper Trinity	Village Walker Creek	Site 6	1.59	1963	1988	1993
Cedar Creek	Muddy Cedar Creek	Site 87A	4.80	1955	2082	2212
Chambers	Boss Branch	Site 38	0.55	1960	2407	2702
Richland	Post Oak Creek	Site 95	1.81	1956	2083	2135
Lower Trinity Tehuacana	Lake Creek	Site 2	1.36	1954	2354	2384

*Note: * Sedimentation Rates from FNI 2021 Basis of Design Reports for NRCS*

Table 2.30: Estimated Loss of Sediment Pool and Flood Control Pool Capacity due to Sedimentation – Detailed Calculations

Trinity Region Sub-basin	Creek	NRCS Dam ID	Year Built	Drainage Area (square miles)	Sediment Pool Storage (acre-feet)	Flood Pool Storage (acre-feet)	Total Capacity (acre-feet)	Sediment Rate Estimate (acre-feet/square miles/year)		Sediment Rate Estimate (acre-feet/year)		FNI 2021 Sedimentation Rate Estimate (acre-feet/year)	Average or FNI 2021 Sedimentation Rate (acre-feet/year)	Estimated Years to Fill Sediment Pool	Estimated Year when Sediment Pool is Filled	Additional Years to fill 15% of Flood Pool	Estimated Year when 15% of Flood Pool is Lost
								High	Low	Low	High						
Upper West Fork Trinity	Blue Creek	Big Sandy Creek Site 43	1981	3.2	111	782	893	--	--	--	--	0.07	0.07	1982	3963	1,279	5242
Upper West Fork Trinity	Blue Creek	Big Sandy Creek Site 44	1981	2.0	77	494	571	--	--	--	--	0.09	0.09	1069	3050	609	3660
Denton Creek	Denton Creek	Site 25A	1961	2.2	103	575	678	10	1.5	21.6	3.2	--	12.42	10	1971	5	1976
Elm Fork Trinity	Clear Creek	Site 53	1963	4.4	243	1,129	1,372	0.76	0.37	3.4	1.6	--	2.50	122	2085	43	2128
East Fork Trinity	Buffalo Creek	LEF Site No. 3	1953	2.0	172	623	795	4	2	7.9	4.0	2.26	2.26	95	2048	22	2070
East Fork Trinity	Buffalo Creek	UEFL Site No. 5B	1955	4.8	307	1,376	1,683	--	--	--	--	1.77	1.77	217	2172	73	2245
East Fork Trinity	Rutherford Branch	Site 1B	1957	2.1	175	568	743	3	1	6.2	2.1	--	4.10	53	2010	10	2020
Lower West Fork Trinity	Clear Fork	Site 21	1956	2.8	148	645	793	1	0.3	2.8	0.8	--	1.79	103	2059	33	2093
Upper Trinity	Turkey Creek	Site 1	1954	3.2	118	1,006	1,124	0.4	0.1	1.3	0.3	--	0.80	185	2139	152	2291
Upper Trinity	Grays Creek	Site 5	1954	3.2	308	983	1,291	6	2.7	19.2	8.6	--	13.92	28	1982	5	1987
Upper Trinity	Village Walker Creek	Site 6	1963	0.4	32	105	137	7.68	1.13	2.8	0.4	--	1.59	25	1988	5	1993
Cedar Creek	Muddy Cedar Creek	87A (New Terrell City Lake)	1955	14.3	488	4,968	5,456	0.45	0.22	6.4	3.2	--	4.80	127	2082	130	2212
Chambers	Boss Branch	Site 38	1960	3.4	197	1,411	1,608	0.22	0.11	0.7	0.4	--	0.55	447	2407	295	2702
Richland	Post Oak Creek	Site 95	1956	4.3	184	934	1,118	0.43	0.40	1.9	1.7	--	1.81	127	2083	52	2135
Lower Trinity Tehuacana	Lake Creek	Site 2	1954	3.4	435	1,000	1,435	0.5	0.3	1.7	1.0	--	1.36	400	2354	30	2384

Results also show that four sites that should theoretically be experiencing a significant reduction in their flood control effectiveness. However, sedimentation rates do change significantly over time. More recent sedimentation rate estimates are typically much lower due to significant improvements in agricultural practices and the implementation of erosion control policies among other factors. The RFPG experience suggest that sedimentation rates reported in these early documents can be quite conservative and not representative of current rates. For example, the sedimentation rates estimated in the early documents for Site 3 in the East Fork Trinity sub-basin range from four to 7.9 acre-feet per year, while the most recent estimates calculated by FNI (2021) resulted in a rate of 2.26 acre-feet. This is a 44 percent reduction from the low estimate indicated in the early documentation.

The results of this high-level assessment suggest that at a regional scale, sedimentation will not pose a significant limitation to achieving flood control benefits from these structures within the 30-year planning horizon. However, the RFPG recognizes that 15 structures is a relatively small sample size, and further analysis is required to comprehensively assess the impacts of sedimentation on these structures, especially at the local scale. Sedimentation was not used in determining future flood risk for this regional flood plan due to the minimal effect at the regional scale. Reduction in reservoir capacity may be looked at in greater detail by local entities and in future planning cycles.

Anticipated Impacts of Major Geomorphic Changes in Flood Risk

Geomorphic changes in fluvial systems have a clear relationship with flood hazard protection. Fluvial systems are a series complex feedback loops where many interrelated variables influence both flood hazards and changes in a river condition. In short, the geometry of river systems changes when the influencing variables, such as hydrology (caused by things such as climate change, land use changes, stormwater infrastructure, etc.) and sediment dynamics such as erosion, sediment deposition, and sediment transport change. This ultimately relates back to flood hazards because of increases or decreases in flood conveyance inherent to changes in river geometry.

Most flood hazard assessments assume the capacity of river channels to convey flood flows is stationary, with the thought that changes in flood frequency are primarily driven by hydrology. However, several studies have shown that while hydrology has a greater influence on flood hazards and flood variability, identifying potential geomorphic changes is important because flood hazards and flood variability is not driven by hydrology alone.

Predicting Geomorphic Changes

Quantitatively predicting geomorphic channel changes requires intense data collection and modeling. These requirements are further magnified at larger scales because the factors that control the geomorphology of a system are variable throughout a watershed. At the regional scale, there is significant heterogeneity within a river system. As such, geomorphic channel changes and sediment dynamics are difficult to quantify at the regional scale because of the lack of available data, number of interrelated influential variables, and differences in the local conditions within a watershed.

Including predicted geomorphic changes into flood assessment is often not appropriate or feasible at the regional scale. This is because the uncertainty of predictions becomes exceedingly high with the introduction of additional variables/complexity, which can lead to erroneous flood predictions (Stanzel & Natchnebel, 2009). However, this does not mean that general effects of geomorphic channel changes on flood risks should not be considered.

Effects of Geomorphic Changes on Flood Risks

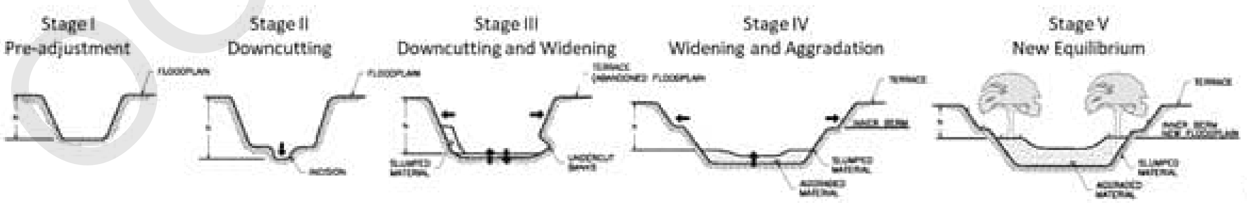
While major geomorphic changes can occur at the regional scale, their effect on flood risks are most apparent at the local level. This is because of the variability of geomorphic conditions within a river. Local changes in the channel geometry and sediment dynamics of the system can have profound effects on flood inundation extents at smaller scales. This section provides high-level descriptions of how geomorphic changes can affect flood risks.

Hydrology and Channel Changes

River geometry changes to accommodate the amount of flow it receives. Both increases and decreases in flow regime can initiate these changes. Common causes of hydrologic changes include urbanization/land-use changes, implementation of stormwater infrastructure (such as detention/retention ponds), climate change, and reservoir release schedules.

Increased flow often occurs when a watershed urbanizes or has land-use changes. Flow in streams become flashier because surface runoff reaches streams more quickly and in greater magnitude due to increased smooth impermeable surfaces that prevent infiltration of water into the ground. While this gets floodwaters downstream more quickly, stream geometries will enlarge via erosion to accommodate the additional flow. This is manifested by channel downcutting until the stream slope can accommodate the discharge without scouring the channel bed; and by channel widening caused by overly steepened stream banks following downcutting. *Figure 2.53* shows the processes involved in the channel evolution model.

Figure 2.53: Diagram of Channel Downcutting and Channel Widening



Channel enlargement is a gradual process that migrates from downstream to upstream between local baselevels or hardpoints. Local baselevels are features that prevent the channel from downcutting. Examples may include tributary confluences, bedrock outcrops, concrete-lined channels, and culvert crossings. Geometric changes to the channel (i.e., channel enlargement) typically affect flood levels within these bounded local baselevels.

Locally, channel enlargement may increase the flow capacity and reduce flood risks. This effect scales with river size/drainage area. Flood capacity is less impacted by erosion in larger streams than in smaller streams because the amount of material removed relative to the channel size is less in larger streams. In smaller streams, it is common for erosion to create enough capacity to completely remove overbank flows during flood events. Likewise, significant amounts of erosion in larger streams may only have a marginal effect on flood inundation levels.

This does not mean that erosion is solely beneficial to flood risks. There are adverse impacts of erosion brought about by increased hydrology including:

- Direct erosion impacts to homes, infrastructure (for example, stormwater outfalls, waterlines, sewer lines, roads, bridges, culverts, etc.), and private property adjacent to the stream
- Channel geometry used in flood assessment analyses becoming outdated
- Excess sediment yields sourced from channel erosion and subsequent downstream effects

Decreased flow in the stream can also occur due to the presence of detention/retention ponds, lakes/reservoirs, and other factors. This can cause channels to aggrade because flows no longer have enough stream power to carry the sediment in the system. As a result, channel capacity decreases as sediment aggrades in the channel, and flood levels can rise for a given storm event. In addition to aggradation, erosion can also occur on stream banks caused by deposition patterns/sediment bars directing flow into stream banks.

Other Considerations

It is often not feasible to evaluate regional scale geomorphic changes and their potential effects on flood hazards because of the significant uncertainties introduced into flood hazard assessment without accounting for the intensive data requirements, extensive analysis of interrelated variables, and system heterogeneity. Major geomorphic changes and their effects on flood hazards are most prominently experienced at the local level and can be accounted for at this scale.

The above sections provide high-level examples of the connection between geomorphic changes and flood hazards at specific locations due to local sediment dynamics or bank erosion. As such, mitigation of flood hazards is often a maintenance concern located at specific areas or pieces of infrastructure (such as easements, culverts, retention/detention ponds, reservoirs, etc.). The maintenance responsibilities of these areas, and therefore much of flood hazard mitigation practices, falls to the owners of these assets.

One method used by numerous cities and regulatory bodies to account for uncertainty in geomorphic changes at a high level includes erosion hazard setbacks (also known as erosion clear zone, stream buffer area, etc.). This consists of a buffer area around the stream system that is not allowed to be disturbed without prior investigation. Multiple methods of creating this setback distance have been developed in design criteria manuals and local flood plans as a means of accounting for the uncertainty in future geomorphic changes without intense data requirements. Maintaining a buffer around streams provides numerous benefits including:

- Allowing for geomorphic channel adjustments to occur within an allotted lateral extent without significantly affecting flood inundation extents;
- Reducing hydrologic changes in the stream by slowing overland flow via riparian vegetation;
- Improving water quality via riparian vegetation filtering surface runoff;
- Reduction of bank erosion and subsequent excess sediment due to streambanks increased resistance to bank erosion from the roots of established riparian vegetation (i.e., bank vegetation reduces stream bank erosion); and
- Prevention of erosion impacts to homes, infrastructure, and property adjacent to the stream.

For larger streams with more thorough flood inundation mapping, setbacks may not be as effective at reducing flood risk due to their relatively small buffer distances from streams compared to mapped floodplains. However, in smaller watersheds with limited flood analysis, setbacks can be an effective means of providing an extra layer of protection with relatively low effort.

Future Conditions H&H Model Availability

Table 2.31 shows a list of projects that include H&H models with future conditions. Details for two of the projects follow:

- The 2021 Interagency Flood Risk Management (InFRM) Watershed Hydrology Assessment for the Trinity Region: A watershed model was built for the Trinity Region with input parameters that represented the physical characteristics of the watershed. The rainfall-runoff model for the basin was completed using the basin-wide Hydrologic Engineering Center – Hydrologic Modeling System (HEC HMS) model developed for the Trinity Basin Corps Water Management System (CWMS) implementation as a starting point. This model was further refined by adding additional detailed data, updating the land use, and calibrating the model to multiple recent flood events. Through calibration, the updated HEC-HMS model was verified to accurately reproduce the response of the watershed to multiple, recently observed storm events, including those similar in magnitude to a 100-year flood. Finally, frequency storms were built using the depth area analysis in HEC-HMS and the latest published frequency rainfall depths from NOAA Atlas 14 (NOAA, 2018). These frequency storms were run through the verified model, yielding consistent estimates of the 100-year and other frequency peak flows at various locations throughout the basin. The InFRM model is the basis of the USACE Corridor Development Certificate model which incorporates flood event peak discharges based on anticipated watershed development up to the year 2055.

Table 2.31: Hydrology and Hydraulic Models by Project

Project	Model Name	Date Created	Stream Section	HEC RAS version	Steady or Unsteady state	Model Developer
Interagency Flood Risk Management (InFRM) Watershed Hydrology Assessment for the Trinity River Basin	AP_Freq_002yr AP_Freq_005yr_NOAA AP_Freq_025yr AP_Freq_050yr AP_Freq_250yr	09/17/2018	Trinity Bay, Lewisville Lake, Lavon Lake, Grapevine Lake, Ray Roberts Lake, Benbrook Lake, Joe Pool Lake	HEC-HMS 4.3	Steady Flow	USACE
Interagency Flood Risk Management (InFRM) Watershed Hydrology Assessment for the Trinity River Basin	AP_Freq_002yr_NOAA AP_Freq_200yr_NOAA_WF	01/18/2021	Trinity Bay, Lewisville Lake, Lavon Lake, Grapevine Lake, Ray Roberts Lake, Benbrook Lake, Joe Pool Lake	HEC-HMS 4.3	Steady Flow	USACE
Interagency Flood Risk Management (InFRM) Watershed Hydrology Assessment for the Trinity River Basin	AP_Freq_002yr_NOAA_WF AP_Freq_005yr AP_Freq_005yr_NOAA_WF AP_Freq_010yr AP_Freq_010yr_NOAA_WF AP_Freq_025yr_NOAA_WF AP_Freq_050yr_NOAA AP_Freq_050yr_NOAA_WF AP_Freq_100yr_NOAA AP_Freq_100yr_NOAA_WF AP_Freq_200yr AP_Freq_500yr_NOAA_WF	05/7/2021	Trinity Bay, Lewisville Lake, Lavon Lake, Grapevine Lake, Ray Roberts Lake, Benbrook Lake, Joe Pool Lake	HEC-HMS 4.3	Steady Flow	USACE
Interagency Flood Risk Management (InFRM) Watershed Hydrology Assessment for the Trinity River Basin	AP_Freq_010yr_NOAA	01/11/2019	Trinity Bay, Lewisville Lake, Lavon Lake, Grapevine Lake, Ray Roberts Lake, Benbrook Lake, Joe Pool Lake	HEC-HMS 4.3	Steady Flow	USACE
Interagency Flood Risk Management (InFRM) Watershed Hydrology Assessment for the Trinity River Basin	AP_Freq_100yr AP_Freq_500yr	12/10/2018	Trinity Bay, Lewisville Lake, Lavon Lake, Grapevine Lake, Ray Roberts Lake, Benbrook Lake, Joe Pool Lake	HEC-HMS 4.3	Steady Flow	USACE
Interagency Flood Risk Management (InFRM) Watershed Hydrology Assessment for the Trinity River Basin	AP_Freq_500yr_NOAA	01/14/2019	Trinity Bay, Lewisville Lake, Lavon Lake, Grapevine Lake, Ray Roberts Lake, Benbrook Lake, Joe Pool Lake	HEC-HMS 4.3	Steady Flow	USACE
Marine Creek Frequency and Probability Maximum Flood Study	Marine Creek	03/1/2008	Marine Creek	HEC-HMS 4.0	Steady Flow	City of Fort Worth, TRWD

- Marine and Cement Creek Frequency and Probability Maximum Flood Study: Marine Creek is in the northwest portion of Tarrant County. The headwater of Marine Creek is approximately 3.5 miles northwest of Saginaw, Texas, and the flow is in a general southeasterly direction. The Marine Creek confluence with the West Fork of the Trinity River is just downstream of the Fort Worth Stockyards near Samuel Avenue, north of downtown Fort Worth. The total drainage area of the Marine Creek watershed is approximately 22.2 square miles, including portions of the City of Saginaw, Fort Worth, Lake Worth, Sansom Park, and unincorporated Tarrant County. H&H models for the study were developed using HEC-HMS version 3.4 and HEC-RAS version 4.0, as well as GIS applications.

Future Conditions Flood Hazard Approach

When developing a predictive assessment for future conditions flood risk, two major factors were considered: unmitigated population increase and projected future rainfall. The future conditions mapping for cycle 2 of the RFP leverages the 2025 Future Condition Cursory Floodplain (Year 2060) study data developed by the TWDB. TWDB developed high-resolution future flood risk maps for the state using Fathom modeling framework. The maps integrate minimal, moderate, and significant climate forcing scenarios alongside projected land use changes and land subsidence effects to comprehensively represent future flood risk. Incorporating these datasets enables more detailed estimation of how future conditions may alter floodplain extents and flood risk within the basin.

Future Conditions – Land Use and Projected Rainfall

Recent advancements in climate modeling now allow for more refined projections of future rainfall under different warming scenarios. The TWDB's April 2025 floodplain mapping report, developed using Fathom Climate dynamics, incorporates such projections through a change-factor method. This approach uses outputs from four high-resolution global climate models (GCMs) selected from the High Resolution Model Intercomparison Project (HighResMIP) under the SSP5-8.5 emissions scenario. To provide more accurate results, these projections have been bias corrected using the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3) methodology in comparison to historical data from 1980 to 2014. Change factors are calculated as the median ratio of maximum daily precipitation (RX1 day) over 2020-2050 relative to 1962-1992 baseline. These factors are normalized by each GCM's projected temperature increase, yielding precipitation change factors per degree of warming. This methodology, assuming a linear scaling of extreme precipitation with global warming levels (GWLs) ranging from 0.21ºC to 5ºC relative to preindustrial level, supports the assessment of future rainfall changes beyond 2050. These bias-corrected, GWL-scaled change factors are directly integrated into hyetograph generation, enabling projected rainfall to be incorporated into flood modeling.

The TWDB's work provides a comprehensive dataset for both present and future (2060) rainfall, based on minimal, moderate, and significant projections of changes in extreme precipitation under a 2^{o}C warming scenario in 2060. These projections represent the central 66% of possible outcomes (corresponding to the 17th, 50th, and 83rd percentiles). The TWDB provides this input dataset as a 1km raster covering the entire state of Texas. For the minimal climate forcing scenario (17th percentile), the projected increase in 100-year 24-hour precipitation ranges from -0.06 to 0.37 inch, indicating a minimal increase with some localized decreases in precipitation. In contrast, the moderate climate forcing scenario shows a more substantial increase with precipitation ranging from 0.32 to 0.76 inch. The most significant climate forcing scenario projects a considerable increase in precipitation, ranging from 0.69 to 2.55 inches. The spatial distribution of present rainfall and the projected increases for 2060 across the Trinity River Basin are visually represented in *Figure 2.54*. Furthermore, *Table 2.32* provides the median increase in precipitation across the Trinity River Basin for various rainfall frequencies under all scenarios. This data suggests that incorporating these future rainfall values provided in the Fathom report into the basin's flood models will likely lead to increased precipitation intensity, thereby increasing the chances of flooding in the region. Consequently, utilizing this dataset provides conservative estimates for planners to assess future flood risk effectively.

In addition to the Fathom dataset, the ongoing efforts by TWDB to develop future rainfall frequency grids, leveraging both historical rainfall trends and climate model projections, could also be utilized for future rainfall assessment and flood risk evaluations in the region.

Figure 2.54: Comparisons between Current Rainfall and Projected Rainfall (Current Rainfall) over the Trinity River Basin

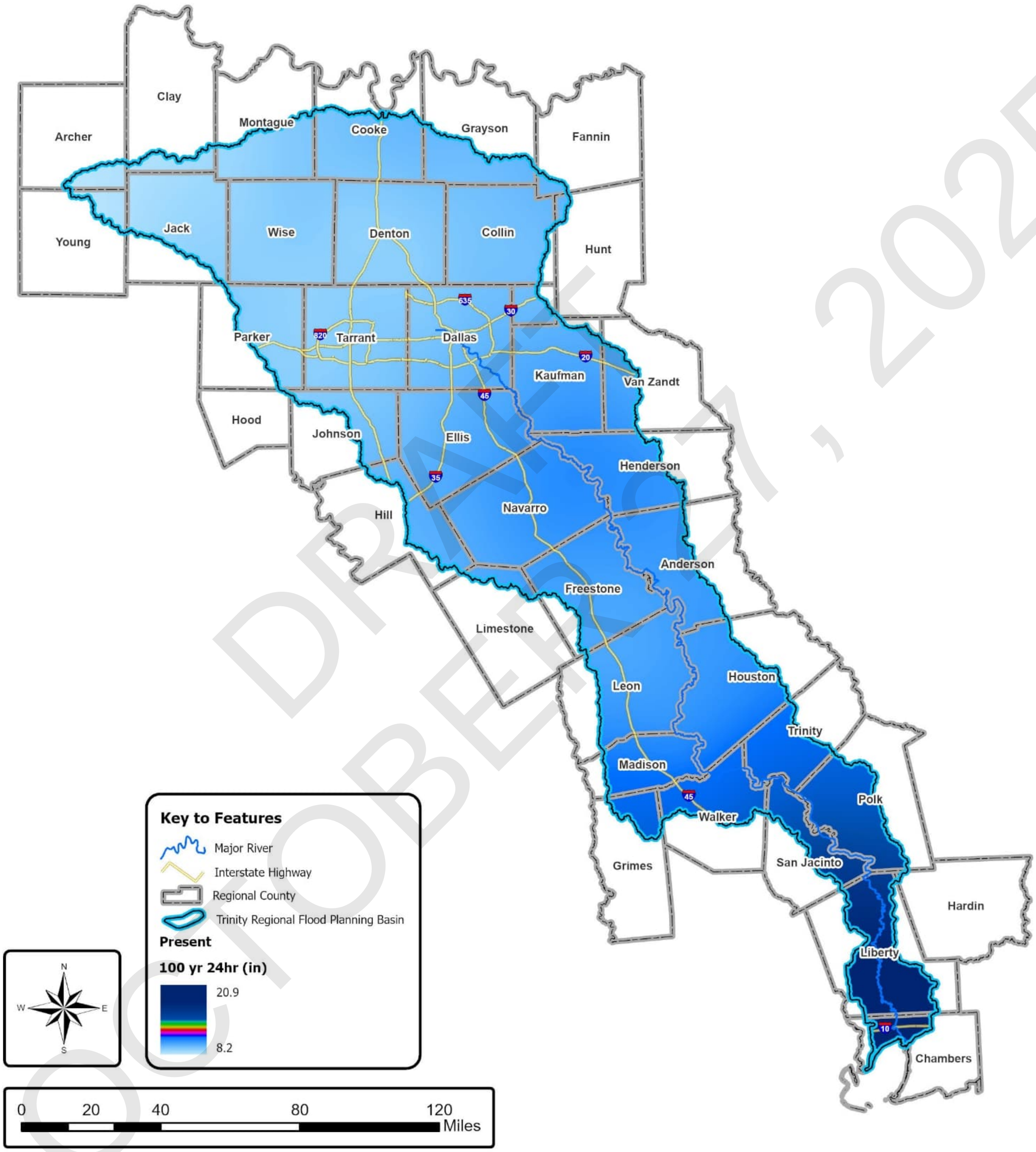


Figure 2.55: Comparisons between Current Rainfall and Projected Rainfall (17th Percentile) over the Trinity River Basin

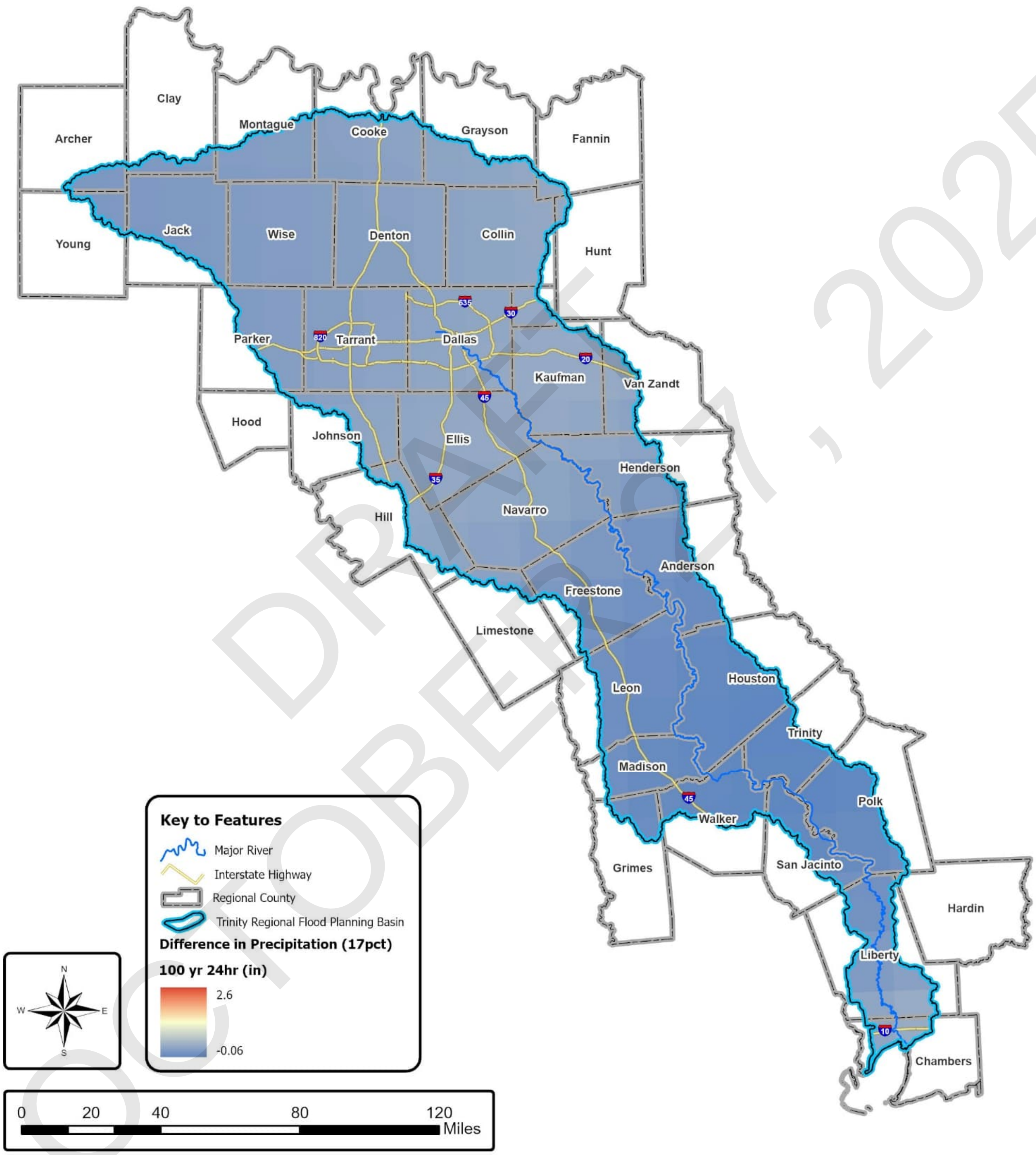


Figure 2.56: Comparisons between Current Rainfall and Projected Rainfall (50th Percentile) over the Trinity River Basin

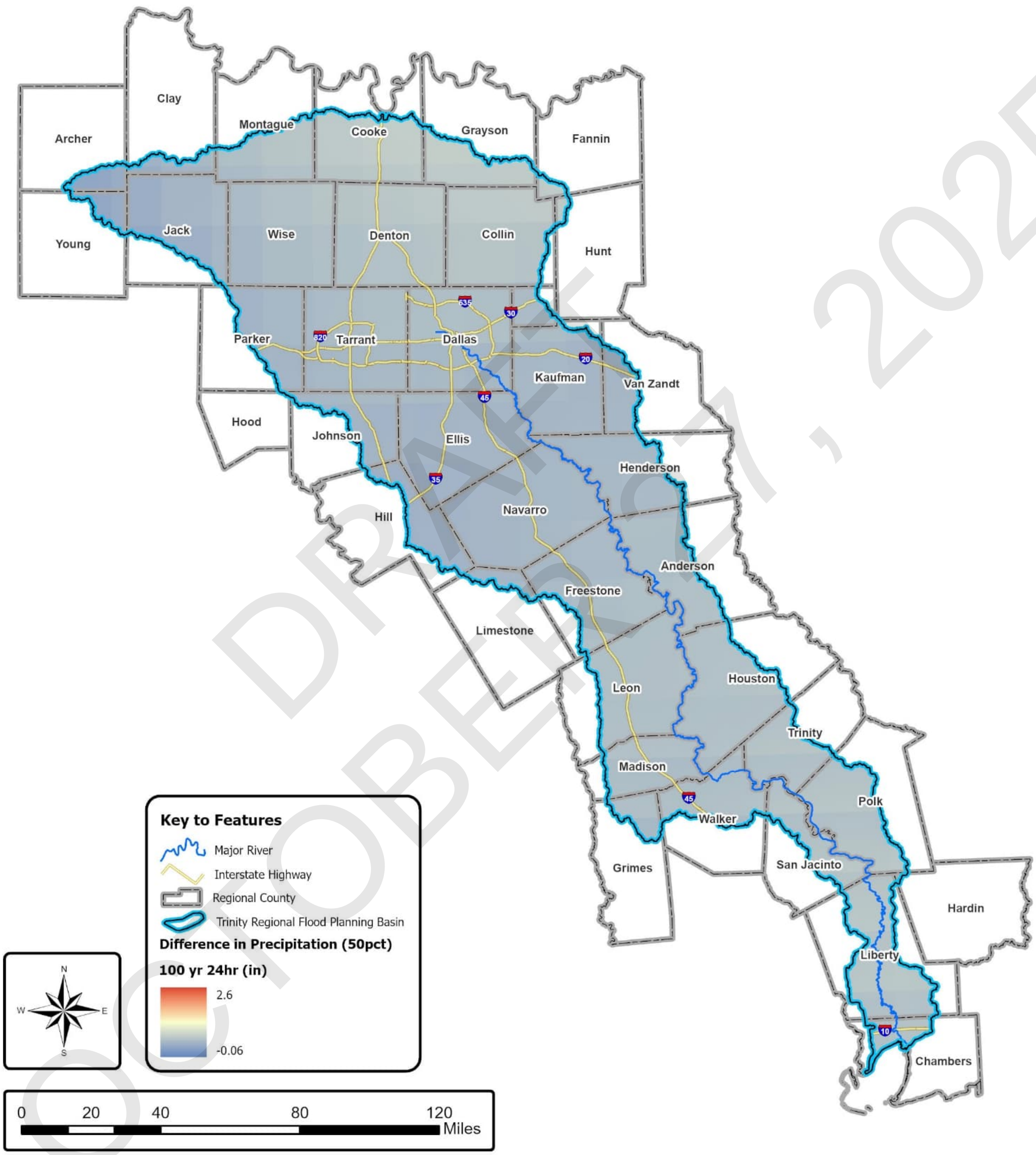


Figure 2.57: Comparisons between Current Rainfall and Projected Rainfall (83rd Percentile) over the Trinity River Basin

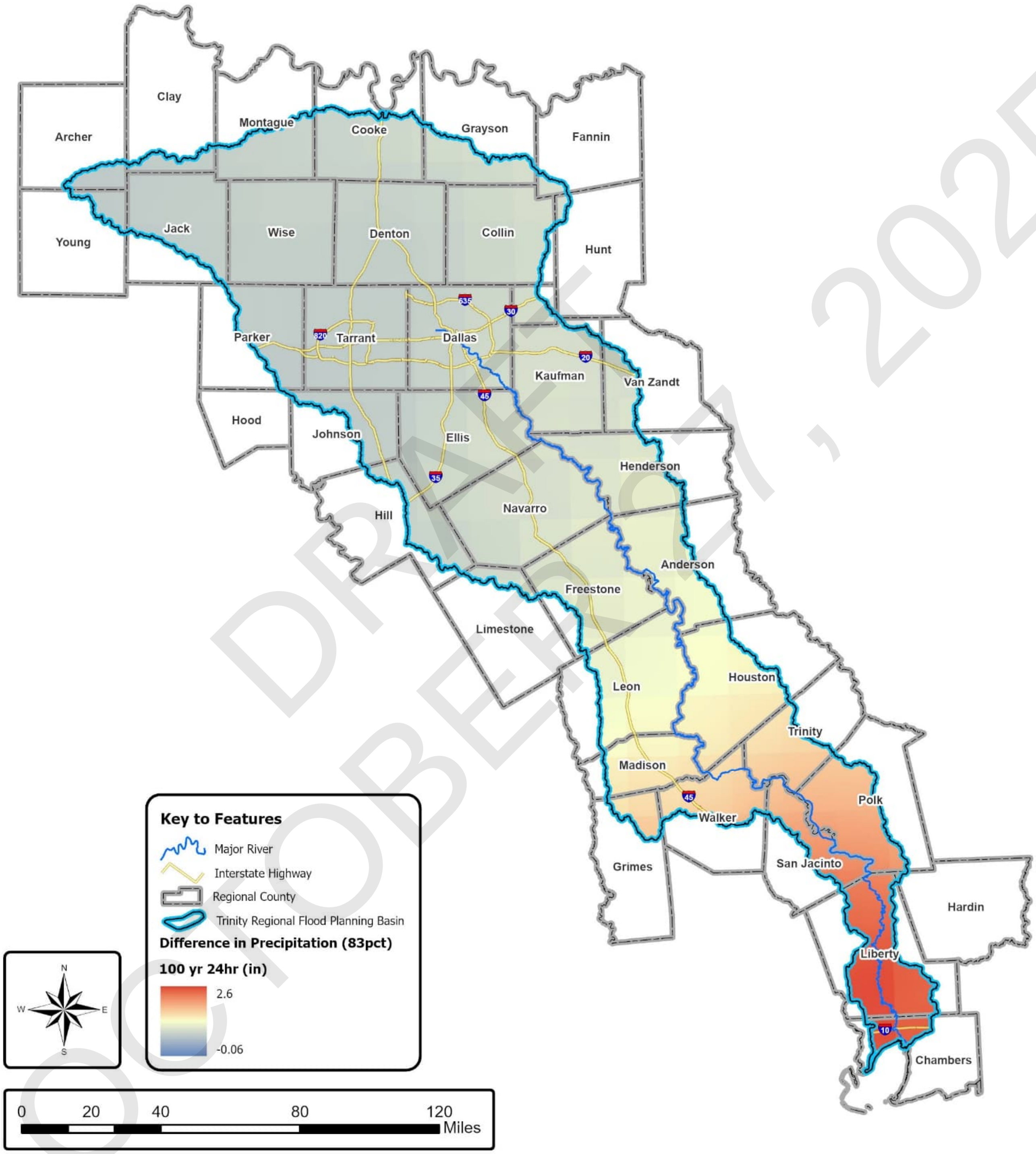


Table 2.32: Median Values of Current Rainfall and Projected Rainfall (17th, 50th, and 83rd Percentiles) over the Trinity River Basin

Frequency (24-hr)	Present (in)	Future (2060) 17pct (in)	Future (2060) 50pct (in)	Future (2060) 83pct (in)
5yr	5.15	5.27	5.44	5.64
10yr	6.13	6.28	6.48	6.71
25yr	7.57	7.74	7.99	8.27
100yr	10.03	10.29	10.52	10.92
500yr	13.62	14.07	14.28	14.81

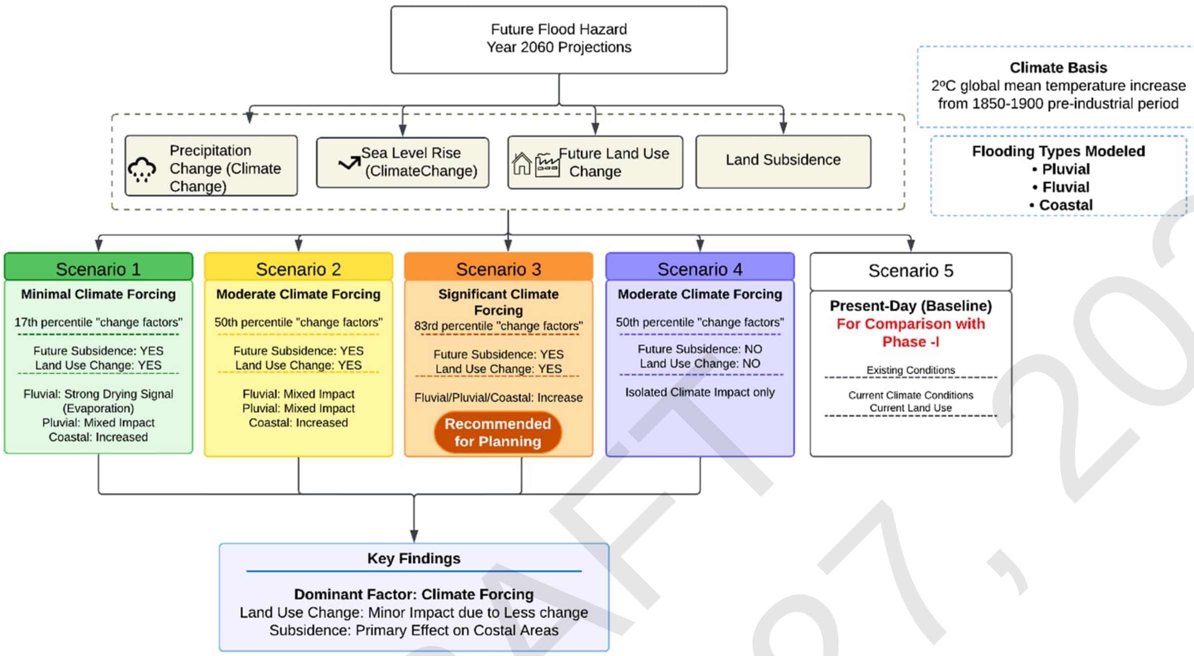
Summarization of Flood Hazard Methodology for future conditions using Fathom

The future conditions mapping for this cycle leverages the 2025 Fathom Phase-II study conducted by the TWDB, which provides a high-resolution, climate informed dataset that can serve as a valuable reference for delineating potential future 10-year, 100-year and 500-year flood hazard within the Trinity Region. The study integrates four primary drivers influencing future flood risk: projected precipitation changes, sea level rise, land use changes projected through 2060, and land subsidence (*Figure 2.58*). The Fathom study produces potential cursory future conditions floodplains in four scenarios based on outputs from the Coupled Model Intercomparison Project Phase 6 (CMIP6) datasets.

Using outputs from CMIP6 global climate models under various forcing scenarios, the Fathom framework adjusts existing rainfall intensities, peak fluvial flows, and coastal water levels by applying change factors derived from General Circulation Models (GCM) ensembles at the 17th, 50th, and 83rd percentiles. These percentiles represent minimal, moderate, and significant climate forcing scenarios respectively, based on a 2^{o}C warming relative to the 1800-1900 pre-industrial baseline. This approach allows the study to capture a range of plausible future conditions and associated uncertainties in flood hazard projections. The resulting outputs include detailed 3-meter resolution inundation maps for 10-year, 100-year, and 500-year flood events, with uncertainty bounds defined by percentile ranges that reflect variability in climate projections.

By incorporating these data, the Fathom methodology provides consistent model-backed, spatially detailed, and scenario-based flood hazard estimates that explicitly account for climate change, land use, and land-subsidence. This dataset enhances the ability to identify expanded flood risk areas, including pluvial, fluvial, and coastal flood hazards, thereby supporting more informed, transparent, and comprehensive long-term flood risk planning in the Trinity Region.

Figure 2.58: Methodological Framework adopted by Fathom for Future Flood Risk Identification

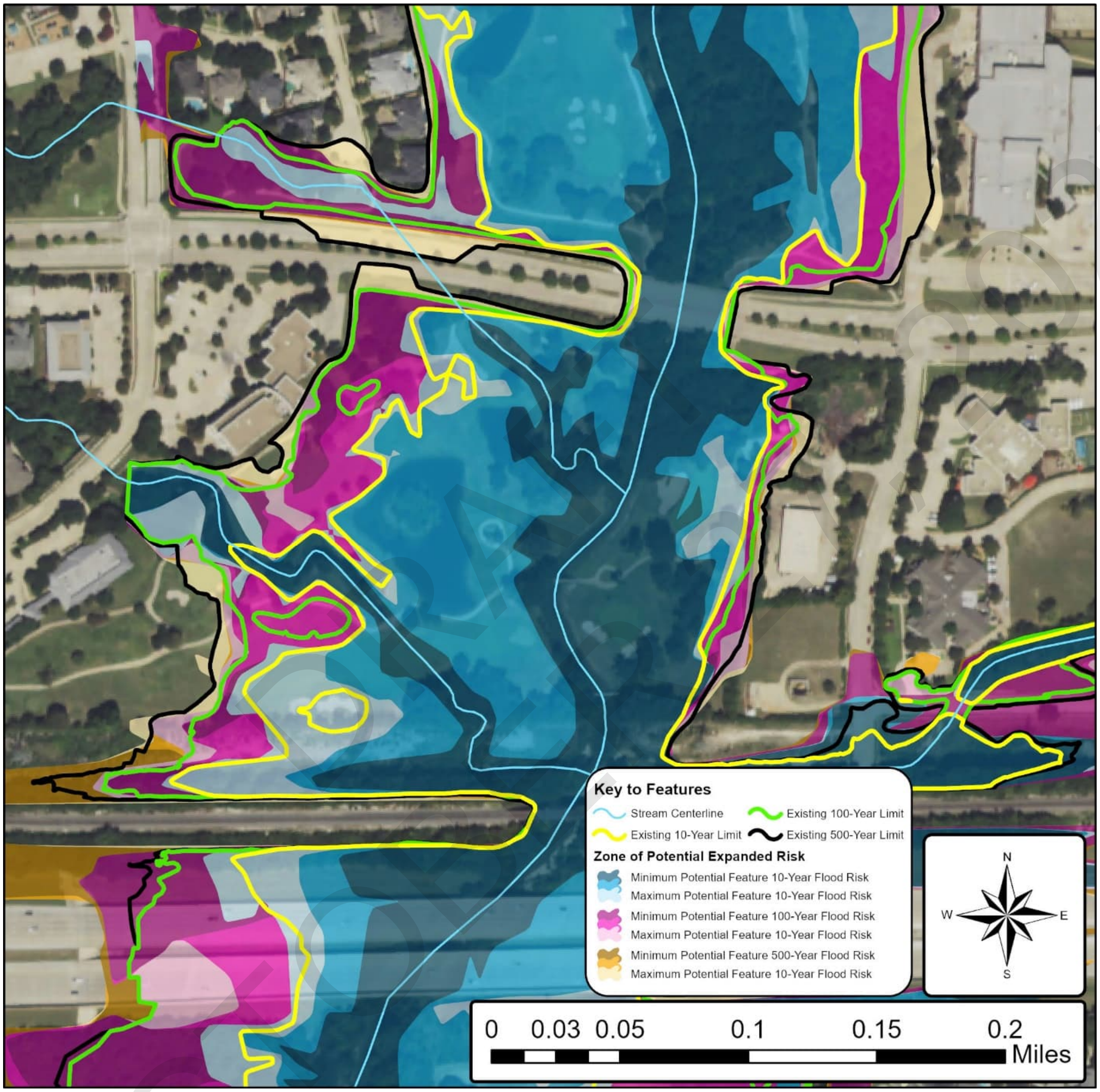


The Fathom data generally shows reduced flooding in some areas for Scenarios 1 and 2. The TWDB recommended that RFPGs use Scenario 3, which accounts for significant future climate variation, subsidence, and land use change, representing the worse-case flood inundation scenario in Texas. For the Trinity Region, the future conditions mapping was considered as a range between scenarios 1 and 3 to show a zone of potential minimum to potential maximum future flood mapping extents. *Figure 2.59* shows an example of the range of potential flood risk.

The data developed in this flood plan are strictly intended for planning purposes and shall not be used for regulatory purposes. To emphasize this point, the potential future 100-year floodplain is presented in this planning cycle as a range between the Fathom 2060 Scenario 1 and Scenario 3 flood extents (zone of potential expanded risk). The methodology addresses the uncertainty and variability resulting from the study. The exposure and vulnerability assessment data are extracted from the maximum potential future 10-year, 100-year, and 500-year floodplain limits.

Large maps showing the future conditions floodplain extents developed for the Trinity Region are included in *Appendix B*.

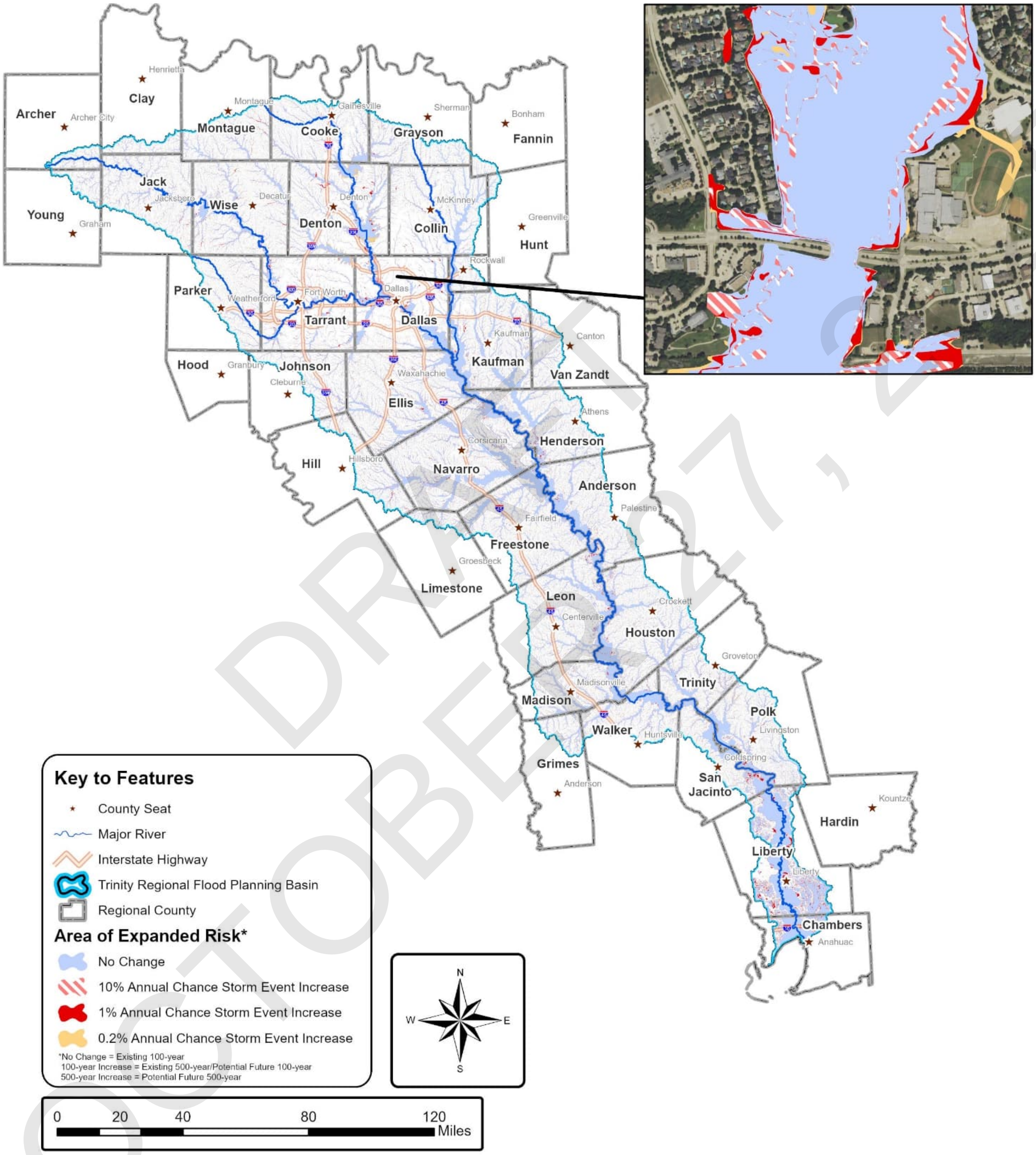
Figure 2.59: Example of 2024-2028 Planning Cycle Range of Potential Future Conditions Flood Risk Data



Potential Future Floodplain Changes

The potential 30-year potential future conditions floodplain quilt generally resulted in larger mapping extents when compared to the existing conditions floodplain quilt. *Figure 2.60* (See *Appendix B* for a larger version map) shows the areas of expanded risk between the existing and future conditions mapping.

Figure 2.60: Potential Expanded Risk between Existing and Future Conditions Floodplains



The largest increases in the potential future 100-year floodplain are seen in Collin, Dallas, Denton, Ellis, Navarro, and Tarrant counties. While Chambers County shows minimal increase from existing to future conditions, it must be noted that Chambers County has a high percentage of the land areas in the Trinity Region within the potential future floodplain (63 percent). This is because Chambers is a coastal county located along the Trinity Bay and East Bay with relatively flat terrain, which can be inundated with coastal flooding coupled with riverine flooding from the Trinity River. Hardin and Hood counties have less than 20 percent of their land area in the Trinity Region and, therefore, exhibit small floodplain area percentages. *Table 2.33* shows the floodplain area increases between the existing and future conditions mapping, in addition to the percent county area in the potential future mapping.

Per the future conditions mapping methodology and *Figure 2.61,* the horizontal increases in potential future mapping extents are shown as a range of potential minimum and maximum extents.

Table 2.33: Future Conditions Flood Hazard Flood Type by County

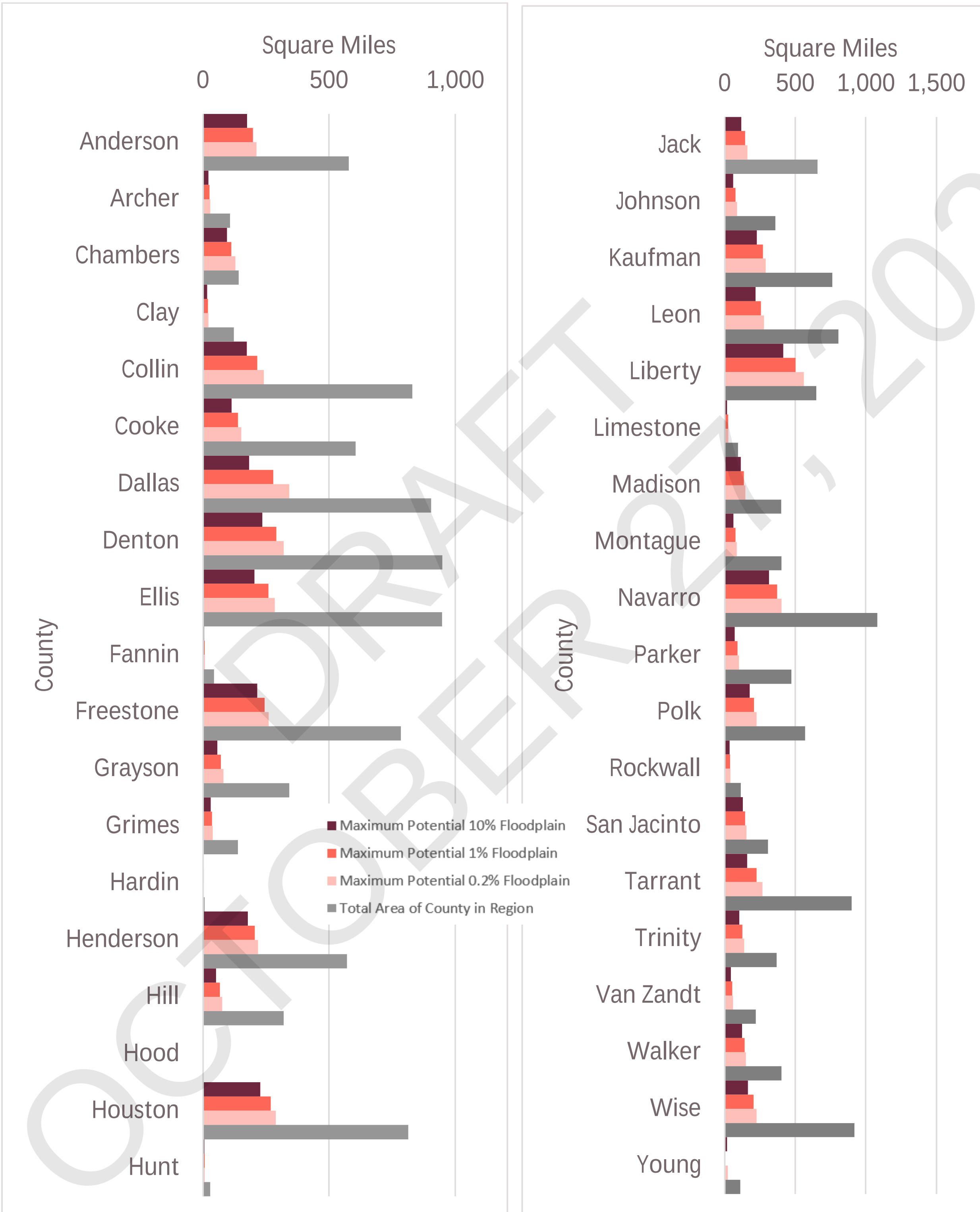
County	10% Annual Chance Flood Risk - Area in Riverine Flood Type (sq.mi.)	10% Annual Chance Flood Risk - Area in Coastal Flood Type (sq.mi.)	1% Annual Chance Flood Risk - Area in Riverine Flood Type (sq.mi.)	1% Annual Chance Flood Risk - Area in Coastal Flood Type (sq.mi.)	0.2% Annual Chance Flood Risk - Area in Riverine Flood Type (sq.mi.)	0.2% Annual Chance Flood Risk - Area in Coastal Flood Type (sq.mi.)
Anderson	175.6	-	23.1	-	13.8	-
Archer	21.6	-	4.4	-	3.1	-
Chambers	34.3	61.1	14.9	1.7	14.6	1.4
Clay	16.5	-	3.4	-	2.3	-
Collin	173.7	-	41.8	-	25.8	-
Cooke	113.7	-	25.4	-	12.6	-
Dallas	183.3	-	95.9	-	62.9	-
Denton	235.3	-	55.9	-	28.8	-
Ellis	204.7	-	54.7	-	26.1	-
Fannin	5.3	-	1.5	-	0.9	-
Freestone	215.3	-	28.9	-	17.0	-
Grayson	57.3	-	14.5	-	9.3	-
Grimes	30.6	-	5.3	-	3.5	-
Hardin	2.3	-	1.0	-	0.9	-
Henderson	178.3	-	26.9	-	13.7	-
Hill	52.6	-	14.6	-	8.7	-
Hood	0.3	-	0.1	-	0.0	-
Houston	227.5	-	41.1	-	20.1	-
Hunt	5.6	-	0.9	-	0.5	-

County	10% Annual Chance Flood Risk - Area in Riverine Flood Type (sq.mi.)	10% Annual Chance Flood Risk - Area in Coastal Flood Type (sq.mi.)	1% Annual Chance Flood Risk - Area in Riverine Flood Type (sq.mi.)	1% Annual Chance Flood Risk - Area in Coastal Flood Type (sq.mi.)	0.2% Annual Chance Flood Risk - Area in Riverine Flood Type (sq.mi.)	0.2% Annual Chance Flood Risk - Area in Coastal Flood Type (sq.mi.)
Jack	119.0	-	26.5	-	16.7	-
Johnson	61.2	-	16.3	-	9.8	-
Kaufman	228.0	-	44.6	-	19.6	-
Leon	218.6	-	39.1	-	21.4	-
Liberty	393.9	22.9	86.6	0.2	59.2	0.1
Limestone	18.7	-	5.5	-	2.6	-
Madison	115.5	-	20.5	-	10.8	-
Montague	63.3	-	14.8	-	8.1	-
Navarro	315.6	-	56.2	-	31.6	-
Parker	71.0	-	20.3	-	10.7	-
Polk	177.9	-	30.0	-	18.7	-
Rockwall	35.4	-	3.6	-	2.2	-
San Jacinto	129.2	-	16.2	-	10.0	-
Tarrant	159.4	-	66.6	-	41.7	-
Trinity	104.7	-	21.7	-	12.5	-
Van Zandt	45.6	-	8.2	-	5.1	-
Walker	123.6	-	17.7	-	9.9	-
Wise	166.1	-	39.8	-	20.7	-
Young	17.6	-	3.9	-	2.5	-

The 1% flood hazard does not incorporate the 10% flood hazard to avoid overlapping polygons

The 0.2% flood hazard does not incorporate the 1% flood hazard to avoid overlapping polygons

Figure 2.61: Future Conditions Flood Hazard Areas (in sq mi) by County



Data Gaps

Future conditions mapping data gaps include the existing conditions data gaps in addition to the unavailability of extensive detailed study future flood models and associated mapping data in the Trinity Region.

Modeling Uncertainties and Limitations

It is important to acknowledge that all flood models are subject to uncertainty due to the inherent limitations of input data sources and model assumptions. While the Fathom Phase II study represents a significant methodological improvement for statewide future conditions mapping, understanding its limitations is key to the appropriate application of its data. The key sources of uncertainty in this project are summarized in *Table 2.34*.

Table 2.34: Uncertainties and Limitations of Fathom Models

Uncertainty Source	Description	Impact on Model Outputs
Terrain Data (DEM)	LiDAR with varying dates/sources; gaps filled with alternate datasets	Inaccurate elevations affect floodplain boundaries; artifacts (striping, gaps)
Channel Bathymetry	Estimated via slope/width; no direct surveys	Potential over/under-estimation of flow depths
Boundary Conditions	Inputs from RFFA, NOAA, GCMs (rainfall, discharge, storm surge)	Sensitive to climate scenarios; changes flood extent predictions
Climate Change Factors	Based on GCM ensembles; scenarios at 17%, 50%, 83% percentiles	Varying future scenarios; large influence on flood risk projections
Manning's n	Derived from LULC proxies; no field validation	Affects flood wave dynamics; depth and speed of water may vary
Levee & Defenses	USACE data; may miss small, local defenses	Underestimation of protection levels in some areas
Land Subsidence	Kriging of NOAA & HGSD GPS data; projected to 2060	Increases flood susceptibility in subsiding areas
Drainage Systems	Urban drainage/stormwater systems not fully modeled; generalized standards	Urban flood levels may be overestimated (if good drainage) or underestimated (if poor drainage)

The model's foundational accuracy is highly dependent on its representation of the ground surface. While the model uses the best available high-resolution LIDAR for its Digital Elevation Model (DEM), this terrain data comes from various sources collected in different years, which can introduce minor inconsistencies or fail to capture recent land surface changes. Similarly, since direct surveys of river channel bathymetry are not available statewide, channel depths are estimated using proxies like river width and slope, which may lead to over- or under-estimation of flow depths in certain areas.

The water that drives the floods—the model's boundary conditions—is another source of uncertainty. These inputs for rainfall, river discharge, and storm surge are derived from statistical analyses and are most uncertain for very extreme, rare events. This uncertainty is magnified when projecting into the future. The future climate change factors are derived from ensembles of Global Climate Models (GCMs), which produce a wide spread of possible outcomes. To account for this, the study provides multiple scenarios (minimal, moderate, and significant) that have a large influence on the final flood risk projections.

Finally, the model must make simplifying assumptions about how water interacts with natural and man-made features. The friction of the land surface, or Manning's n, is derived from land use data and affects the simulated speed and depth of floodwaters. The model incorporates major flood defenses from the USACE National Levee Database but may miss smaller, local levees, potentially overestimating flood risk in those specific areas. Conversely, urban drainage systems are represented by generalized standards rather than being explicitly modeled, which could lead to an overestimation of flooding in areas with good drainage or an underestimation where drainage is poor.

Future Conditions Flood Exposure Analysis

The 2060 TWDB scenario 3 cursory floodplain mapping was used to develop the 30-year potential future conditions floodplain quilt for the Trinity Region. For this planning cycle, the potential future flood exposure and vulnerability analysis consisted of two approaches/components:

- Approach 1 - Future Exposure and Vulnerability with Existing Development: Estimated the structure count and vulnerability of existing buildings, critical facilities, infrastructure systems, population, and agriculture potentially exposed to flooding by overlaying the future conditions floodplain quilt developed for the Trinity Region o
- Approach 2 - Future Exposure and Vulnerability with Future Development: Estimated additional exposure and vulnerability by identifying areas of existing and known flood hazard and future flood hazard areas where development might occur within the next 30 years if the current land development practices in the Trinity Region continues

Approach 1 – Future Exposure and Vulnerability with Existing Development

The 30-year potential future conditions floodplain quilt was overlaid with the same GIS layers (buildings, critical facilities, agricultural areas, roads, and LWCs) as in *Task 2A* to get an estimation of exposure to the future mapping based on existing development. For population estimates, the greater of the day or night population attributes was used for the exposure population estimates per TWDB guidance. Using the TWDB future conditions flood data for year 2060 (Scenario 3), approximately 275,000 existing buildings in the TWDB database are partially or completely within the future conditions floodplains.

Buildings, Critical Facilities, Infrastructure, and Agriculture Exposure Totals by County

Figure 2.62 shows the total exposure counts of buildings, critical facilities, infrastructure, and agriculture by county of existing development to the future floodplains. The highest counts are in the populated areas of Collins, Dallas, Denton, and Tarrant counties in the Upper Subregion. Chambers, Henderson, and Liberty counties also show significant counts.

Residential Population Exposure Totals by County

Figure 2.63 shows the residential population exposure to the future floodplain quilt by county. As shown in *Figure 2.62*, high populations exposures occur in the Collin, Dallas, Denton, and Tarrant counties in the Upper Subregion, as well as the coastal Liberty County in the Lower Subregion. Because the population count is the greater of the day or night numbers, the worst possible scenario was assumed where the maximum number of people present are exposed to the future conditions floodplain quilt.

Figure 2.62: Potential Future Development (Total Count of Buildings, Agricultural Land, and Infrastructure) Exposure in Future Conditions Floodplain Quilt by County

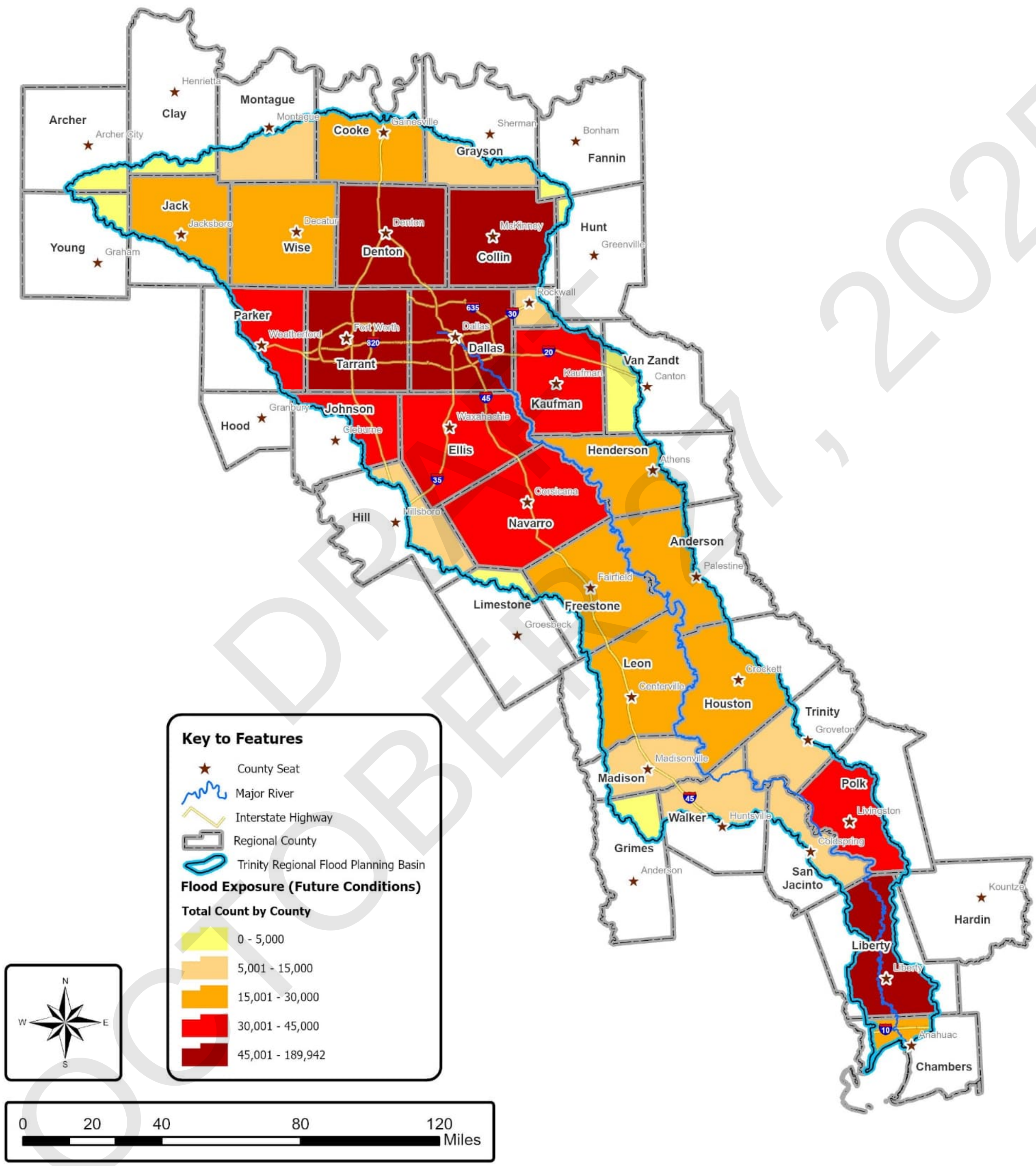
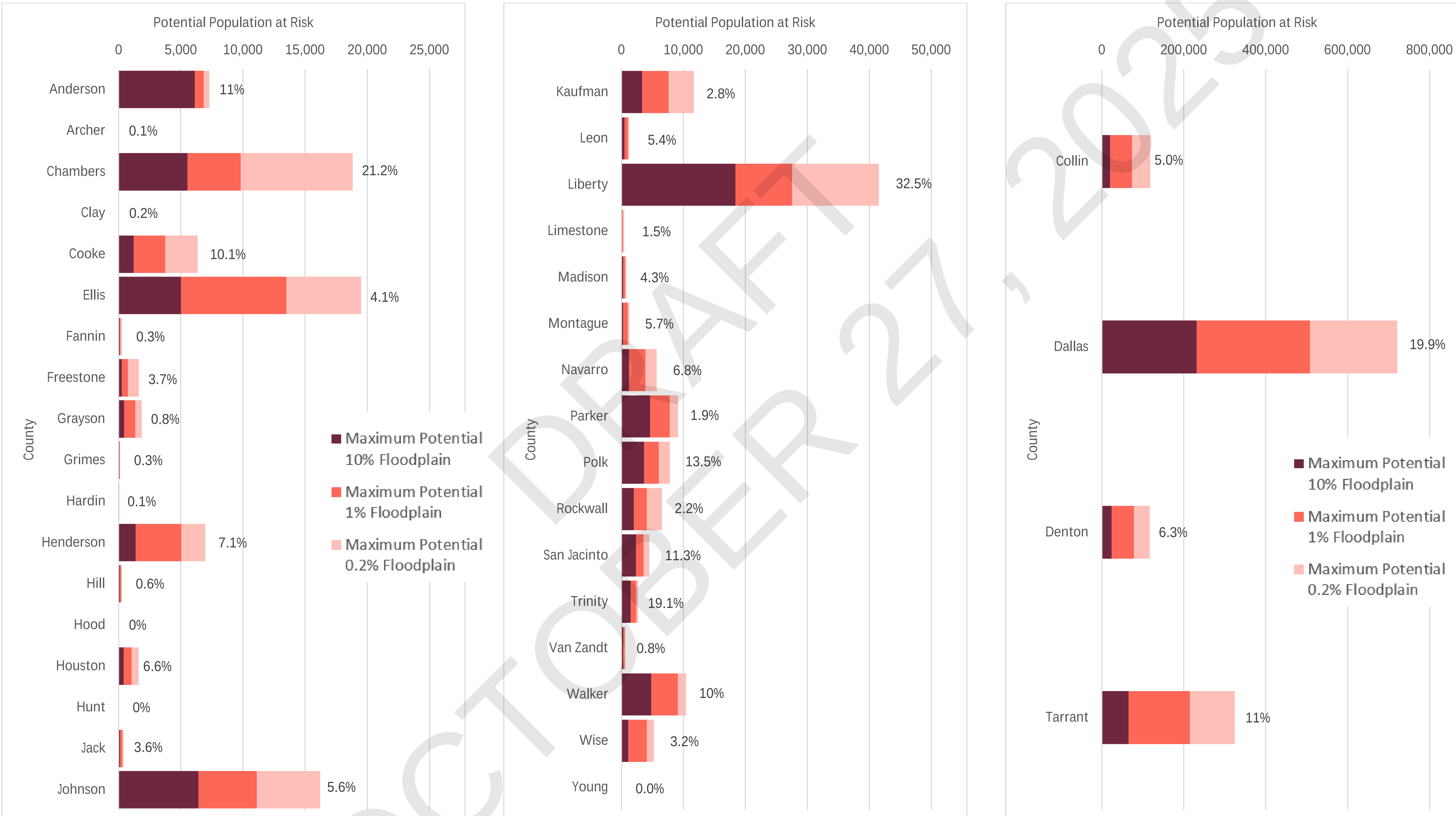


Figure 2.63: Potential Population at Risk in Future Conditions Floodplain Quilt



Building Exposure Totals by County

Figure 2.64 shows the existing building type exposure distribution in the Trinity Region with the future conditions floodplain quilt.

Residential Properties

Figure 2.65 shows the maximum residential exposure additions to the existing conditions floodplain quilt exposure estimates, that result in the exposure counts for the potential future conditions 10-year, 100-year and 500-year mapping. The largest increases occur in Collin, Dallas, Denton, Liberty, and Tarrant counties. Chambers, Ellis, Henderson, Johnson, Kaufman, Polk, and San Jacinto counties also showed significant increases in exposure to the future floodplain.

Non-Residential Properties

Figure 2.66 shows the total exposure counts by county of existing non-residential buildings to the future floodplains. In addition, *Figure 2.67* includes a comparison exposure to existing conditions. The upper chart in *Figure 2.67* refers to existing conditions exposure while the lower chart applies to future conditions exposure. Overall, increases in exposure to the future floodplains for all non-residential buildings are projected, with the largest increases in Collin, Dallas, Denton, and Tarrant counties. Tarrant County has very little agricultural exposure to floodplains. Dallas, Ellis, and Tarrant counties show industrial buildings in the floodplain with increases in exposures from existing to the future floodplains. The comparison chart also reveals that the agriculture sector has a very small percentage of non-residentials structures. Flood exposure can be extensive across several counties and significant.

Critical Facilities Exposure Totals by County

The Trinity Region's existing critical facilities exposure to the potential future conditions mapping is shown in *Figure 2.68*. The largest increases occur in Collin, Dallas, Denton, Liberty, and Tarrant counties. Chambers, Ellis, Henderson, Johnson, Kaufman, and Navarro counties also show significant increases.

Roadway Crossings and Roadway Segments

Road and railroad crossing in the Trinity Region at risk of flooding to future conditions mapping are shown in *Figure 2.69*.

Agricultural Areas and Crop Values

Crop and livestock production dollar losses due to the 30-year future conditions mapping are summarized in *Table 2.35* and *Table 2.36* and *Figure 2.70*. Anderson, Cooke, Collin, Denton, Ellis, Freestone, Henderson, Hill, Houston, Kaufman, Jack, Leon, Liberty, Limestone, Madison, Navarro, Van Zandt, and Wise counties have high agriculture exposure values to the future conditions mapping. The largest increases from existing conditions to future conditions were seen in Clay, Denton, Ellis, Fannin, Hill, Hunt, Leon, Limestone, and Van Zandt counties.

Figure 2.64: Building Type Distribution in the Future Conditions Floodplain Quilt

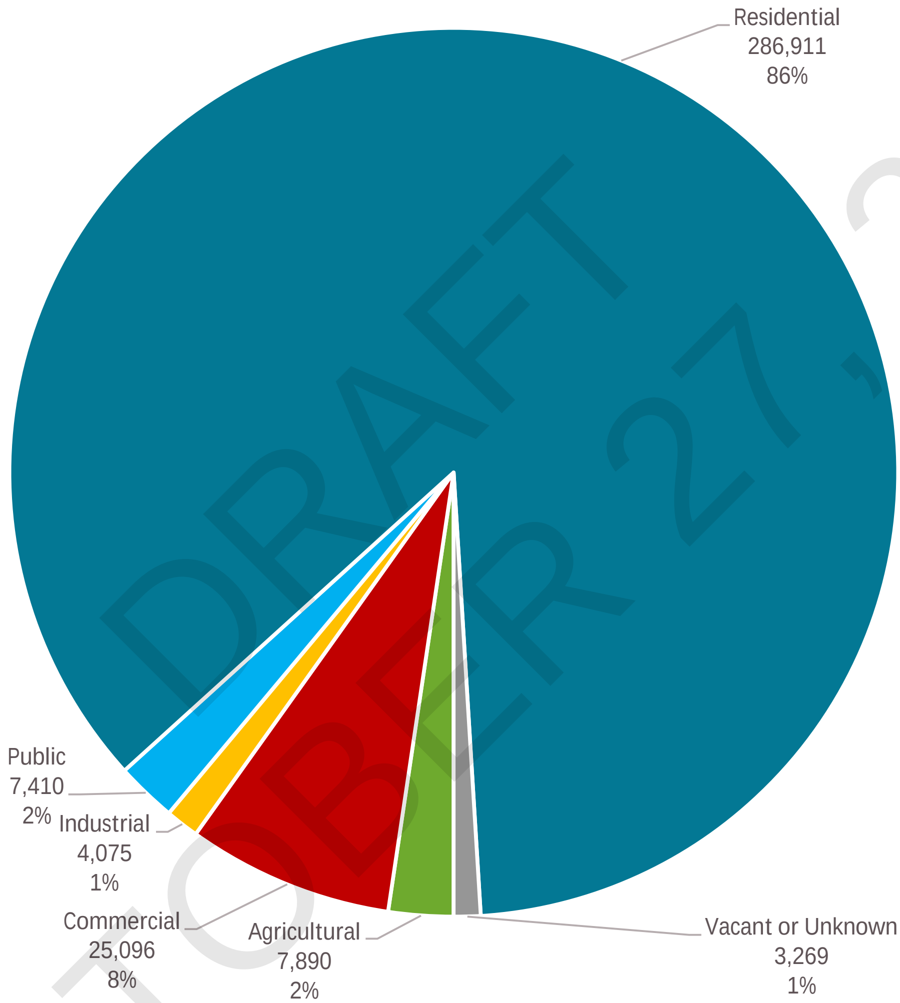


Figure 2.65: Potential Residential Structures at Risk in Future Conditions Floodplain Quilt

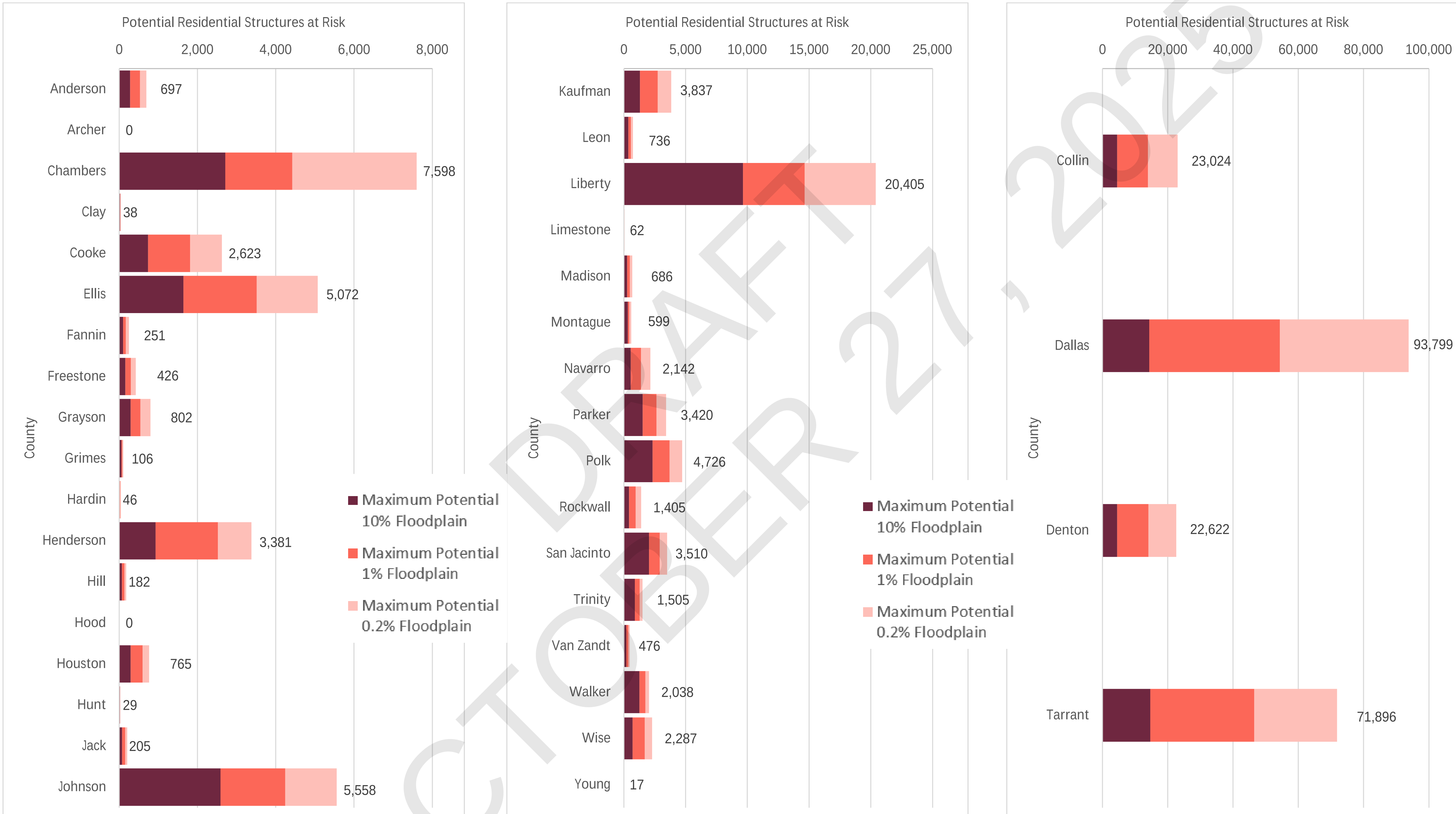


Figure 2.66: Potential Non-Residential Structures at Risk in Future Conditions Floodplain Quilt

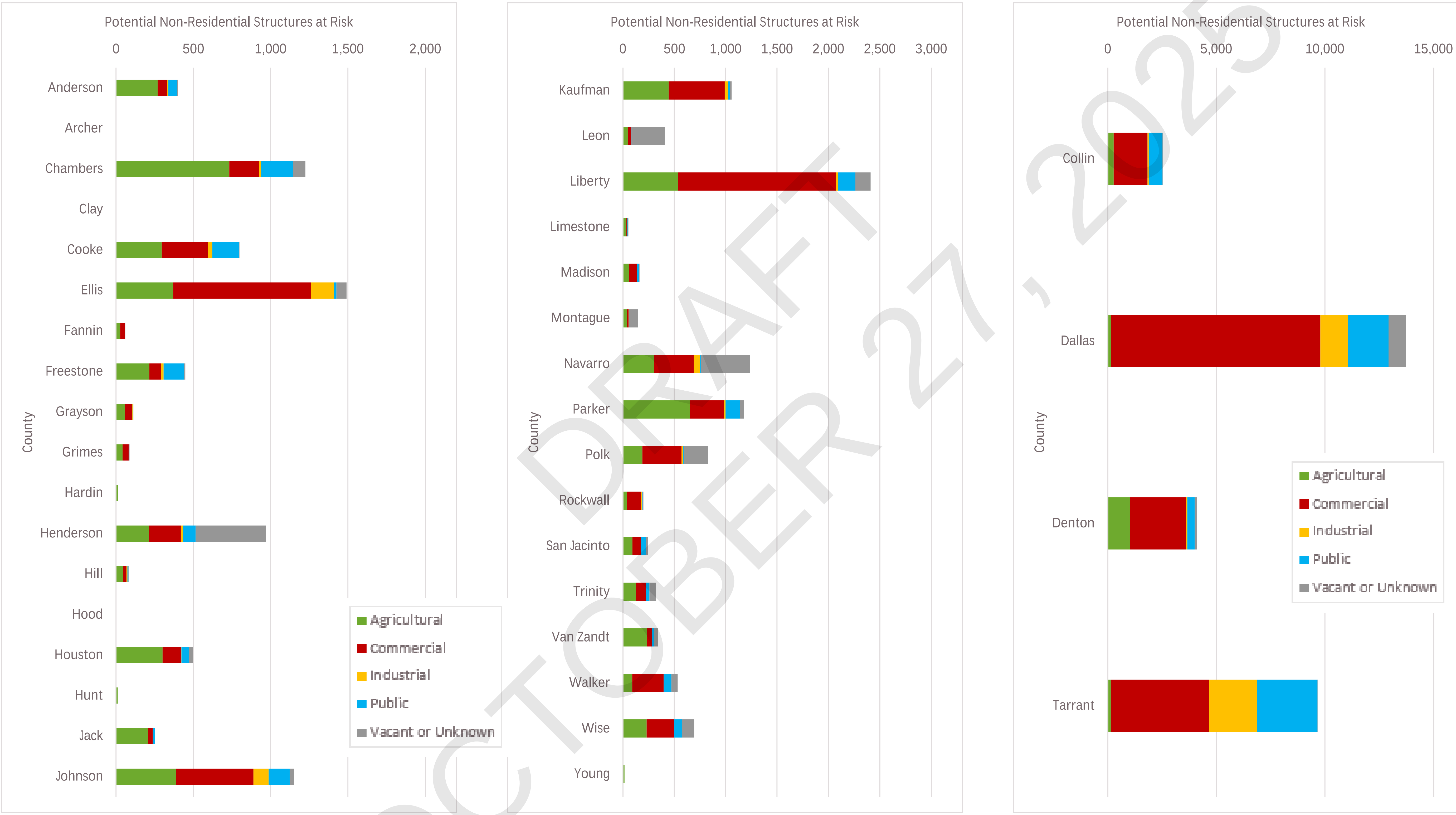


Figure 2.67: Comparison of Existing and Future Conditions Non-Residential Structures at Risk

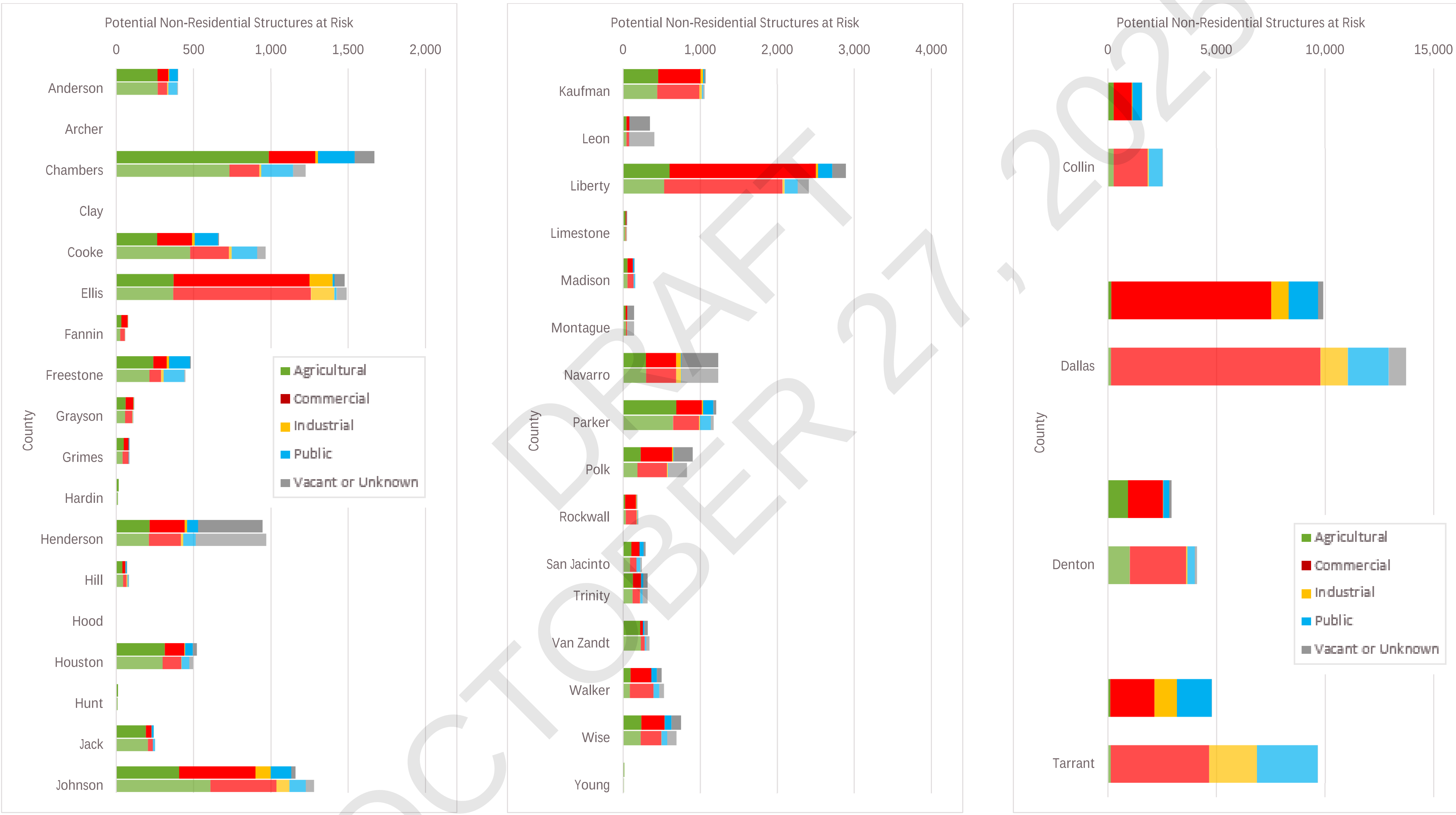


Figure 2.68: Potential Critical Facilities at Risk in Future Conditions Floodplain Quilt

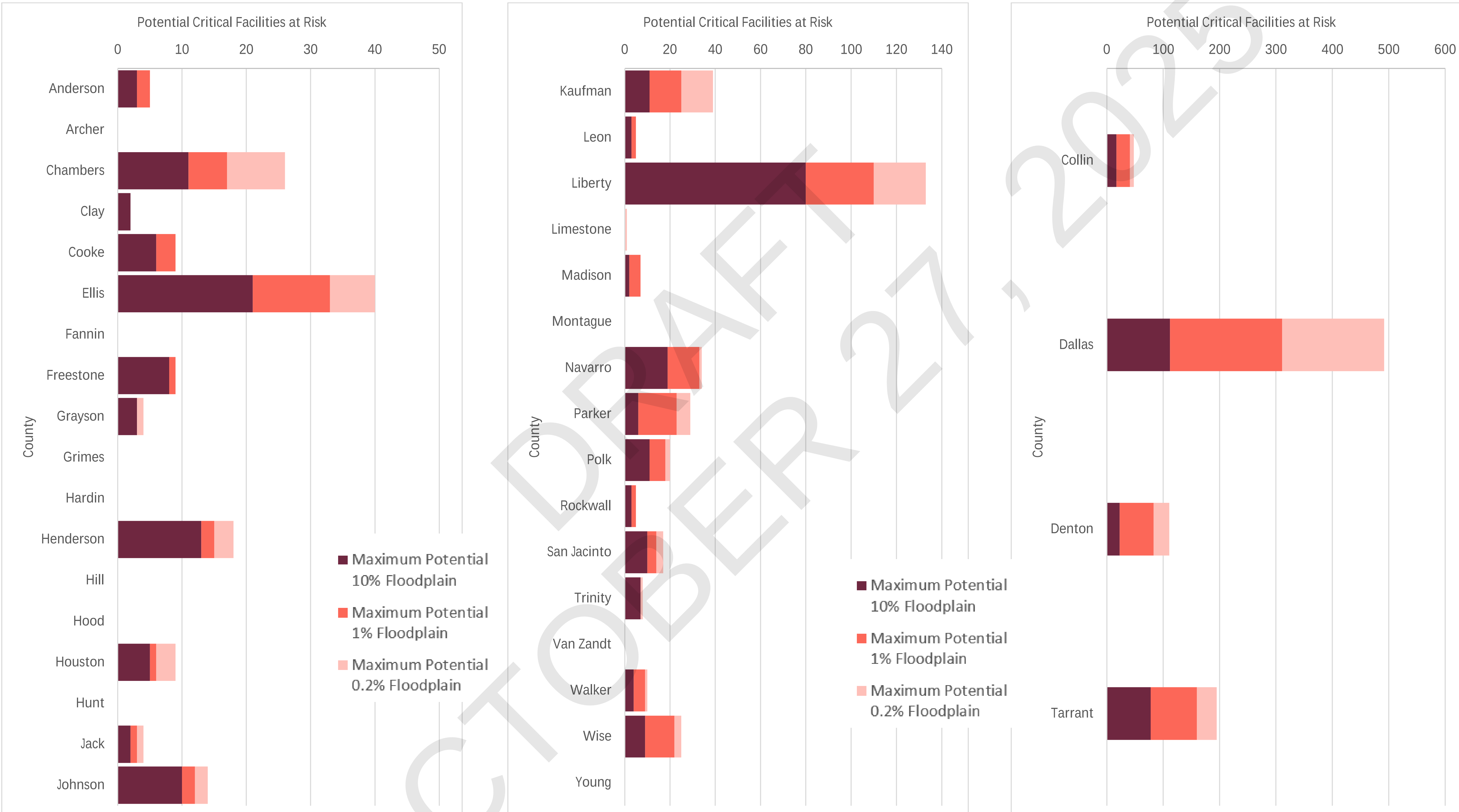


Figure 2.69: Linear Miles of Roadway at Risk in Future Conditions Floodplain Quilt

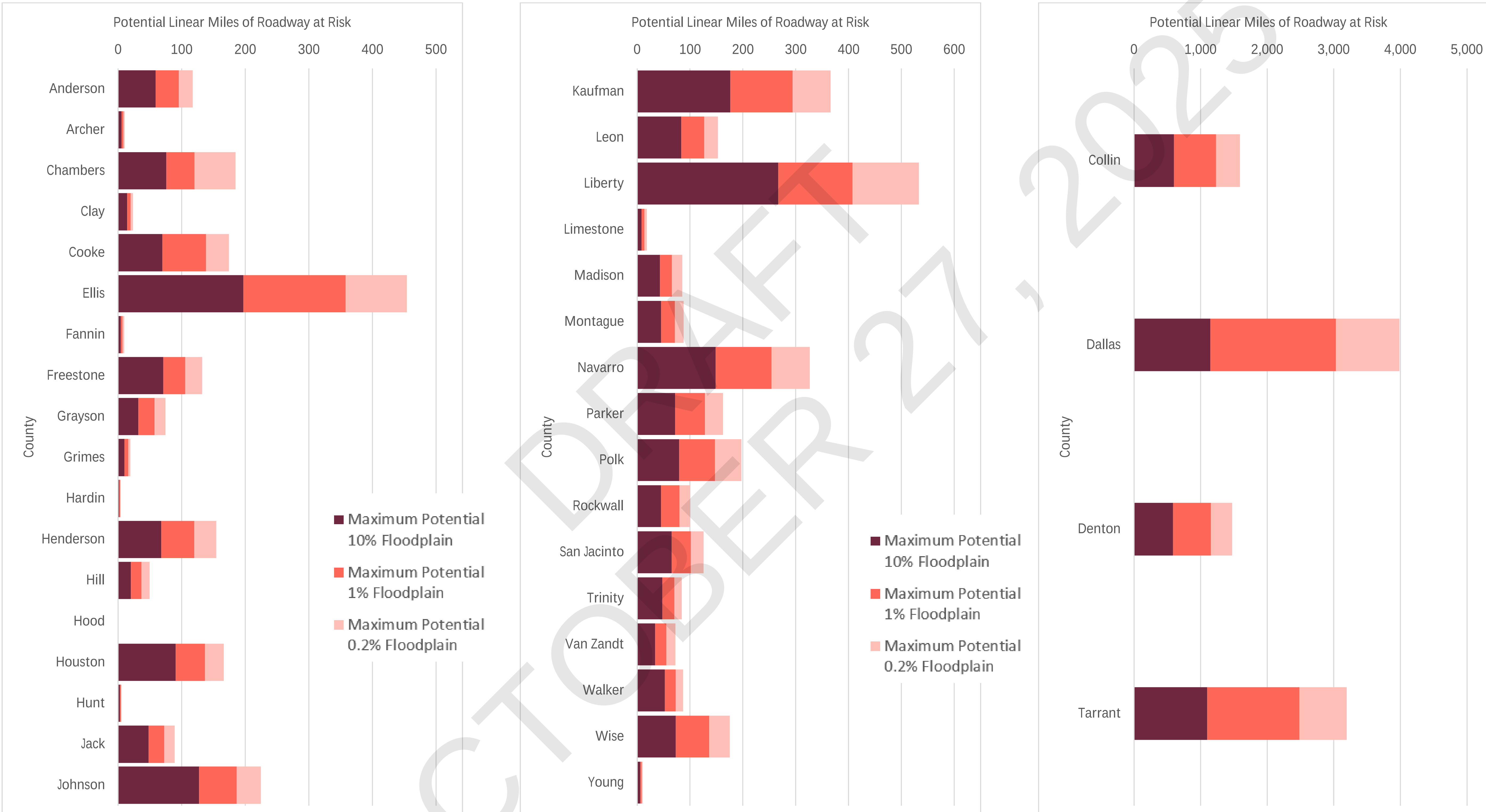


Figure 2.70: Agricultural Land at Risk in Future Conditions Floodplain Quilt

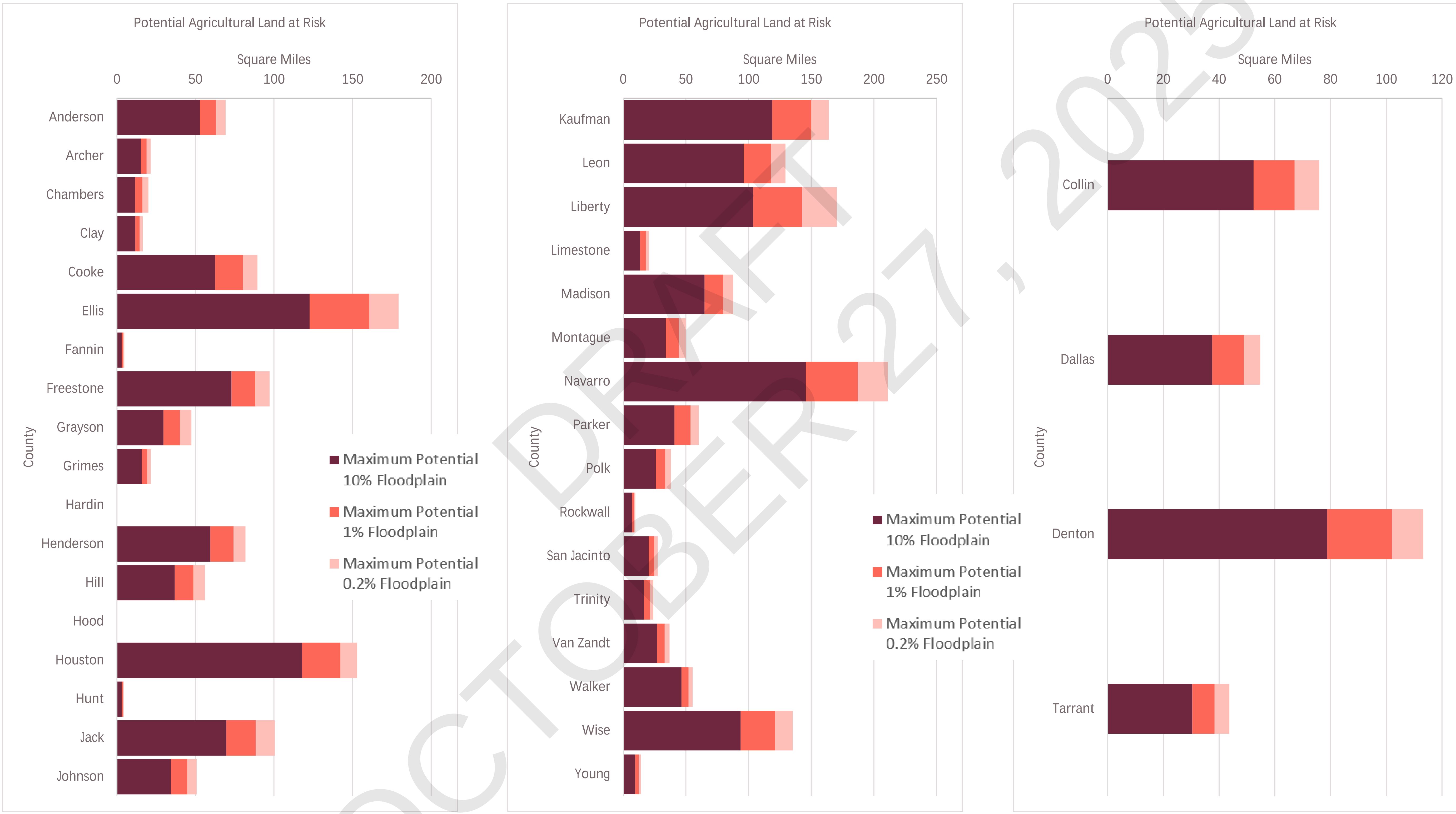


Table 2.35: Exposed Crop (Farming) Production Dollar Losses in Future Conditions Floodplain Quilt

County	$ Losses in Future 10-Year	$ Losses in Future 100-Year	$ Losses in Future 500-Year
Anderson	$24,077,227	$427,387	$7,811
Archer	$824,765	$273,077	$151,513
Chambers	$23,153,086	$3,533,920	$11,042,093
Clay	$216,511	$161,599	$133,661
Collin	$4,278,046	$1,619,547	$998,187
Cooke	$2,407,999	$741,785	$344,071
Dallas	$10,944,682	$892,892	$1,229,490
Denton	$2,751,940	$984,102	$506,642
Ellis	$8,401,354	$2,659,361	$1,318,671
Fannin	$1,482,580	$852,120	$652,691
Freestone	$2,834,479	$150,575	$9,232
Grayson	$2,103,564	$1,196,759	$872,003
Grimes	$0	$0	$0
Hardin	$0	$0	$0
Henderson	$8,844,016	$344,822	$137,530
Hill	$8,567,892	$3,764,352	$2,669,074
Hood	$6,687,249	$209,802	$458,047
Houston	$9,753,021	$393,060	$157,854
Hunt	$230,509	$213,166	$89,833
Jack	$400,675	$135,652	$87,891
Johnson	$1,958,859	$784,206	$522,336
Kaufman	$5,669,764	$887,381	$108,848
Leon	$2,078,689	$250,127	$125,339
Liberty	$10,337,089	$3,820,571	$1,946,553
Limestone	$1,637,405	$508,802	$323,170
Madison*	$0	$0	$0
Montague	$3,033,008	$851,840	$307,781
Navarro	$3,980,267	$1,207,559	$881,135
Parker	$1,376,445	$691,233	$375,373
Polk	$2,312,184	$138,353	$64,975
Rockwall	$262,368	$74,701	$45,791
San Jacinto	$3,525,402	$218	$0
Tarrant	$1,026,683	$537,339	$307,357
Trinity	$2,114,806	$286	$574
Van Zandt	$1,271,813	$165,869	$241,311
Walker	$7,768,896	$2,790	$543
Wise	$4,112,393	$1,421,816	$386,061
Young	$148,804	$102,429	$73,142.30

**USDA/NASS Crop and Livestock Values were unavailable for Madison County*

**The 1% flood hazard does not incorporate the 10% flood hazard to avoid overlapping polygons*

**The 0.2% flood hazard does not incorporate the 1% flood hazard to avoid overlapping polygons*

Table 2.36: Exposed Livestock (Ranching) Production Dollar Losses in Future Conditions Floodplain Quilt

County	$ Losses in Future 10-Year	$ Losses in Future 100-Year	$ Losses in Future 500-Year
Anderson	$31,380,296	$6,462,230	$4,021,539
Archer	$18,879,671	$4,396,673	$3,202,516
Chambers	$6,836,573	$2,903,312	$2,271,597
Clay	$8,751,386	$2,022,919	$1,412,881
Collin	$8,486,198	$2,250,600	$1,341,583
Cooke	$12,418,163	$3,516,166	$1,820,179
Dallas	$2,236,934	$849,463	$384,353
Denton	$20,158,289	$5,818,031	$2,789,015
Ellis	$4,978,335	$1,529,608	$746,669
Fannin	$4,689,396	$1,669,433	$990,530
Freestone	$20,292,649	$4,245,918	$2,493,396
Grayson	$5,249,791	$1,728,081	$1,168,420
Grimes	$11,363,210	$2,445,655	$1,617,948
Hardin	$527,408	$536,697	$707,830
Henderson	$6,262,214	$1,742,091	$904,710
Hill	$5,486,207	$1,569,107	$897,685
Hood	$690,159	$156,382	$122,342
Houston	$20,354,202	$4,361,852	$1,934,042
Hunt	$5,668,251	$1,254,207	$701,486
Jack	$6,130,119	$1,641,983	$1,067,209
Johnson	$6,538,995	$1,875,347	$1,085,526
Kaufman	$8,002,896	$2,260,012	$1,080,546
Leon	$52,656,134	$11,805,950	$6,434,874
Liberty	$12,522,264	$4,715,363	$3,470,054
Limestone	$14,286,618	$4,925,867	$2,325,985
Madison*	$0	$0	$0
Montague	$6,109,241	$1,858,403	$1,029,673
Navarro	$8,157,180	$2,300,093	$1,300,686
Parker	$8,152,921	$2,561,691	$1,302,863
Polk	$1,262,080	$369,698	$219,059
Rockwall	$369,248	$88,218	$52,299
San Jacinto	$1,942,287	$466,416	$286,056
Tarrant	$2,955,021	$760,498	$510,662
Trinity	$1,178,245	$352,986	$208,877
Van Zandt	$14,843,953	$3,340,624	$2,114,052
Walker	$5,532,350	$728,171	$424,134
Wise	$6,243,186	$1,813,242	$954,829
Young	$3,179,361	$925,363	$597,365

**USDA/NASS Crop and Livestock Values were unavailable for Madison County*

**The 1% flood hazard does not incorporate the 10% flood hazard to avoid overlapping polygons*

**The 0.2% flood hazard does not incorporate the 1% flood hazard to avoid overlapping polygons*

Hardin County had no agricultural exposure in the Trinity Region. (Less than one percent of the land area of Hardin County is in the Trinity Region.) Even though Madison County showed a large agriculture area exposure to the future conditions mapping (a little more than Anderson County), no data is available from the 2022 USDA Census of Agriculture County Profiles.

Approach 2 – Future Exposure and Vulnerability with Future Development

Estimated Future development in the Floodplain (Do Nothing Scenario): Current development trends, combined with future population projections, are used to estimate future developments within future conditions floodplains. The United States Census Bureau's County level annual building permits survey data from 1991 to 2024 (33 years) along with TWDB's population projections are used to determine the average number of new building permits per unit change in population for each county in the Trinity Region. The number of new permits is divided by the change in population for each year from 1991 to 2024. The average over the 33-year period is reported as the average number of permits per unit population change.

The county-specific number of permits per unit change in population is multiplied by the respective county level change in population between existing and future conditions to estimate the potential number of new buildings in the future. The TWDB's county level population data (supplemented with Esri demographic data) for 2025 and 2060 is used to determine the county change in population between existing and future conditions.

Table 2.37 summarizes the county level number of permits per unit change in population (as determined from United States Census data), existing and future populations, and existing and future estimated buildings in the Trinity Region.

Table 2.37: Estimated Future Development per County

County	Average # Permits per Unit Population Change	Existing Buildings (TWDB 2025)	Existing County Population (TWDB 2025)	Future County Population (TWDB 2060)	Future Additional Buildings (Estimated 2060)	Future Total Buildings (Estimated 2060)
Anderson	0.085	18,411	57,333	63,746	512	7,561
Archer	1.440	199	8,932	9,960	0	0
Chambers	0.419	13,683	55,993	88,999	5161	24,686
Clay	0.613	840	10,110	11,503	103	18
Collin	0.284	271,492	1,252,112	2,373,092	16046	70,119
Cooke	0.225	27,243	42,973	62,905	3999	5,798
Dallas	0.592	691,873	2,672,301	3,627,334	119954	401,516
Denton	0.196	235,409	1,050,039	1,866,215	23020	74,972
Ellis	0.254	72,106	232,869	479,939	6655	29,082
Fannin	0.120	4,488	36,980	101,706	435	614
Freestone	0.114	16,193	20,335	44,475	1248	2,390
Grayson	0.244	14,156	150,459	242,865	880	1,654
Grimes	0.119	2,933	33,220	38,277	299	108
Hardin	0.321	131	58,430	71,410	2	73
Henderson	0.190	39,502	84,571	97,557	6709	5,094
Hill	0.125	5,953	38,071	44,937	188	280
Hood	0.120	50	66,156	88,785	0	0
Houston	0.070	14,849	21,721	24,260	1284	1,246
Hunt	0.230	892	116,564	271,952	43	35
Jack	0.061	6,450	8,896	11,190	509	392
Johnson	0.270	49,936	210,562	291,047	5083	16,824
Kaufman	0.120	58,051	197,985	423,277	4360	17,377
Leon	0.017	16,486	16,401	23,340	1148	1,358
Liberty	0.852	32,123	112,075	128,028	19752	43,856
Limestone	0.253	2,868	21,767	30,206	142	326
Madison	0.097	10,103	13,534	18,886	936	755
Montague	0.051	10,836	21,570	22,223	776	1,130
Navarro	0.235	32,921	56,809	83,221	4252	5,099
Parker	0.134	51,043	168,625	472,097	4376	27,373
Polk	2.435	25,215	54,807	58,008	11158	7,411
Rockwall	0.303	24,743	131,655	291,850	2525	9,942
San Jacinto	0.463	14,205	29,566	39,789	7405	5,618
Tarrant	0.294	614,685	2,228,987	2,978,034	68399	130,629
Trinity	0.063	9,647	13,408	14,130	3171	2,339
Van Zandt	0.046	12,766	61,915	76,407	896	603
Walker	0.208	17,725	83,036	102,757	3895	12,308

County	Average # Permits per Unit Population Change	Existing Buildings (TWDB 2025)	Existing County Population (TWDB 2025)	Future County Population (TWDB 2060)	Future Additional Buildings (Estimated 2060)	Future Total Buildings (Estimated 2060)
Wise	0.074	41,993	80,723	162,282	3582	8,765
Young	0.165	538	17,738	34,274	25	12

Future development Exposure with Floodplain Management Variables: Future Developments within Future Conditions Floodplains section discuss future developments in the floodplain (Do Nothing Scenario) and estimate the number of potential buildings per county in 2060 using the number of permits per unit change in population. However, the number of permits per unit change in population in the future conditions floodplains are not expected to be the same as the county level values since development in future conditions floodplains are likely to be regulated by floodplain regulations (assuming existing floodplain management practices do not change). Therefore, four criteria are used to determine weighting factors for development in the future conditions floodplains:

- FEMA's Community Rating System (CRS)
- Participation in the NFIP
- Adoption of higher standards
- Presence or absence of a Hazard Mitigation Plan (HMP)

Figures showing spatial distribution of these factors in the Trinity Region are included in *Appendix B*. CRS applicable discounts ranging from 0 to 45 percent are converted to normalized scores ranging from 0 to 1. For example, a community with a CRS rating of 5 (or 25 percent discount) receives a score of 0.56. Each community is assigned a score of 1 or 0 depending on participation or non-participation in NFIP, respectively. Similarly, a score of 1 is assigned to communities adopting higher standards and 0 for others. Communities with a HMP are assigned a score of 1 and 0 for those without a HMP. The community level scores for each criterion are averaged at the county level. Each county level criterion is assigned an equal weight of 0.25 and is summed to generate one weighted score for each county. A higher score implies more rigorous regulations associated with floodplain development. Therefore, a county with a weighted score of 1 implies that the likelihood of floodplain development is close to 0. The floodplain number of permits per unit change in population for such instance is 0 or county level number of permits per unit change in population multiplied 1 minus the weighted score. The weighting factors are determined as 1 minus the weighted scores and are subsequently multiplied by the county level number of permits per unit change in population to determine floodplain number of permits per unit change in population. *Table 2.38* summarizes the scores for each criterion, weighting factor, and floodplain number of permits per unit change in population by county in the Trinity Region.

Table 2.38: Development Factor Per Unit Change in Population

County	Average # Permits per Unit Population Change	NFIP Score	CRS Score	HMP Score	Higher Standards Score	Weighting Factor	Floodplain # Permits per Unit Population Change
Anderson	0.09	1	0	0	0.67	0.58	0.05
Archer	1.44	1	0	0	0	0.75	1.08
Chambers	0.42	1	0.03	0	0.86	0.53	0.22
Clay	0.61	1	0	0	1	0.5	0.31
Collin	0.28	0.96	0	0.88	0.79	0.34	0.1
Cooke	0.23	0.88	0	0	0.63	0.62	0.14
Dallas	0.59	1	0.04	0.08	0.96	0.48	0.28
Denton	0.2	0.91	0.01	0.67	0.85	0.39	0.08
Ellis	0.25	0.88	0	0.94	0.75	0.36	0.09
Fannin	0.12	1	0	1	0.67	0.33	0.04
Freestone	0.11	0.67	0	0	0	0.83	0.09
Grayson	0.24	0.7	0	1	0.8	0.38	0.09
Grimes	0.12	0.33	0	1	0	0.67	0.08
Hardin	0.32	1	0	0	1	0.5	0.16
Henderson	0.19	1	0	0	0.92	0.52	0.1
Hill	0.13	0.63	0	0	0.63	0.69	0.09
Hood	0.12	1	0	0	0.5	0.63	0.07
Houston	0.07	0.8	0	1	0.4	0.45	0.03
Hunt	0.23	1	0	1	1	0.25	0.06
Jack	0.06	1	0	0	0	0.75	0.05
Johnson	0.27	0.9	0	0.1	0.5	0.63	0.17
Kaufman	0.12	0.63	0	0.38	0.63	0.59	0.07
Leon	0.02	0.86	0	0	0.57	0.64	0.01
Liberty	0.85	1	0	0	0.5	0.63	0.53
Limestone	0.25	0.75	0	0.25	0	0.75	0.19
Madison	0.1	0.67	0	0.33	0.67	0.58	0.06
Montague	0.05	1	0	0	0.67	0.58	0.03
Navarro	0.23	0.63	0	0.16	0.47	0.69	0.16
Parker	0.13	0.91	0	0.09	0.64	0.59	0.08
Polk	2.44	0.8	0	0	0.6	0.65	1.58
Rockwall	0.30	0.83	0	0	0.67	0.63	0.19
San Jacinto	0.46	1	0	0	0.75	0.56	0.26
Tarrant	0.29	1	0.03	0	0.94	0.51	0.15
Trinity	0.06	1	0	0	0.33	0.67	0.04
Van Zandt	0.05	1	0	0	1	0.5	0.02
Walker	0.21	1	0	0	0.33	0.67	0.14
Wise	0.07	0.85	0	0.38	0.62	0.54	0.04
Young	0.16	1	0	0	1	0.5	0.08

The 2025 TWDB buildings dataset is used to determine the existing structure and exposed population in the existing and future 10-year, 100-year and 500-year floodplains. The exposed population in the floodplains at the county level divided by the existing population provides an estimate of the percent of the county population exposed to flood risk. Assuming that the percent of exposed population at the county level in the future conditions floodplains remains unchanged from existing conditions, the existing percent exposed population multiplied by the future county population provides the future exposed population in the future conditions floodplains. The additional future population in the future conditions floodplains multiplied by the floodplain number of permits per unit population change provides an estimate of additional future buildings in future conditions floodplains. *Table 2.39*, *Table 2.40*, and *Table 2.41* summarize the existing buildings and population in the existing conditions floodplains, and future estimated buildings and population in future conditions floodplains. For these tables, the 1% flood hazard does not incorporate the 10% flood hazard and the 0.2% flood hazard does not incorporate the 1% flood hazard to avoid overlapping polygons.

Future Conditions Vulnerability Analysis

Vulnerabilities of Structures, Low Water Crossings, and Critical Facilities

The 2025 TX F-SVI data was used to estimate community vulnerability in the context of the potential future conditions flood quilt. The SVI values for all the structures, critical facilities, and LWCs exposed to the future conditions floodplain quilt are summarized by county average and shown in *Figure 2.71*.

Table 2.39: Estimated Building and Population in Existing and Future Floodplain (10-Year)

County	Existing Buildings in Existing Floodplain	Existing Population in Existing Floodplain	Existing Buildings in Future Floodplain	Future Buildings in Future Floodplain	Future Population in Future Floodplain
Anderson	83	51	490	490	57
Archer	-	-	-	-	-
Chambers	2,924	4,701	3,436	4,048	7,472
Clay	8	5	24	24	6
Collin	762	2,509	5,544	5,762	4,755
Cooke	534	515	1,180	1,214	754
Dallas	4,366	36,678	18,850	22,576	49,786
Denton	1,738	2,536	6,467	6,618	4,507
Ellis	691	1,172	2,429	2,542	2,415
Fannin	69	38	135	138	105
Freestone	251	116	486	499	254
Grayson	146	151	356	365	244
Grimes	60	30	116	116	35
Hardin	15	22	21	22	27
Henderson	420	329	1,404	1,409	380
Hill	16	74	111	112	87
Hood	1	-	1	-	-
Houston	257	165	562	563	184
Hunt	8	3	26	26	7
Jack	53	11	215	215	14
Johnson	2,664	5,164	3,291	3,624	7,138
Kaufman	554	508	1,898	1,939	1,086
Leon	202	108	588	588	154
Liberty	9,980	15,305	11,300	12,460	17,484
Limestone	13	8	41	42	11
Madison	203	170	351	355	237
Montague	299	219	412	412	226
Navarro	790	393	1,368	1,397	576
Parker	1,327	3,955	2,198	2,761	11,073
Polk	2,103	2,767	2,853	3,109	2,929
Rockwall	148	319	525	598	707
San Jacinto	1,691	1,891	2,173	2,343	2,545
Tarrant	8,785	24,556	19,098	20,330	32,808
Trinity	850	1,280	1,086	1,089	1,349
Van Zandt	164	113	419	420	139
Walker	1,066	2,196	1,610	1,682	2,718
Wise	448	402	1,102	1,118	808
Young	16	1	22	22	2

Table 2.40: Estimated Building and Population in Existing and Future Floodplain (100-Year)

County	Existing Buildings in Existing Floodplain	Existing Population in Existing Floodplain	Existing Buildings in Future Floodplain	Future Buildings in Future Floodplain	Future Population in Future Floodplain
Anderson	610	6,433	444	480	7,153
Archer	1	5	2	3	6
Chambers	903	1,482	2,214	2,407	2,356
Clay	19	10	11	11	11
Collin	4,815	21,118	10,941	12,778	40,024
Cooke	1,175	1,482	1,430	1,526	2,169
Dallas	15,243	78,051	49,205	57,134	105,945
Denton	3,793	10,784	11,754	12,395	19,166
Ellis	2,881	8,001	2,578	3,348	16,490
Fannin	118	79	96	101	217
Freestone	377	585	259	325	1,279
Grayson	349	473	297	324	763
Grimes	73	36	51	51	41
Hardin	17	12	17	17	15
Henderson	2,109	3,351	2,091	2,142	3,866
Hill	123	90	110	111	106
Hood	1	-	1	-	-
Houston	648	683	536	539	763
Hunt	17	6	8	8	14
Jack	244	212	193	196	267
Johnson	1,833	4,020	2,107	2,366	5,557
Kaufman	2,240	4,937	1,909	2,306	10,555
Leon	567	599	392	395	852
Liberty	3,307	5,887	5,753	6,199	6,725
Limestone	54	118	50	59	164
Madison	315	263	297	303	367
Montague	194	226	179	179	233
Navarro	1,228	2,173	1,256	1,419	3,183
Parker	1,602	3,164	1,627	2,078	8,858
Polk	1,866	2,723	1,672	1,924	2,882
Rockwall	710	2,972	634	1,318	6,588
San Jacinto	1,109	1,366	987	1,110	1,838
Tarrant	7,384	28,481	37,063	38,492	38,052
Trinity	579	686	510	512	723
Van Zandt	347	256	292	293	316
Walker	824	3,578	673	791	4,428
Wise	1,415	2,970	1,276	1,395	5,971
Young	10	4	7	7	8

Table 2.41: Estimated Building and Population in Existing and Future Floodplain (500-Year)

County	Existing Buildings in Existing Floodplain	Existing Population in Existing Floodplain	Exiting Buildings in Future Floodplain	Future Buildings in Future Floodplain	Future Population in Future Floodplain
Anderson	257	316	282	284	351
Archer	1	-	0	0	-
Chambers	4,282	9,348	3,930	5,148	14,858
Clay	3	1	5	5	1
Collin	3,391	13,370	10,057	11,220	25,340
Cooke	523	1,964	1,053	1,181	2,875
Dallas	27,579	181,073	46,334	64,729	245,785
Denton	4,459	28,864	9,757	11,473	51,299
Ellis	1,652	4,938	2,013	2,488	10,177
Fannin	88	106	106	113	292
Freestone	182	392	241	285	857
Grayson	206	401	296	319	647
Grimes	40	28	48	48	32
Hardin	26	25	25	26	31
Henderson	616	735	1,194	1,205	848
Hill	69	74	74	75	87
Hood	-	-	-	-	-
Houston	270	268	286	287	299
Hunt	14	6	10	10	14
Jack	108	88	141	142	111
Johnson	1,342	2,987	1,634	1,827	4,129
Kaufman	1,084	2,683	1,429	1,645	5,736
Leon	179	247	260	261	352
Liberty	8,362	17,199	6,651	7,954	19,647
Limestone	37	109	42	50	151
Madison	150	108	240	242	151
Montague	139	651	209	210	671
Navarro	688	915	1,082	1,150	1,340
Parker	903	2,658	1,100	1,479	7,442
Polk	1,136	1,512	1,237	1,376	1,600
Rockwall	297	1,194	509	784	2,647
San Jacinto	717	918	686	769	1,235
Tarrant	11,922	44,736	28,734	30,979	59,769
Trinity	260	253	287	288	267
Van Zandt	165	120	184	185	148
Walker	409	4,171	377	515	5,162
Wise	740	988	837	876	1,986
Young	3	1	4	4	2

Figure 2.71: Future Conditions Social Vulnerability Index by County

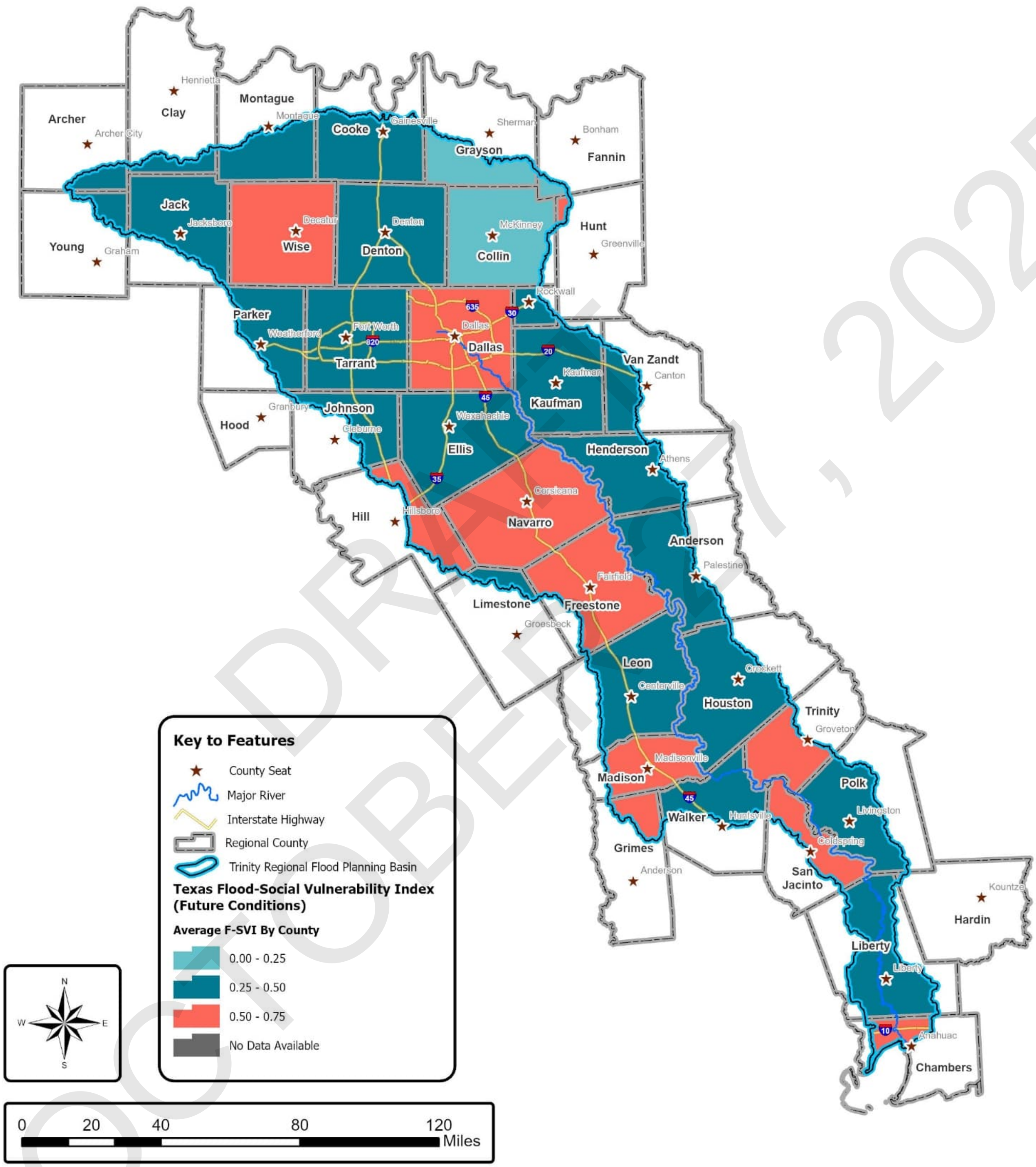
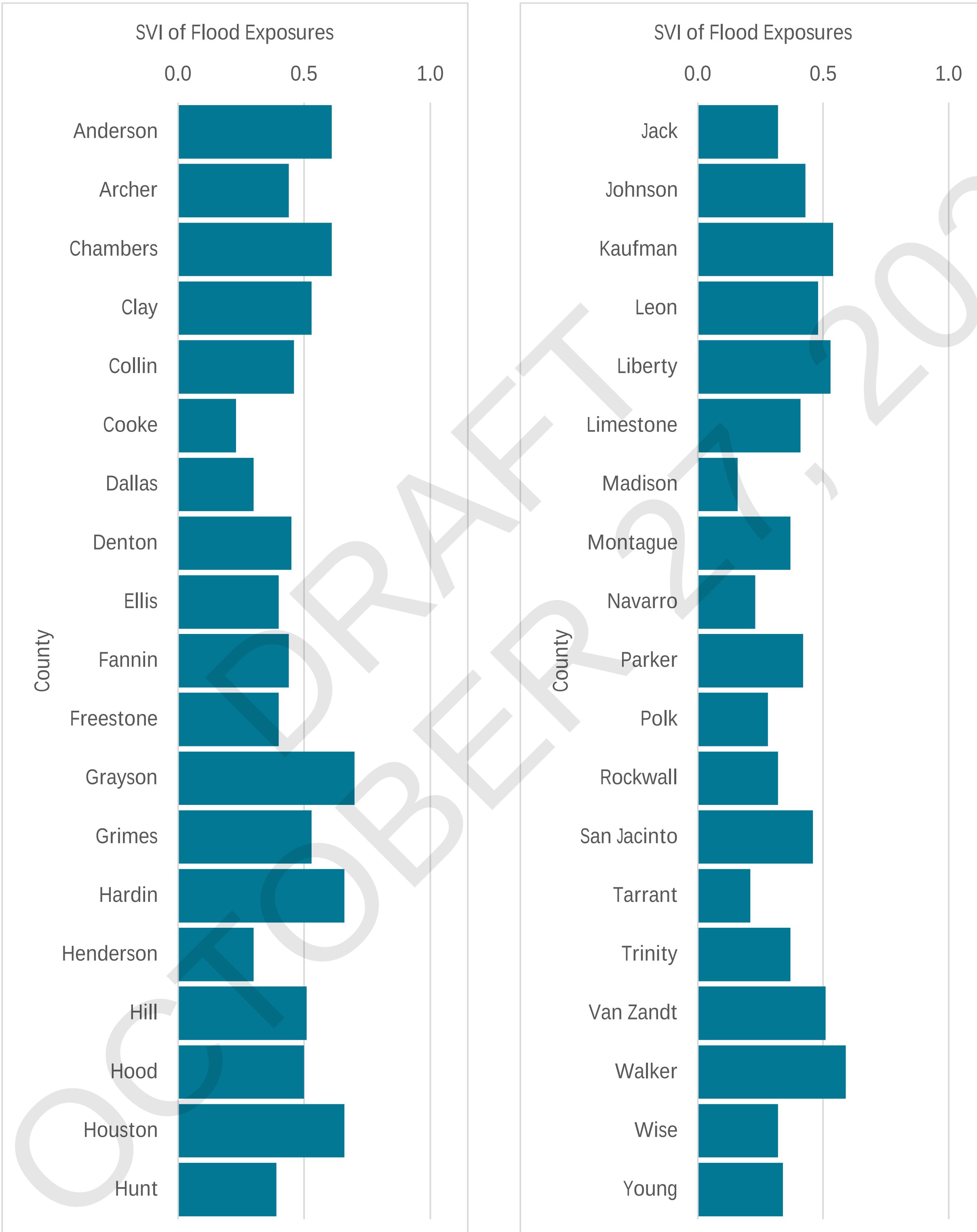


Figure 2.72 shows the countywide average distribution of SVI with regards to the exposed structures, critical facilities, and LWCs in the Trinity Region. *Figure 2.72* shows Clay, Collin, Denton, Parker, and Rockwall counties as being the least vulnerable with respect to the future conditions exposure of structures, critical facilities, and LWCs. TWDB has a threshold of 0.75 as an indicator for highly vulnerable areas. At the county level, none of the counties in the region reached this threshold. Large, detailed maps for the vulnerability assessment are shown in *Appendix B*.

Figure 2.72: Future Conditions Texas Flood-Social Vulnerability Index Average by County



Future Flood Mitigation Projects with Dedicated Funding

Future FMPs with dedicated construction funding scheduled for completion within the next 30 years are included in the Current Mitigation Projects section of this plan. Typically, funding committed for FMPs is within a shorter timeframe than the 30-year TWDB planning period. Once the funding is committed, the project moves forward as the funding usually must be spent within a specified timeframe.

Resiliency of Communities

The resiliency ratings of communities in the Trinity Region, previously discussed in the Resiliency of Communities section, helps predict a community's ability and readiness to recover quickly from disruptions associated with flood-related disasters. This means that the current resiliency rating in the Trinity Region is a measure of the communities' abilities within the region to prepare for future threats, absorb impacts, and recover and adapt after a flood.

Recent developments in flood data science and data development such as FEMA's planned shift from binary in/out floodplain mapping to graduated risk analysis and Risk Rating 2.0 will help create better risk-informed communities. Local communities, regional entities, state and federal authorities, as well as floodplain-related organizations continue to encourage and advocate for higher standards and No Adverse Impacts (NAI).

These and many other floodplain management practices will create plans and systems that future-proof communities in the Trinity Region.

Summary of Future Conditions Flood Exposure and Vulnerability Analyses

The future conditions floodplain anticipates 51 percent more structures and 52 percent more people potentially will be impacted when compared to current conditions.

The future flood risk, exposure, and vulnerability assessment for the Trinity Region are summarized in *TWDB-Required Table 5* located in *Appendix A*. The *TWDB-Required Table 5* provides 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 1* through *22* are provided in *Appendix B* as digital data. *TWDB-Required Table 2.2*, included in *Appendix A*, outlines the geodatabase deliverables included in this Technical Memorandum as well as spatial files and tables.

Bibliography

Anthoff, D., Nicholls, R. J., Tol, R. S., & Vafeidis, A. T. (2006). *Global and regional exposure to large rises in sea-level: a sensitivity analysis.*

Arrighi, C., Tarani, F., Vicario, E., & Castelli, F. (2017). Flood Impacts on a Water Distribution Network. *Natural Hazards and Earth System Sciences*.

Asquith, W. H., & Roussel, M. C. (2004). *Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas.* U.S. Geological Survey, Water Resources Division. Austin, TX: U.S. Department of the Interior. Retrieved from https://pubs.usgs.gov/sir/2004/5041/pdf/sir2004-5041.pdf

Bierwagen, B. G., Theobald, D. M., Pyke, C. R., & Morefield, P. (2010). National Housing and Impervious Surface Scenarios for Integrated Climate Impact Assessments. *Proceedings of the National Academy of Sciences*, 107.

Braun, C. L., & Ramage, J. K. (2020). *Status of Groundwater-Level Altitudes and Long-Term Groundwater-Level Changes in the Chicot, Evangeline, and Jasper Aquifers, Houston-Galveston Region, Texas, 2020.* Houston: U.S. Geological Survey.

Church, J. A., & White, N. J. (2006). A 20th Century Acceleration in Global Sea-Level Rise. *Geophysical Research Letter*, 4.

Church, J. A., & White, N. J. (2011, March 30). Sea-Level Rise from the Late 19th to the Early 21st Century. *Surveys in Geophysics*, pp. 585-602.

Church, J. A., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, A., Levermann, A., . . . Unnikrishnan, A. A. (2013). *Sea Level Change.* Cambridge: Cambridge University Press.

Department of the Army. (2013). *Incorporating Sea Level Change in Civil Works Programs.* Washington, D.C.: United States Army Corps of Engineers.

ESRI. (2025). *ESRI Demgraphics Data*. Retrieved from ESRI: https://www.esri.com/en-us/arcgis/products/data/data-portfolio/demographics

Freese and Nichols, Inc. (2021). *Lower East Fork Laterals of the Trinity River Watershed.* Freese and Nichols, Inc.

Galloway, D. L., & Coplin, L. S. (1999). Managing Coastal Subsidence. *Land Subsidence in the United States*, 35-48.

Galloway, D. L., Jones, D. R., & Ingebritsen, S. E. (1999). *Land Subsidence in the United States.* Washington, D.C.: U.S. Geological Survey.

Hall, J. A., Gill, S., Obeysekera, J., Sweet, W., Knuuti, K., & Marburger, J. (2016). *Regional Sea Level Scenarios for Coastal Risk Management.* Alexandria: SERDP.

Herrera-García, G., Ezquerro, P., Tomás, R., Béjar-Pizarro, M., López-Vinielles, J., Rossi, M., . . . Ye, S. (2021). *Mapping the Global Threat of Land Subsidence.* Science.

Hershfield, D. M. (1961). *Rainfall Frequency Atlas of the United States.* Washington, D.C.: U.S. Department of Agriculture.

Huber, M., & White, K. (2017). *Sea level change curve calculator.* USACE Responses to Climate Change Program.

Jevrejeva, S., Moore, J. C., & Grinsted, A. (2010, April 3). How will sea level respond to changes in natural and anthropogenic forcings by 2100? *Geophysical Research Letters*, p. 5.

Kasmarek, M. C., & Johnson, M. R. (2013). *Groundwater Withdrawals 1976, 1990, and 2000–10 and Land-Surface-Elevation Changes 2000–10 in Harris, Galveston, Fort Bend, Montgomery, and Brazoria Counties, Texas.* U.S. Geological Survey.

Liu, Y., Li, J., Fasullo, J., & Galloway, D. L. (2020). Land subsidence contributions to relative sea level rise at tide gauge Galveston Pier 21, Texas. *Scientific Reports*.

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Pean, C., Berger, S., . . . Zhou, B. (2021). *Climate Change 2021: The Physical Science Basis.* New York City: IPCC.

National Academies of Science, Engineering, and Medicine. (1994). *Science Priorities for the Human Dimensions of Global Change.* Washington, D.C.: National Academies Press. doi:https://doi.org/10.17226/9175

Nicholls, R. J., & Cazenave, A. (2010, June 18). Sea-Level Rise and Its Impact on Coastal Zones. *Science, 328*(5985), pp. 1517-1520.

Nicholls, R. J., & Tol, R. S. (2006). *Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century.* The Royal Society Publishing.

Nielsen-Gammon, J., & Jorgensen, S. (2021). *Climate Change Recommendations for Regional Flood Planning.* College Station: Office of the Texas State Climatologist.

NOAA. (2018). National Oceanic and Atmospheric Administration Atlas 14 Point Precipitation Frequency Estimates. Silver Spring, Maryland, United States of America.

NOAA. (2021, July 20). *Billion-Dollar Weather and Climate Disasters: Time Series*. Retrieved from National Oceanic and Atmospheric Administration National Centers for Environmental Information: https://www.ncdc.noaa.gov/billions/time-series/TX

NOAA. (2022). *Tides & Currents*. Retrieved from National Oceanic and Atmospheric Administration: https://tidesandcurrents.noaa.gov/sltrends/

Parris, A. S., Bromirski, P., Burkett, V., Cayan, D. R., Culver, M., Hall, J., . . . Weiss, J. (2012). *Global sea level rise scenarios for the United States National Climate Assessment.* National Oceanic and Atmospheric Administration.

Rahman, A., Tharzhiansyah, M., Rizky, M., & Vita, H. (2021). Problems and Urban Sustainable Development in Wetlands Based on the Thermal Conditions. *IOP Conference Series: Earth and Environmental Science* (p. 780). IOP.

Rahmstorf, S. (2007). *A Semi-Empirical Approach to Projecting Future Sea-Level Rise.* American Association for the Advancement of Science.

Rentschler, J., & Salhab, M. (2020). *People in Harm's Way: Flood Exposure and Poverty in 189 Counties.* Washington, D.C.: World Back.

Shukla, P. R., Skea, J., Buendia, E. C., Masson-Delmotte, V., Portner, H. O., Roberts, D. C., . . . Malley, J. (2019). *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.* IPCC.

Sohl, T. L. (2018, September 27). Conterminous United States Land Cover Projections - 1992 to 2100. United States of America.

Stanzel, N. C., & Natchnebel, H. P. (2009). Incorporating River Morphological Changes to Flood Risk Assessment Uncertainties, Methodology, and Application. *Natural Hazards and Earth System Science*, 789-799.

Stork, S. V., & Sneed, M. (2002). *Houston-Galveston Bay Area, Texas, from Space: A New Tool for Mapping Land Subsidence.* Houston: U.S. Geological Survey.

Strand, R. I., & Pemberton, E. L. (1987). *Reservoir Sedimentation in Design of Small Dams.* Denver: U.S. Bureau of Reclamation.

Swain, D. L., Wing, O. E., Bates, P. D., Done, J. M., Johnson, K. A., & Cameron, D. R. (2020). Increased Flood Exposure Due to Climate Change and Population Growth in the United States. *Earth's Future*, 17.

Tate, E., Asif, R., Emrich, C., & Sampson, C. (2021). Flood Exposure and Social Vulnerability in the United States. *Natural Hazards*, 106.

TCEQ. (2006, November). *Guidelines for Operation and Maintenance of Dams in Texas.* Retrieved from Texas Commission on Environmental Quality: https://www.tceq.texas.gov/assets/public/comm_exec/pubs/gi/gi357/gi-357.pdf

Texas A&M Natural Resources Institute. (2020, August 2). *Texas Land Trends Data.* Retrieved from Texas Land Trends: https://data.txlandtrends.org/trends/riverbasin/Trinity

Texas Living Water Project. (2017). *Understanding Subsidence in the Houston-Galveston Region.* Austin: Texas Living Water Project.

Texas State Soil and Water Conservation Board. (2021, September 19). *Flood Control Program*. Retrieved from Texas State Soil and Water Conservation Board: https://www.tsswcb.texas.gov/programs/flood-control-program

Texas Water Development Board. (1993-2020). Volumetric and Sedimentation Survey Results. Austin, Texas, United States of America.

TWDB Flood Planning Frequently Asked Questions. (2021, July 22). Retrieved from Texas Water Development Board: https://www.twdb.texas.gov/flood/planning/faq.asp

TWDB TX F-SVI. (2025). Texas Flood Social Vulnerability Index. Austin, Texas, United States of America.

United States EPA. (2016). Updates to the Demographic and Spatial Allocation Models to Produce Integrated Climate and Land Use Scenarios (ICLUS) (Version 2) (External Review Draft). *United States Environmental Protection Agency*, 600.

United States Soil Conservation Service. (1983). Sedimentation. In U. S. Service, *SCS National Engineering Handbook.* Soil Conservation Service, United States Department of Agriculture.

USACE. (2021). Fort Worth District Pertinent Data. Fort Worth, Texas, United States of America.

USACE. (2022, May 01). Sea-Level Change Curve Calculator (Version (2022.34)). United States Army Corps of Engineers.

USACE. (2024). *Dams of Texas*. Retrieved from National Inventory of Dams: https://nid.usace.army.mil/#/

USDOA. (1955). *Big Sandy Creek Watershed.* United States Department of Agriculture.

Vermeer, M., & Rahmstorf, S. (2009). Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences*, 106.

Walsh, K. J., Camargo, S. J., Vecchi, G. A., Daloz, A. S., Elsner, J., Emanuel, K., & Henderson, N. (2014). Hurricanes and climate: The U.S. CLIVAR working group on hurricanes. *Bulletin of the American Meteorological Society*, pp. 997-1017.

Wing, O., Bates, P., Smith, A., Sampson, C., Johnson, K., Fargione, J., & Morefield, P. (2018). Estimates of Present and Future Flood Risk in the Conterminous United States. *Environmental Research Letters*, 13.

Wuebbles, D. J., Fahey, D. W., Hibbard, K. A., Dokken, D. J., Stewart, B. C., & Maycock, T. K. (2017). *Climate Science Special Report.* Washington, D.C.: U.S. Global Change Research Program.

Xue, Y.-Q., Zhang, Y., Ye, S.-J., Wu, J.-C., & Li, Q.-F. (2005). *Land Subsidence in China.* Environmental Geology.

Zervas, C., Gill, S., & Sweet, W. (2013). *Estimating Vertical Land Motion from Long-Term Tide Gauge Records.* Silver Spring: National Oceanic and Atmospheric Administration.