

## Appendix 4.5

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TO: Texas Water Development Board DATE: July 2023  
FROM: Lower Brazos Regional Flood Planning Group  
SUBJECT: Lower Brazos Flood Early Warning System Investigation

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### Purpose

In February 2022, the Texas Water Development Board provided the Lower Brazos Regional Flood Planning Group (RFPG) with additional funding and an additional project schedule to allow for the RFPG to prepare an amendment of the Final Regional Flood Plan (RFP). The objective of this amendment as set forth by the TWDB was to “perform identified potential Flood Management Evaluations (FMEs) to, for example, evaluate flood risks in areas with currently limited flood risk data, and to evaluate flood risk reduction solutions, including feasibility studies and preliminary engineering needed to identify, evaluate, and recommend additional potentially feasible Flood Mitigation Projects (FMPs).”

The Lower Brazos RFPG discussed several efforts that could be performed to fulfill the scope provided by the TWDB. One of these efforts was to perform an evaluation of current Flood Early Warning Systems (FEWS) throughout the region to identify locations in need of improved monitoring or gauge systems to provide alerts of flooding conditions. This evaluation was consistent with several of the overarching goals and themes within the Lower Brazos RFP. Having better information during storm events allows residents to make more informed decisions and contributes to the overarching goal of the regional flood planning effort – to protect against the loss of life and property. This primary goal is reflected in *Chapter 3: Floodplain Management Practices and Flood Protection Goals* which includes four strategies aiming to increase the coverage of flood warning systems and gauges in the Lower Brazos region and *Chapter 7: Flood Response Information and Activities* which discusses the importance of FEWS in a community’s preparation and response to severe rain events. Additionally, the need for more FEWS and gauges was a recurring sentiment voiced by the public throughout the Lower Brazos Survey, public meetings, and the flood mitigation actions submitted for inclusion in the Lower Brazos RFP.

### Existing Systems and Coordination

The first step in identifying potential locations in need of FEWS and gauges in the Lower Brazos Region was determining where systems and gauges are already in place. Although related, gauges and FEWS were looked at separately for some of this analysis. In this document, gauges are singular instruments used to measure, store, and transmit stage and flow information of streams, rivers, lakes, and other significant bodies of water. Conversely, FEWS refers to an integrated system used by a local community or region, that is reliant on gauge or other live measurement data, to calculate, display, or notify entities and residents of flood risk. These systems vary across the flood planning region and can incorporate feedback systems such as websites, text alerts, and sirens to provide real-time information during flooding events. Localized FEWS often serve a singular entity or community and provide flood risk data in a way that is most applicable to the areas flood risk type, rainfall, terrain, and drainage infrastructure. Regional FEWS are hosted by state or federal agencies and provide general flood risk data for entire networks of streams and rivers throughout the state or country.

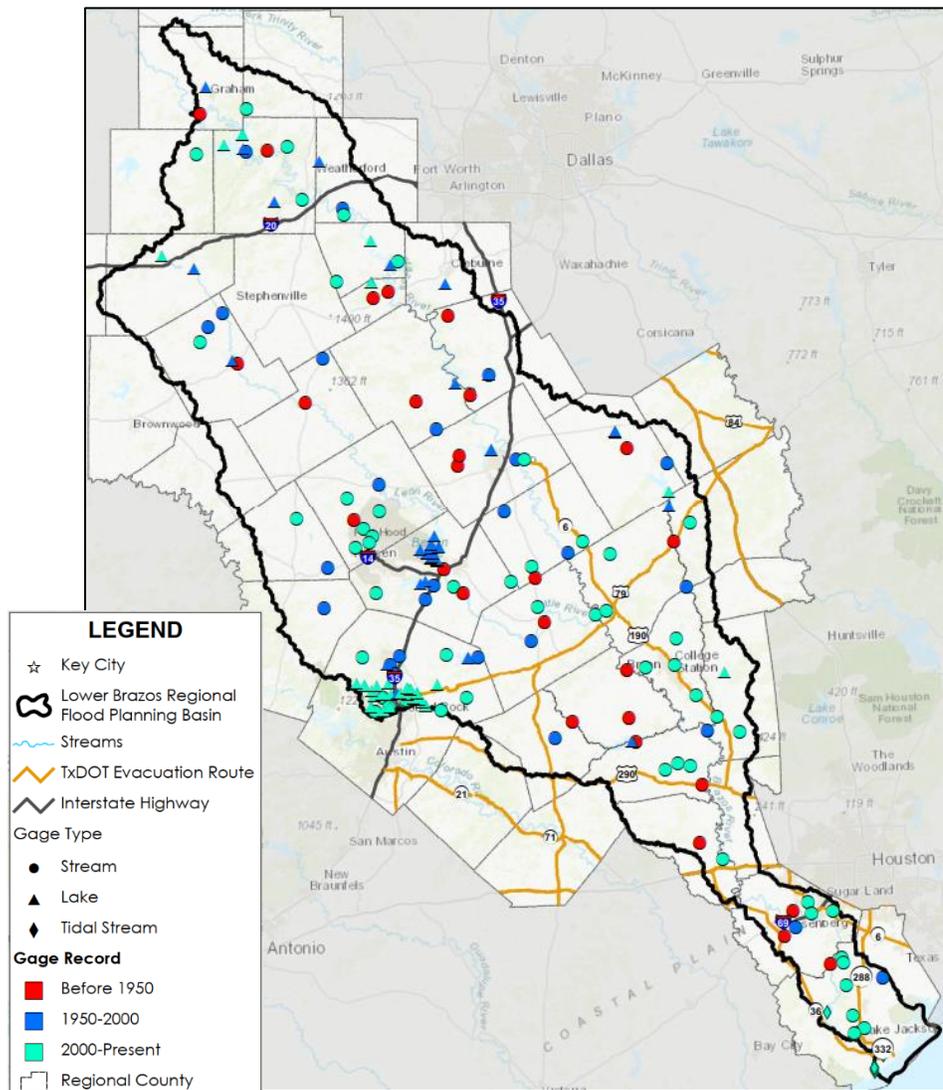
Lower Brazos Survey results and regional entities such as the United States Geological Survey (USGS) and National Weather Service (NWS) were consulted to understand what methods communities currently utilize to provide

flood related warnings during severe rain events. Both regional and local systems were identified based on publicly available information. A gap analysis was then performed to identify additional locations where FEWS could benefit communities with high flood risk.

### USGS Gages

The USGS has an extensive gauge network across the nation ([Water Resources of the United States—National Water Information System \(NWIS\) Mapper \(usgs.gov\)](https://water.usgs.gov/nwis/)). This network consists of many types of gauges including atmospheric, springs, groundwater, and surface-water sites. However, for the evaluation of FEWS and gauges in the Lower Brazos Region, only surface-water sites were of interest. USGS surface-water gauges can be found along major tributaries, rivers, streams, and lakes across the Lower Brazos Region, as seen in *Figure 1*. Over 170 active riverine and reservoir gauges were identified within the region. These gauges date back to as early as 1905 and provide an average of 30,000 record counts each.

**Figure 1 USGS Gage Distribution**



The USGS NWIS Mapper was one of the major sources used to identify existing gauge information that could be leveraged within an FEWS. For information on active rain events, gauges with live data are invaluable to

communities in identifying where severe flooding may occur, where roads may become impassible, and where to focus their response efforts. However, there are additional benefits provided by gauges with historical flow or water surface elevation records. Gauges can be used to also predict the potential flows and water surface elevations during storm events.

Gauges with over 30 years of data records can be utilized to document peak flows and corresponding water surface elevations. These records can then be used to determine flows and water surface elevations for frequency storm events. This information can be leveraged to map potential flood risk for different recurrence intervals, identify structures that may be prone to frequent flooding, and inform communities on when rain events may become severe flooding events. Within the Lower Brazos Region, there are many gauges with periods of record well over 30 years, as shown in Exhibit A. These gauges are well distributed throughout the region, mostly near population centers and lakes.

### ***NWS System***

Another tool available to the flood planning region is the National Water Model ([Office of Water Prediction \(noaa.gov\)](https://www.noaa.gov)). This tool simulates and forecasts how water moves throughout streams and rivers across the nation by utilizing many real time data points, including USGS gauges, as simulation checkpoints. Users can view live short (18 hour), medium (10 day), and long (30 day) range flow forecasts. Future updates to the National Water Model will include the integration of hydraulic and hydrologic models from federal, state, and local entities that will utilize the forecasted flows to project Flood Inundation Mapping (FIM).

In discussion with representatives from the NWS that work within the Lower Brazos Region, the accuracy and performance of the National Water Model would be bolstered by adding more gauges to the reference network. Gauges provide points for the modeling data to tie in to measured historical and live data, increasing the accuracy of the overall mapping and prediction results.

### ***InFRM***

The Interagency Flood Risk Management (InFRM) team created a tool that provides flood risk information to portions of the Lower Brazos Region and other areas across the state of Texas. This system utilizes the data collected at USGS gages, compounded with NWS forecasting, to create estimated flood inundation mapping. Using the Flood Decision Support Tool (<https://webapps.usgs.gov/infrm/fdst/?region=fema6>) users can view inundation extents and depths for current stage levels at incorporated USGS gages, estimated mapping for simulated stage conditions, and stage trends at gages with noticeable WSE increases or decreases. The InFRM Flood Decision Support Toolbox provides valuable information to communities that have data within their area. However, there are currently a limited number of USGS gages currently incorporated into the system, each with only a few miles of associated inundation mapping upstream and downstream of the gage, leaving many areas to rely on the USGS and NWS systems that provide more complete coverage of the region.

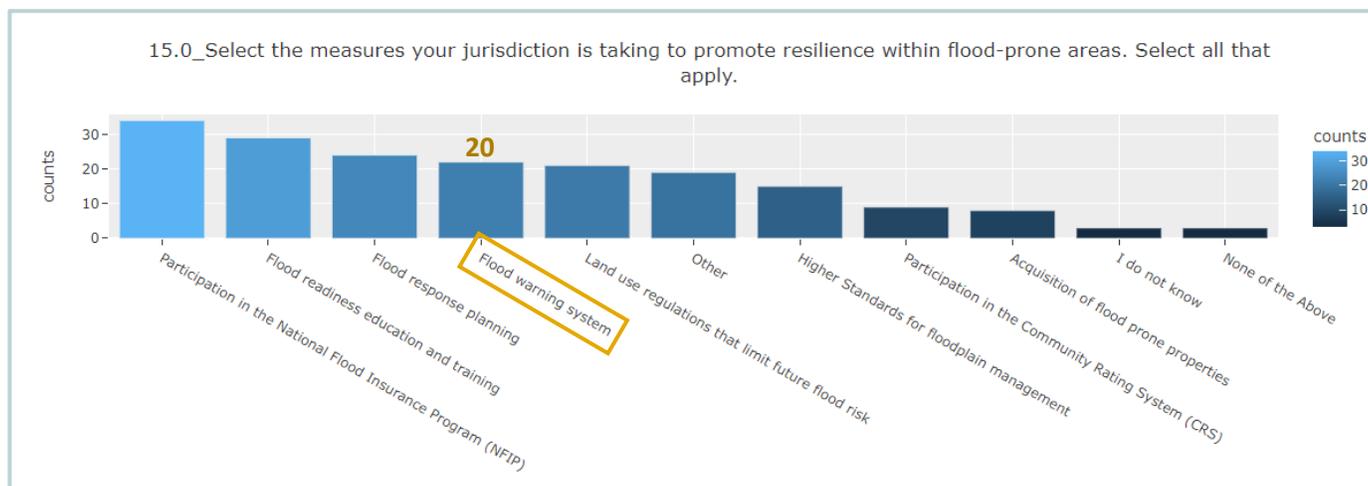
### ***Local Flood Warning Systems***

An assessment of local flood warning systems was performed using publicly available information and survey data. Results from the Lower Brazos Interest Group Survey, discussed in *Chapter 10: Adoption of Plan and Public Participation*, and the flood mitigation actions received and gathered as discussed in *Chapter 4: Assessment and Identification of Flood Mitigation Needs*, were used to determine general interest in FEWS and gauges throughout the region. A desktop analysis was also performed to evaluate what systems are currently in place in communities across the Lower Brazos Region.

Survey Results

Four questions in the 2021 Lower Brazos Interest Group Survey gave communities the opportunity to express interest or ongoing efforts in respect to FEWS and gauges. In response to these questions, 36 entities indicated interest in developing or advancing their flood warning capacity. These responses can be seen in *Figure 2* through *Figure 5*.

**Figure 2 Interest Group Survey Question 15 Responses**



**Figure 3 Interest Group Survey Question 32 Responses**

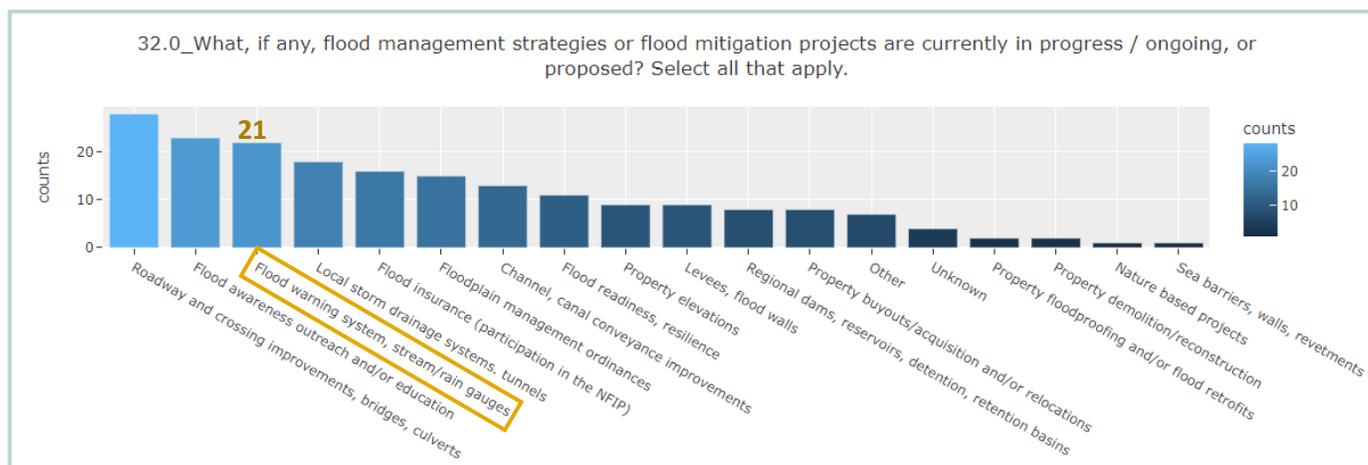


Figure 4 Interest Group Survey Question 42 Responses

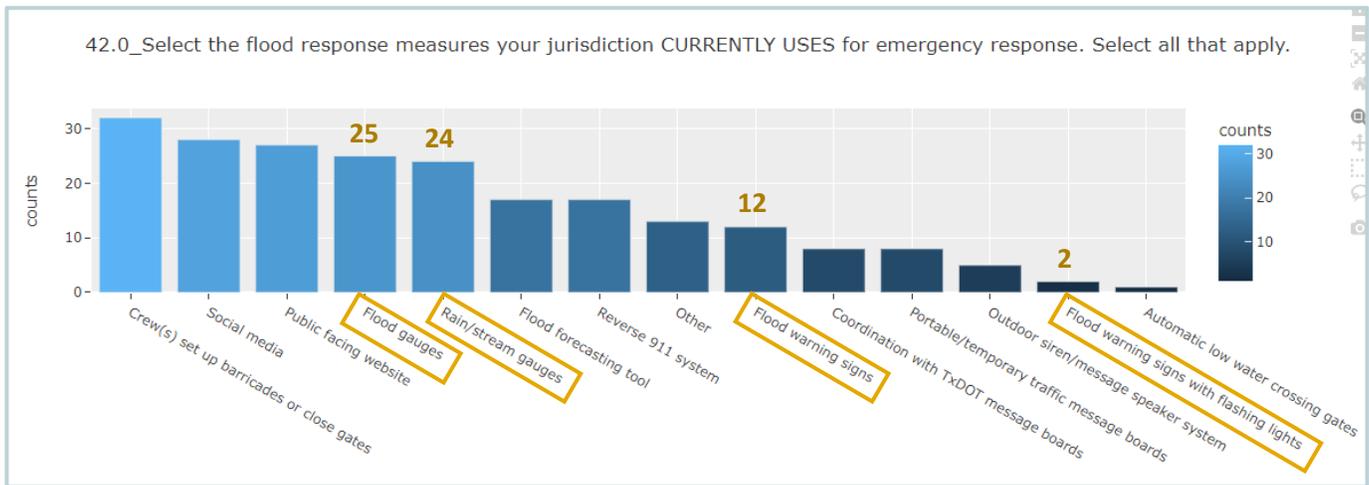
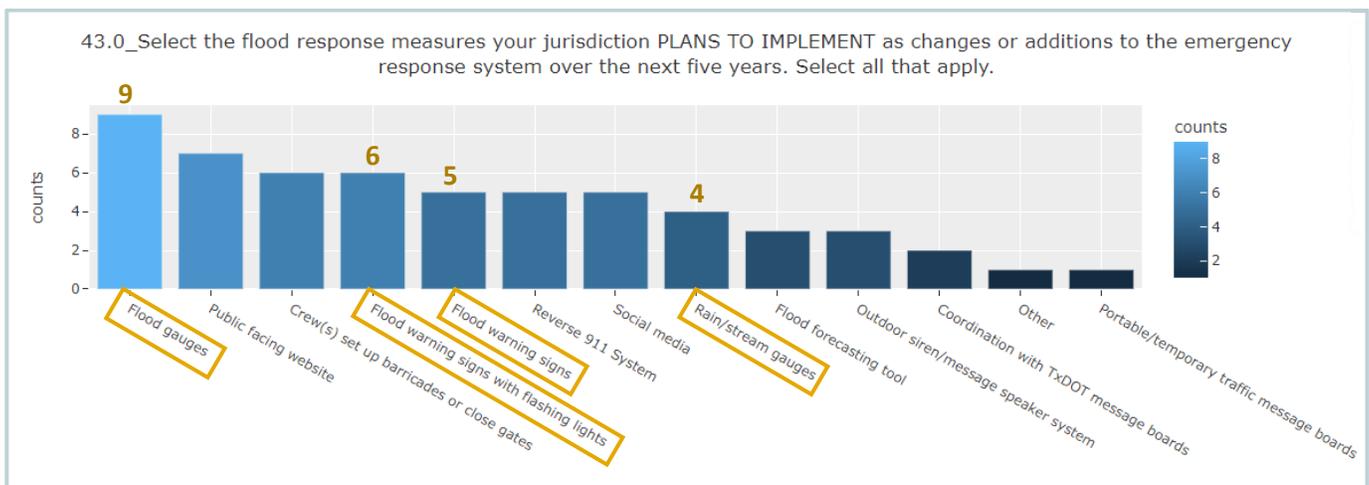


Figure 5 Interest Group Survey Question 43 Responses



The use of flood warning systems varies across the region. Of the 36 entities that expressed interest, only seven had local systems or gauges that they currently utilize for flood warning. Over half of the entities did not have any information on flood warning available for residents. Ten of the 36 rely on information from regional systems, including the National Weather Model and USGS gauges, to inform flood response actions such as road closures and notifications to residents of severe flooding conditions.

Although these responses represent only a small portion of all the entities in the Lower Brazos Region, the interest in FEWS and gauges, and the current lack of local systems, was found to represent the region as a whole. Entity websites, Hazard Mitigation Plans, and other publicly available documentation was referenced to determine the existing systems, or lack of, in major cities and counties that did not provide survey responses. Interest in implementing local systems, and current dependence on regional systems and gauges, was found to extend to entities outside of those that responded to the Lower Brazos Survey.

## High Risk Areas

To help prioritize where additional gauges and FEWS would be most beneficial, gaps in coverage were cross referenced with high-risk locations.

### 4A Flood Risk

Results from *Chapter 4A.3: Areas with Significant Flood Risk Gaps and Flood Mitigation Needs* were leveraged to define areas of high flood risk. This previously completed analysis incorporated 11 categories that assess flood risk as well as the ability of communities to respond to severe flood events:

- Number of Buildings in Flood-Prone Areas
- Number of Low Water Crossings
- Agricultural Areas in Flood-Prone Areas
- Number of Critical Facilities in Flood-Prone Areas
- Number of Communities not Participating in NFIP
- Number of Communities Participating in CRS with Rating Lower than 10
- Damaged or Failing Infrastructure
- Availability of a Hazard Mitigation Action Plan
- Number of Disaster Declarations
- Number of FEMA Claims
- Social Vulnerability Index

Exhibit A shows the locations of the existing gauges within the Lower Brazos Region contrasted with areas of highest flood risk.

This information was overlaid with existing USGS gauges to determine high flood risk areas lacking significant gauge coverage. As a result, ten areas were identified as potential candidates for FEWS or additional gauges:

- Southwest Erath County
- Williamson County
- McLennan County
- West Waller County
- Southern Lower Brazos (including Brazoria and Fort Bend Counties)
- Brazos and Navasota River Confluence
- West Bell County
- Central Burleson County
- Nolan River Watershed
- Aquilla Lake Watershed

Each of these areas was further investigated to determine the types of flood risk present, number of structures at risk, major roads affected during flood events, and low water crossings in the vicinity. Additionally, the type of flood risk experienced within the identified areas was determined through evaluation of the contributing drainage areas, flood sources, and typical depths of flooding. This information was cross referenced with the land use and density of population centers within the locations to determine whether the communities would benefit more from gauges or FEWS. Further analysis that may consider riverbed slope, flood depth, base flows, land use and other factors is recommended to prioritize gauges.

## *Evacuation Routes*

Another critical element used to identify locations that could benefit from additional gauges were the evaluation of evacuation routes. Evacuation routes are critical during natural disasters, which often involve extreme flooding conditions. Stream crossings along all TxDOT evacuation routes were analyzed to determine if there are currently any gauges, flood warning signs, or other flood response infrastructure to monitor potential overtopping. Locations where streams are prone to overtopping the road without flood warning infrastructure, were considered as optimal locations for gauge placement. Exhibit B shows evacuation crossings with and without gauges.

Many of the major stream crossings flagged as not having gauge data, do have gauges several miles upstream or downstream of the point of interest that help inform flooding conditions. However, several of the minor stream crossings, including those prone to overtopping, did not have nearby gauge coverage. These locations were further investigated, especially if they also fell within one of the ten locations identified as potential candidates for installing FEWS or additional gauges.

## *NWS Gauge Wishlist*

The final piece of data that was used to identify potential locations for additional gauges or FEWS was a gauge “wish list” provided by the Galveston Branch of the NWS. This list was developed by the NWS through a survey sent to regional stakeholders in the southernmost portion of the Lower Brazos watershed. Using local knowledge, a list of locations that would most benefit from additional gauging was compiled.

Since the NWS gauge wish list was compiled several years ago, some of the high priority locations have been addressed in recent years. However, there were some locations that coincided with the evacuation routes and high flood risk areas that were considered during this analysis. These locations were given priority, regardless of surrounding at-risk structure counts or low water crossings.

## **Recommendations**

Recommendations were tailored based on flood risk types and sources as well as the size of population centers within the identified areas.

Since local FEWS are somewhat costly to implement and maintain, communities with populations greater than 20,000 in high flood risk areas may consider the use of these systems. In contrast, gauges were recommended for more rural areas to monitor rainfall and water surface conditions. By partnering with the USGS, or other regional entities, these rural communities could tie into a larger gauge network and more extensive flood risk data without having to develop or maintain their own website interfaces, modeling, or forecasting technologies.

Additional consideration was given to the type of flood risk and number of flooding sources. Gauges provide a significant amount of information along large riverine networks; however, they may not provide sufficient information on urban structural flooding and ponding caused by localized flooding through dense population centers. For areas with many sources of flooding, or localized flooding issues, local FEWS were recommended to provide more granular data. The recommended locations for gauges and local FEWS can be seen in Exhibit C.

The recommendations provided based on the analysis performed have not been prioritized or ranked. However, the data used to determine the placement recommendations could be used to determine an implementation plan that could include prioritization based on severity of need, or viability of the placement.

## Gauge Locations to Support Regional Flood Early Warning Systems

The West Waller County area was identified as being better suited for potential gauge placements and incorporation into regional FEWS. Being a rural county comprised of small towns, there is not a population center large enough to support a local FEWS. However, there is significant riverine flooding along several of the tributaries that contribute to the Brazos River which forms the western boundary of the county. Three potential gauge locations were identified at major road and stream crossings: two at TxDOT evacuation routes, one at a location identified within the NWS gauge wish list, and over 1,500 nearby at-risk structures.

The Southern Lower Brazos area has significant population centers along with a number flood sources. However, several entities within the identified area have local systems and gauges. This coverage provides data on localized flooding for Sugar Land and many of the Levee Improvement Districts (LIDs) within the southern portions of Fort Bend County and northern portions of Brazoria County. Due to this existing infrastructure, two potential gauges were recommended for locations without a localized system that have severe riverine flooding. Both locations were identified in the NWS gauge wish list, and one coincides with a TxDOT evacuation route. These potential gauge locations can be seen in *Table 1*.

**Table 1 Potential Gauge Locations in Southern Portion of Lower Brazos Region**

Gauge Location	Interest Area	TxDOT Evacuation Route	On NWS Wish List
I10 and Bessie's Creek	West Waller County	Yes	No
FM 1887 and Irons Creek	West Waller County	No	No
US 290 and Clear Creek	West Waller County	Yes	Yes
FM 1093 and Orchard Creek	Southern Lower Brazos	No	Yes
FM 288 and Bastrop Bayou	Southern Lower Brazos	Yes	Yes

Other potential gauges locations were recommended for the central and northern portions of the Lower Brazos watershed. However, there are not established TxDOT evacuation routes in this region, and the NWS gauge wish list does not cover this portion of the watershed. Therefore, potential gauge locations were driven by the number of nearby at-risk structures and low water crossings.

Williamson County is like the Southern Lower Brazos area in that it has dense population, multiple sources of flooding, and existing local systems and gauges. Two potential gauge locations were identified for locations with over 1,000 nearby structures at-risk and several nearby low water crossings that are not covered by the local systems in the southwestern portion of the county.

In the McLennan County area there were no identified public facing local FEWS. However, the InFRM Flood Decision Tool does provide coverage for a segment of the Brazos River which is central to the county. Additional flooding in the County is caused by many tributaries that ultimately contribute to the Brazos River. Potential gauge locations were identified along the outskirts of the City of Waco in more rural areas that could not support a local FEWS. The identified locations are at the intersections of large tributaries and major thoroughfares with over 500 nearby at-risk structures.

Potential gauge locations were also identified along major creeks and streams for several of the more rural counties with high flood risk. In Southwest Erath County, near the confluence of the Brazos and Navasota Rivers,

Central Burleson, and Aquilla Lake Watershed, gauges were placed at locations with multiple nearby low water crossings and hundreds of nearby at-risk structures. These potential gauge locations can be seen in *Table 2*.

**Table 2 Potential Gauge Locations in Northern Portion of Lower Brazos Region**

Gauge Location	Interest Area	At-Risk Structures	LWCs
FM 1660 and San Gabriel River	Williamson County	530	4
FM 397 and Bull Branch	Williamson County	170	4
US 84 and Harris Creek	McLennan County	150	2
FM 317 and South Bosque River	McLennan County	150	4
SH 6 and Cedar Creek	Brazos and Navasota River Confluence	410	4
SH 22 and Hackberry Creek	Aquilla Lake Watershed	70	3
FM 166 and Davidson Creek	Central Burleson County	140	1
FM 8 and North Bosque River	Southwest Erath County	290	10

These gauge locations are representative of areas with high flood risk that could likely benefit from the data provided by a riverine gauge. However, further investigation would be needed to determine if these locations are viable placements for constructability and maintenance. Vibrations caused by vehicular traffic on crossing roads, bridge safety, and ease of access would need to be vetted before funding for construction and implementation could be pursued. To account for this, as well as coordination needs between local entities and regional partners, the potential gauge placements were grouped together as a Flood Management Strategy (FMS) with a total estimated strategy cost of \$150,000. As locations and sponsors are further vetted and finalized, estimated construction and maintenance costs would need to be calculated for each gauge.

### **Local Flood Early Warning System Development**

A few major population centers within the Lower Brazos Region were identified as optimum locations for developing local FEWS. The cities of Killeen, Cleburne, Stephenville, Waco, and Georgetown are all located in areas with high flood risk with multiple sources of flooding, and have a limited number of USGS gauges. The ongoing flood warning efforts and infrastructure in these five cities were further investigated.

Most of the identified locations do not have any public facing flood warning system. Some currently depend on regional systems to inform their residents on emergencies involving flooding. The City of Cleburne and City of Killeen have warning sirens and text systems that notify residents of emergency conditions. However, these systems are intended to be used for all emergency conditions and are not supported by any local gauging or live flood risk data. The cities of Waco, Stephenville, and Georgetown do not have public facing local flood warning systems. The recommended locations for local FEWS are summarized in *Table 3*.

**Table 3 Potential Local FEWS Locations**

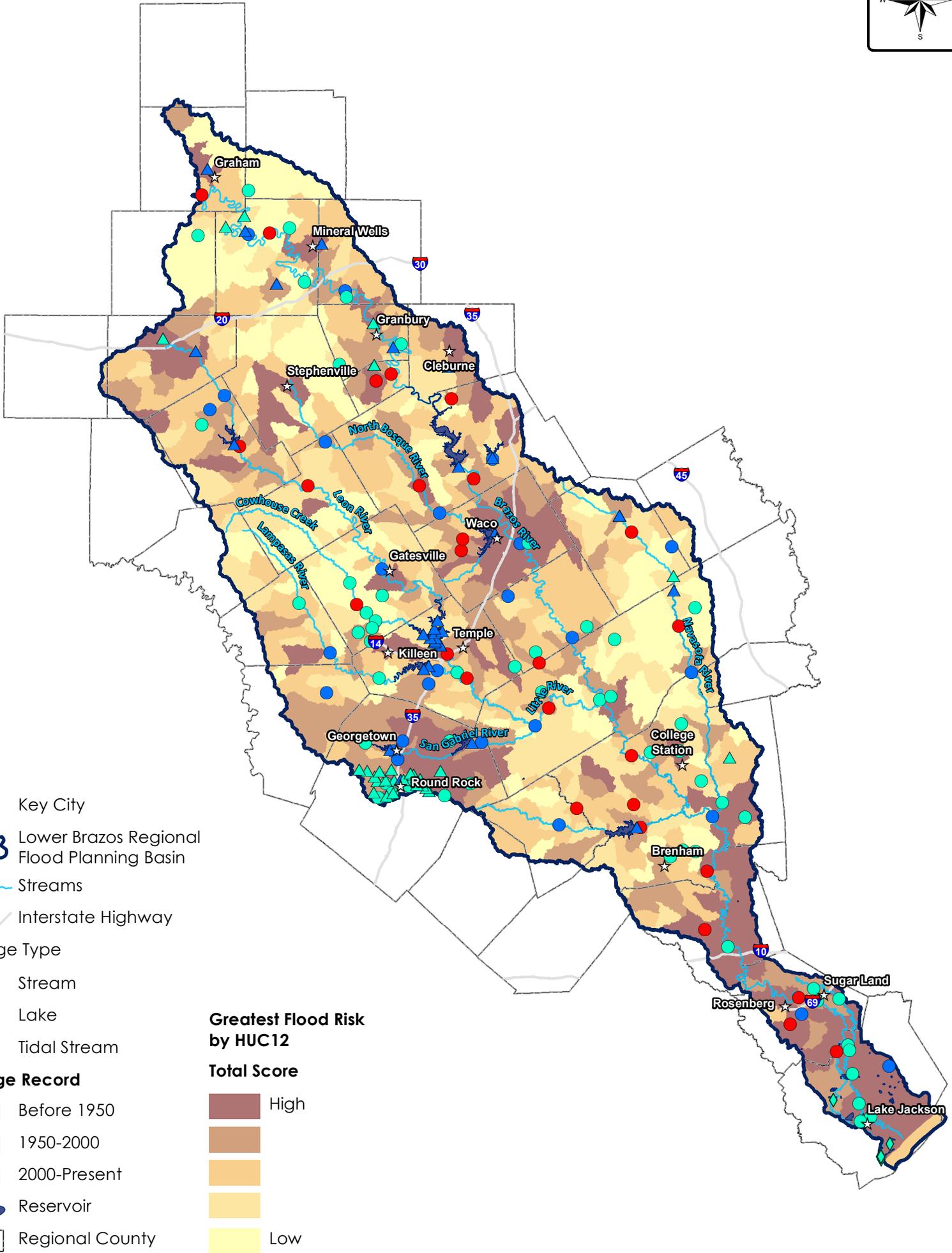
FME ID	FME Name	At-Risk Structures	Community Population	FME Cost
081001115	City of Killeen FEWS	1,200	153,000	\$100,000
081001117	City of Cleburne FEWS	1,200	31,000	\$100,000
081001300	City of Stephenville FEWS	360	21,000	\$100,000
081001301	City of Waco FEWS	6,500	138,000	\$100,000
081001302	City of Georgetown FEWS	1,200	67,000	\$100,000

Although these cities were identified as potentially viable locations for local FEWS implementation, the needs and capabilities of the entities are not identical. Due to this, FMEs are recommended for each city with a cost estimate of \$100,000 to study the implementation of a local FEWS. After these evaluations, FMPs could be developed and included in the Lower Brazos Regional Flood Plan to pursue funding needs associated with implementation and construction of a local FEWS and supporting gauges.

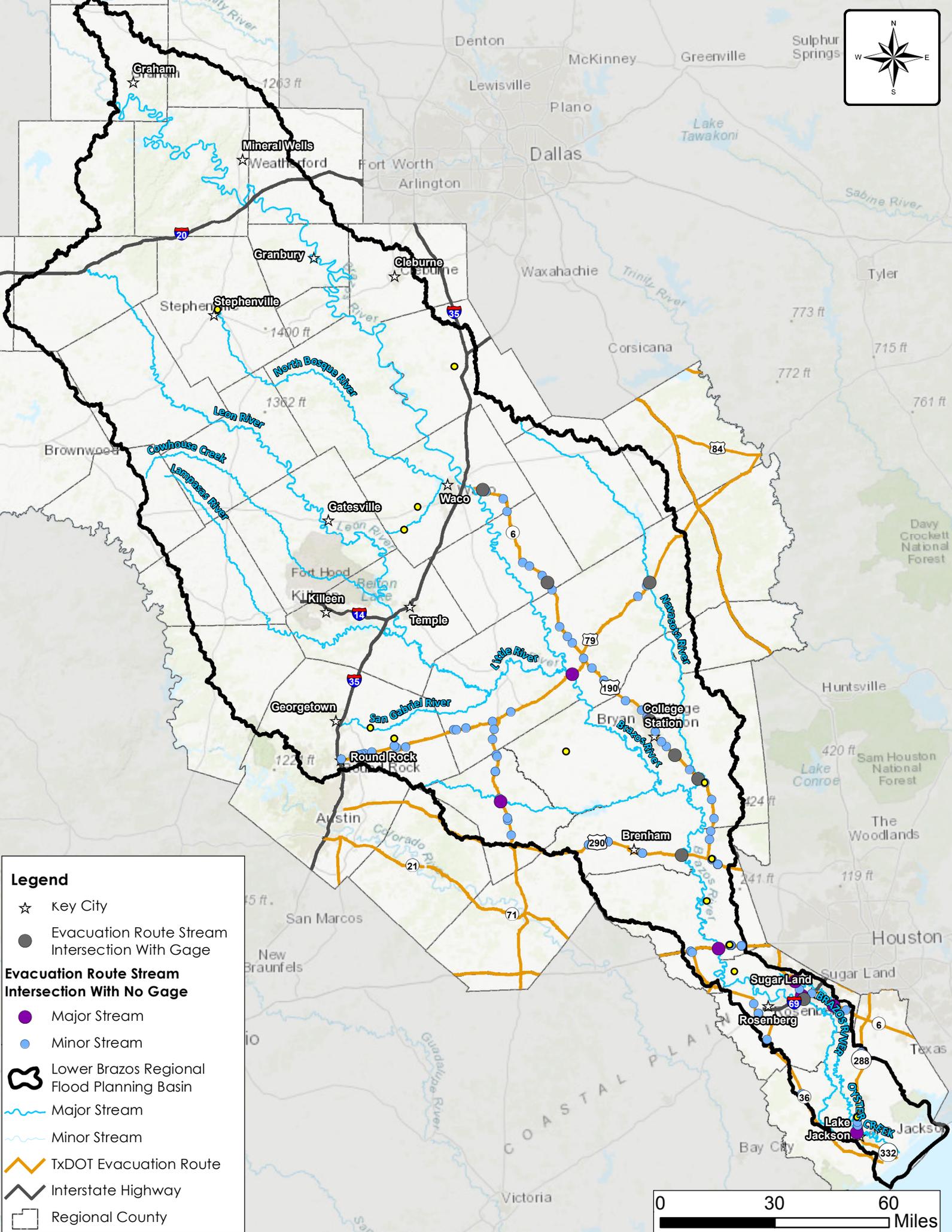
## Conclusion

The potential gauge and local FEWS locations identified in this memorandum are representative of areas with high flood risk that would benefit from the information provided by additional flood warning. However, these recommendations are not exhaustive. Many other cities and locations throughout the region could benefit from the information provided by gauges and FEWS. These systems can bolster modeling and mapping by providing historical information to estimate frequency storms more accurately, provide information to entities on how likely roads and structures are to be inundated during storm events, and be used in forecasting. By increasing the number of gauges and FEWS in the Lower Brazos Region, the public will have access to better information on flooding conditions and be able to make more informed decisions during storm events.

# Exhibit A

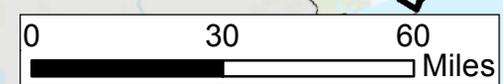


## Exhibit B

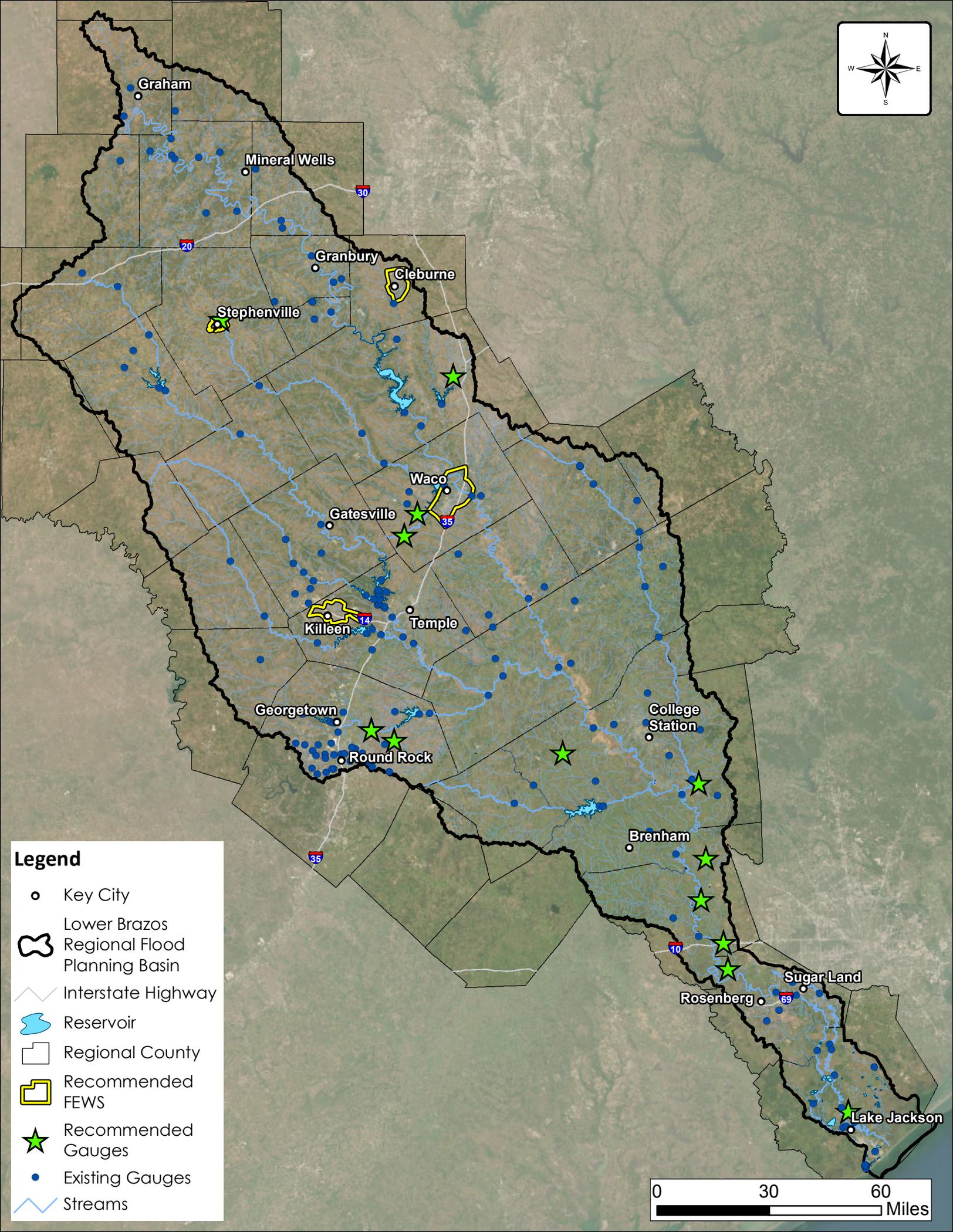


**Legend**

- ☆ Key City
- Evacuation Route Stream Intersection With Gage
- Evacuation Route Stream Intersection With No Gage
- Major Stream
- Minor Stream
- Lower Brazos Regional Flood Planning Basin
- Major Stream
- Minor Stream
- TxDOT Evacuation Route
- Interstate Highway
- Regional County



## Exhibit C



**Legend**

- Key City
- Lower Brazos Regional Flood Planning Basin
- Interstate Highway
- Reservoir
- Regional County
- Recommended FEWS
- ★ Recommended Gauges
- Existing Gauges
- Streams

