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Recommendations for New Stream and Rain Gages in Texas TWDB Contract No. 1600012027

Final Report

Dec 31, 2016

Executive summary

Despite a growing network of rain and flow monitoring stations, a better understanding of flood frequency and magnitude, and more sophisticated modeling and warning systems, floods continue to result in casualties and infrastructure damage in Texas, where rates of both are higher than any other state, according to data compiled by the National Flood Insurance Program. To address this issue, the Texas Water Development Board has increased spending on flood protection planning grants and directed the U.S. Geological Survey to install some 20 additional stream gages across the state, at locations deemed high priority by the National Weather Service River Forecasting Centers. In August of this year, the Texas Water Development Board hired the Aqua Strategies - Vieux and Associates team to identify locations for an additional 30 stream gages, and determine where gaps need to be filled in the existing weather station network.

An objective, analytical framework for identifying communities with the most pressing need for additional stream gages and weather stations for improved flood forecasting services is described herein. The priority communities identified were those that are not currently served or inadequately served by existing forecasting efforts. The approach laid out in this report will allow the Texas Water Development Board to choose locations for additional monitoring, with quantitative information provided on improved lead time each stream gage would provide for the identified communities.

A total of 42 new full range real-time stream gages are recommended in this report. Focusing on vulnerable communities and their associated watersheds will help optimize expenditure of funds and increase the number of communities that can be protected. In addition, we have recommended a few existing U.S. Geological Survey stream gages be used by the National Weather Service in their flood forecasting activities, and suggest the conversion of some National Weather Service monitoring stations to forecast points.

Finally, a map is also provided in the report, showing where we recommend new weather stations be installed, based on gaps in the existing rain gage network and prioritized based on the population density within these gaps. Combined, these additional rain and stream gages should help provide better flood forecasts and warnings in the future, to reduce the risk of casualties and damage from events like the 2015 Memorial Day floods.

Acronyms

AGL	Above Ground Level
AHP	Analytical Hierarchy Process
AHPS	Advanced Hydrologic Prediction Service
ABRFC	Arkansas-Red Basin River Forecast Center
CID	Community Identification Number
CONUS	Continental United States
d/s	Downstream
EJ	Environmental Justice
EJSCREEN	Environmental Justice Screening Mapping Tool
FEMA	Federal Emergency Management Agency
GBRA	Guadalupe-Blanco River Authority
HAS	Hydrometeorology Analysis and Support
HSA	Hydrologic Service Area
LCRA	Lower Colorado River Authority
LMRFC	Lower Mississippi River Forecast Center
MPE	Multisensor Precipitation Estimator
MRMS	Multi-Radar/Multi-Sensor
MSC	Map Service Center
NCEI	National Center for Environmental Information
NCEP	National Center for Environmental Prediction
NEXRAD	Next Generation Weather Radar
NFHL	National Flood Hazard Layer
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NWS	National Weather Service

NWSRFS	National Weather Service River Forecast System
QPE	Quantitative Precipitation Estimates
RFC	River Forecast Centers
RIW	Relative Importance Weights
SAC-SMA	Sacramento Model & Soil Moisture Accounting
SDP	Storm Data Publication
SED	Storm Events Database
SFHA	Special Flood Hazard Area
SHELDUS	Spatial Hazard Events and Losses Database
SI	Suitability Index
SRLP	Severe Repetitive Loss Property
TPWD	Texas Parks and Wildlife Department
TWDB	Texas Water Development Board
u/s	Upstream
USGS	United States Geological Survey
WFO	Weather Forecast Office
WGRFC	West Gulf River Forecast Center

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1 Background and introduction

Devastating floods are not new to Texas. In December 1913, up to 25 inches of rainfall fell over parts of Houston on already saturated ground, resulting in severe flooding and 180 drownings. A few years later, in 1921, a rain gage in San Antonio recorded 39.7 inches of rain in just 36 hours, inundating parts of the city and drowning 51 people[1]. In September 1952, in the middle of the state's drought of record, heavy and widespread rainfall across the Hill Country (up to 26 inches in places) caused Lake Travis to rise by 57 feet in 14 hours. Five people died and 17 homes were destroyed due to this flood event. Had Mansfield dam not been there, flooding downstream, through Austin and beyond, would have been much worse.

Over the Memorial Day weekend of 2015, heavy rain fell on the Blanco Watershed, in the part of the Hill Country known locally as "Flash Flood Alley". The Blanco River, which runs through the picturesque City of Wimberley, rose 33 feet in just three hours early Sunday morning, cresting at about 40 feet (27 feet above flood stage), tearing up 100-year old cypress trees from the river bank, destroying homes and bridges, claiming 13 lives, and taking out the only stream gage at or above Wimberley. While the National Weather Service (NWS) issued several flood warnings for Wimberley, better monitoring of rainfall and flows in the watershed above the city might have provided more lead time and a better estimate of the peak flows and water levels heading towards town.

Operational hydrology and the development of flood forecasts by the NWS is consolidated at the River Forecast Centers (RFCs), where hydrologic data assimilation and forecasting is performed. River forecasting is based on hydrometeorological analysis to produce input for basin models. This function is performed by the Hydrometeorology Analysis and Support (HAS) unit at each RFC. Weather Forecast Offices (WFOs) issue flood warnings and watches to the public through the internet, news media, core partners such as emergency managers, National Oceanic and Atmospheric Administration (NOAA) Weather Radio, and other direct or indirect methods.

The NWS responsibility for river forecasting in the state of Texas falls within three RFCs. The northern part of Texas including the Panhandle is in the Red River Basin is forecast by the Arkansas-Red Basin RFC (ABRFC), located in Tulsa Oklahoma. The West Gulf RFC (WGRFC) in Fort Worth, Texas has responsibility for rivers draining into the western Gulf of Mexico along the Texas coast, from and including the Rio Grande to the Sabine River Basins. A small portion of east Texas comprised primarily of the Sulphur and Cypress River basins is forecast by the Lower Mississippi RFC (LMRFC) located in Slidell, Louisiana.

Each WFO provides site-specific hydrologic products and other hydrologic services for its Hydrologic Service Areas (HSA). HSAs are generally coincident with county warning and

[1] Both flood events are described in the Houston Chronicle, April 23, 2016.

forecast areas. Site-specific hydrologic forecast and warning products are provided for the HSA in addition to areal hydrologic products such as flash flood watches for a county warning area. There are ten WFOs that serve at least some portion of Texas.

The principal activities of the RFC center on river forecasting for flood warnings and water management, which includes assimilation of observations, modeling and forecasting, and interaction with the user community, including the WFOs. The primary responsibilities of the RFCs related to this project are:

1. Continuous modeling of stream discharges and water levels for flood warning and water management activities; and
2. Development of guidance products and coordination with WFOs in support of the WFO flash flood warning and river flood warning programs.

At the core of the National Weather Service River Forecast System (NWSRFS) is the Sacramento Model and Soil Moisture Accounting (SAC-SMA) described by Burnash (1995). Runoff processes are highly variable in space and time and are difficult to capture within a modeling framework. Rainfall-runoff models therefore are highly parameterized and require extensive calibration, even on a seasonal basis. The SAC-SMA model representation of soil moisture is spatially lumped across the sub-basin. Soil profile representation in the model, as a soil column with upper and lower storage zones, also presents uncertainties in model forecast output. In fact, nearly 20 parameters are available in the SAC-SMA model to control the rates of runoff, interflow, and baseflow, all of which contribute to the stream hydrograph. Calibration of the models in the NWSRFS is key to reliable forecasts and must be done with historical stream gage data (Smith et al., 2003). The forecaster therefore needs to be able to use the model with different parameter choices and input sequences to determine the error structure of the forecasts. This requires the forecaster to be intimately involved in the process. First the model is adjusted to agree with current streamflow observations as an initial condition, then soil moisture, precipitation input, and possibly other parameters are adjusted to initiate model states and produce river forecasts. Once the calibrated model has been used to determine the precipitation excess, unit hydrographs, flood wave routing and reservoir releases are used to estimate the streamflow at more than 4,000 forecast locations nationwide (NRC, 1997).

Improvements to the RFC forecast system were initiated in 1997 for the Des Moines River Basin in Iowa. Called the Advanced Hydrologic Prediction Service (AHPS), the system has now been expanded to all basins in the 13 RFC areas. AHPS forecast products represent compilation and processing of the most recent observations and more accurate and higher resolution forecast products. Recent advances include: new model calibration strategies, distributed modeling approaches, ensemble forecasting and data assimilation techniques, enhanced data analysis procedures, flood-forecast inundation maps, hydraulic routing models, and multi-sensor precipitation estimation techniques. The format and content of the hydrologic products and information are also being improved (McEnery et al., 2005).

Input to the NWS RFC basin models relies on analysis of two primary data sources consisting of rain gage data and radar estimates of current precipitation. Forecast precipitation is based on ensemble forecast precipitation from numerical weather prediction model output produced at the National Center for Environmental Prediction (NCEP). Observations of precipitation are key to accurate river forecasts. Rain gage observations are point-source measurements of accumulated precipitation over discrete time intervals such as daily, hourly or finer time steps. Rain gage networks that provide these observations are managed and maintained by cooperating federal, state, and local agencies. Because the NWS has limited ownership of these gage networks, it has little control over their operation and maintenance or choice of location. Additional rain gages in basins lacking adequate numbers, or in areas of radar gaps can improve the accuracy of model input. In this report, the term "basin" refers to NWS RFC forecast basins.

The goal of precipitation data processing is to define the spatial distribution of precipitation over appropriate time intervals. NWS developed the Multisensor Precipitation Estimator (MPE) and uses it at the WFOs and RFCs. MPE combines radar rainfall estimates with rain gage measurements and produces a suite of multisensor rainfall estimates. Spatially variable bias correction of the radar precipitation estimate is needed due, in part, to the limited effective range of the radar beam (Seo and Breidenbach, 2002). Recent developments in quantitative precipitation estimates resulted in the Multi-Radar Multi-Sensor (MRMS) product that has a higher spatial resolution (Zhang et al., 2016). This data source is being used by the RFCs for flood forecasting.

As stated by the National Research Council (NRC, 1997), "it is not possible to make an accurate forecast with inaccurate or incomplete data, even with the most advanced models and interactive tools." To fulfill the objectives of this project, additional rain gages are recommended to aid in the hydrometeorological analysis used operationally at the WGRFC. Further, stream gages are recommended and prioritized for vulnerable communities. River forecasting operations at the RFCs and the NWS rely heavily on stream gages for model initiation during operations, and for calibration with historical streamflow. Adding to the network of USGS stream gages will be beneficial to the NWS forecasting operations.

Flooding is the most common type of natural disaster and Texas leads the nation in both flood insurance losses[2] and flood-related fatalities[3]. The state's proximity to a large source of moisture – the Gulf of Mexico – together with other factors such as latitude, population density around streams and rivers, topography, and geology are conducive to flash flooding.

The first stream gage in Texas was installed 127 years ago, on the Rio Grande near El Paso. Today the USGS maintains a network of 555 stream and 145 lake level gages cross the state of Texas, providing near real-time access to the data for each site (TWDB Board Memo

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[2] U.S. Flood insurance loss statistics from Jan 1978 through Sep 30, 2001. NFIP.

[3] U.S. Flood fatalities from 1960 – 1995. NOAA National Center for Environmental Information (NCEI) Storm Data publications.

August 11, 2016). Until recently, the TWDB supported the costs of 53 streamflow and 35 lake level gages, through a Joint Funding Agreement with the USGS. In December 2015, the Office of the Governor and the TWDB executed a Memorandum of Understanding, providing funding for additional stream gages in Texas and to enhance flood notification systems. Shortly thereafter, 12 high priority stream gage sites and one lake level site were identified by the NWS and TWDB, and were installed, or are to be installed in the near future. Three of these stream gages were installed above Wimberley. Sites were selected in consultation with the City of Wimberley, the Guadalupe-Blanco River Authority (GBRA), and other stakeholders. A further 19 new high priority stream gages are expected to be installed in Fiscal Year 2017. These sites have been identified as top priority by GBRA and the NWS.

In addition to the funds provided for the high priority monitoring sites identified already, the TWDB also provided funds for the installation of additional monitoring at the following locations:

- Hays County: 10 new rain gages, 25 water level gages, five reservoir stations;
- Uvalde County: 13 river stage gages;
- GBRA: Eight new rain gages near North Caldwell County and eight more in Eastern Hays County;
- Cameron County: 16 water level sensors;
- North Central Texas COG: Equipment at a number of low water crossings;
- City of Buda: Five water level sensors;
- City of Sealy: Four water level sensors; and
- Bandera County: Two USGS stream gages.

Construction and installation of gages at these sites is ongoing. There appears to be only two full-range USGS stream gages that will be installed resulting from this other TWDB initiative. It is important to note that there might be some overlap between the areas identified above for flood warning improvements and the list of stream and rain gages we have developed through this project. At the time of publication, the full details of the sites and type of monitoring equipment proposed above was not available. TWDB staff should ensure no duplication of sites occurs through these two initiatives, prior to selection and installation of gages recommended in this report.

A preliminary list of potential new forecast locations and stream gage sites was compiled by the WGRFC[4]. The locations for these proposed stream gages was based on their desire to improve the NWSRFS flood forecasting model for areas underserved across their forecast responsibilities in Texas. The TWBD goal on this project, being closely aligned with NWS priorities, is to provide monitoring infrastructure to improve the accuracy and timeliness of flood warnings that can be developed and conveyed in time for evacuations to take place, and casualties avoided in communities along flood-prone rivers.

[4] Patrick Sneeringer, forecaster WGRFC provided a list of desired stream gages.

This project seeks to identify the 30-40 best locations for stream gages to meet these TWDB goals and to complement those recommendations with suggestions on the placement of rain gages[5]. The cost of installation of each new stream gage is approximately $50,000, depending on the location; subsequent operation and maintenance costs typically run about $17,000 per year. The USGS was unable to provide any matching funds for these new gages and therefore the state will bear the full cost of installation and maintenance of these new gages.

In addition to stream gages, the TWDB is interested in identifying locations for new weather stations. Rainfall is the main input into the flood forecasting models, and data gaps in the precipitation network can lead to erroneous or missed flood forecasts. Fortunately, there is a network of radars (NEXRAD) that provides coverage for most of the state, but with gaps present at locations beyond the range of the radars in this network. This dataset is complemented by a network of some 2,700 rain gages that the NWS uses in the flood forecasting activities in Texas. Nevertheless, neither system of rainfall measurement is perfect for rainfall-runoff studies or real-time flood forecasting. Furthermore, there are some notable gaps in the radar and rain gage coverage, particularly in West Texas.

The TWDB would like to identify areas of the state where there are communities vulnerable to flooding and where flood notification systems are unsatisfactory due to lack of stream gages and weather stations. Flooding will continue to happen in Texas, but this additional equipment should improve the warning capabilities for those areas. Specifically, the scope of work (Request for Qualifications NO. 580-16-RFQ0023) requested by the TWDB is as follows.

A. Identify communities in Texas that, due to limited or non-existent stream and weather monitoring, receive inadequate warning from the National Weather Service's Advanced Hydrologic Prediction Service or other flood warning systems.
B. List in order of priority communities needing additional monitoring based on factors that must include propensity for flash floods, historical number of fatalities due to flooding, and severe and repetitive economic losses due to flooding. The factors may also include population temporarily or permanently residing within designated Federal Emergency Management Agency flood hazard areas and other factors.
C. Identify locations where additional real-time stream gages and weather stations would improve flood forecasting based on hydrometeorological models for priority communities. Locations of new stream gages and weather stations must be optimized to provide adequate lead times for flood warnings, while keeping overall costs low to increase the number of communities that can be supported.

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[5] We use the term rain gage and weather station interchangeably in this report. While rainfall is the main weather input into the hydrological models, other weather-related data are also important and may serve other purposes. Our recommendations are for rain gages, with additional sensors at these sites, if deemed important and useful by the TWDB.

D. Where appropriate, suggest alterations to existing data collection infrastructure that would provide enhancement to hydrometeorological models (e.g. existing instruments whose reporting frequency could be increased in order to provide more value for flood warning).

As this project got underway, we established a relationship with representatives of the agencies directly impacted by this TWDB initiative (see Section 5.0). The USGS will be installing stream gages at identified locations and the NWS RFCs will be using the new stream gage locations for setup of new forecast and observation points. New rain gages will improve their precipitation estimates. This team of individuals has contributed experience, expertise and guidance to help identify useful sources of data, provide insight into the current flood forecasting systems. In addition to the TWDB, representatives from the NWS and the USGS participated in meetings and made themselves available by phone and email to answer questions. Their input was extremely valuable.

2 Methodology

We have developed two complementary approaches for the identification of locations for new stream gages and rain gages. For identifying stream gage locations, first communities were ranked according to their vulnerability within an analytical framework, and second, model simulation was used to test feasibility of stream gage locations. For rain gages, we looked at a couple of different approaches for identifying gaps in the existing network. The methodology developed for each is described in the following sections.

2.1 Stream gage location prioritization

An objective, analytical framework was used to identify communities with the most pressing need for additional stream gages and weather stations. The communities identified were those that are not currently served or inadequately served by existing forecasting services, those benefitting most from improved flood forecasting services. A consistent framework, called the analytic hierarchy process (AHP), was applied across the entire state, helping to identify vulnerable communities, for proposed stream gages.

The decision-making methodology embodied by AHP is most useful when decision factors are dissimilar, making it unclear how they can be combined to make rational and defensible selection of alternatives. Since its introduction by Saaty (1980), AHP has been applied in a wide variety of practical settings to model complex decision problems. Its ability to rank and quantitatively assess decision alternatives has led to many applications in diverse areas described in Saaty (2004). Spatial-AHP, as described by Siddiqui et al. (1996), is an adaptation of the AHP process to decision-making with geospatial representation of limiting environmental factors governing landfill siting. Application of the AHP methodology applied herein for prioritization of communities vulnerable to flooding is novel but consistent with the overall methodology used in AHP to rank alternatives based on a range of dissimilar decision factors, such as economic losses due to floods, fatalities, frequency of flooding, and social justice indicators. Before ranking a community, inclusionary criteria were applied according to flood forecasting restrictions or physical impracticality. The AHP decision-making method involves five steps:

1. Identifying the decision factors to rank communities;
2. Structuring these decision factors within a decision hierarchy;
3. Assigning relative importance weights to each element;
4. Aggregating the combined weights in a suitability index for each community; and
5. Ranking the communities according to the suitability index.

Decision factors were used to relate attributes to suitability concerning a particular goal. Once the decision factors for a given problem were identified, they were arranged in a decision hierarchy. At each level in the hierarchy, subfactors and sub-subfactors were identified for development of relative importance weights and overall suitability index. Based on the suitability index, ranking was performed for those communities that meet inclusionary conditions, as described next.

2.1.1 Inclusionary criteria

The AHP decision-making methodology must first consider whether a community (e.g. incorporated city or unincorporated county) should be included in the analysis. Three conditions were defined as existing circumstances that would remove a community from consideration, which are:

1. A community has an existing and sufficient flood warning system;
2. A community is outside of an existing AHPS river forecast basins; and
3. AHPS total basin size upstream of a community is smaller than 50 square miles.

If a community fell under any one category, it was removed from the AHPS community prioritization process. In the case of large cities and multiple basins within the city, each basin was assessed independently. Communities with existing and sufficient flood warning systems, such as the City of Austin Flood Early Warnings System or the Harris County Flood Warning System were also removed from consideration, though each was investigated to determine geographic extent, density and location of existing monitoring stations. Communities outside of existing AHPS forecast basins are often near the Gulf of Mexico. AHPS does not provide flood forecasting for communities outside of its basins and therefore are not considered in this study. If a community, such as an unincorporated county near the coast, overlaps an AHPS basin, the overlapping portion was considered within the AHP community prioritization process. Figure 1 shows a map of inclusionary areas within Texas and the NWS RFC river forecast basins, and those non-inclusionary areas along the coast excluded from further consideration. A list of these basins is provided in Appendix A. Basins smaller than approximately 50 square miles (including any contributing upstream watersheds) are typically too small to offer sufficient lead time in the event of flooding. However, because these basins are smaller, the magnitude of the floods these communities experience is smaller too.

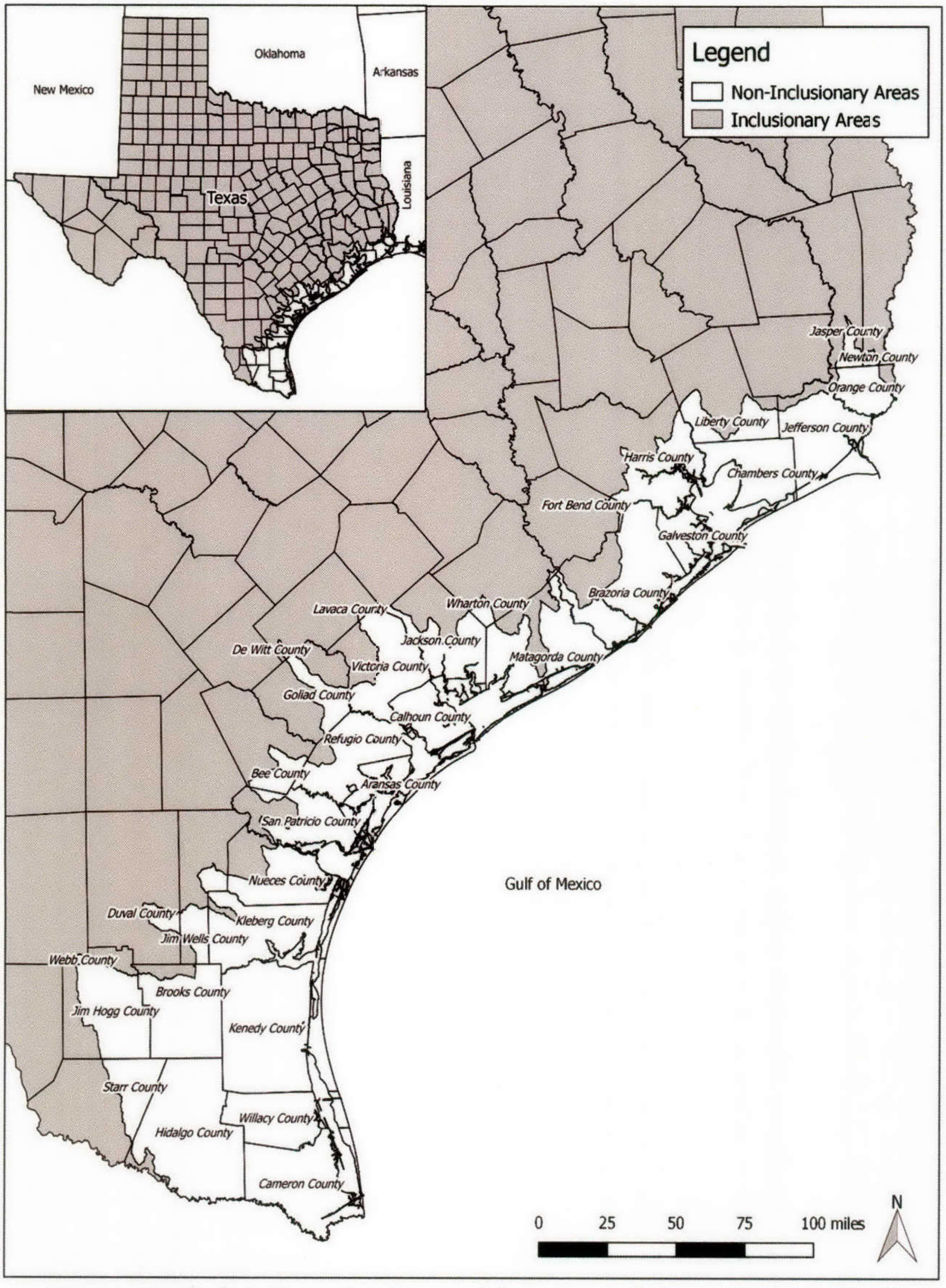

Figure 1. Areas included for analysis (gray) and those areas excluded from analysis (white).

2.1.2 Datasets identified and used

Several publicly available datasets were used as AHP decision factors, which are described individually as follows.

National Flood Insurance Program claim payments
The Federal Emergency Management Agency (FEMA) provides National Flood Insurance Program (NFIP) historical claim payment data. Data for the entire State of Texas was provided by FEMA Region IV, Denton, Texas, for the period from 1/1978 to 8/31/2016. Claim payment data is organized by individual property and grouped within a community that participates in the NFIP. The NFIP uses a community identification number (CID), which could represent an incorporated city, unincorporated county, levee improvement district or other. We use the term "community" in this report to represent a NFIP defined community, which has a unique CID. Throughout this report the NFIP defined community will be the structure for other datasets, and for ranking vulnerable communities through the AHP. Claim payment data is commonly divided into three categories: mitigated or non-mitigated properties, Repetitive Loss Property (RLP), and Severe Repetitive Loss Property (SRLP) and are described below:

- **Mitigated or non-mitigated properties:** Mitigation measures for a property can include the following, "...elevating buildings above the level of the base flood, demolishing buildings, and removing buildings from the Special Flood Hazard Area (SFHA) as part of a flood control project" (Repetitive Loss FAQ). Mitigation measures can also include local drainage projects. A properties' history of claim payments still exists if it has been mitigated.
- **Repetitive Loss Property (RLP):** "...is a structure covered by a contract for flood insurance made available under the NFIP that: has incurred flood-related damage on 2 occasions, in which the cost of the repair, on the average, equaled or exceeded 25 percent of the market value of the structure at the time of each such flood event, and at the time of the second incidence of flood-related damage, the contract for flood insurance contains increased cost of compliance coverage" (Hazard Mitigation Assistance Guidance).
- **Severe Repetitive Loss Property (SRLP):** "...is a structure that: is covered under a contract for flood insurance made available under the NFIP, has incurred flood related damage – for which 4 or more separate claims payments (includes building and contents) have been made under flood insurance coverage with the amount of each such claim exceeding $5,000, and with the cumulative amount of such claims payments exceeding $20,000, or for which at least 2 separate claims payments (includes only building) have been made under such coverage, with the cumulative amount of such claims exceeding the market value of the insured structure" (Hazard Mitigation Assistance Guidance).

The NFIP Severe Repetitive Loss Property dataset is included within the AHP as a decision factor. This dataset represents properties that have a history of frequently being flooded and have a strong potential to be flooded into the future. The dataset provides NFIP total payments made within a community, and is normalized by population from the U.S. Census Bureau.

The NFIP Repetitive Loss Property dataset is also included within the AHP. This dataset represents properties that have a history of being flooded and have the potential to be flooded into the future. The dataset includes more communities than the SRLP dataset due to the lower thresholds. Within this dataset two subsets were extracted and used within the AHP as decision factors:

- **NFIP Repetitive Loss Property Claim payment frequency dataset.** The frequency of claim payments was calculated for each community and normalized by population from the U.S. Census Bureau. This provides a dataset without the influence of claim payments, which may skew preference towards communities with higher property values.
- **NFIP Repetitive Loss Property Non-mitigated claim payments dataset.** Non-mitigated claim payments dataset represents properties that have not yet been mitigated and have a strong potential to be flooded in the future. Non-mitigated properties within a community were extracted from the RLP database and normalized by population from the U.S. Census Bureau.

The FEMA NFIP datasets used in the AHP as decision factors only have data from communities that participate in the NFIP. Appendix B lists the 134 communities and 5 unincorporated regions of counties that currently do not participate in the NFIP. The average 2015 population of communities not participating in the NFIP is 629 people (U.S Census Bureau). Some of the reasons given by communities for not wanting to participate in NFIP are: lack of flood damage, not enough properties that would be in the floodplain, not enough resources to appoint a floodplain manager, and the time it would take to regulate floodplains[6]. Although the NFIP datasets do not have data from these communities the other datasets used within the AHP process do.

Basin slope

Basin slope is a dataset used within the AHP as an indicator of flash flood potential and the associated risk of quickly rising and higher velocity flood waters. AHPS basins used for river forecasting were provided by the NWS and have mean basin slope values attributed with them. Each basin's mean slope was spatially paired with a community. If multiple basins overlapped a single community, then the basin with the maximum slope was assigned to the community.

Flood fatalities

The Storm Events Database (SED), through NOAA National Center for Environmental Information (NCEI), documents storms or significant weather phenomena which cause fatalities, injuries, significant property damage or disruption to commerce (Storm Events Database). The SED provides data from 1/1950 to present and is spatially aggregated at the

[6] Personal communication with Tom Kustelski (FEMA, Region VI), 11/21/16.

state and county level. SED event descriptions have evolved throughout the years and have only provided event types such as flash flooding or flooding since 1996. The SED is made up of monthly Storm Data Publications, and contains the original event data.

Research has identified discrepancies in the Storm Data Publications and SED, including underreporting and inconsistency in event details. Sharif et. al. (2015) analyzed flood fatalities in Texas from 1959 – 2008, using monthly Storm Data Publications. Their analysis reviewed 600 monthly Storm Data Publications to minimize discrepancies with the SED and provide the most accurate dataset of flood fatalities in Texas. Sharif (2016) also compared the SED with the Spatial Hazard Events and Losses Database (SHELDUS) published by the Hazards and Vulnerability Research Institute (2016), which is a similar compendium of hazard data, but found that the SED was more comprehensive.

Flood fatalities is a dataset used within the AHP. The dataset is a combination of the Sharif et. al. (2015) analysis of SED data from 1959-2008, with SED data from 2009 through 08/2016. This resulted in a more accurate and temporally complete dataset. The flood fatality dataset is at the county level and normalized by population from the U.S. Census Bureau.

EPA Environmental Justice

The EPA Environmental Justice Screening and Mapping Tool (EJSCREEN) provides EPA with a nationally consistent dataset and approach for combining environmental and demographic indicators. The tool includes a database of eleven (11) different Environmental Justice (EJ) index values that are a combination of environmental and demographic information. There are six (6) demographic indicators including:

- Percent minority population;
- Percent low-income;
- Percent less than high school education;
- Percent linguistic isolation;
- Percent individuals under age 5; and
- Percent individuals over age 64.

Of the 11 EJ indexes, the four most relevant were used:

- Proximity to Major Direct Water Dischargers;
- Proximity to Risk Management Plan Sites;
- Proximity to Treatment Storage and Disposal Facilities; and
- Proximity to National Priorities List Sites.

The EJ index values were assigned to 2010 Census Block Groups and the average of the four index values was calculated for each Block Group. Using GIS, the Block Group extents were intersected with NFIP communities. The highest average index value that overlapped a community was used within the AHP.

Texas population projections
Population projections is a dataset used within the AHP. This dataset considers counties with high population growth as an indicator of where flood forecasting will serve an increased population into the future. Additionally, these high population growth regions may change the hydrology and increase the frequency of flooding. The dataset is percent projected population growth from 2020-2070 at the county level (TWDB state water planning population projections).

Notes on normalizing datasets by population
To obtain more comparable statewide datasets spanning a wide range of urban and rural population densities, several datasets were normalized by population. For this project normalizing means dividing a dataset value by the population of the applicable community. To normalize values, only the U.S. Census Bureau population data was used to provide consistency across datasets.

When normalizing NFIP claims data by population, the average year of claims for a community was used to determine applicable population value. If population estimates for cities or unincorporated counties were not available from the U.S. Census Bureau (e.g., prior to 1990), then the *closest in time* population data was used (e.g., 1990). Since U.S. Census Bureau population estimates are not yet available for 2016, 2015 population estimates were used where applicable.

If datasets did not have specific date information but rather a range of time it occurred (e.g. flood fatalities in the SED) then the average year within that range was used. If the average year fell outside of the U.S. Census Bureau yearly population estimates, then a linear interpolation was used to estimate population between decades. This approach is used and advised by the Texas Demographic Center[7].

2.1.3 AHP weighting and ranking

The AHP decision hierarchy used for this study has three levels, as shown in Figure 2. The elements in Level 2 and 3 (i.e. level 2 datasets or level 3 groups in each dataset) each have defined weights, which are known as relative importance weights (RIWs). An RIW value represents the importance of one element over another within each respective level or group. Level 1 is the ranking of vulnerable communities through a suitability index (SI), which is calculated from level 2 and 3 RIW.

RIWs are defined through an objective pairwise comparison process. This process assigns an intensity of importance value, which are classified in Figure 3. For example, if dataset "a" has a strong importance over dataset "b" then it would be assigned an importance value of 5. An RIW can be calculated once pairwise comparison values are determined between

[7] Helen You (Texas Demographic Center) personal communication.

each element in a level or group. The RIW in level 2 sum to 1.0 and RIW in the level 3 dataset groups also sum to 1.0. More information on calculations in the AHP (such as RIW and SI) can be found in Saaty (2008).

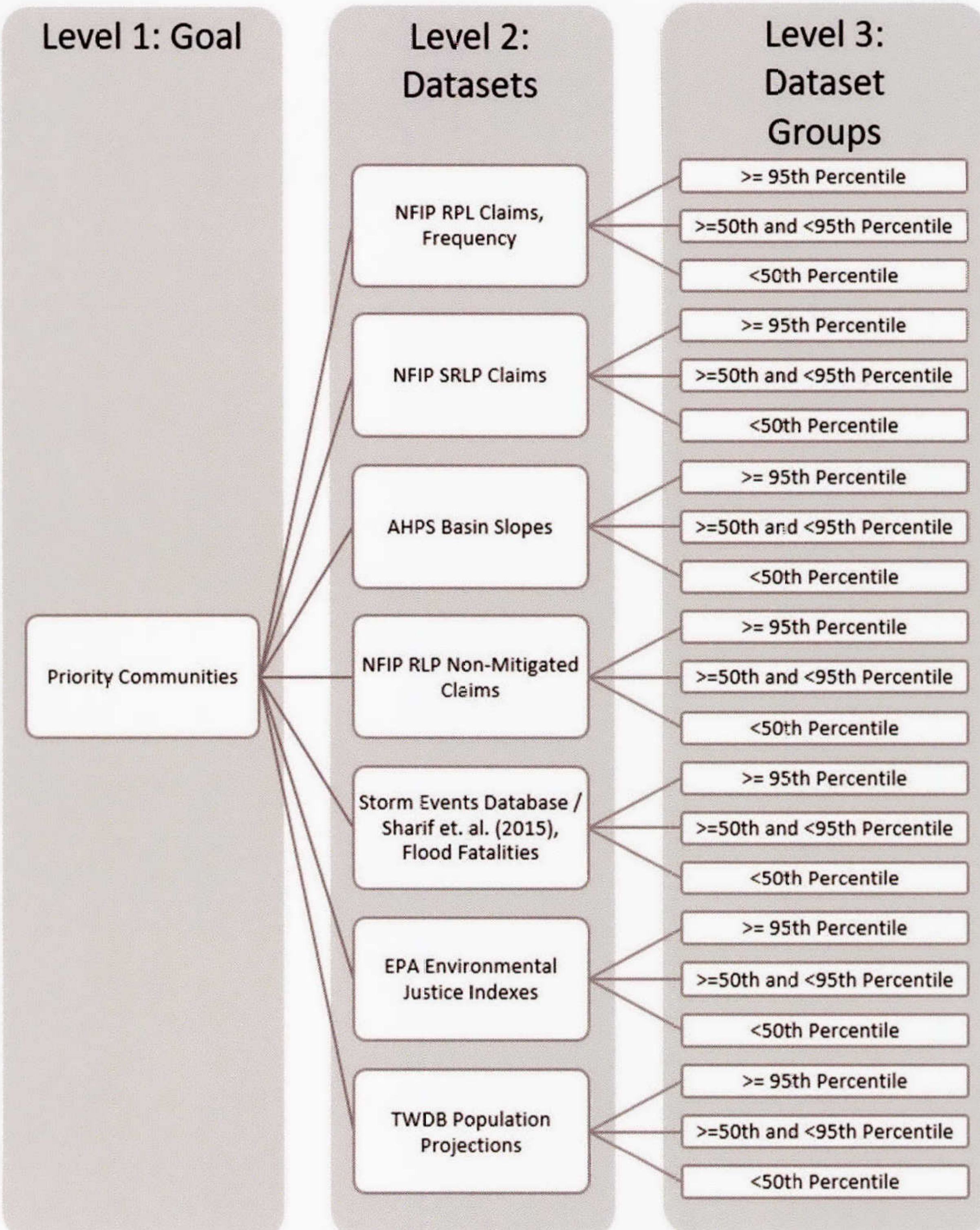

Figure 2. AHP decision hierarchy showing the three levels used in this study: datasets (level 2) and dataset groups (level 3).

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Figure 3. The fundamental scale of absolute numbers used in the AHP process (Saaty, 2008).

The AHP decision-making process starts at the third level, where a community's dataset value is grouped within one of three percentile ranges and assigned a RIW according to its respective range. For datasets at the county level (flood fatalities and population projections) the county level dataset value was applied to all communities within the respective county. The RIW for each percentile range was determined through AHP pairwise comparisons. The three percentile ranges and their respective level 3 RIW for every dataset are defined in Table 1. Note that in the RIW of 0.659 for the 95th percentile and above is the most important with the largest weight.

Table 1. Dataset percentile ranges and level 3 RIW.

Dataset Percentile Ranges	Level 3 RIW
>=95th percentile	0.659
>=50 and <95th percentile	0.263
<50th percentile	0.079

The second level RIW was calculated through the same AHP pairwise comparison process and are listed in Table 2. Certain dataset RIWs were higher than others due to a variety of factors such as the quality or resolution of the dataset. Two reasons why the flood fatality dataset has a RIW of only 0.086 is because data are available only at the county level and furthermore 76 percent of flood fatalities were vehicle related (Sharif et. al, 2015). Vehicle related flood fatalities are different than flood fatalities from insufficient community flood warning systems and often require different infrastructure. Each AHP pairwise comparison was decided by the team developing the tool.

Table 2. Level 2 RIW for each dataset.

Incorporated datasets	Relative Importance Weight
NFIP RLP Claims, Frequency	0.265
NFIP SRLP Claims	0.206
AHPS Basin Slopes	0.206
NFIP RLP Non-Mitigated Claims	0.160
Storm Events Database / Sharif et. al. (2015), Flood Fatalities	0.086
EPA Environmental Justice Indexes	0.053
TWDB Population Projections	0.023

The *NFIP SRLP Claims* and *NFIP RLP Non-Mitigated Claims* datasets have instances where a community is within the dataset because of a single property that has flooded multiple times. If that community has a small normalizing population, it can receive an unrepresentatively high RIW. To avoid these instances, if a community has only a single property in its respective dataset a level 3 RIW of 0.079 (the less than 50th percentile range RIW) was assigned. Adjustment within the two datasets does not affect other dataset's RIW.

The final product of the AHP is the ranking of communities, based on their vulnerability to flooding, through the calculation of a suitability index (SI). Exclusionary areas and their respective excluded communities were removed from the AHP ranking, which was then re-ranked. The top 120 ranked communities were individually assessed to decide whether a stream gage would benefit said communities' flood forecasting. The following resources were used in this assessment:

- FEMA National Flood Hazard Layer (NFHL) or the Flood Map Service Center (MSC) for base flood elevations and flood zones;
- Existing AHPS observation and forecasting locations (AHPS downloads);
- AHPS basin delineations and surface area (NWS);
- National Hydrography Dataset (Geospatial Data Gateway);
- Existing U.S. Geological Survey stream gage locations;
- Government units: Texas counties and State of Texas (Geospatial Data Gateway);
- U.S. Census Bureau Block Group population (TIGER/Line);
- U.S. Census Bureau ZIP Code Tabulation Areas; and
- Texas Water Development Board Existing Reservoirs (GIS Data)

The individual assessment process for a vulnerable community considered a variety of factors, including:

- Distance to the nearest upstream or downstream AHPS forecast or observation point;
- AHPS relative basin size and total contributing basin size;
- Local tributaries;
- Reservoirs upstream or downstream;
- General location of properties in the NFIP Repetitive Property Loss database;
- Relative population density; and
- Local knowledge of region

After assessing an AHP ranked vulnerable community a decision was made whether a stream gage was needed and could improve flood forecasting for said community. If affirmative, then V*flo*® was run to assess a location upstream which would provide sufficient warning time for the vulnerable community (see Section 2.1.8).

2.1.4 Recreational areas

Rivers are a significant recreational attraction to paddlers, fishermen, birders, campers and hikers, so it is not surprising that camping areas and parks are plentiful along the banks of Texas rivers. Flash flooding can place park-goers at risk, particularly in remote areas, in camping areas located within the flood plain and where primary access points involve low water crossings. Recreational vulnerabilities to flooding were evaluated as part of this project by considering the NWS Texas River Recreation Advisory, and through coordination with the Texas Parks and Wildlife Department (TPWD).

Although discontinued in October of 2016, the WGRFC Texas River Recreation Advisory (TRRA) was recommended by NWS staff as a starting place to inform on locations pertinent to river recreation (Table 3). Of the locations included in the list, eleven NWS river advisory locations are forecasts of dam releases below reservoirs. Two of the below-reservoir locations are already forecast points: the Angelina River below Sam Rayburn and the Neches River below Town Bluff. The remainder of the reservoir advisory locations consist of information provided by dam operators (either by rule or prior to significant changes). These areas are not further considered because high flow releases generally have multi-day lead times and any localized river flooding below these reservoir locations is already covered by existing downstream AHPS flood forecast locations.

Of the 15 TRRA locations formerly issued by the WGRFC, only one was not at an existing AHPS location. The TRRA location at Garner State Park on the Frio River lacks an existing upstream flood forecast, and the nearest downstream forecast is 10 miles downstream at

Concan, TX. Only Garner State Park on the NWS River Recreation Advisory list has been prioritized for new stream gaging station installation.

Table 3. NWS WGRFC Texas River Recreation Advisory locations and notes.

River	Location	Notes
Sabine River	Gladewater US271	Existing AHPS forecast point
Sabine River	Toledo Bend Dam	First d/s forecast point at Burkeville
Village Creek	Kountze FM418	Existing AHPS forecast point
Angelina River	Sam Rayburn Dam	Existing AHPS forecast point
Neches River	Alto	Existing AHPS forecast point
Neches River	Town Bluff Dam	Existing AHPS forecast point
Clear Fork Trinity	Benbrook Dam	First d/s forecast point at Fort Worth
Denton Creek	Grapevine Dam	First d/s forecast point on Elm Fork
Elm Fork Trinity River	Lewisville Dam	First d/s forecast point at Carrollton
Trinity River	Livingston Dam	First d/s forecast point at Goodrich
Brazos River	Possum Kingdom Dam	First d/s forecast point at Palo Pinto
Brazos River	Dennis FM1543	Existing AHPS forecast point
Brazos River	Granbury Dam	First d/s forecast point at Glen Rose
Lampasas River	Stillhouse Dam	First d/s forecast point at Little River
Colorado River	San Saba US190	Existing AHPS forecast point
Llano River	Llano SH16	Existing AHPS forecast point
Pedernales River	Johnson City	Existing AHPS forecast point
Colorado River	Austin US183	Existing AHPS forecast point
Guadalupe River	Spring Branch FM311	Existing AHPS forecast point
Guadalupe River	Canyon Dam	First d/s forecast point at Sattler
San Marcos River	San Marcos Luling SH80	Existing AHPS forecast point
Guadalupe River	Cuero US77A/87/183	Existing AHPS forecast point
Frio River	Garner State Park	**NO EXISTING FORECAST
Pecos River	Pandale	Existing AHPS forecast point
Rio Grande River	Presidio	Existing AHPS forecast point
Rio Grande River	Boquillas (RGV)	Existing AHPS forecast point

TPWD manages over 90 state parks, natural areas and historical centers located throughout the state of Texas. The TPWD assistance superintendent at Guadalupe River State Park was contacted for information on how TPWD manages flood risk at that park. While no campsites are located within the flood plain at that park, the park has experienced flood damages and damage minimization measures are implemented prior to flood events Indicators used to determine when to begin damage minimization and facility closures varies from park to park but indicators generally include upstream USGS gaging station readings, observations by local upstream landowners, flood forecasts and current park conditions. TPWD[8] was also asked to provide a short list of state parks where improved river flood forecasting would be beneficial. Priorities suggested to TPWD included those factors associated with safety (i.e. overnight camping spots within the floodplain) and factors consistent with the vulnerable community characteristics: fatalities, flash flood potential and repetitive historical damages. Parks experiencing damages resulting from lake shore or reservoir flooding were not included due to the slower, more predictable water level rise at those locations.

Of thirteen priority parks identified by TPWD, nine parks are located in the vicinity of existing nearby AHPS forecast locations (Table 4). TPWD's top priority is Garner State Park. Garner is located on the Frio River within Uvalde County, which is a ranked vulnerable area. Dinosaur Valley State Park is located on the Paluxy River in Somervell County and Palo Duro Canyon is located on the Prairie Dog Town Fork of the Red River, just downstream of the City of Canyon. The fourth park without a nearby forecast is South Llano River State Park, located on the South Llano River near the City of Junction. Four parks are not located within the vicinity of existing forecasts and were considered alongside the AHP-identified vulnerable communities for further vetting. These are identified with "**" in the table below.

Table 4. TPWD priority parks.

TWPD Priority	Park Name	Notes
1	Garner SP	**No u/s forecast on Frio River (Uvalde County)
2	McKinney Falls SP	Covered by City of Austin forecast and d/s AHPS forecast point
3	Brazos Bend SP	Existing forecast point adjacent at Rosharon
4	Stephen F. Austin SP	Existing forecast point 40mi u/s at Hempstead
5	Dinosaur Valley SP	**No u/s forecast on Paluxy River (Somervell County)
6	Goliad SP	Existing forecast point adjacent at Goliad
7	Colorado Bend SP	Existing forecast point 20mi u/s at San Saba
8	Palo Duro Canyon SP	**No u/s forecast. Forecast could also benefit City of Canyon
9	Guadalupe River SP	Existing forecast point 10mi u/s near Comfort
10	Pedernales Falls SP	Existing forecast point 15 mi u/s at Johnson City
11	Devils River SNAs	Existing forecast points u/s at Bakers Crossing
12	South Llano River SP	**No u/s forecast on South Llano River
13	Lyndon B. Johnson SP	Existing forecast point 15mi u/s at Fredericksburg

2.1.5 Additional coastal areas identified by NWS

The overall focus of this project is to provide additional capability for flood forecasting in rivers and streams near vulnerable communities. In areas along the Texas coast, the main causes of flood-related damages are related to surge of coastal waters and landfall of

[8] Chistopher Beckcom, TPWD Headquarters

tropical storms or hurricanes. To focus new stream gage recommendations and help focus prioritization on inland areas, the AHPS forecast basins were used as a mask to determine which communities are most dependent on AHPS forecasts (Figure 4).

Coordination with WGRFC staff during early phases of this project lead to inclusion of additional areas near the coast (Figure 5). These additional areas are where the WGRFC are planning or have been requested to provide additional future flood forecasting.

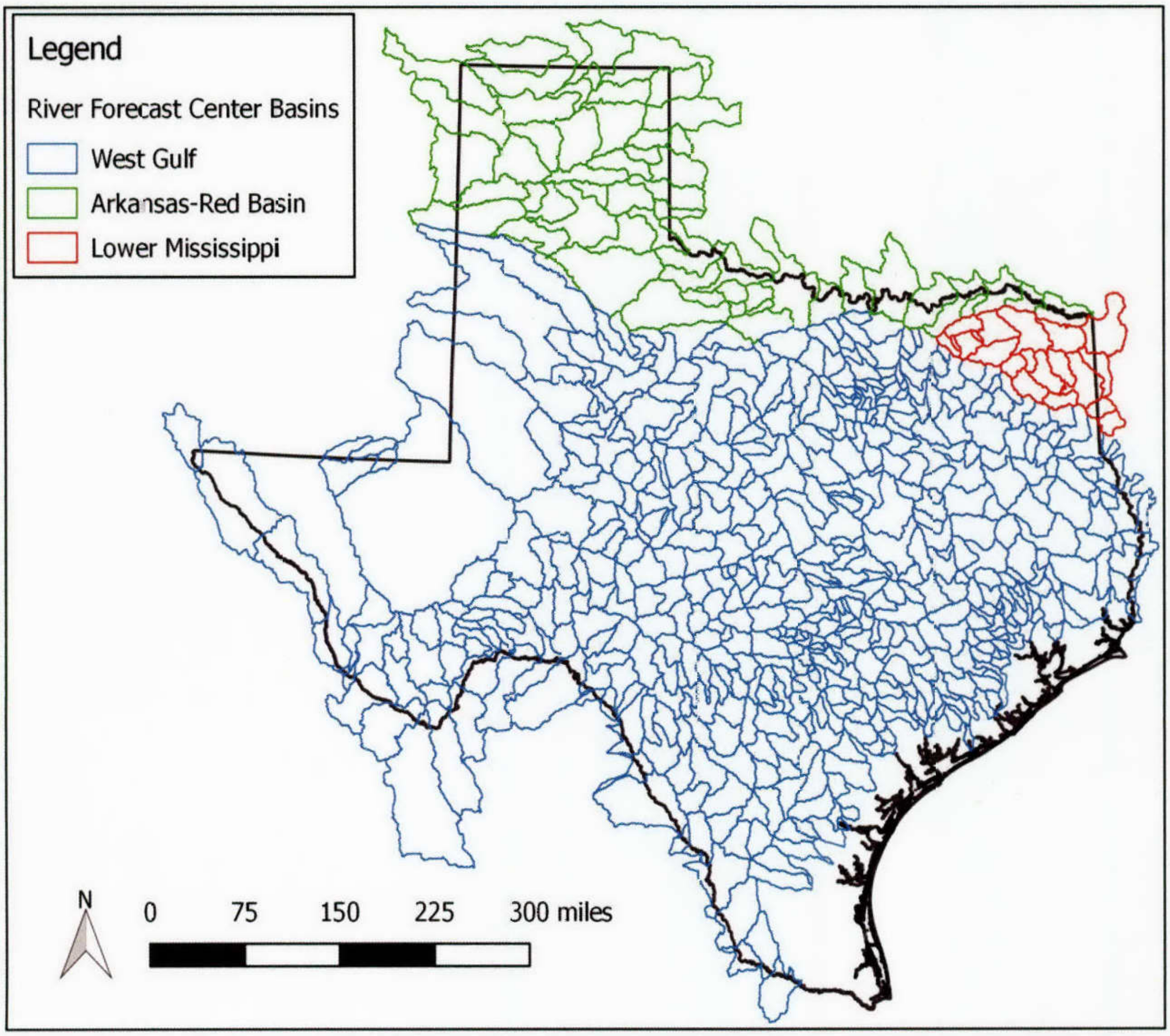

Figure 4. RFC AHPS basins within Texas.

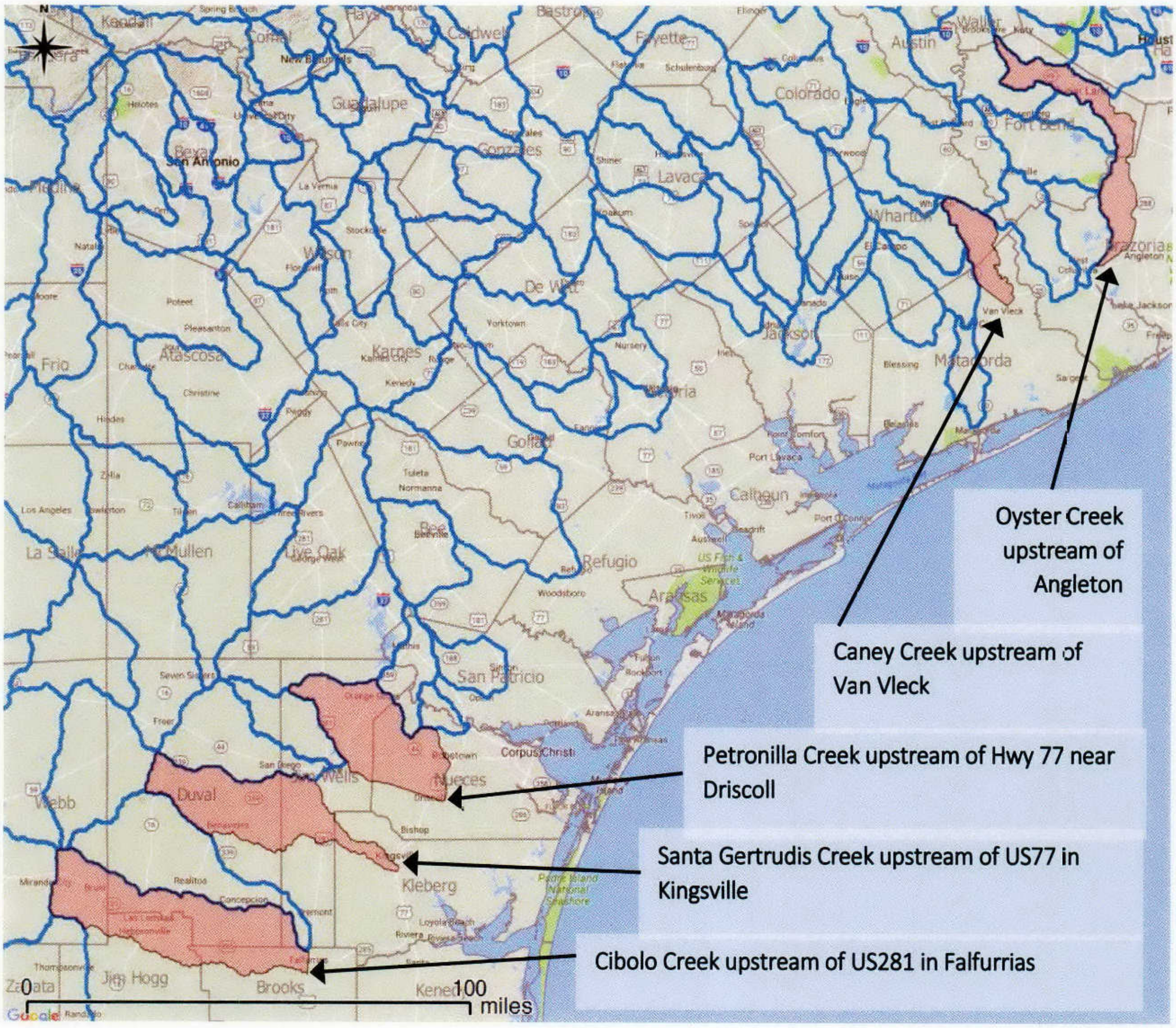

Figure 5. AHPS basins (blue outline) with additional coastal plain areas (salmon shading] to be included in the community vulnerability assessment.

2.1.6 Consideration of the NWS and stakeholder requested stream gages

In addition to the stream gage locations identified by AHP, we also considered recommendations from the NWS and other stakeholders, such as Comal County, City of Waco and Tarrant Regional Water District. These proposed stream gage locations were reviewed separately, however we used the same criteria for vetting as we did for the AHP output. Specifically, we looked at ungaged basin area, proximity to vulnerable community, existence of other gages, etc. It is important to note that lack of historical flood damage in a community does not imply that floods will not occur there in the future. Communities that did not rank high with our AHP tool because they lack historical flood damage, were often identified by the NWS or stakeholders, and considered in this analysis.

2.1.7 Potential use of other stream gages

In some parts of the state, there are stream gages operated by entities other than the NWS and USGS. As previously discussed, some cities operate their own flood forecasting systems, with rain and stream gages. Other entities use their own stream gages for monitoring flows into reservoirs, water accounting, or other purposes. Where the equipment is adequate, the rating curve development methodology meets current USGS standards and reporting for these gages is in real time, the NWS has indicated they can and will use these gages in their flood forecasting operations. A good example of a set of NWS-usable stream gages are those operated by the Lower Colorado River Authority. Flows from these stream gages are reported in real time and available online at: hydromet.lcra.org. One of the communities that ranked high on the vulnerability list is Jonestown, on the North side of Lake Travis. Instead of recommending a new stream gage for Big Sandy Creek, which runs through that community, the NWS[9] suggested that they begin using that stream gage in the flood forecasting activities, thus sparing the expense of installing a new gage.

2.1.8 Selecting stream gage locations

Once the vulnerable community was identified, an upstream gage location was evaluated in terms of its ability to provide lead-time before the flood wave reaches the downstream community. Model simulation with a gridded representation of watersheds in and surrounding the state was used to understand the potential for improved flood forecasting gained from the addition of an upstream stream gage.

Model overview
The gridded model, V*flo*®, described by Vieux (2016), was used to simulate potential flooding upstream of vulnerable communities. This model is based on recently developed distributed modeling technology; radar and rain gage precipitation inputs; and gridded parameters derived from GIS and remotely sensed data. The modeling approach is suited for distributed hydrologic forecasting in post-analysis and for continuous operational flood modeling. The hallmark of V*flo*® is its prediction of flow rates and stage in every grid cell defined by the hydraulics of overland and channel flow. An integrated network-based hydraulic approach to hydrologic prediction has advantages that make it possible to represent both local and main-stem flows with the same model setup, simultaneously. This integrated approach is applicable for urban and natural watershed applications, reservoir inflow forecasting, flood prediction, and hydrologic analysis. Figure 6 shows an example of a drainage network comprising a watershed with finite element connections between each grid cell. This stream network is from the Elm Fork of the Trinity River and was used in this project to model lead-time gained from an upstream gage location above Lindsay, Texas.

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[9] Patrick Sneeringer (NWS WGRFC), personal communication.

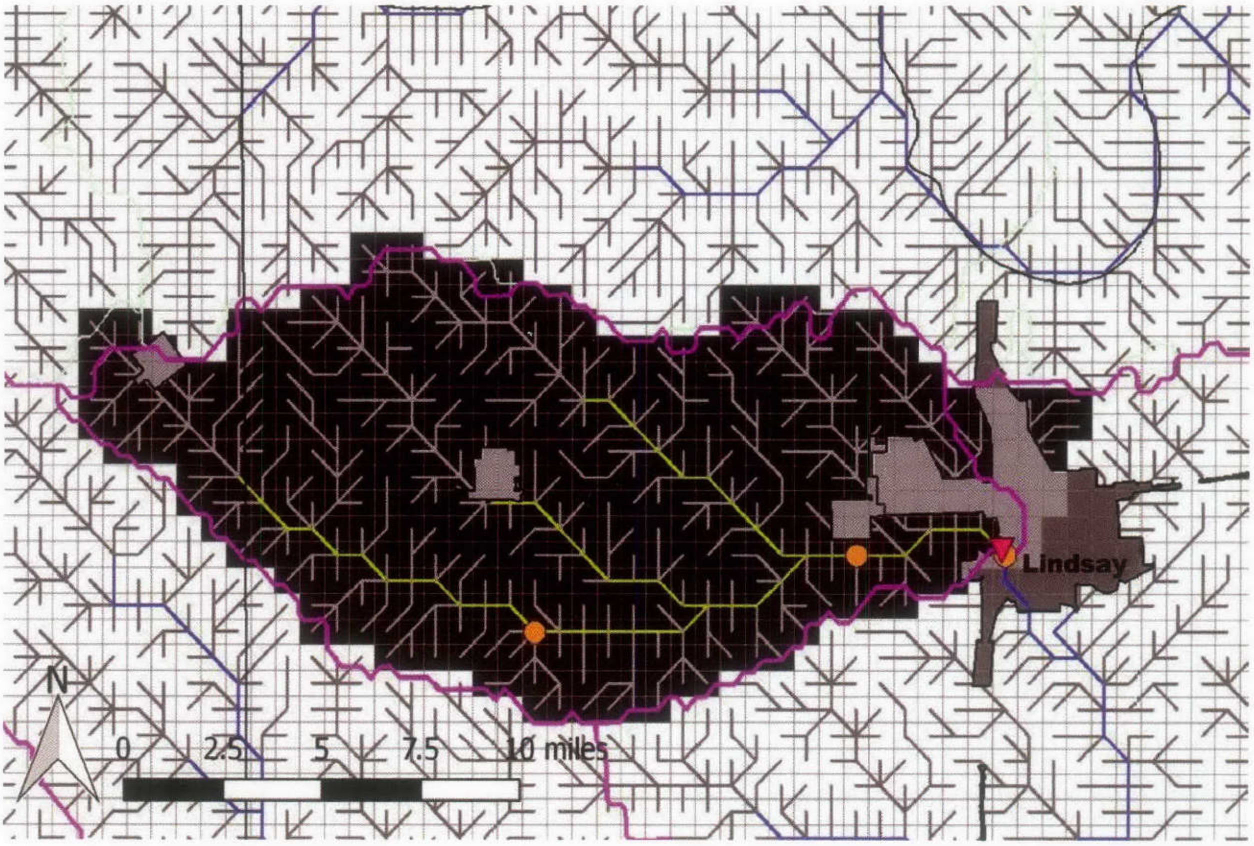

Figure 6. Grid-cell representation and drainage network used on the Elm Fork of the Trinity River.

The modeling approach relies on the hydraulics of the drainage network coupled with time-series of rainfall intensities to define the watershed response. This physics-based approach is used by the City of Austin Flood Early Warning System to produce stage forecasts at high resolution in rural, urban, and peri-urban watersheds. For application in this project, the model covers the entire state at a 1-km resolution (0.6 miles), and uses USGS National Hydrographic Database flowlines to represent segments of the stream network. To simulate the potential lead-time gained, historic extreme rainfall was transposed to each basin to help test and evaluate potential benefits gained from a proposed upstream gage location above vulnerable communities. To do this, timing and peak discharge were modeled at the candidate stream gage locations and comparisons made with downstream forecast locations in terms of lead-time and ratio of upstream over downstream peak discharge.

The Wimberley example

Analysis of potential lead time associated with a proposed stream gage location is illustrated for the flood event affecting the town of Wimberley, Texas on May 23-24, 2015. This model and the hydrometeorological input used in the analysis for the Blanco River watershed were used to test a hypothetical gage location above the town.

Figure 7 shows the rainfall total from this event distributed over the Blanco watershed, with the maximum rainfall total of 8.32 inches (indicated by an 'x') upstream above

Wimberley Texas. From this map of rainfall, derived from the NWS MPE, the storm hyetograph for the maximum intensity rainfall grid is presented in Figure 8. This event is used for testing the effectiveness of potential gaging stations upstream of vulnerable communities.

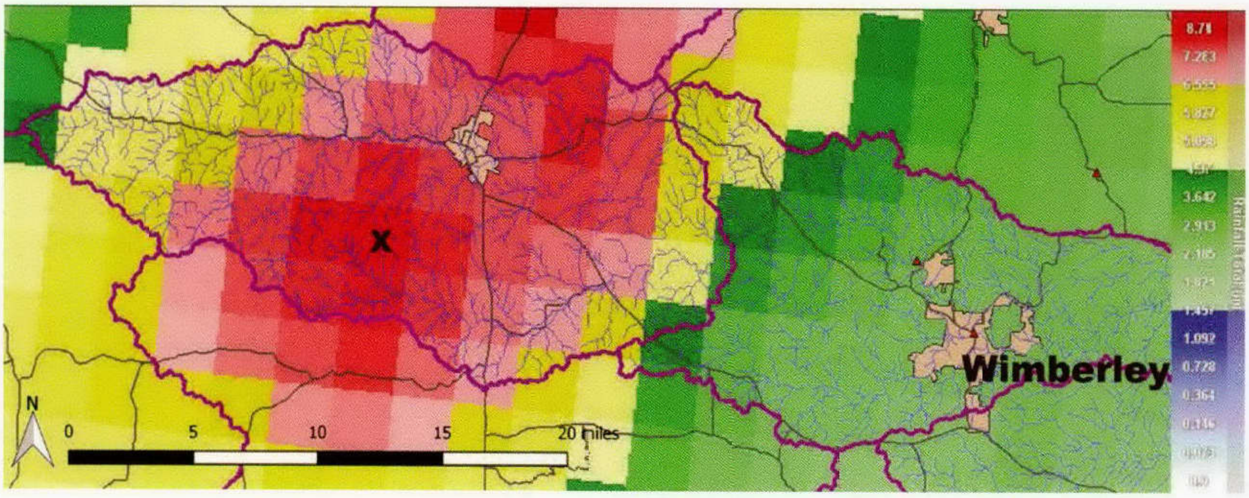

Figure 7. Blanco River watershed and storm total May 23-24, 2015

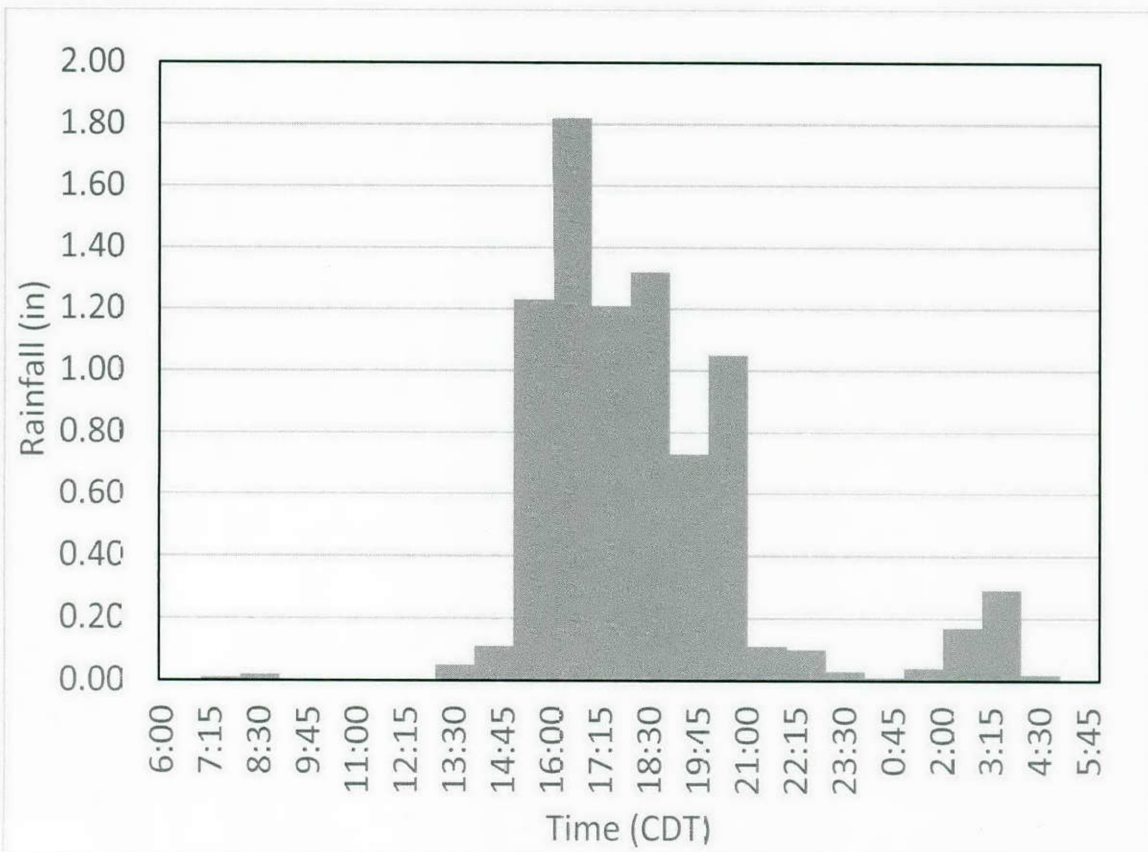

Figure 8. Memorial Day hyetograph, showing rainfall rates and total rainfall of 8.74 inches.

The model simulation of flood wave travel time for the stream network depicted in Figure 9 shows that a 1 hour and 20-minute lead time could be gained from a new stream gage at FM32 near Fisher (indicated by 'Gage'), which is upstream of Wimberley, TX. The simulated hydrographs shown in the lower portion result from using the Memorial Day hyetograph shown above (Figure 8). A boundary condition was set at this location and then used to forecast downstream river conditions at Wimberley. The simulated upstream peak flow was 126,000 cfs at the proposed location, while the downstream peak was estimated at 146,000 cfs at the USGS stream gage, shown as a red triangle (08171000). The increase in flow is due to inflow between the upstream and downstream stream locations.

With the lead time gained, sufficient time would be available for the NWS to issue a flood warning, and emergency managers to mobilize and help protect residents in the path of impending flood disaster. This approach was used to guide the selection and prioritization of new stream gage locations for communities vulnerable to flooding. Appropriate locations for stream gages (typically bridges and other areas with easy access to the river) were prioritized in each watershed. The simulated flows at each proposed monitoring site were then compared to the flows simulated at the downstream vulnerable community.

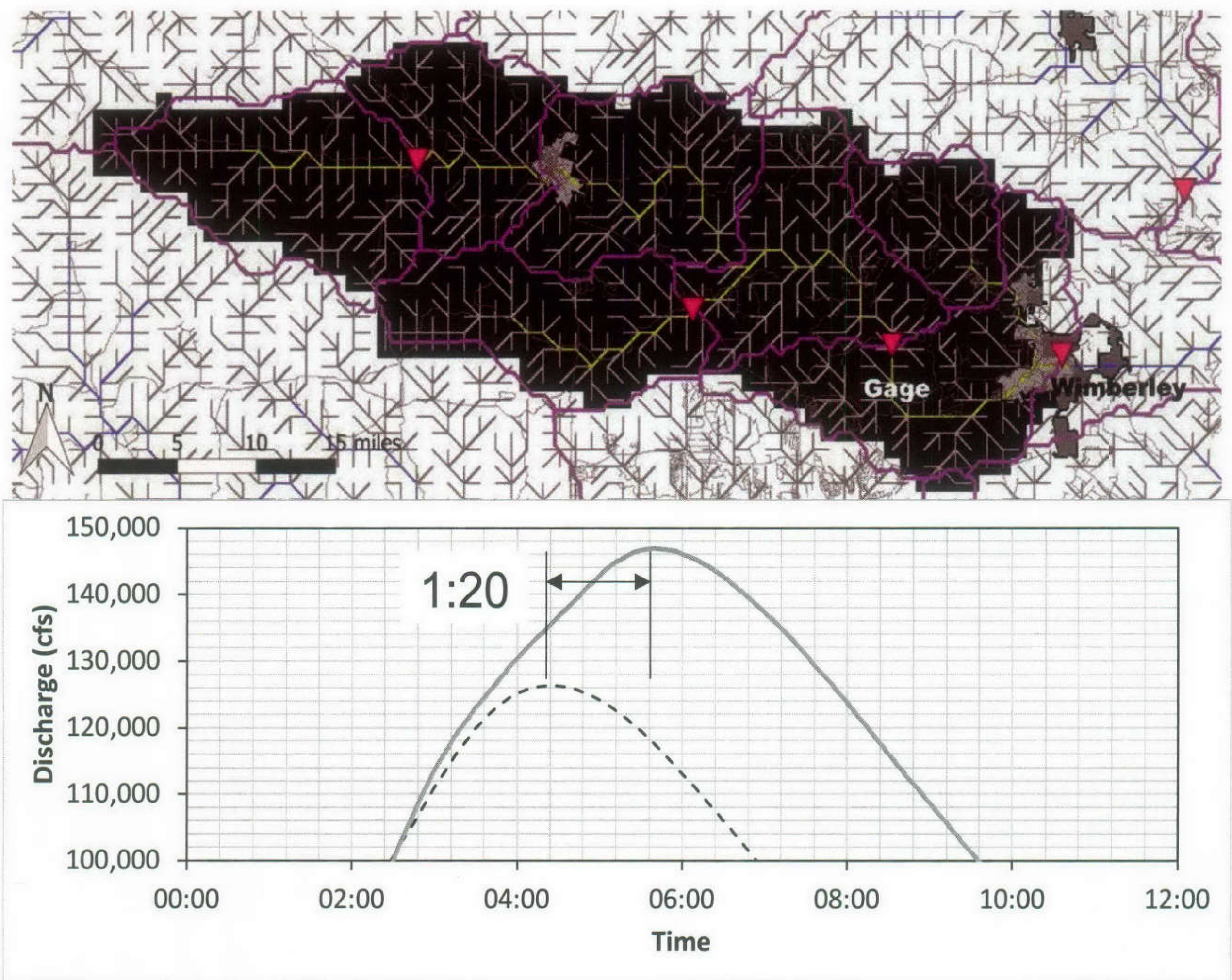

Figure 9. Lead time gained by installing a new stream gage in the Blanco River at the FM32 Bridge.

More information on the V*flo*® model can be found on the flash drive provided to the TWDB with this report.

The flash drives contains the following files:

1. vflo-6.1.56-install - Computer model install file requires adding ".exe" to execute installation. A 30-day license is issued upon registration by user.
2. Wimberley_PeakHyetograph_May_23-24_2015.rrp - Rainfall intensities used in the model to simulate lead time and peak ratios.
3. Texas1k_v6.3.bopx - Final V*flo*® model file containing model parameters and watch points set for analysis of potential stream gage locations.
4. Solving V*flo*®: Online User Guide - Operations manual describes the solving procedure in V*flo*®. Additional information is available online from the V*flo*® Help menu.

For more information on V*flo*®, please contact Vieux and Associates.

2.2 Rain gage location prioritization

Precipitation coverage for the state of Texas employed by the NWS consists of rain gage and radar observations used together to provide maps of rainfall over the forecast basins. Rain gages are needed for estimation of Quantitative Precipitation Estimates (QPE) either alone or in conjunction with radar. Precipitation maps are generated from these two sensor systems, covering each river basin forecast by the NWS. In areas where radar does not effectively cover, rain gages are the primary measurement, while in other areas covered by radar, they are used to enhance the accuracy of the QPE derived from the combination of radar and gage. There are more than 2,700 hourly rain gage sites in Texas operated by various agencies and transmitted in real-time to the NWS for use in river forecasting. The hourly gages used by NWS that cover Texas are shown in Figure 10.

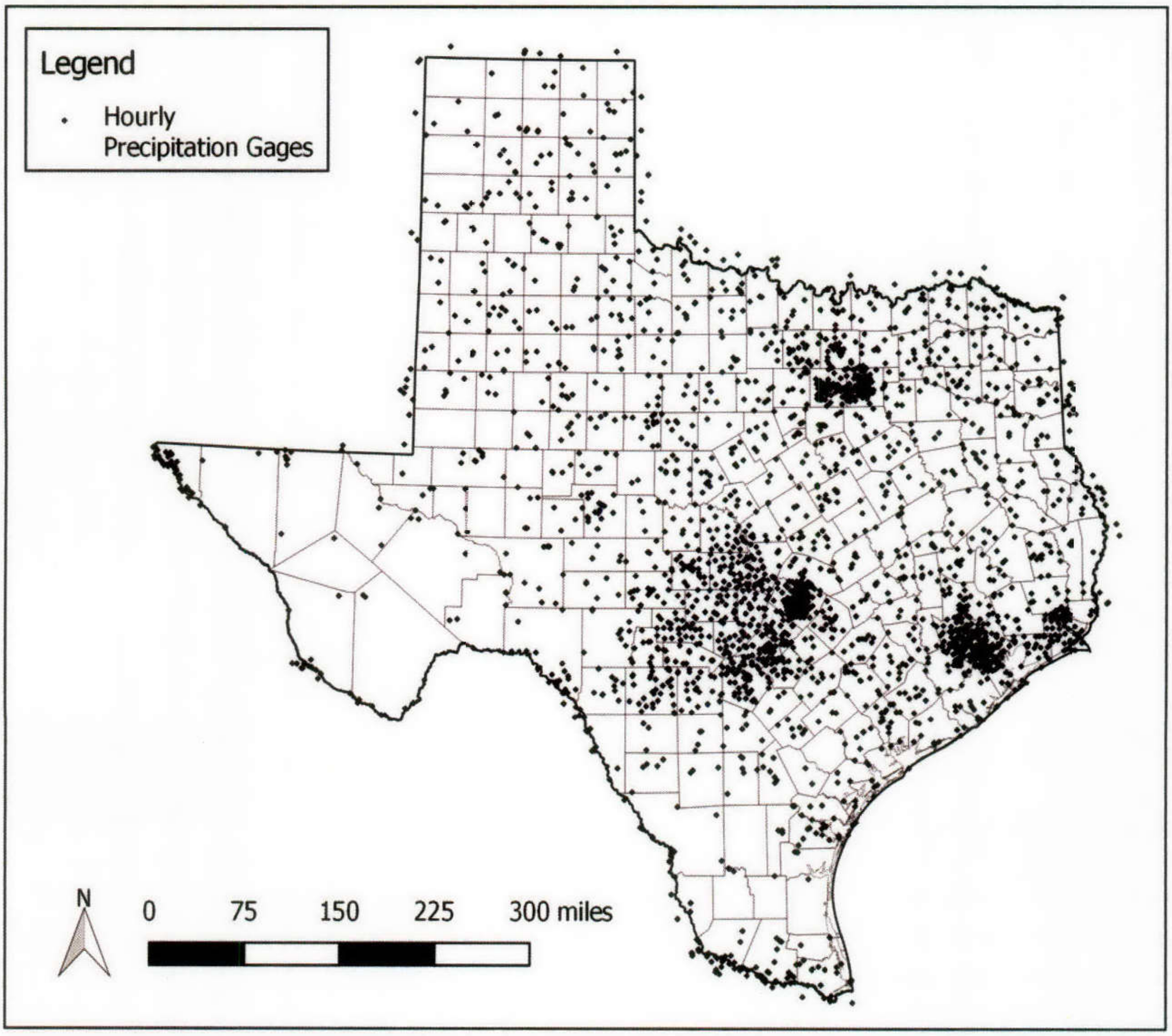

Figure 10. Rain gage network locations in Texas

The rain gages used by the NWS represent a comprehensive collection of available real time rain gages. These rain gages are maintained by several different entities including commercial, federal, state, university, municipal and river authority entities. No additional existing gages were identified that could be upgraded to real time reporting. Non-real-time observation locations currently being used by NWS are either located in close proximity to existing real-time locations, or consist of volunteer observer daily measurements and either lack automated communication infrastructure or consist of equipment that is incapable of being upgraded.

2.2.1 NEXRAD radar coverage

The next generation radar (NEXRAD) is operated by NWS for detection of severe weather and estimation of precipitation for river forecasting. The Continental United States (CONUS) NEXRAD radar network consists of 160 radars. Rain gage stations are used to correct for bias in the QPE. Tilt angles of the radar cause the signals to extend from the radar at an angle above ground level (AGL). Curvature of the earth and refraction of the microwave signals result in beam bending away from the earth surface. Measurements farther away from the antenna are thus higher in the atmosphere and can overshoot shallow precipitation, limiting its effective range. The radar beam elevation increases with distance from the radar, such that an elevation of 4,000 ft AGL, which overshoots most rainfall-generating processes, is at 89 nautical miles (nm). Those stations that intersect Texas are plotted in Figure 11 with the 89-nm buffer. Gaps in NEXRAD radar coverage are evident in East, South and West Texas where additional rain gages could be required.

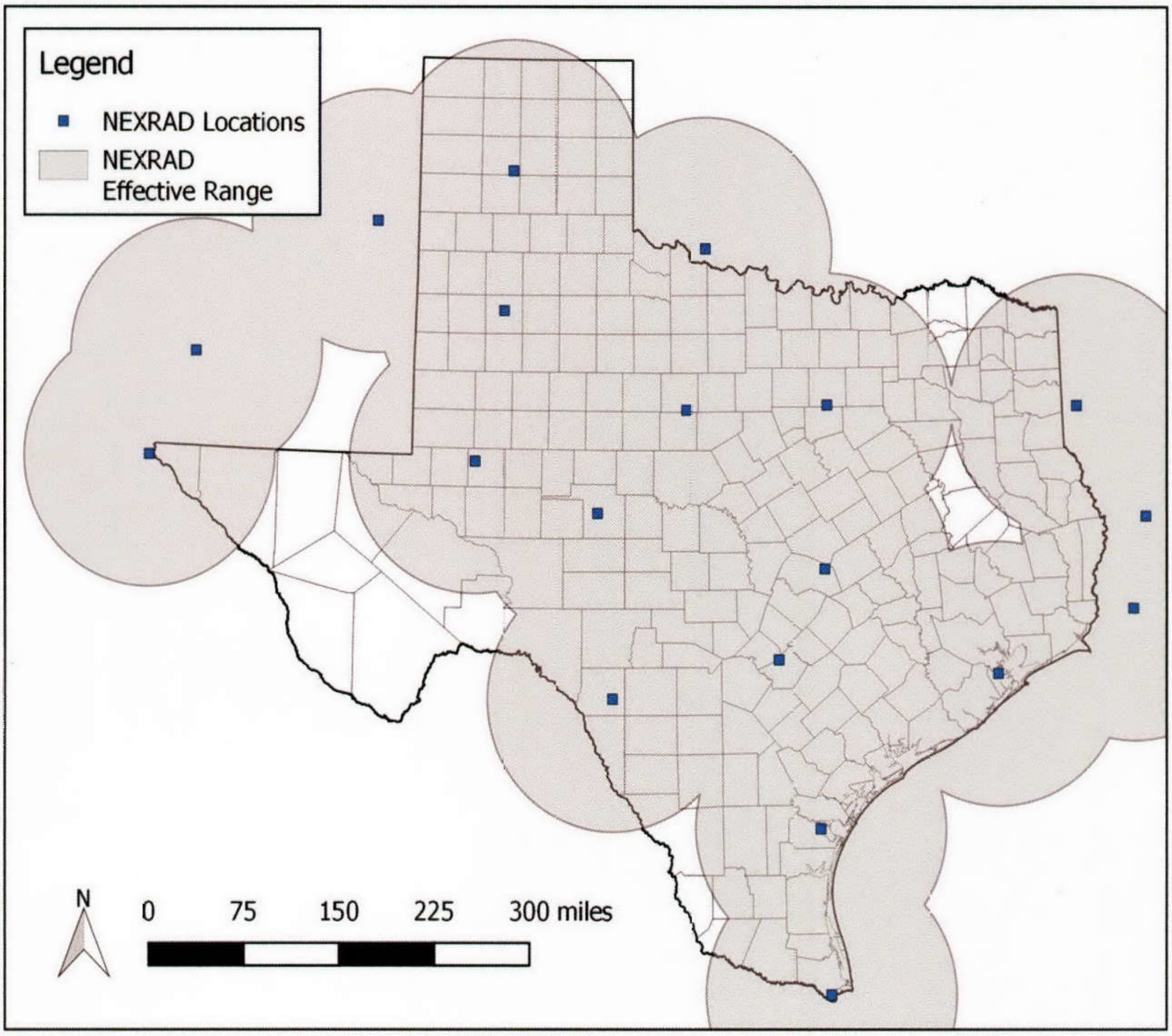

Figure 11. Buffer around NEXRAD radar stations at 89 nm showing gaps in radar coverage.

2.2.2 Rain gage coverage

To identify priority locations for new rain gages, basins with either no hourly reporting rain gages or ones with only one within each delineated area were identified. Figure 12 presents those basins with zero or one hourly reporting rain gage in each basin. Note that one gage at the outlet of the subbasin is not geographically ideal for estimation of precipitation over the basin area. There are 69 basins with zero gages, though in some instances gage coordinates fall just outside the basin boundary. Because there may be rain gages that are near the basin, and useful for flood forecasting in the basin but still outside the basin, we further examined rain gage density instead of geometric location of gages within each basin.

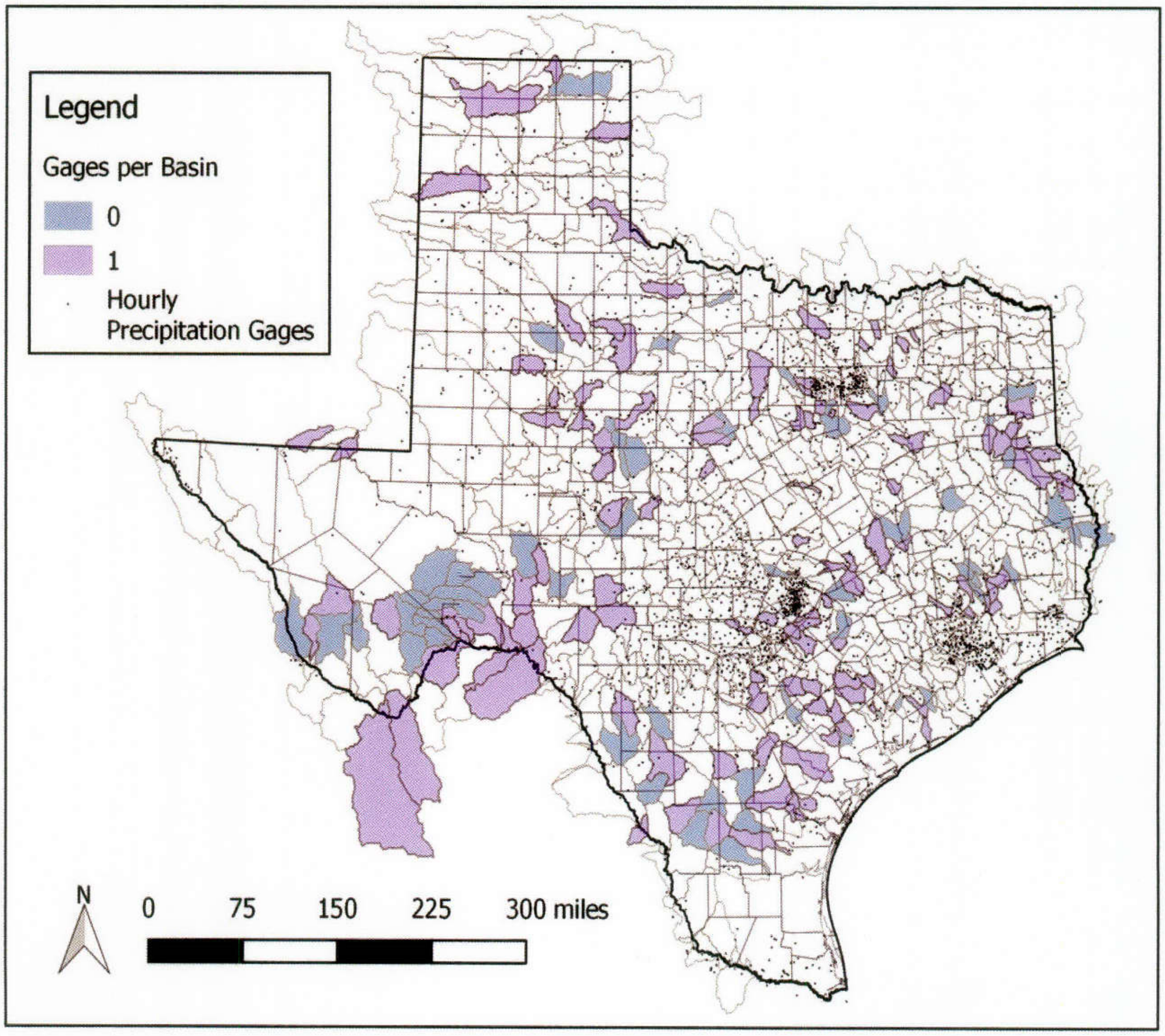

Figure 12. Basins with zero or one rain gage.

Rain gage density was computed by calculating the minimum distance between gages. Figure 13 presents the cumulative distribution of gage separation distance. These distances represent the minimum separation between each gage and its first neighboring gage. There is a noticeable break in the percentile distribution of separation distances above 10 mi that extends out to more than 100 mi, which result from large basins and rain gage spacing in the western region of the river forecast basins of West Texas and the Panhandle. The median spacing between rain gages is 2.9 miles.

Figure 14 shows the rain gage network buffered to 4 x median rain gage spacing (11-mile radius buffer), superimposed on the river forecast basins. This distance was selected to focus attention on areas where rain gage spacing significantly exceeded the median network spacing. Gaps are seen scattered throughout the East, West, and South, as well as the Panhandle of Texas.

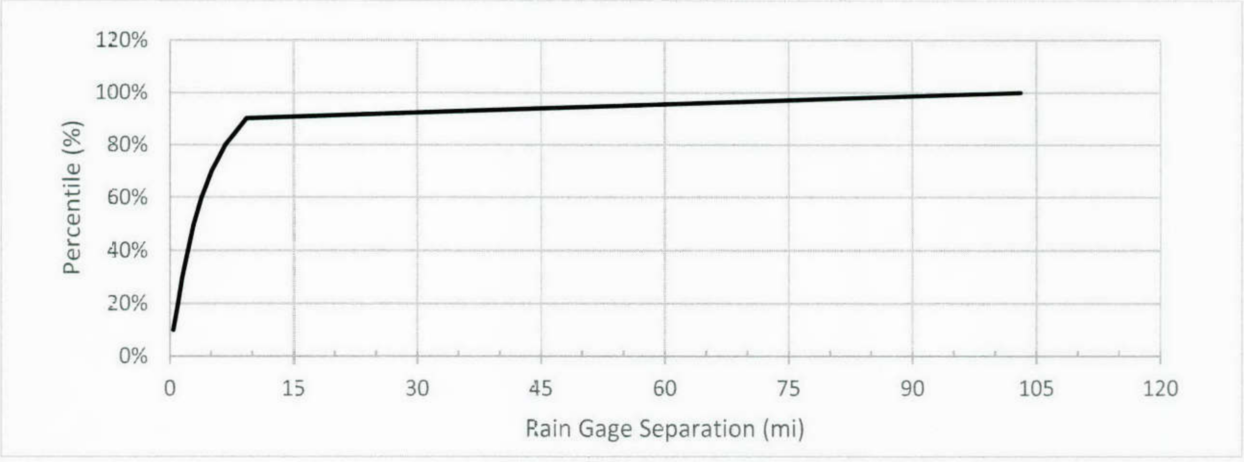

Figure 13. Cumulative distribution of rain gage separation distances.

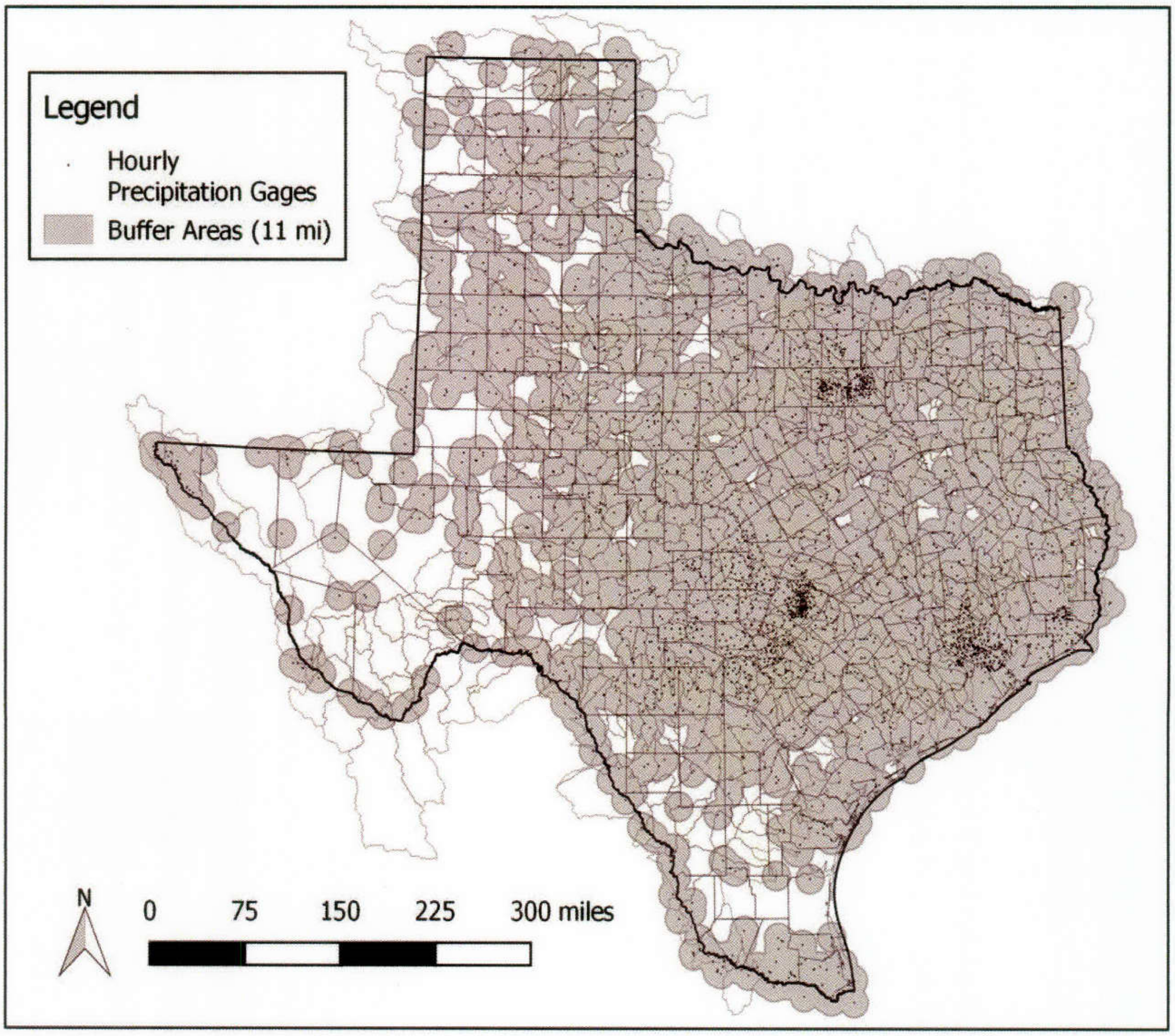

Figure 14. Rain gages with 11-mile radius buffers covering Texas.

2.2.3 Prioritization methodology

To prioritize locations for rain gages, the gaps are color coded by county population density, the logic being that rain gages are needed in places where there are gaps in the existing rain gage network coinciding with areas of higher population density. Because locating proposed rain gage sites at the geometric center of a watershed may not be practical, a more efficient strategy is adopted where gaps are identified and prioritized according to impact, represented by population density. Results are described in Section 3.

3 Results

Using the methodology described in the previous section, and analyzing hundreds of possible sites, the following short list of recommended stream gage sites was developed. Additionally, we developed a map showing gaps where we would recommend rain gages be installed. Results for both analyses are presented in this section.

3.1 Prioritized stream gage locations

In addition to recommending stream gage locations that were identified through the AHP tool, stream gages recommended by the NWS and other stakeholders were reviewed. If a stream gage was found to have the potential to improve flood forecasting for a vulnerable community it was assessed using the same criteria as applied to output from AHP. The final list of 42 recommended stream gage locations are listed in Table 5, below. Stream gage locations are ranked based on the following groupings:

1. AHP recommended and NWS endorsed stream gage;
2. NWS and stakeholder endorsed stream gage;
3. AHP recommended stream gage;
4. Stakeholder endorsed stream gage; and
5. NWS endorsed stream gage.

Within each group, ranking is by AHP priority, if applicable. If AHP ranking is not available, it is ranked per NWS priority groups, if applicable. Detailed maps with supporting information for each recommended stream gage are provided in Appendix C.

Table 5. List of recommended stream gage locations

Priority Group	Rank	Site Description	Latitude	Longitude	AHP Vulnerable Community (if applicable)
1	1	Pedernales River at Hamilton Pool Road	30.340659	-98.139061	Unincorporated Travis County
1	2	Geronimo Creek in Seguin (US 90 or I-10)	29.603484	-97.933481	City of Seguin
1	3	Llano River at FM 102	30.727354	-98.814347	Unincorporated Llano County and Kingsland
1	4	Pecan Bayou at Brownwood	31.731744	-98.973611	Unincorporated Brown County and Brownwood
1	5	Palo Pinto Creek near Santo	32.628703	-98.181684	Unincorporated Palo Pinto County
1	6	San Bernard River at I-10	29.748643	-96.296749	Unincorporated Austin County
1	7	Elm Creek at I-20 near Abilene	32.478527	-99.787117	City of Abilene
1	8	Guadalupe River at FM766	29.147453	-97.318314	Unincorporated De Witt County
1	9	Brazos River at HWY 79	33.273235	-98.931262	Unincorporated Young County
1	10	Petronila Creek at HW 77 near Driscoll, TX	27.684577	-97.743404	Unincorporated Nueces County
1	11	Lake Creek near Dobbin	30.372964	-95.770244	Unincorporated Montgomery County
1	12	Village Creek at HWY 287 near Village Mills	30.480984	-94.394295	Unincorporated Hardin County
2	13	Nolan Creek at I-35 at Belton	31.051349	-97.457150	

Priority Group	Rank	Site Description	Latitude	Longitude	AHP Vulnerable Community (if applicable)
2	14	Nueces River at George West (HWY 59)	28.332955	-98.086842	
3	15	Frio River at RM 377	29.723150	-99.753060	Leakey, Unincorporated Real County and Garner State Park
3	16	Elm Fork Trinity River at FM 1198	33.600934	-97.325013	City of Lindsay
3	17	Elm Creek at FM 89	32.275119	-99.835943	Township of Buffalo Gap and City of Abilene
3	18	Paluxy River at FM 51	32.275045	-97.903898	Unincorporated Somervell County and Dinosaur Valley State Park
3	19	Keechi Creek at SH 337	32.879398	-98.210169	Unincorporated Palo Pinto County
3	20	Navasota River at SH 30	30.607575	-96.181766	City of Navasota
3	21	East Fork of San Jacinto River at SH 150 near Coldspring	30.566867	-95.191211	Unincorporated San Jacinto and Liberty Counties
3	22	Unnamed stream at SH 137 near Ozona	30.754232	-101.204453	Ozona and Unincorporated Crockett County
3	23	Black Cypress Bayou at FM 1617	32.893116	-94.442377	Unincorporated Marion County
3	24	Leon River in Eastland	32.379274	-98.824813	Unincorporated Eastland County
3	25	Neches River at FM 279	32.364847	-95.453577	Unincorporated Smith County
3	26	Oyster Creek at SH 6 in Sugarland	29.634143	-95.651493	Unincorporated Brazoria and Missouri City
3	27	San Saba River at RM 864	30.834700	-100.093926	Unincorporated Menard County
3	28	Palo Duro Creek at Westline Rd	35.035448	-102.150723	Palo Duro Canyon State Park
4	29	Onion Creek at RR 12	30.160408	-98.091985	
4	30	Jim Ned Creek at FM 585	31.828695	-99.170572	
4	31	Atascosa River at HWY 16	29.012841	-98.576884	
5	32	Angelina River near Lufkin	31.457222	-94.725902	
5	33	Clear Fork at Eliasville	32.964643	-98.770444	
5	34	Brushy Creek near Rockdale	30.693263	-97.077220	
5	35	Sabine River at US79 near Carthage	32.225383	-94.226254	
5	36	Brazos River at HWY 105	30.361295	-96.155328	
5	37	Sabine River at Hwy 17 nr Grand Saline	32.721155	-95.635959	
5	38	Red Oak Creek at HWY 660	32.481333	-96.580737	
5	39	Tehuacana Creek at HWY 6	31.536304	-97.032997	

Priority Group	Rank	Site Description	Latitude	Longitude	AHP Vulnerable Community (if applicable)
5	40	Nueces River at FM 1025 (Upper Lake)	28.779173	-99.829414	
5	41	Neches River near Redtown at HWY 7	31.398143	-94.965338	
5	42	Caney Creek at SH 35 near Van Vleck	29.041543	-95.865535	
Note: Rank number 29 – 42 are randomly placed, in no particular order.					

It should be noted that 25 of the above 42 recommended stream gage sites are sites also recommended by the NWS for improvement of the NWSRFS model. A full list of all stream gage sites recommended by the NWS and requested by stakeholders is presented in Appendix D.

3.2 Further recommendations on stream gages

When reviewing AHP vulnerable communities, at times existing infrastructure (for example USGS stream gage or AHPS observation points) were deemed sufficient to provide flood forecasting. Although these situations do not require a stream gage the authors felt it might be valuable to recommend either incorporating an existing USGS gage into AHPS or converting an observation point to a forecast point. These recommendations are provided in the expectation that they would improve flood forecasting for AHP vulnerable communities (Table 6). The 14 stream gages in the table are ranked using the AHP vulnerable community ranking.

Table 6. Recommended USGS stream gages to incorporate into AHPS and recommended AHPS observation points to convert to forecast points.

Rank	AHP Vulnerable Community	AHPS Observation Point LID	USGS or LCRA Gage Number	USGS / LCRA Site Name
1	City of Rose Hill Acres	BIPT2	n/a	
2	Unincorporated Uvalde County and City of Sabinal	n/a	08198000	Sabinal Rv nr Sabinal, TX
3	Unincorporated Comal County and City of Bulverde	CSVT2	n/a	n/a
4	Unincorporated Hays County	DRWT2 or ONIT2	n/a	n/a
5	City of San Marcos	SRUT2 or BSMT2	n/a	n/a
6	Unincorporated Williamson County, City of Cedar Park and City of Round Rock	BCIT2 or BYBT2 or BKFT2	n/a	n/a
7	City of Boerne	CICT2	n/a	n/a
8	City of Jonestown	n/a	3953	Big Sandy Creek near Jonestown
9	Unincorporated Kerr County	n/a	08165300	N Fk Guadalupe Rv nr Hunt, TX

Rank	AHP Vulnerable Community	AHPS Observation Point LID	USGS or LCRA Gage Number	USGS / LCRA Site Name
10	City of Camp Wood	n/a	0818999010	Nueces Rv nr Barksdale, TX
11	Unincorporated Gonzales County	n/a	08174600, 08174970	Peach Ck bl Dilworth, TX and Sandies Ck at FM 108 nr Smiley, TX
12	Village of Salado	n/a	08104300	Salado Ck at Salado, TX
13	Palo Duro Canyon State Park	n/a	07295500 or 07295450	Tierra Blanca Ck abv Buffalo Lk nr Umbarger, TX or Tierra Blanca Ck nr FM 1259 at Hereford, TX
14	South Llano River State Park	n/a	08149900	S Llano Rv at Flat Rock Ln at Junction, TX

3.3 Rain gage prioritization

Using the process described in Section 2.2 to identify gaps in the rain gage network, and overlaying year 2000 county population density for prioritization of these gaps for new rain gages produces Figure 15. Areas in blue – most notably West Texas - have a population density of five persons per square mile, or less. Gaps shown are those that are greater than 100 square miles. Additional consideration should be given to basins with limited radar coverage (Figure 11), or that have zero or only one rain gage (Figure 12).

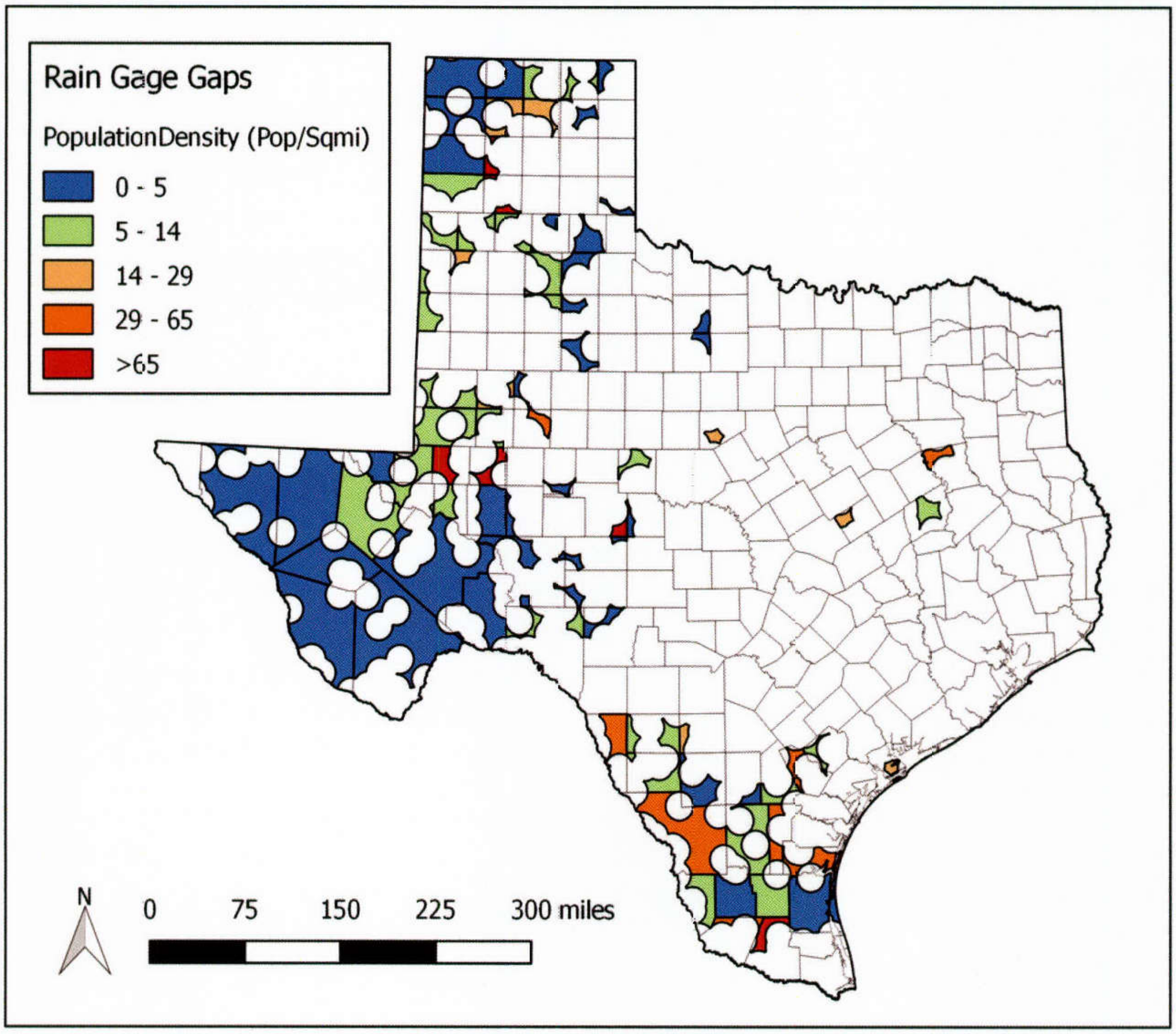

Figure 15. Prioritization of rain gage gaps by population density.

While we have not produced a list of sites for new rain gages, the map above serves as a guide for approximate rain gage locations. Higher priority areas are shown in red, followed by orange, peach, green and blue.

4 Next steps

The list of recommend stream gage sites and the map of proposed rain gage locations presented in the previous section will help the TWDB prioritize expenditures on additional streamflow and weather monitoring for the state of Texas. However, prior to installation of any equipment, each site will need to be further vetted by the USGS. In addition to accessibility, the channel characteristics, geomorphology and other factors at each site needs to be considered.

We have provided a list of 42 recommended stream gage sites in this report, with highest ranked sites at the top of the list. If a site proves to be unsuitable for stream flow monitoring, for whatever reason, an evaluation of the suitability of alternative sites is recommended through consultation with the USGS and the appropriate RFC. These sites have been chosen based on their ability to improve the timeliness and accuracy of flood forecasts for vulnerable communities and moving the site upstream or downstream a significant distance may compromise the ability of the NWS to use that site for that purpose. The TWDB only has funds for an additional 30 stream gages. While some of the sites may prove to be unsuitable for the installation of conventional stream measuring equipment, providing a list of 42 recommended sites should be more than sufficient for choosing an additional 30 stream flow stations.

For the rain gage network in Texas we have identified several gaps that would improve the accuracy of QPE produced by the NWS. Unlike stream gages, rain gages do not need to be located on stream or rivers, even though co-locating equipment with stream gages may result in cost advantages. In fact, many of the existing USGS stream gage sites have rain gages associated with them, some of which the NWS uses. We have developed a map showing where the gaps are and recommend the TWDB work with the West Texas Mesonet (based at Texas Tech University), the USGS, and the TexMesoNet group at the TWDB to determine how much money to dedicate to new weather stations, and where these monitoring sites should be located. We have prioritized areas based on county population density, but there may be other factors to consider when siting any particular rain gage.

As and when new rain and stream gages are installed and additional forecast points are added, the NWS models will need to be updated to take advantage of the additional data to generate improved flood forecasting accuracy.

5 Acknowledgments

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Appendix A: Communities outside of AHPS forecast basins.

FEMA CID	FEMA CID Name	AHPS Status
480575	Starr County Unincorporated	Partially Excluded
485458	Brazoria County Unincorporated	Partially Excluded
480202	Duval County Unincorporated	Partially Excluded
480379	Jackson County Unincorporated	Partially Excluded
480664	Willacy County Unincorporated	Entirely Excluded
481059	Webb County Unincorporated	Partially Excluded
481230	Kenedy County Unincorporated	Entirely Excluded
480287	Harris County Unincorporated	Partially Excluded
485501	Refugio County Unincorporated	Partially Excluded
485494	Nueces County Unincorporated	Partially Excluded
480637	Victoria County Unincorporated	Partially Excluded
480423	Kleberg County Unincorporated	Partially Excluded
485489	Matagorda County Unincorporated	Partially Excluded
481196	Brooks County Unincorporated	Partially Excluded
480438	Liberty County Unincorporated	Partially Excluded
480652	Wharton County Unincorporated	Partially Excluded
481178	Lavaca County Unincorporated	Partially Excluded
480334	Hidalgo County Unincorporated	Partially Excluded
485506	San Patricio County Unincorporated	Partially Excluded
485470	Galveston County Unincorporated	Entirely Excluded
480119	Chambers County Unincorporated	Entirely Excluded
481258	Jim Wells County Unincorporated	Partially Excluded
480101	Cameron County Unincorporated	Entirely Excluded
481171	Dewitt County Unincorporated	Partially Excluded
485452	Aransas County Unincorporated	Entirely Excluded
480026	Bee County Unincorporated	Partially Excluded
480827	Goliad County Unincorporated	Partially Excluded
480228	Fort Bend County Unincorporated	Partially Excluded
481081	Jim Hogg County Unincorporated	Partially Excluded
480097	Calhoun County Unincorporated	Entirely Excluded
485512	Sweeny, City Of	Partially Excluded
481266	Surfside Beach, Village Of	Entirely Excluded
485502	Richwood, City Of	Entirely Excluded
481301	Quintana, Town Of	Entirely Excluded
481255	Oyster Creek, Village Of	Entirely Excluded
480076	Manvel, City Of	Entirely Excluded
480075	Liverpool, City Of	Entirely Excluded
485484	Lake Jackson, City Of	Entirely Excluded
480072	Jones Creek, Village Of	Entirely Excluded
481071	Iowa Colony, City Of	Entirely Excluded
485478	Hillcrest Village, City Of	Entirely Excluded

FEMA CID	FEMA CID Name	AHPS Status
485467	Freeport, City Of	Entirely Excluded
480069	Danbury, City Of	Entirely Excluded
480068	Clute, City Of	Entirely Excluded
480067	Brookside Village, City Of	Entirely Excluded
480066	Brazoria, City Of	Entirely Excluded
481300	Bonney, Town Of	Partially Excluded
480065	Baileys Prairie, Village Of	Partially Excluded
480064	Angleton, City Of	Entirely Excluded
485451	Alvin, City Of	Partially Excluded
480667	San Perlita, City Of	Entirely Excluded
480666	Raymondville, City Of	Entirely Excluded
480665	Lyford, City Of	Entirely Excluded
481074	Laward, City Of	Entirely Excluded
485465	Edna, City Of	Entirely Excluded
480318	West University Place, City Of	Entirely Excluded
485516	Webster, City Of	Entirely Excluded
485513	Taylor Lake Village, City Of	Entirely Excluded
480311	South Houston,City Of	Entirely Excluded
480307	Pasadena, City Of	Entirely Excluded
485491	Nassau Bay, City Of	Entirely Excluded
480305	Morgans Point, City Of	Entirely Excluded
485487	La Porte, City Of	Entirely Excluded
480299	Jacinto City, City Of	Entirely Excluded
480293	Galena Park, City Of	Entirely Excluded
485466	El Lago, City Of	Entirely Excluded
480291	Deer Park, City Of	Entirely Excluded
480987	Woodsboro, Town Of	Entirely Excluded
480540	Refugio, Town Of	Partially Excluded
481586	Bayside, City Of	Entirely Excluded
481086	Austwell, City Of	Entirely Excluded
485503	Robstown, City Of	Partially Excluded
485498	Port Aransas, City Of	Entirely Excluded
480560	Petronila, City Of	Entirely Excluded
480507	Driscoll, City Of	Partially Excluded
480505	Bishop, City Of	Entirely Excluded
480559	Portland, City Of	Entirely Excluded
485480	Ingleside, City Of	Entirely Excluded
480296	Houston, City Of	Partially Excluded
480514	Vidor, City Of	Entirely Excluded
481061	Rose City, City Of	Entirely Excluded
480697	Pine Forest, City Of	Entirely Excluded

FEMA CID	FEMA CID Name	AHPS Status
480638	Victoria, City Of	Partially Excluded
480424	Kingsville, City Of	Partially Excluded
485495	Palacios, City Of	Entirely Excluded
485455	Bay City, City Of	Partially Excluded
480086	Falfurrias, City Of	Entirely Excluded
481514	Devers, City Of	Entirely Excluded
480440	Dayton, City Of	Partially Excluded
481101	Daisetta, City Of	Partially Excluded
481637	Old River-Winfree, City Of	Entirely Excluded
480122	Mont Belvieu, City Of	Entirely Excluded
480349	Weslaco, City Of	Entirely Excluded
480348	San Juan, City Of	Entirely Excluded
481677	Progreso, City Of	Entirely Excluded
480347	Pharr, City Of	Entirely Excluded
481656	Palmview, City Of	Entirely Excluded
480346	Palmhurst, City Of	Entirely Excluded
480345	Mission, City Of	Partially Excluded
480344	Mercedes, City Of	Entirely Excluded
480343	Mcallen, City Of	Entirely Excluded
480342	La Villa, City Of	Entirely Excluded
480341	La Joya, City Of	Partially Excluded
480340	Hidalgo, Town Of	Entirely Excluded
480339	Elsa, City Of	Entirely Excluded
480338	Edinburg,City Of	Entirely Excluded
480337	Edcouch, City Of	Entirely Excluded
480336	Donna, City Of	Entirely Excluded
481571	Alton, City Of	Entirely Excluded
480335	Alamo, City Of	Entirely Excluded
481506	Taft, City Of	Entirely Excluded
485511	Sinton, City Of	Partially Excluded
480558	Odem, City Of	Entirely Excluded
481645	Ingleside On The Bay, City Of	Entirely Excluded
480555	Gregory, City Of	Entirely Excluded
481585	Tiki Island, Village Of	Entirely Excluded
481562	Santa Fe, City Of	Entirely Excluded
485488	League City, City Of	Entirely Excluded
485486	La Marque, City Of	Entirely Excluded
485481	Kemah, City Of	Entirely Excluded
481271	Jamaica Beach, Village Of	Entirely Excluded
485479	Hitchcock, City Of	Entirely Excluded
485469	Galveston, City Of	Entirely Excluded

FEMA CID	FEMA CID Name	AHPS Status
485468	Friendswood, City Of	Entirely Excluded
481569	Dickinson, City Of	Entirely Excluded
485461	Clear Lake Shores, City Of	Entirely Excluded
481589	Bayou Vista, Village Of	Entirely Excluded
485514	Texas City, City Of	Entirely Excluded
485507	Seabrook, City Of	Entirely Excluded
480115	South Padre Island, Town Of	Entirely Excluded
480114	Santa Rosa, City Of	Entirely Excluded
480113	San Benito, City Of	Entirely Excluded
480112	Rio Hondo, Town Of	Entirely Excluded
480110	Rangerville, Town Of	Entirely Excluded
481646	Rancho Viejo, Town Of	Entirely Excluded
481198	Primera, Town Of	Entirely Excluded
480109	Port Isabel, City Of	Entirely Excluded
481580	Palm Valley, City Of	Entirely Excluded
480105	Los Indios, City Of	Entirely Excluded
480108	Los Fresnos, City Of	Entirely Excluded
485483	Laguna Vista, Village Of	Entirely Excluded
480106	La Feria, City Of	Entirely Excluded
481695	Indian Lake, Town Of	Entirely Excluded
485477	Harlingen, City Of	Entirely Excluded
480104	Combes, Town Of	Entirely Excluded
480103	Brownsville, City Of	Entirely Excluded
480102	Bayview, Town Of	Entirely Excluded
485510	Shoreacres, City Of	Entirely Excluded
481510	Cove, City Of	Entirely Excluded
480121	Beach City, City Of	Entirely Excluded
485456	Baytown, City Of	Entirely Excluded
480120	Anahuac, City Of	Entirely Excluded
480396	Premont, City Of	Entirely Excluded
480394	Alice, City Of	Partially Excluded
485504	Rockport, City Of	Entirely Excluded
480012	Fulton, Town Of	Entirely Excluded
485464	Corpus Christi, City Of	Partially Excluded
485453	Aransas Pass, City Of	Entirely Excluded
481698	Taylor Landing, City Of	Entirely Excluded
481297	Nome, City Of	Partially Excluded
485492	Nederland, City Of	Entirely Excluded
481298	China, City Of	Partially Excluded
485457	Beaumont, City Of	Partially Excluded
480828	Goliad, City Of	Entirely Excluded

FEMA CID	FEMA CID Name	AHPS Status
480233	Stafford, City Of	Partially Excluded
480077	Pearland, City Of	Entirely Excluded
480304	Missouri City, City Of	Partially Excluded
481619	Arcola City Of	Partially Excluded
480100	Seadrift, City Of	Entirely Excluded
480099	Port Lavaca, City Of	Entirely Excluded
480098	Point Comfort, City Of	Entirely Excluded
480510	Orange County Unincorporated	Partially Excluded
481080	Jasper County Unincorporated	Partially Excluded
480385	Jefferson County Unincorporated	Partially Excluded
480511	Bridge City, City Of	Entirely Excluded
485499	Port Arthur, City Of	Entirely Excluded
485500	Port Neches, City Of	Entirely Excluded
485475	Groves, City Of	Entirely Excluded
480499	Newton County Unincorporated	Partially Excluded
480515	West Orange, City Of	Entirely Excluded
480513	Pinehurst, City Of	Entirely Excluded
480512	Orange, City Of	Partially Excluded
480742	Clay County Unincorporated	Entirely Excluded
480772	Delta County Unincorporated	Entirely Excluded
481207	Baylor County Unincorporated	Entirely Excluded
481078	Archer County Unincorporated	Entirely Excluded

Appendix B: Communities that do not participate in NFIP

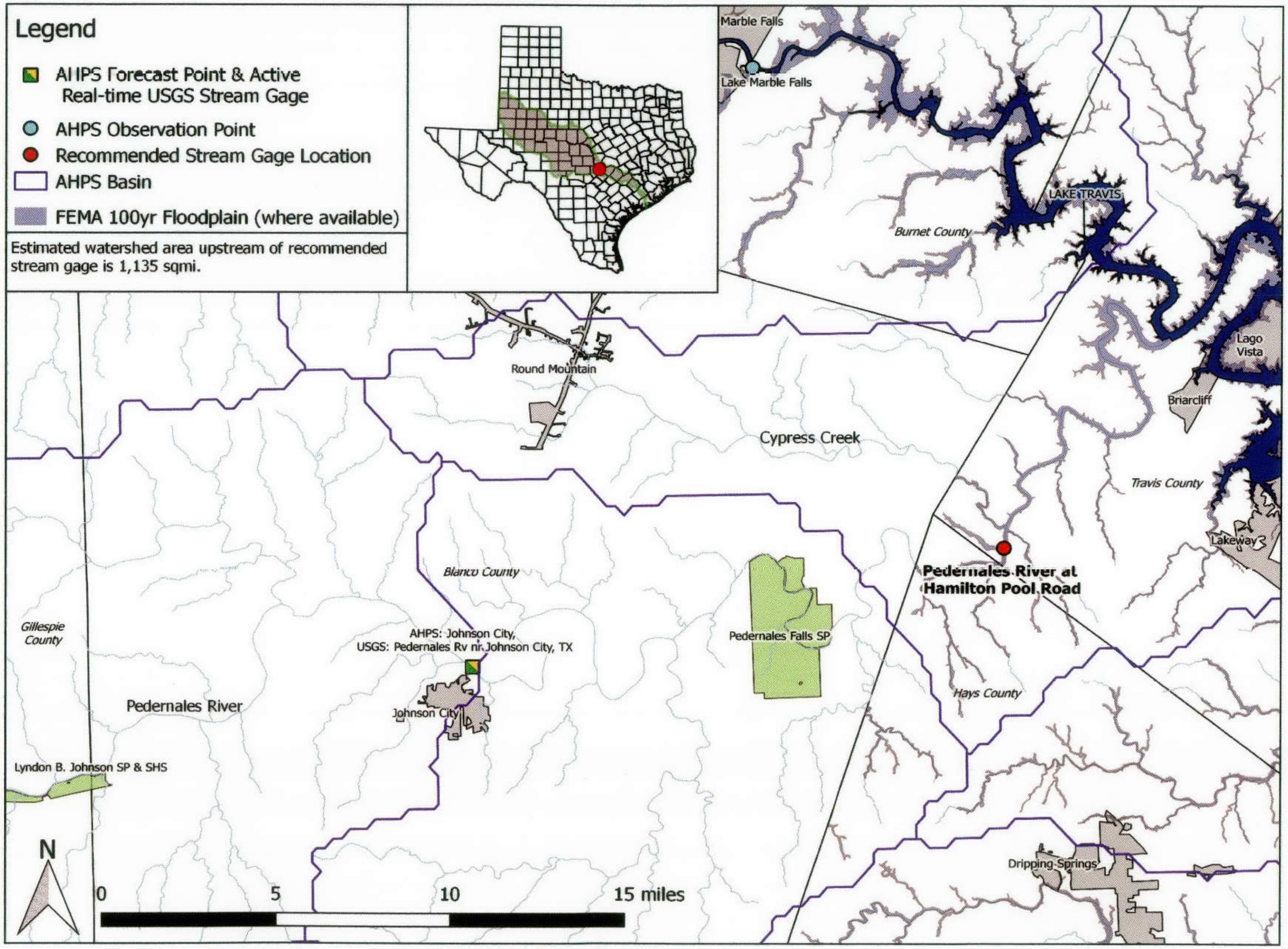
FEMA CID	Community Name
480858	ABBOTT, CITY OF
480960	ADRIAN, CITY OF
481090	ALBA, CITY OF
481546	ALMA, TOWN OF
480894	AMHERST, CITY OF
481547	ANGUS, CITY OF
481664	ANNETTA NORTH, TOWN OF
480982	ANNONA, TOWN OF
480242	AQUILLA, CITY OF
480567	ARP, CITY OF
481093	ASPERMONT, TOWN OF
480731	AVINGER, TOWN OF
480642	BARSTOW, CITY OF
480393	BEDIAS, CITY OF
480830	BELLS, TOWN OF
480888	BENJAMIN, CITY OF
481037	BIG SANDY, TOWN OF
481088	BLACKWELL, TOWN OF
481542	BROWNDELL, TOWN OF
480248	BURKE, CITY OF
481504	CAMPBELL, TOWN OF
480270	CARL'S CORNER, CITY OF
480310	CASHION, CITY OF
481202	CHILLICOTHE, CITY OF
481543	CHIRENO, CITY OF
480702	CHRISTINE, CITY OF
481098	CLAUDE, CITY OF
480408	COMBINE, CITY OF
480136	COOL, TOWN OF
480244	CORRAL CITY, TOWN OF
481511	COVINGTON, CITY OF
481697	CREEDMOOR, CITY OF
480723	CROSS PLAINS, TOWN OF
480391	CUNEY, CITY OF
481214	DAWSON COUNTY UNINCORPORATED
480055	DE KALB, CITY OF
480787	DICKENS, CITY OF
481144	DODD CITY, CITY OF
481309	DORCHESTER, TOWN OF
480733	DOUGLASSVILLE, TOWN OF

FEMA CID	Community Name
480247	EAST MOUNTAIN, CITY OF
480976	EAST TAWAKONI, CITY OF
480635	EDGEWOOD, CITY OF
481146	EDOM, CITY OF
481217	EDWARDS COUNTY UNINCORPORATED
480277	ESTELLINE, CITY OF
480367	EUREKA, CITY OF
480316	EVANT, CITY OF
480003	FRANKSTON, CITY OF
480392	GALLATIN, CITY OF
480949	GARRISON, CITY OF
481148	GARY, TOWN OF
481310	GOLINDA, CITY OF
480250	GOODLOW, CITY OF
480963	GORDON, TOWN OF
480302	GRAYS PRAIRIE, CITY OF
481522	HALLSBURG, CITY OF
480848	HALLSVILLE, CITY OF
481056	HAWKINS, CITY OF
481495	HEBRON, CITY OF
480373	HUTCHINSON COUNTY UNINCORPORATED
481294	IMPACT, TOWN OF
480288	INDUSTRY, CITY OF
480111	JARRELL, CITY OF
480674	KERMIT, CITY OF
480079	LAKEPORT, CITY OF
480278	LAKEVIEW, TOWN OF
480891	LAMAR COUNTY UNINCORPORATED
480597	LATEXO, CITY OF
481015	LAWN, TOWN OF
480907	LEONA, CITY OF
480818	LOCKNEY, CITY OF
480368	LONE OAK, CITY OF
481109	LORAINE, TOWN OF
480806	LOTT, CITY OF
480886	LUEDERS, CITY OF
480736	MARIETTA, TOWN OF
480946	MATADOR, CITY OF
481020	MEADOW, TOWN OF
480924	MELVIN, TOWN OF
481524	MOBEETIE, CITY OF

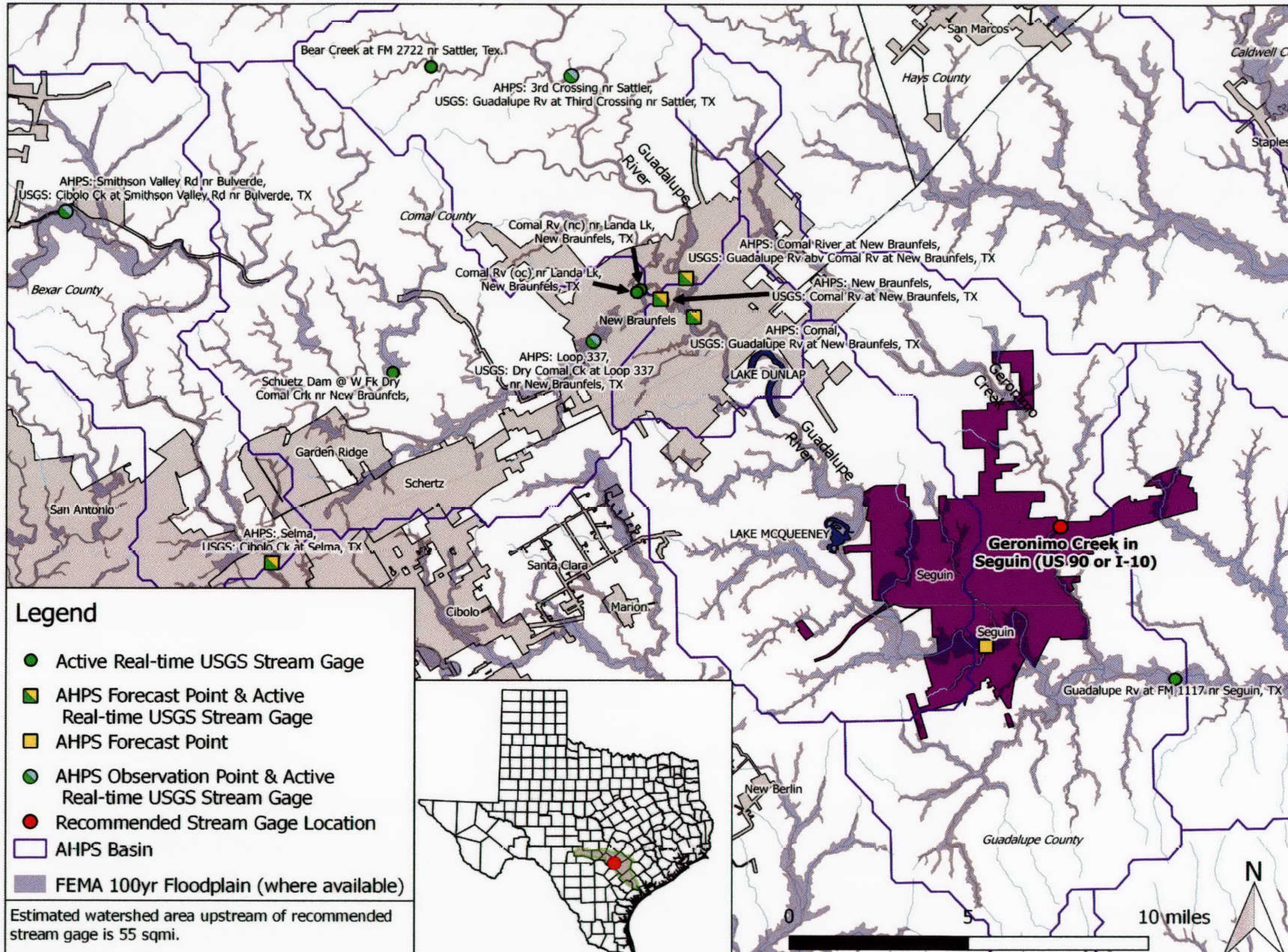
FEMA CID	Community Name
481553	MOORE STATION, CITY OF
481123	MORGAN, CITY OF
481125	MULLIN, CITY OF
481554	MUSTANG, TOWN OF
480382	NAVARRO, CITY OF
481657	NEVADA, CITY OF
480157	NEW CHAPEL HILL, CITY OF
481126	NEWARK, CITY OF
480369	NEYLANDVILLE, TOWN OF
481083	NORTH CLEVELAND, CITY OF
480752	NOVICE, CITY OF
480921	O'DONNELL, CITY OF
481533	OAK GROVE, TOWN OF
480386	OAK VALLEY, CITY OF
480764	PAINT ROCK, TOWN OF
480864	PENELOPE, TOWN OF
480080	PINE ISLAND, CITY OF
480399	POST OAK BEND, CITY OF
480724	PUTNAM, TOWN OF
480645	PYOTE, TOWN OF
480715	QUITAQUE, CITY OF
480628	RANKIN, CITY OF
480176	RED LICK, CITY OF
481158	RETREAT, CITY OF
480562	RICHLAND SPRINGS, CITY OF
480958	RICHLAND, CITY OF
481316	RIESEL, CITY OF
480225	ROBY, CITY OF
481119	ROSEBUD, CITY OF
480387	ROSSER, CITY OF
481160	SADLER, CITY OF
480876	SANFORD, TOWN OF
480751	SANTA ANNA, TOWN OF
481161	SCOTTSVILLE, CITY OF
480564	SCURRY COUNTY UNINCORPORATED
480314	SEVEN OAKS, CITY OF
480867	SMYER, TOWN OF
480317	SOUTH MOUNTAIN, CITY OF
480825	STREETMAN, CITY OF
481024	TALCO, CITY OF
480753	TALPA, TOWN OF

FEMA CID	Community Name
480934	THORNDALE, CITY OF
480914	THORNTON, TOWN OF
480646	THORNTONVILLE, CITY OF
480400	TODD MISSION, CITY OF
481621	TOM BEAN, CITY OF
480473	UNION GROVE, CITY OF
481131	VALENTINE, TOWN OF
480217	VALLEY VIEW, CITY OF
480062	WEBBERVILLE, VILLAGE OF
480855	WEINERT, CITY OF
480938	WESTBROOK, CITY OF
481623	WHITESBORO, CITY OF
480647	WICKETT, CITY OF
481025	WINFIELD, CITY OF
480675	WINK, CITY OF
480573	WINONA, CITY OF
480372	WOLFE CITY, CITY OF

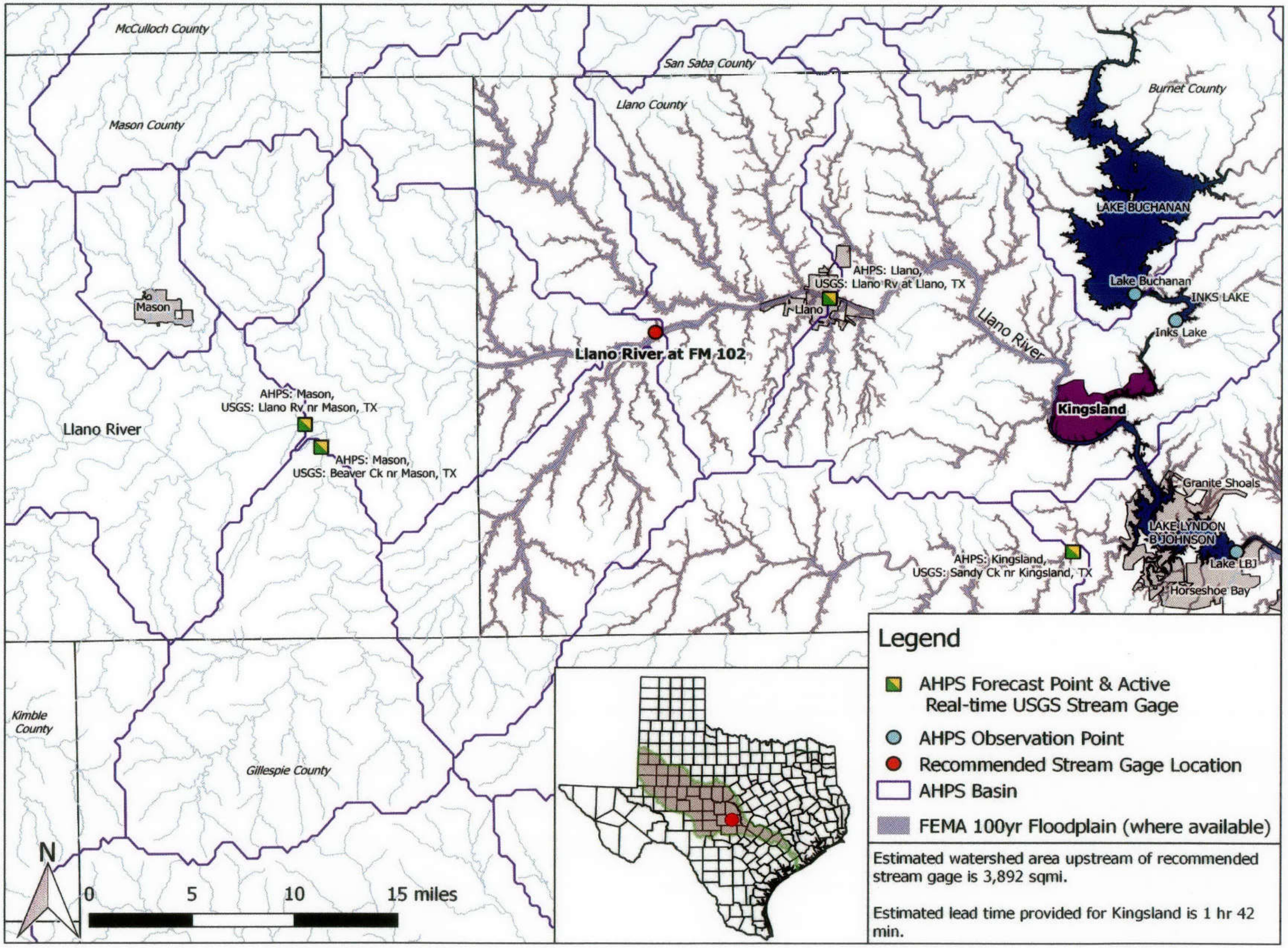
Appendix C: Recommended stream gages



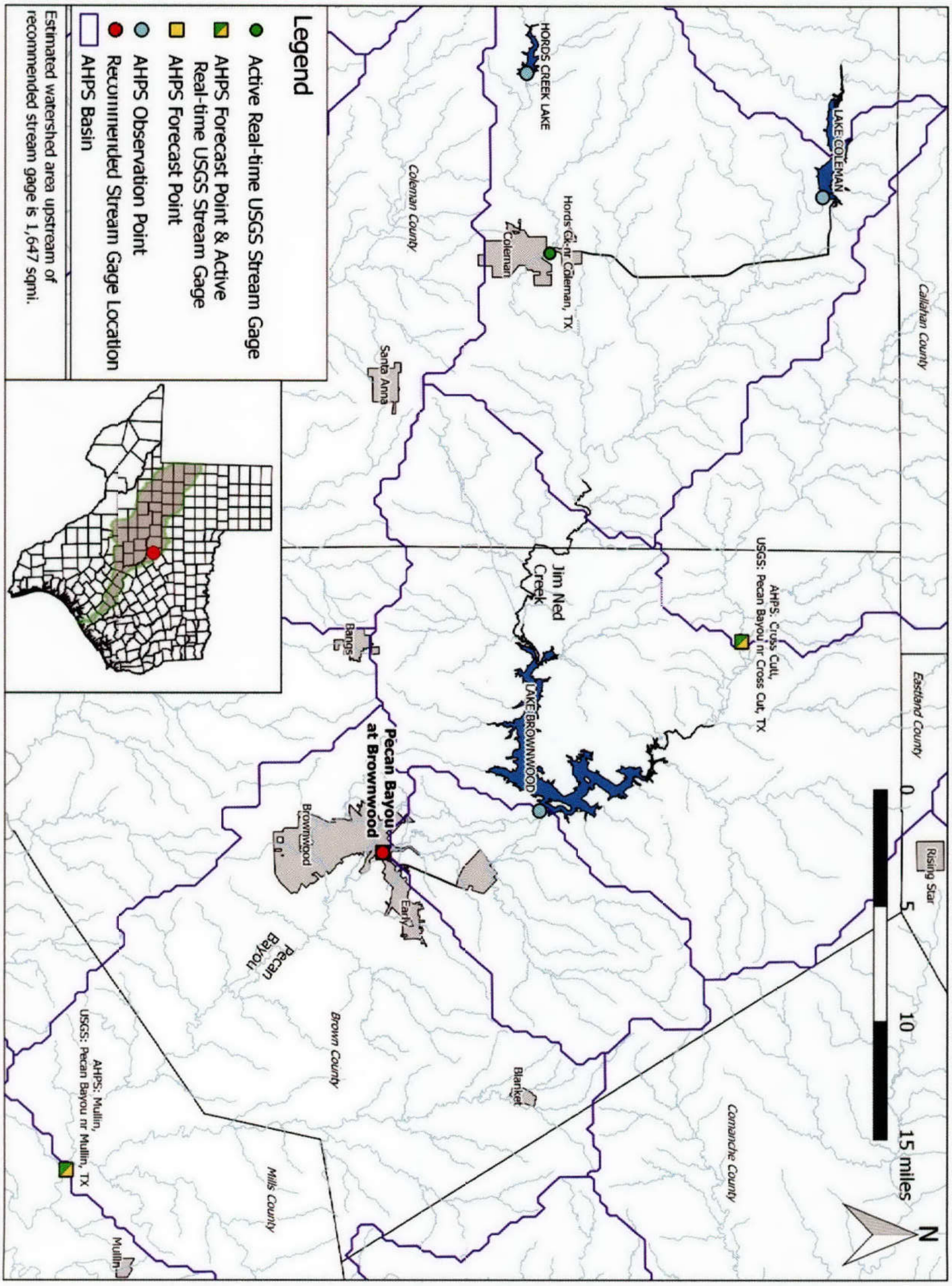
Rank #1: Pedernales River at Hamilton Pool Road, to provide flood forecasting for unincorporated Travis County.



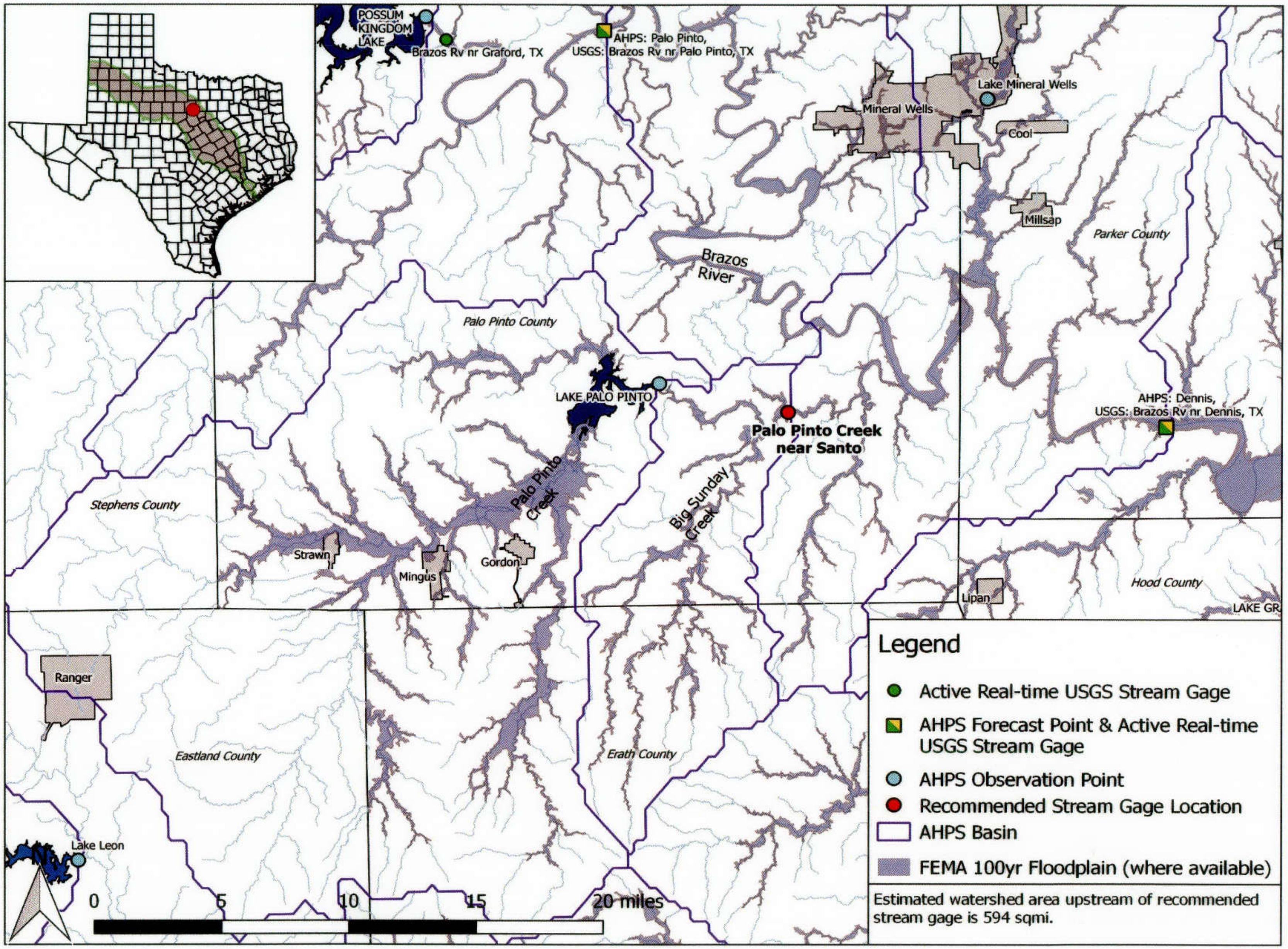
Rank #2: Geronimo Creek in Seguin (US-90 or I-10), to provide flood forecasting for the City of Seguin.



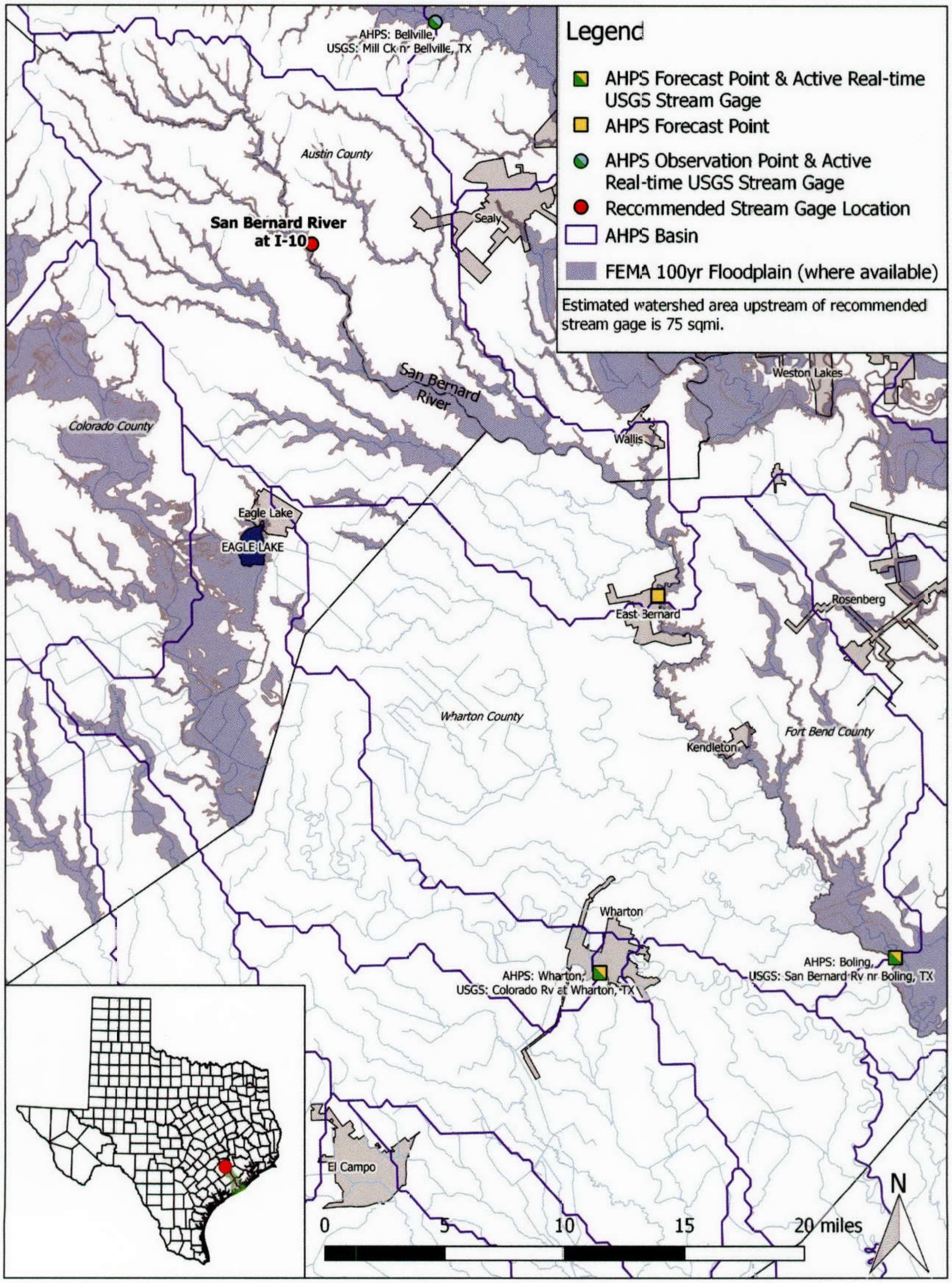
Rank #3: Llano River at FM 102, to provide flood forecasting for unincorporated Llano County and Kingsland.



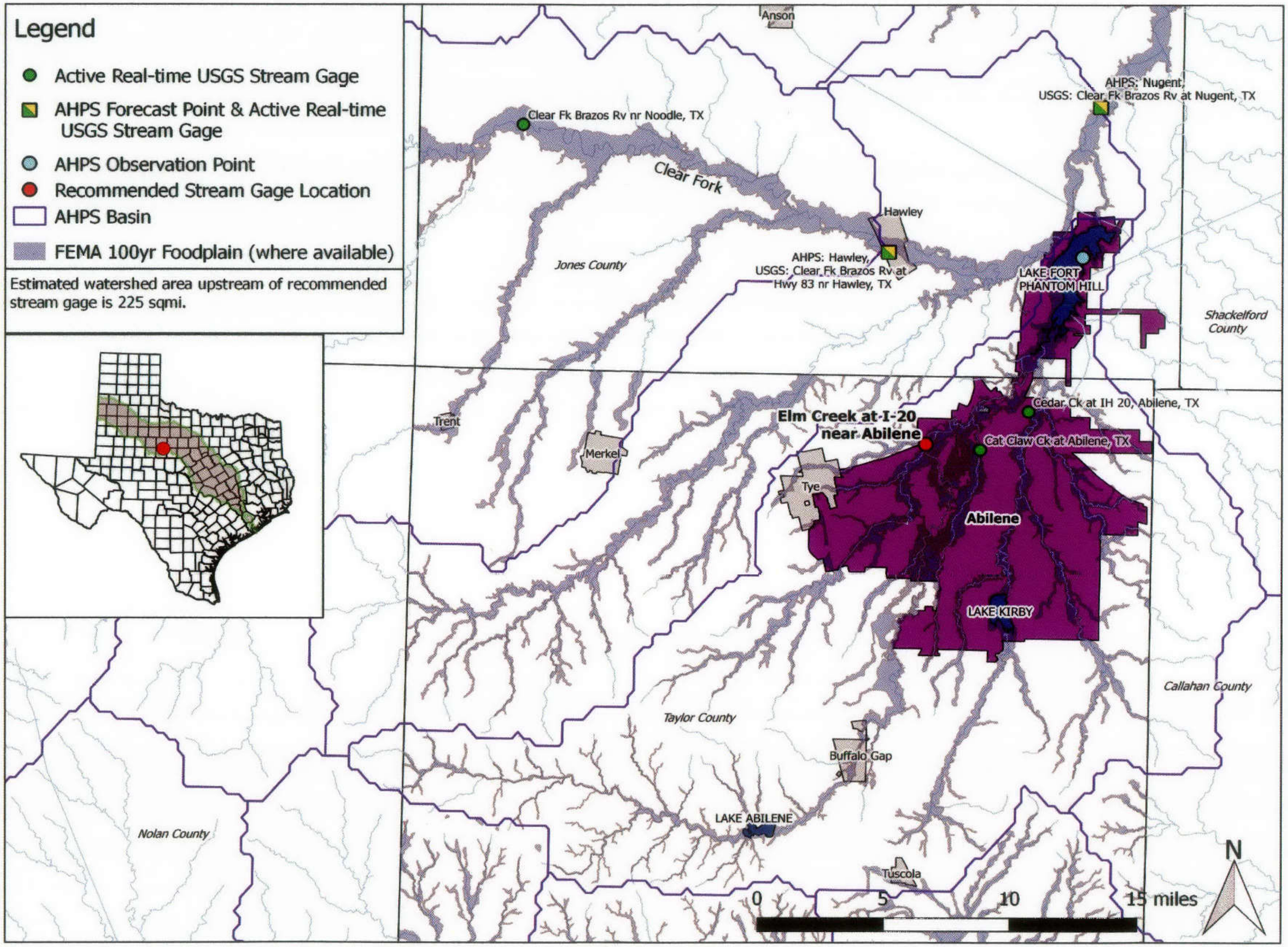
Rank #4: Pecan Bayou at Brownwood, to provide flood forecasting for unincorporated Brown County and Brownwood (Note: recommended stream gage location is an existing AHPS forecast point without a USGS stream gage).



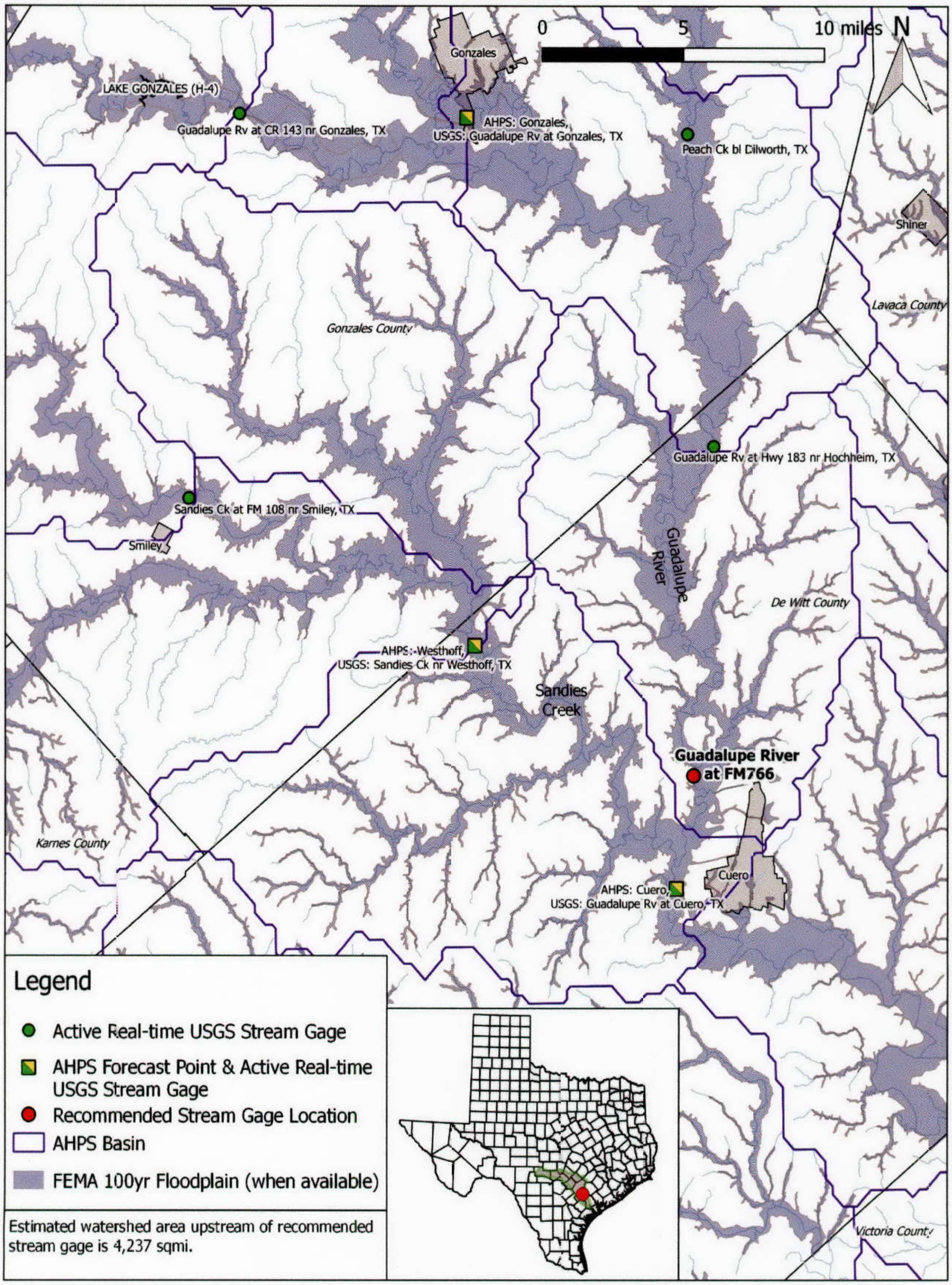
Rank #5: Palo Pinto Creek near Santo, to provide flood forecasting for unincorporated Palo Pinto County.



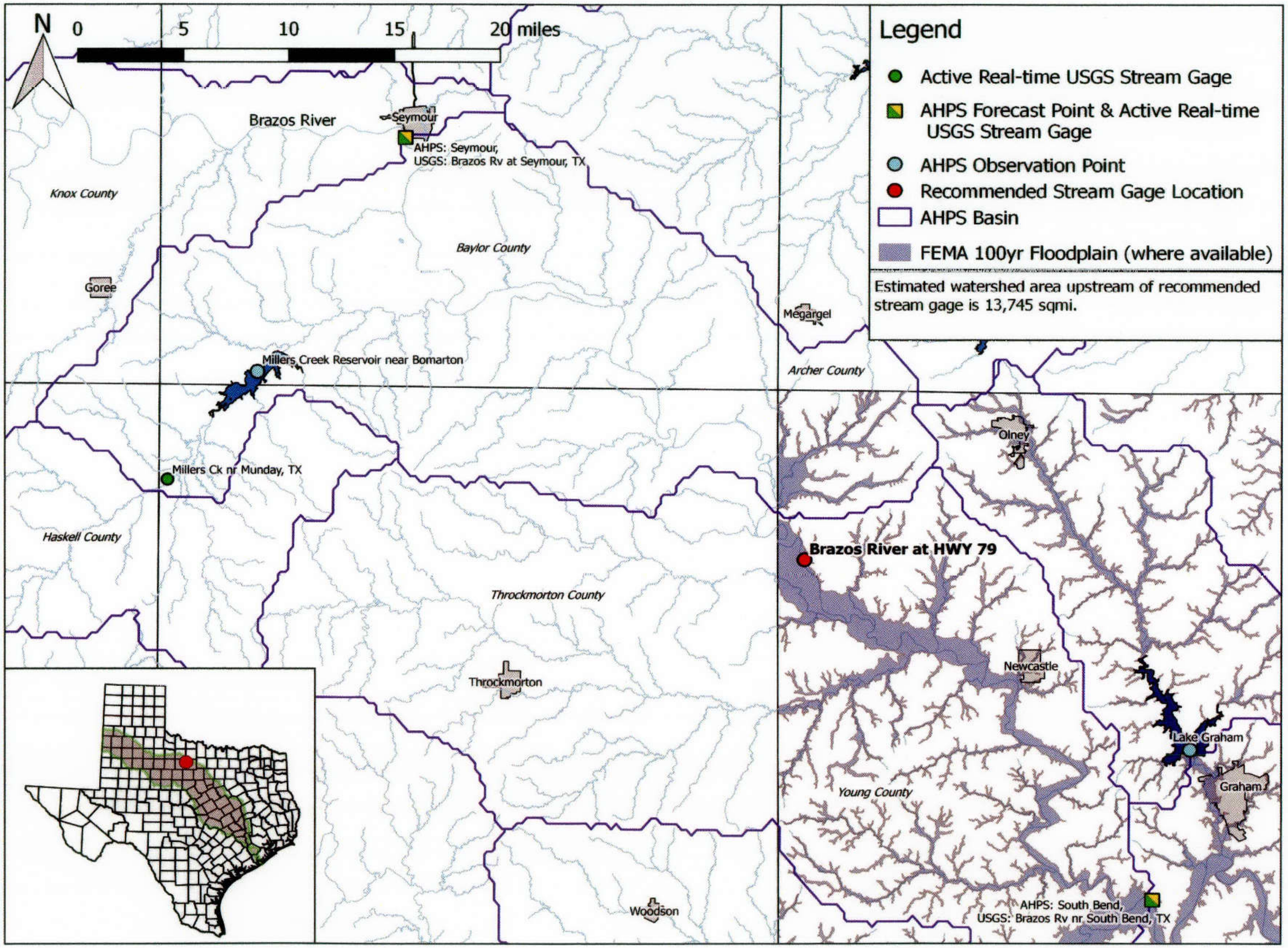
Rank #6: San Bernard River at I-10, to provide flood forecasting for unincorporated Austin County.



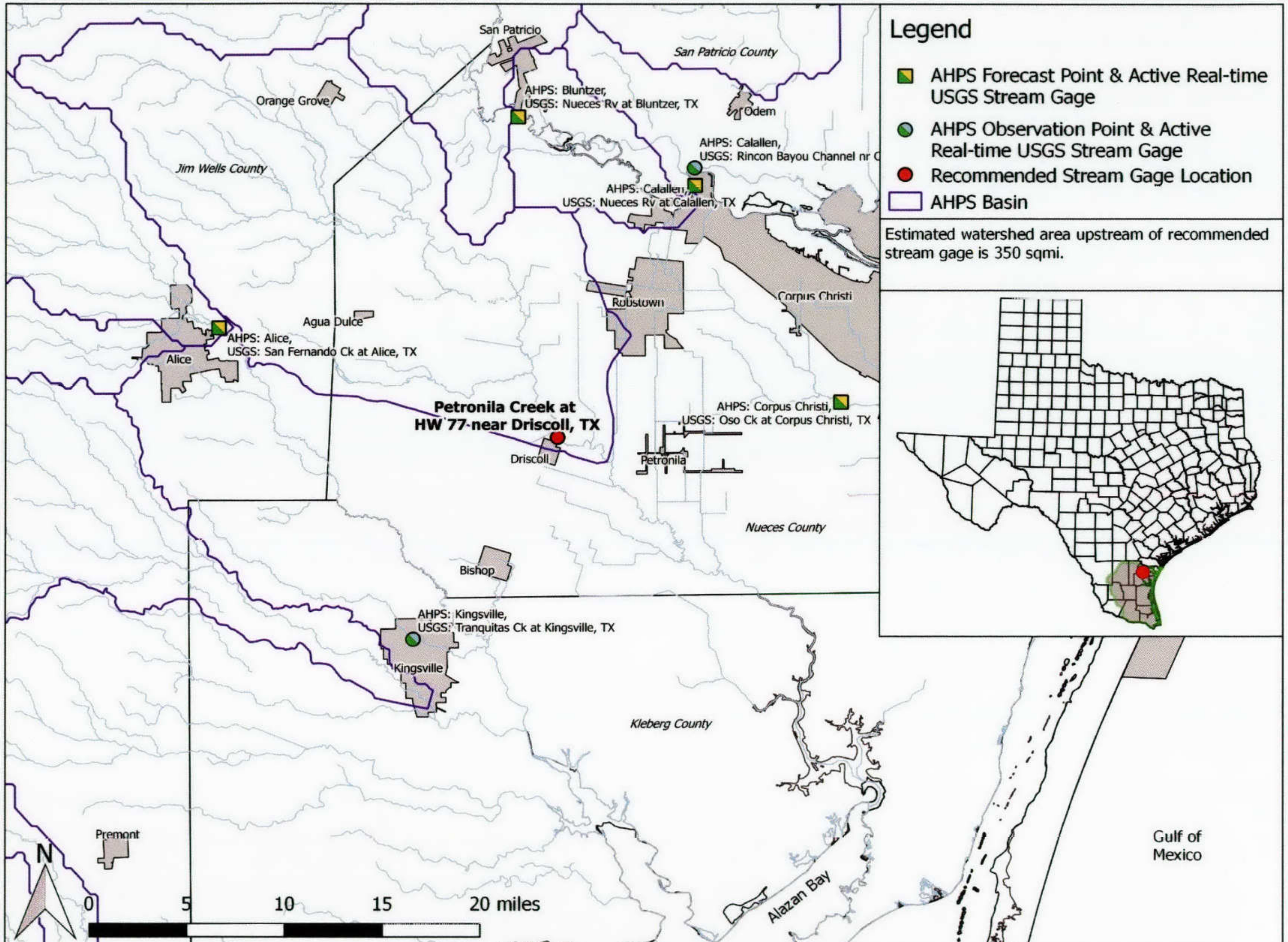
Rank #7: Elm Creek at I-20 near Abilene, to provide flood forecasting for the City of Abilene.



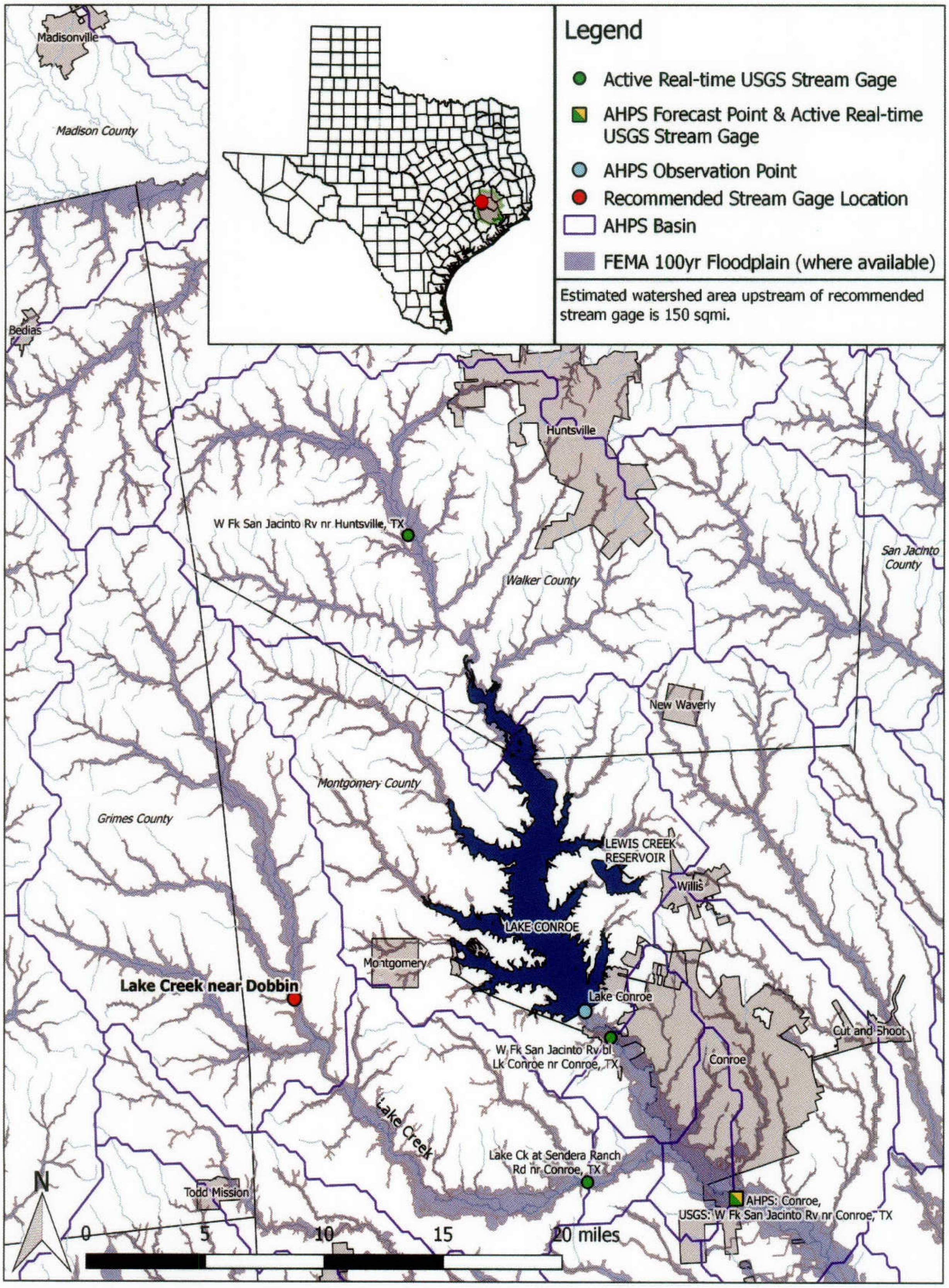
Rank #8: Guadalupe River at FM 766, to provide flood forecasting for unincorporated De Witt County.



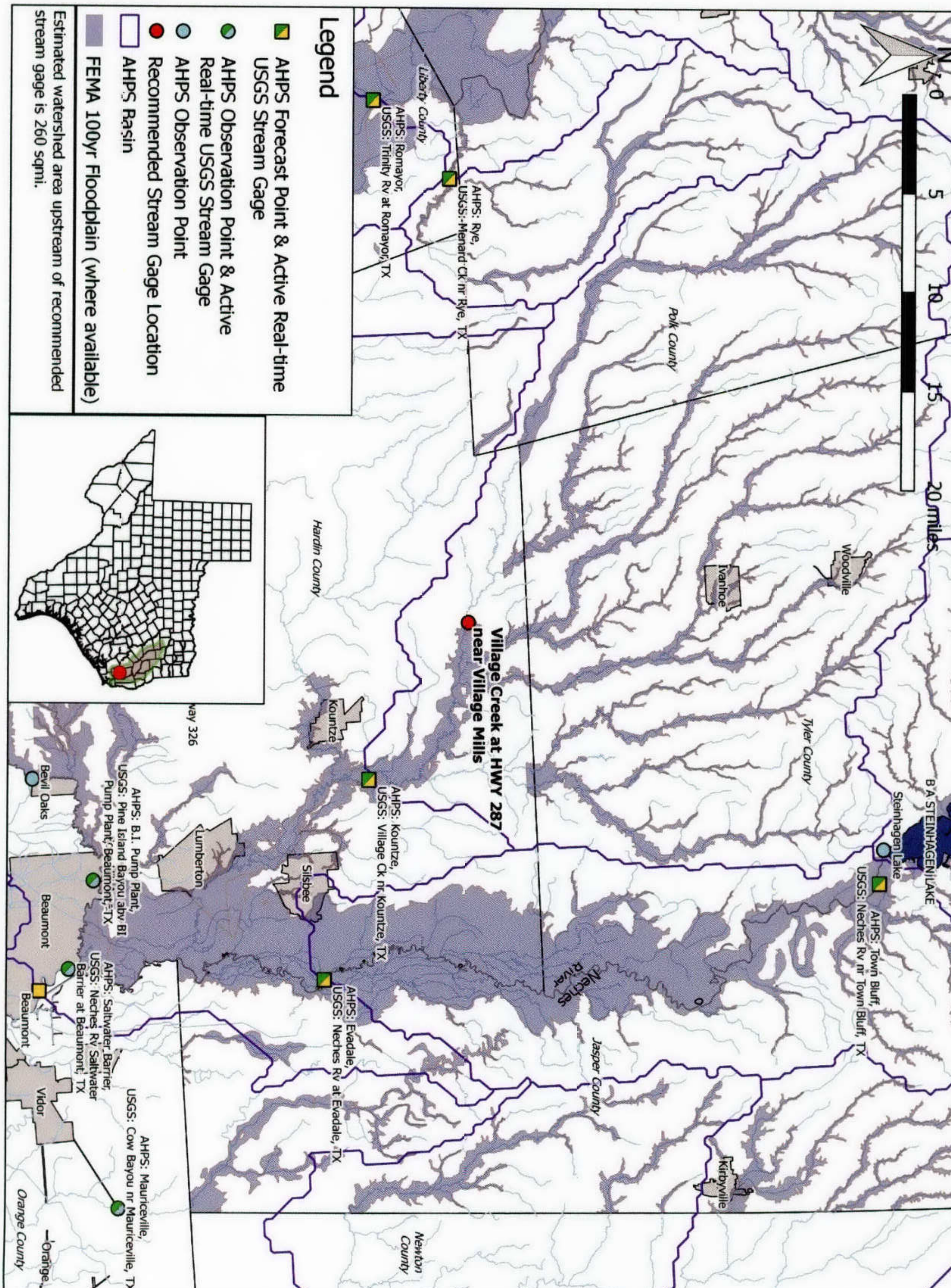
Rank #9: Brazos River at HWY 79, to provide flood forecasting for unincorporated Young County.



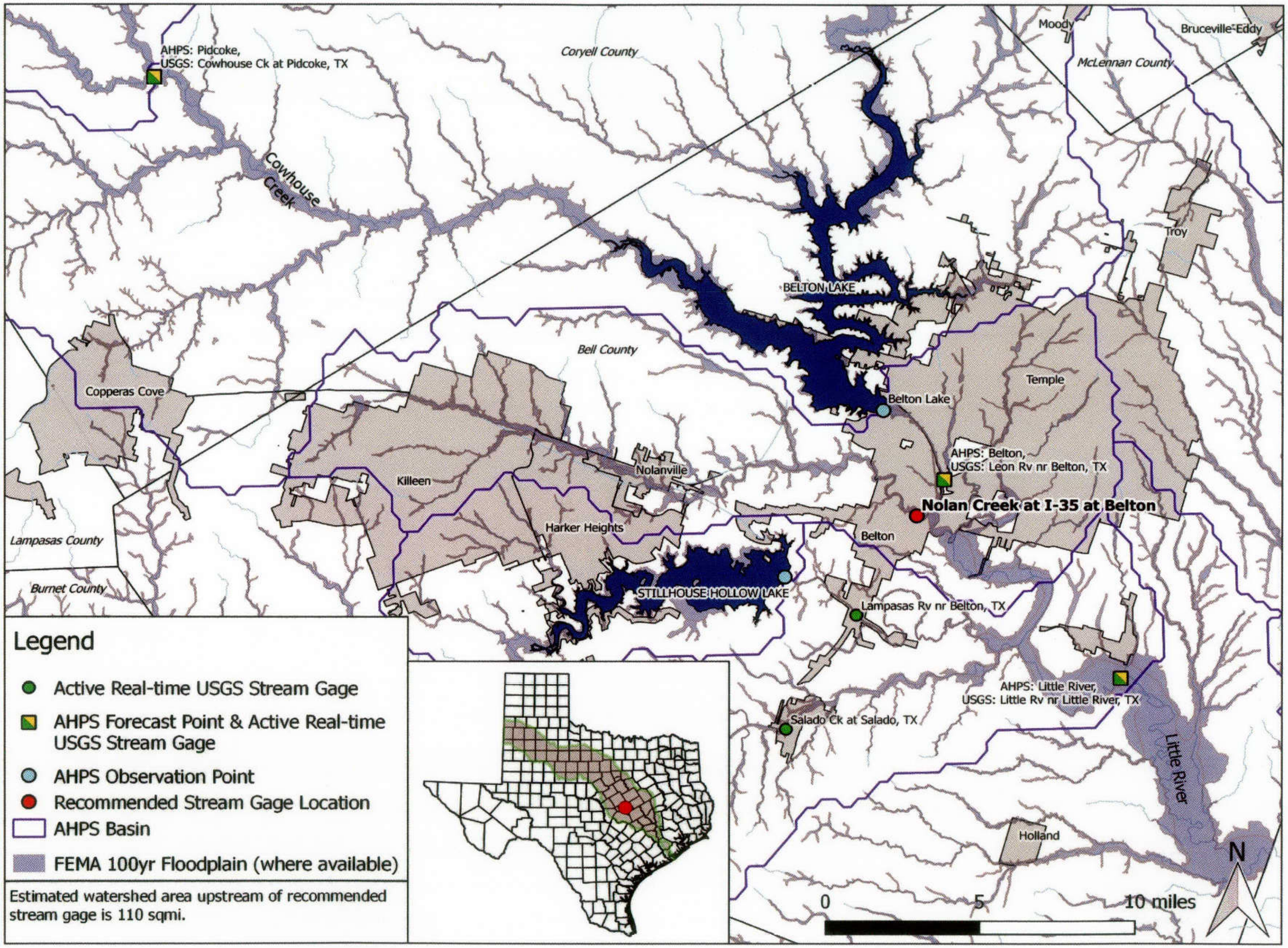
Rank #10: Petronila Creek at HWY 77 near Driscoll, TX, to provide flood forecasting for unincorporated Nueces County.



Rank #11: Lake Creek near Dobbin, to provide flood forecasting for unincorporated Montgomery County.

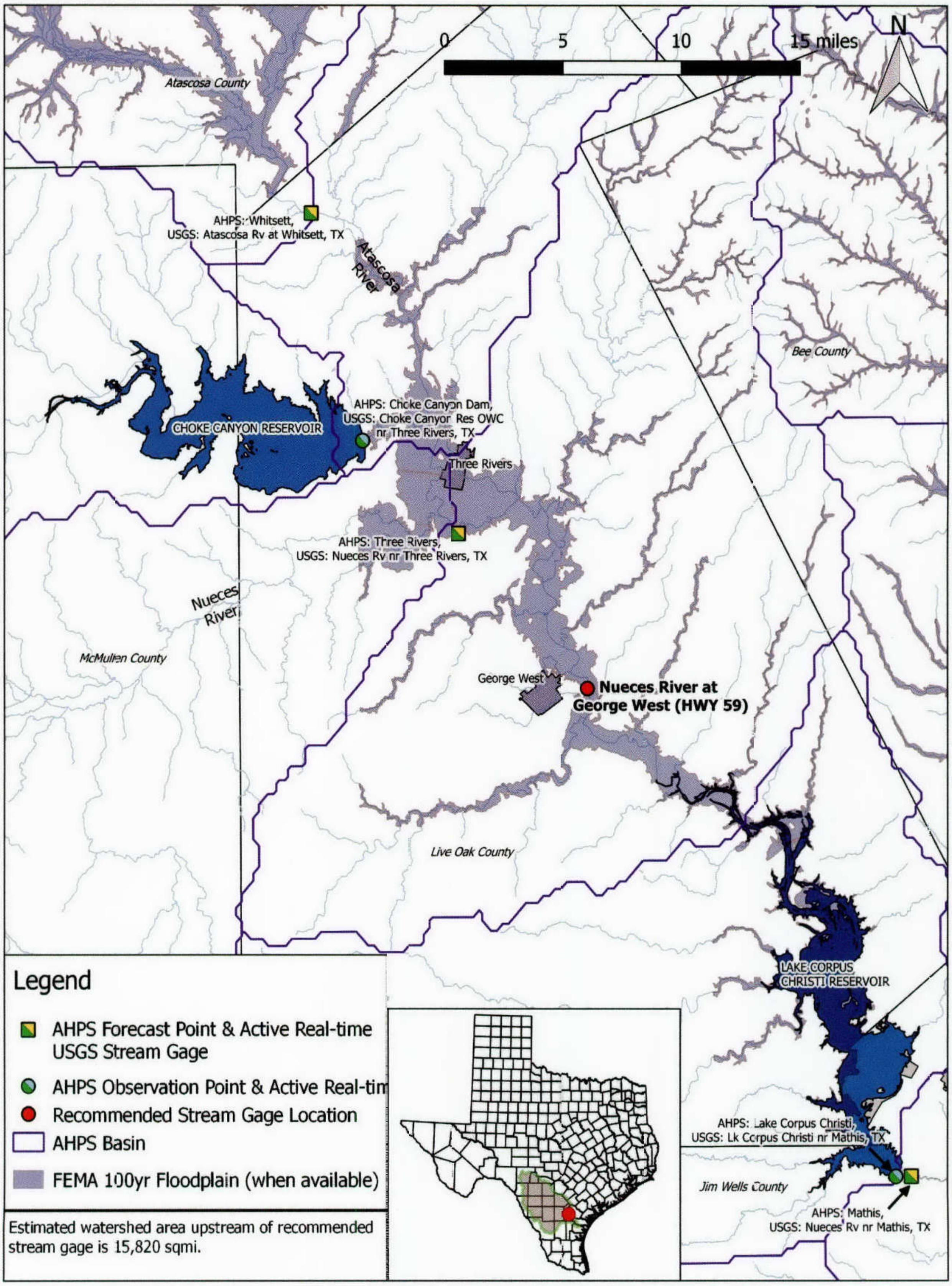


Rank #12: Village Creek at HWY 287 near Village Mills, to provide flood forecasting for unincorporated Hardin County.

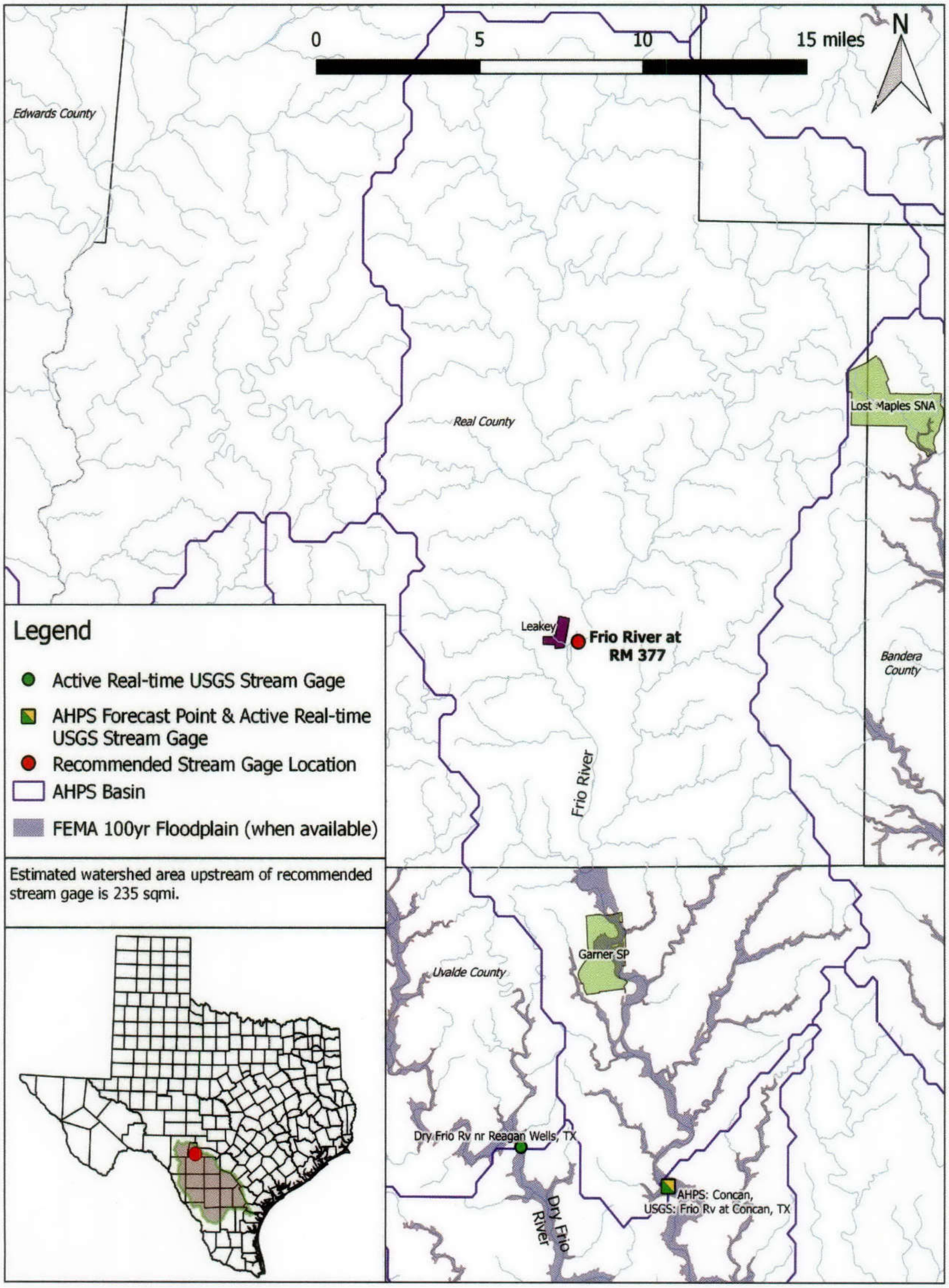


Estimated watershed area upstream of recommended stream gage is 110 sqmi.

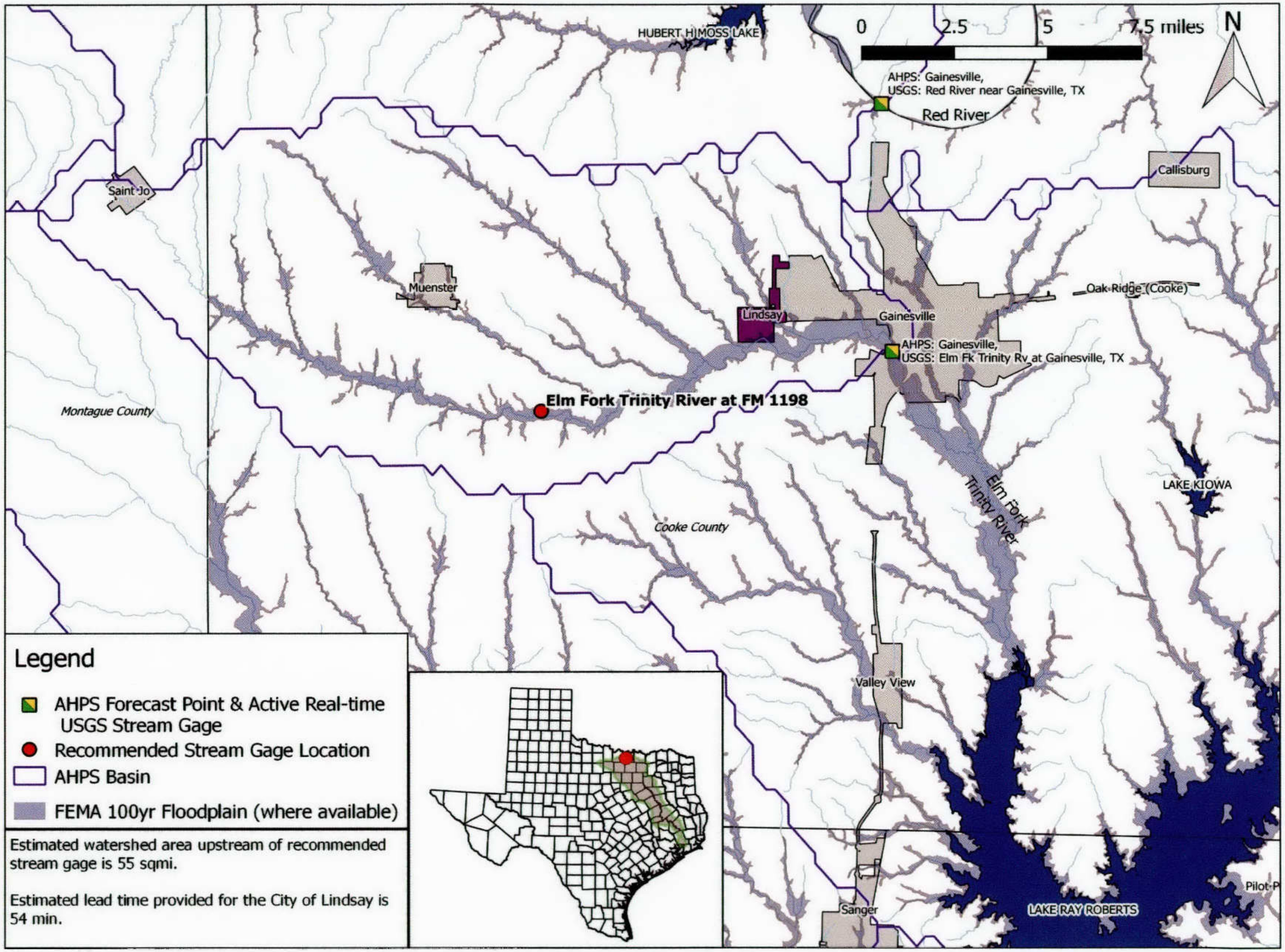
Rank #13: Nolan Creek at I-35 at Belton.



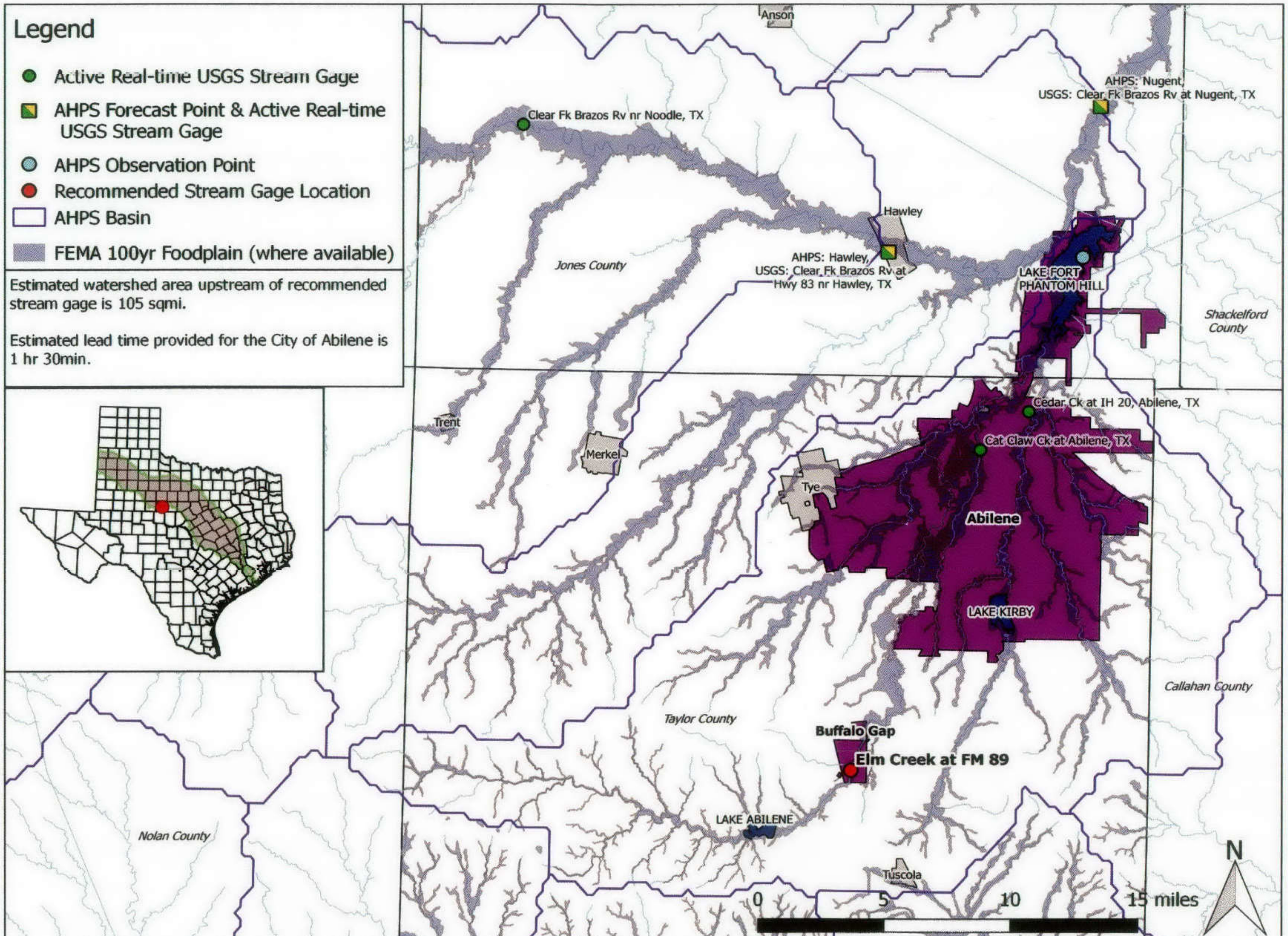
Rank #14: Nueces River at George West (HWY 59).



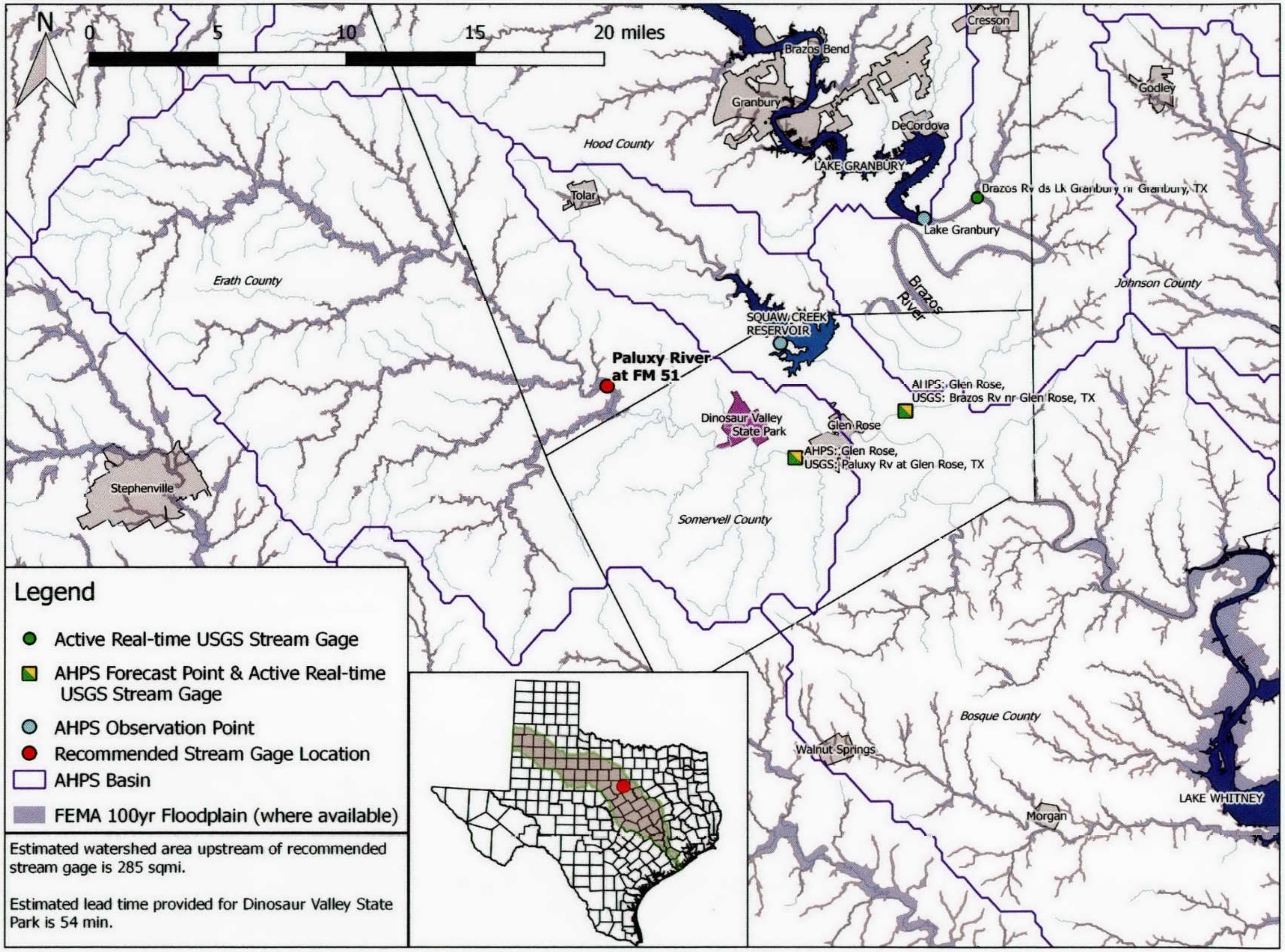
Rank #15: Frio River at RM 377, to provide flood forecasting for the City of Leaky, unincorporated Real County and Garner State Park.



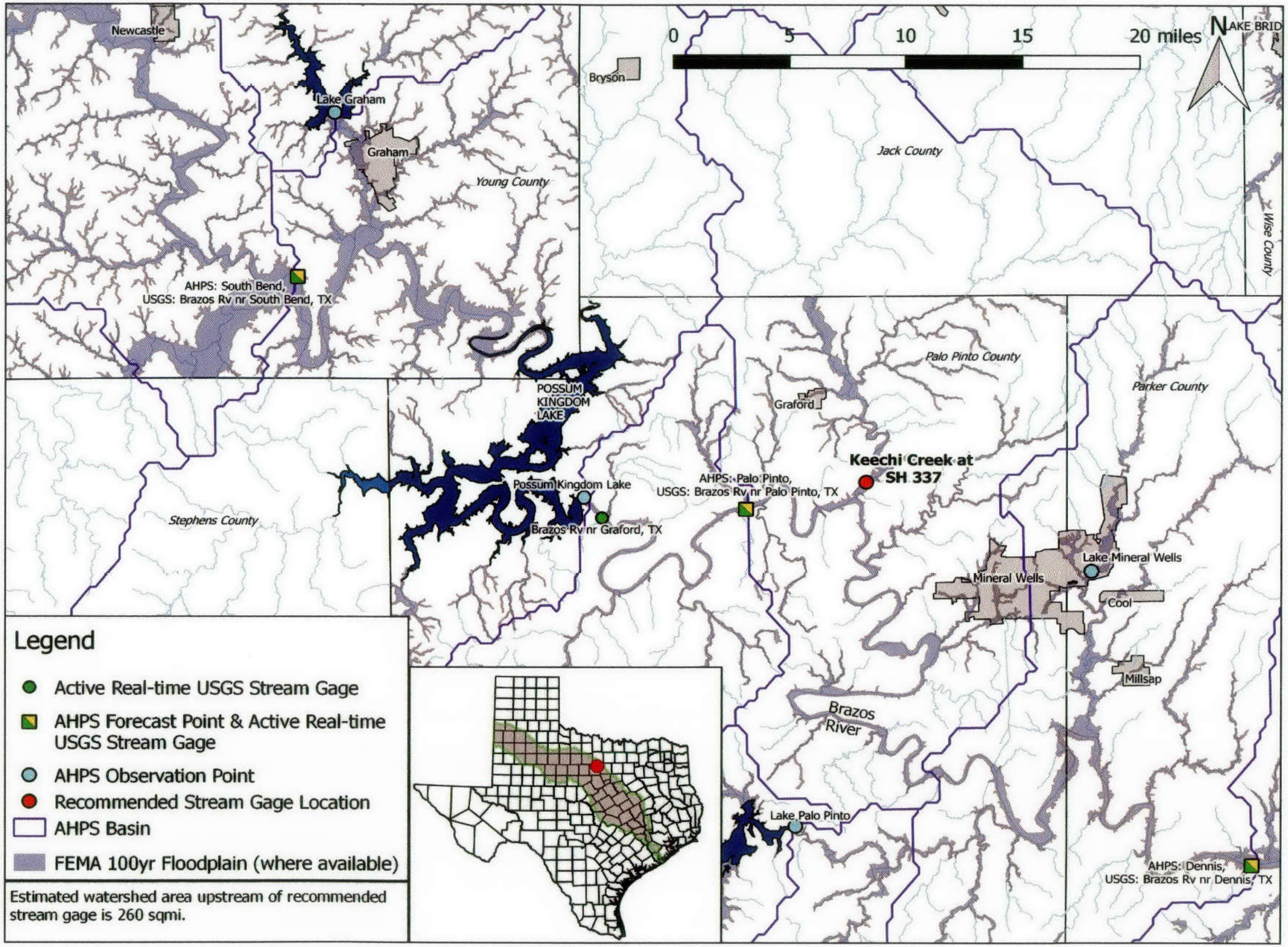
Rank #16: Elm Fork Trinity River at FM 1198, to provide flood forecasting for the City of Lindsay.



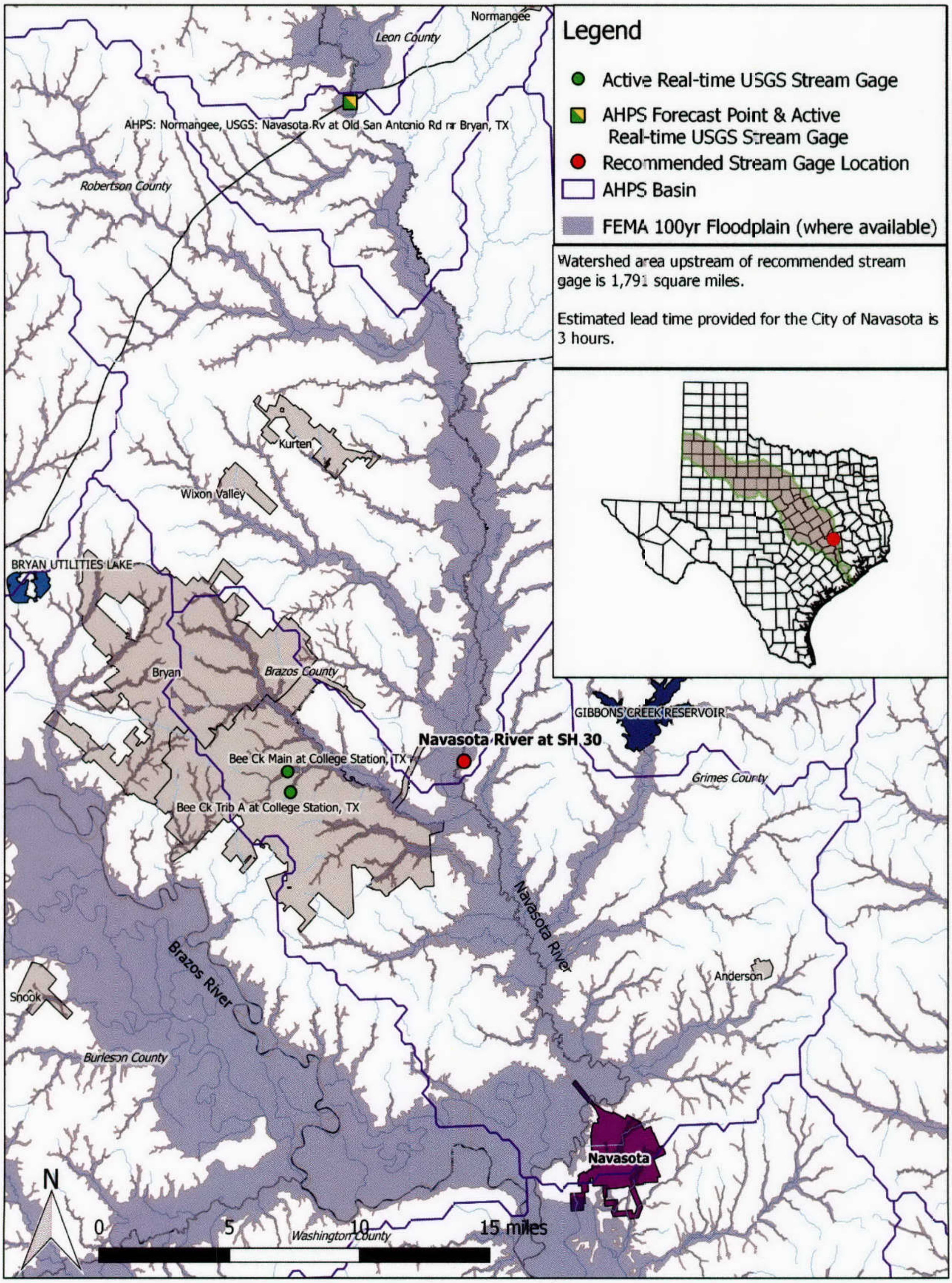
Rank #17: Elm Creek at FM 89, to provide flood forecasting for the Township of Buffalo Gap and the City of Abilene.



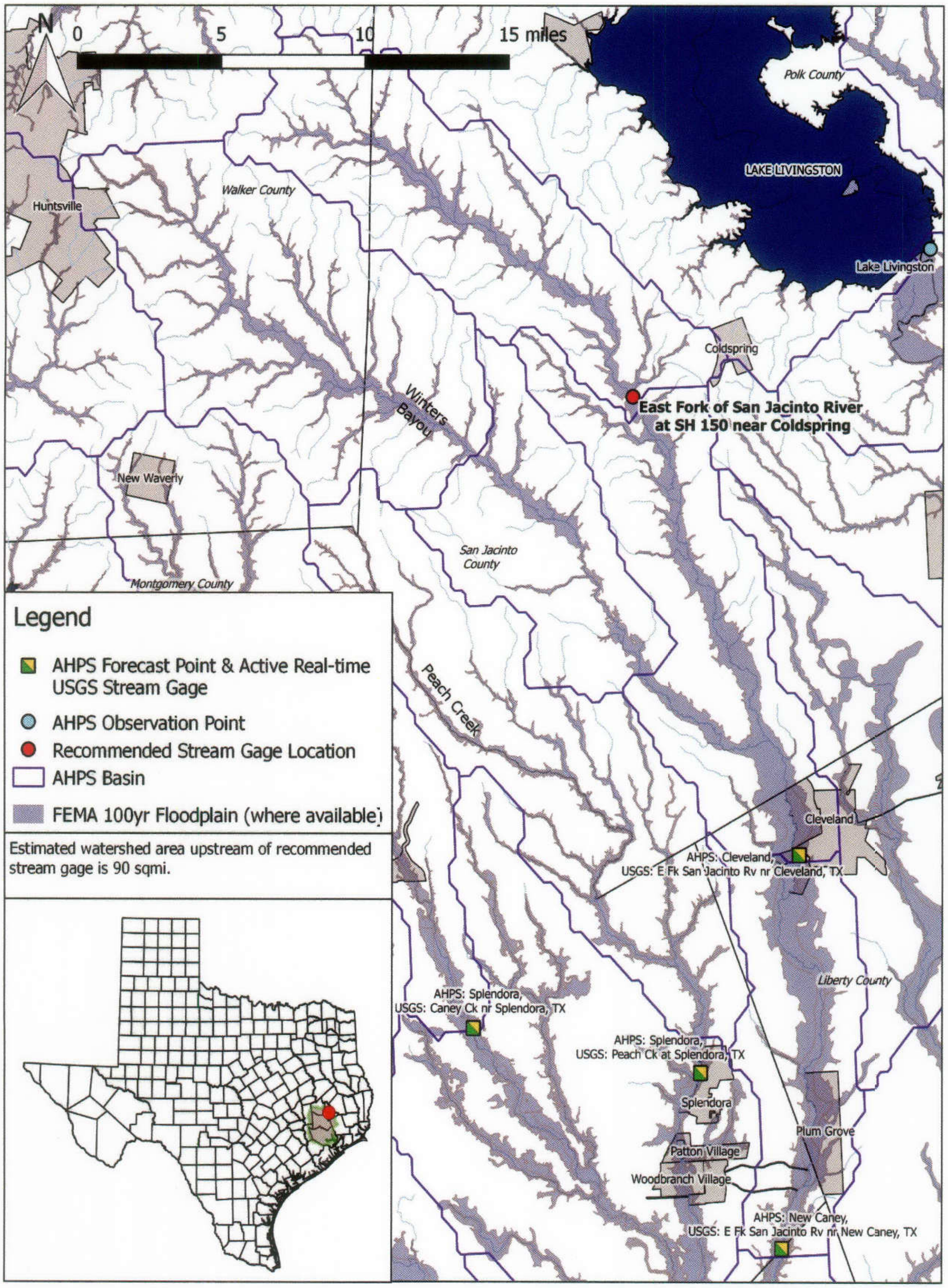
Rank #18: Paluxy River at FM 51, to provide flood forecasting for unincorporated Somervell County and Dinosaur Valley State Park.



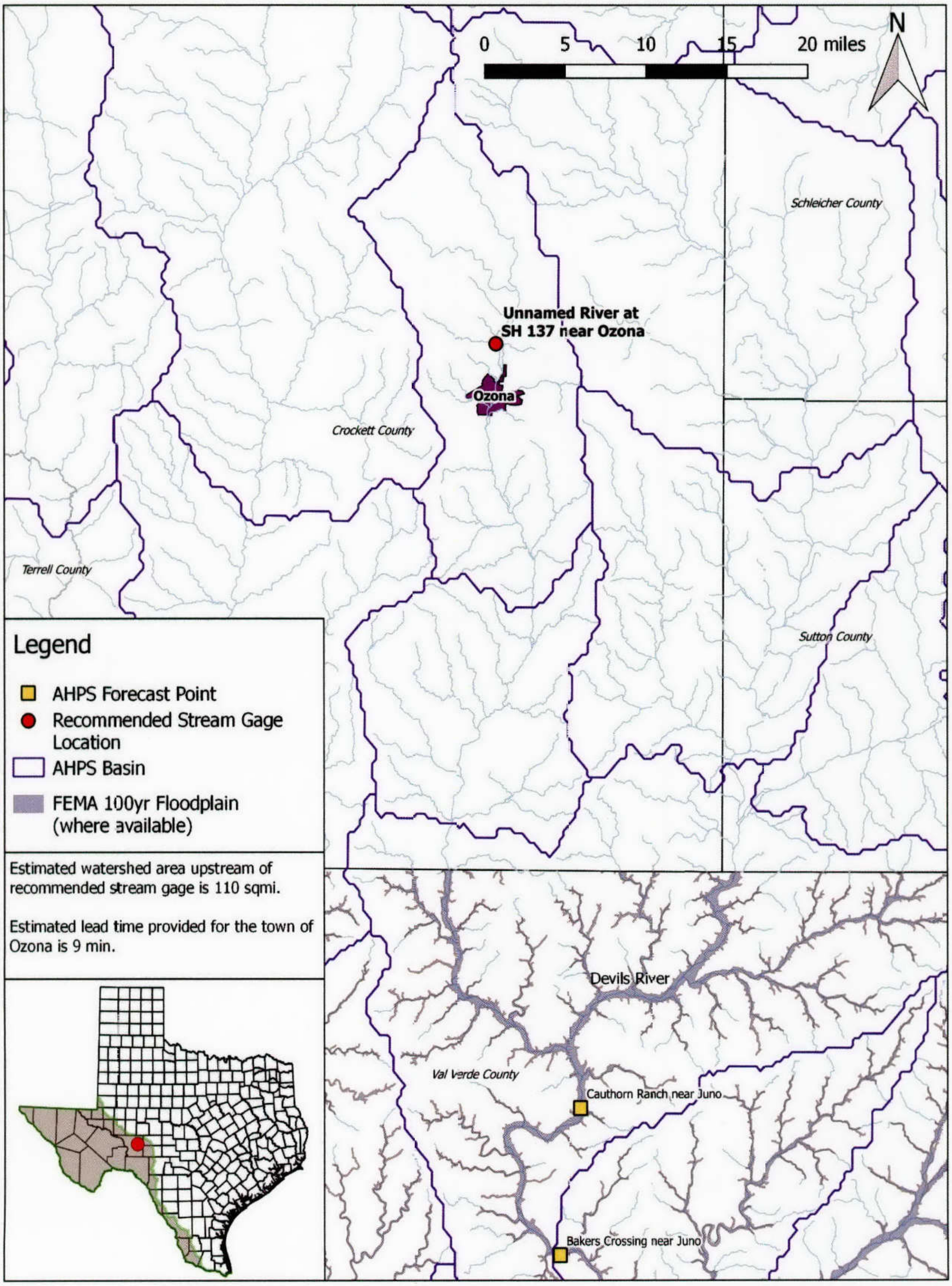
Rank #19: Keechi Creek at SH 337, to provide flood forecasting for unincorporated Palo Pinto County.



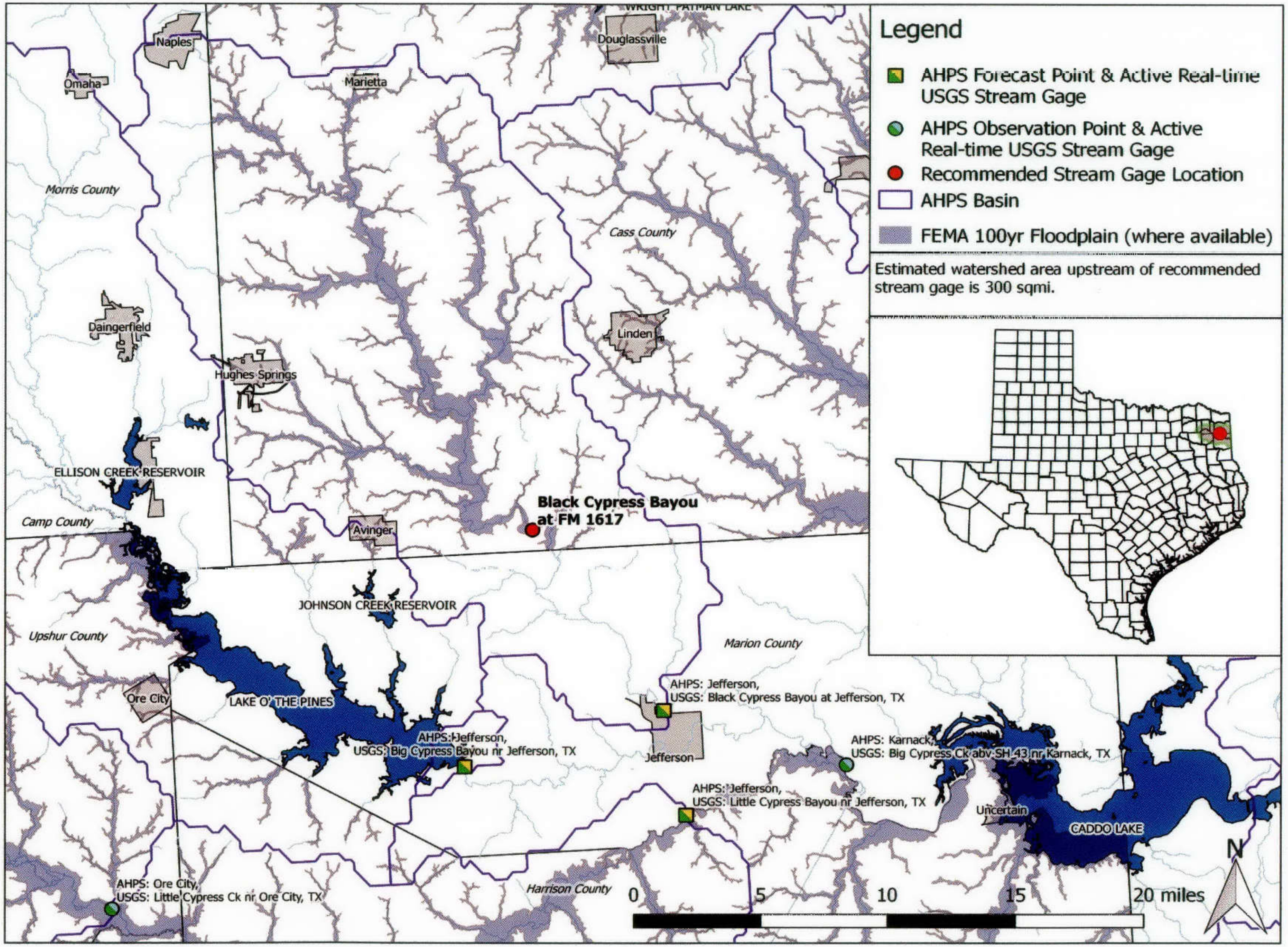
Rank #20: Navasota River at SH 30, to provide flood forecasting for the City of Navasota.



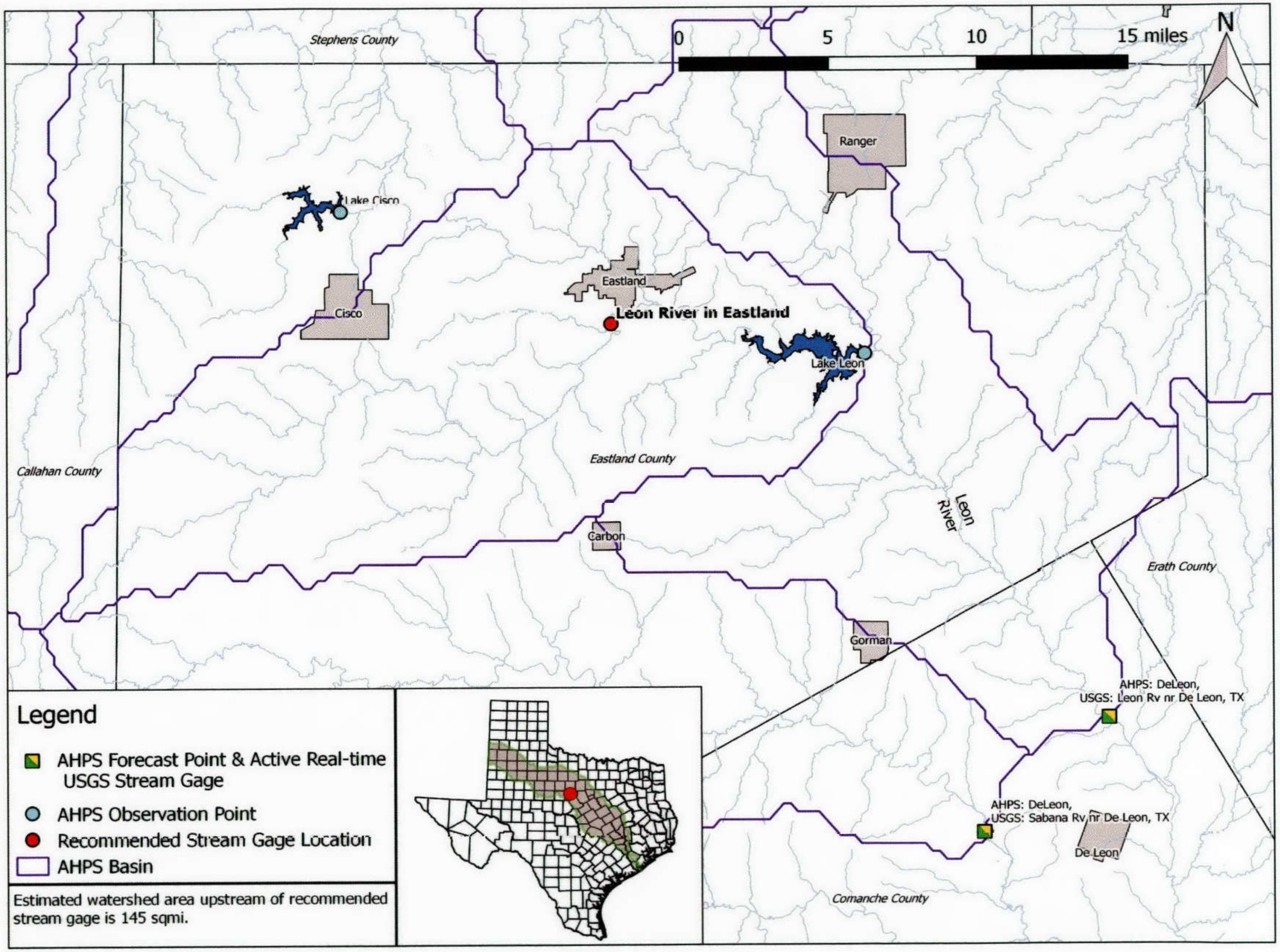
Rank #21: East Fork of San Jacinto River at SH 150 near Coldspring, to provide flood forecasting for unincorporated San Jacinto and Liberty Counties.



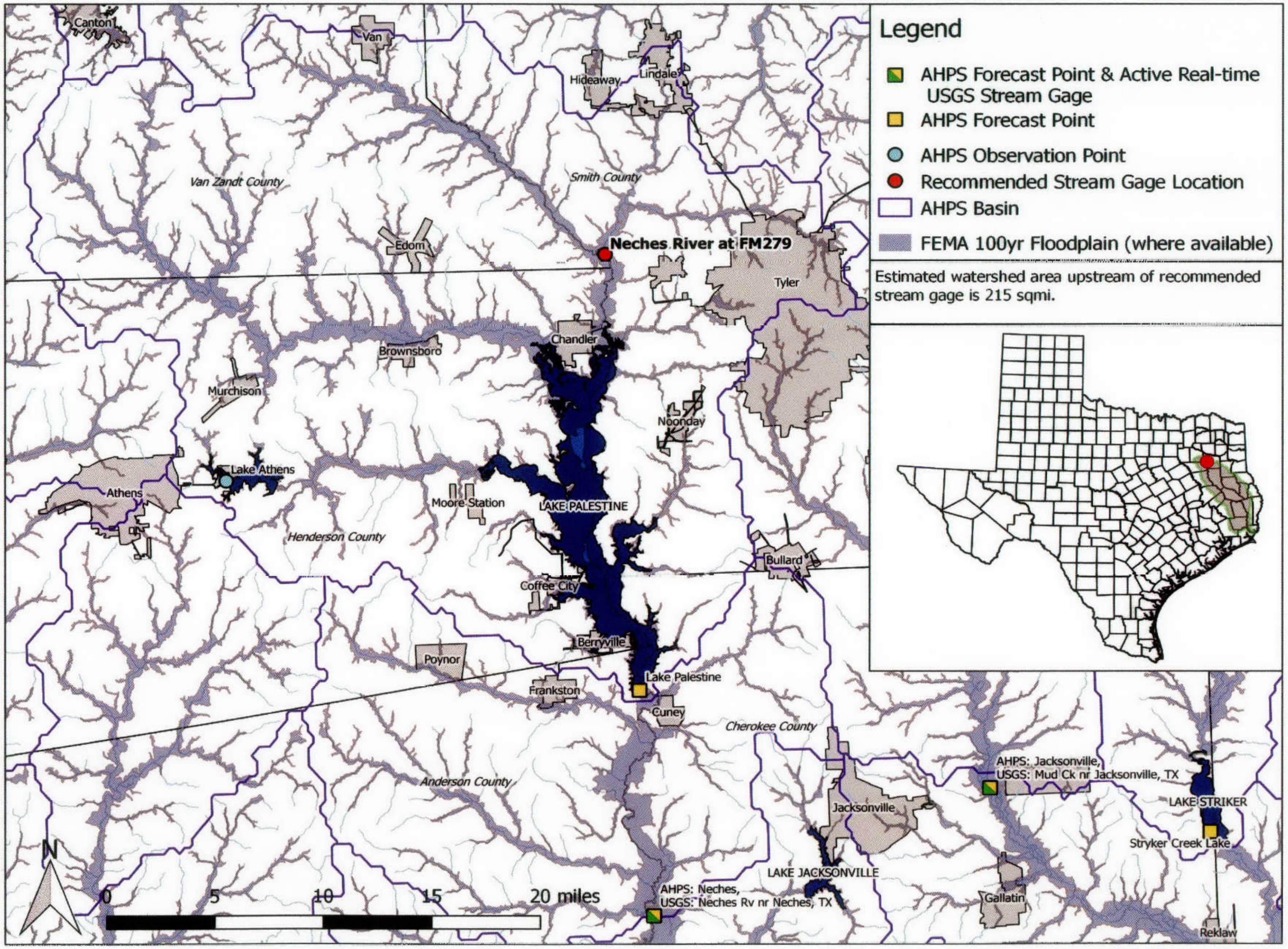
Rank #22: Unnamed stream at SH 137 near Ozona, to provide flood forecasting for Ozona and unincorporated Crockett County.



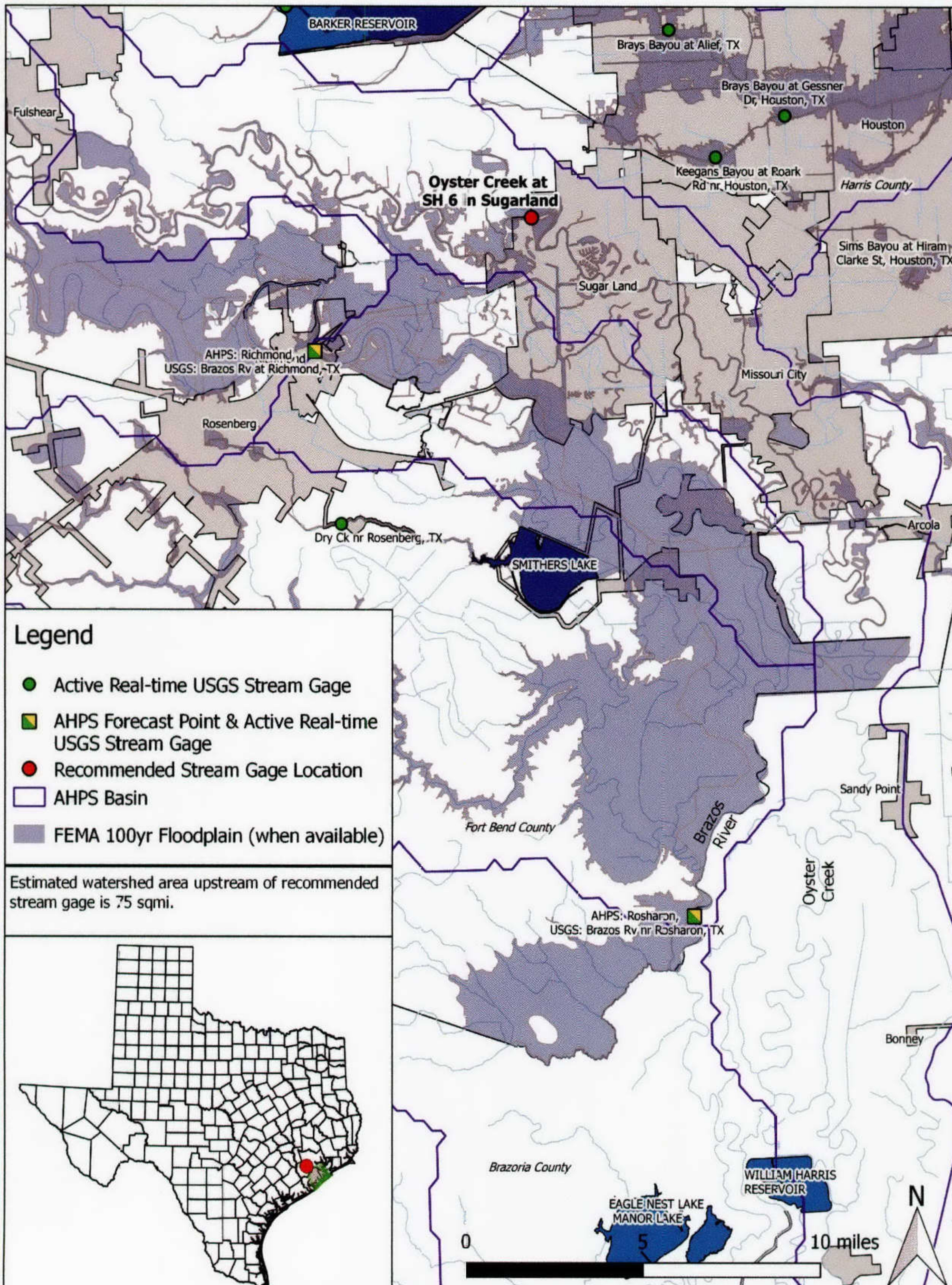
Rank #23: Black Cypress Bayou at FM 1617, to provide flood forecasting for unincorporated Marion County.



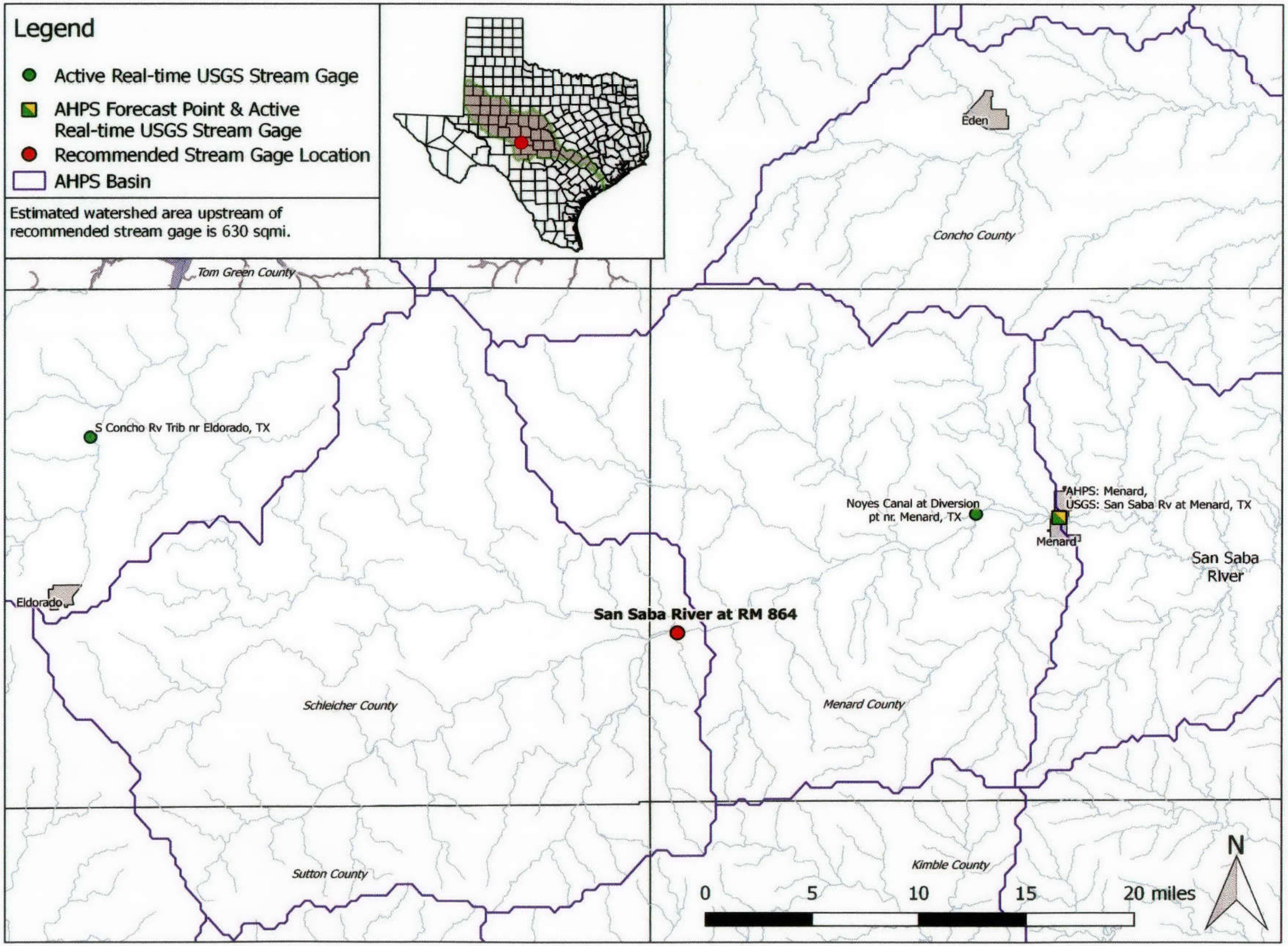
Rank #24: Leon River in Eastland, to provide flood forecasting for unincorporated Eastland County.



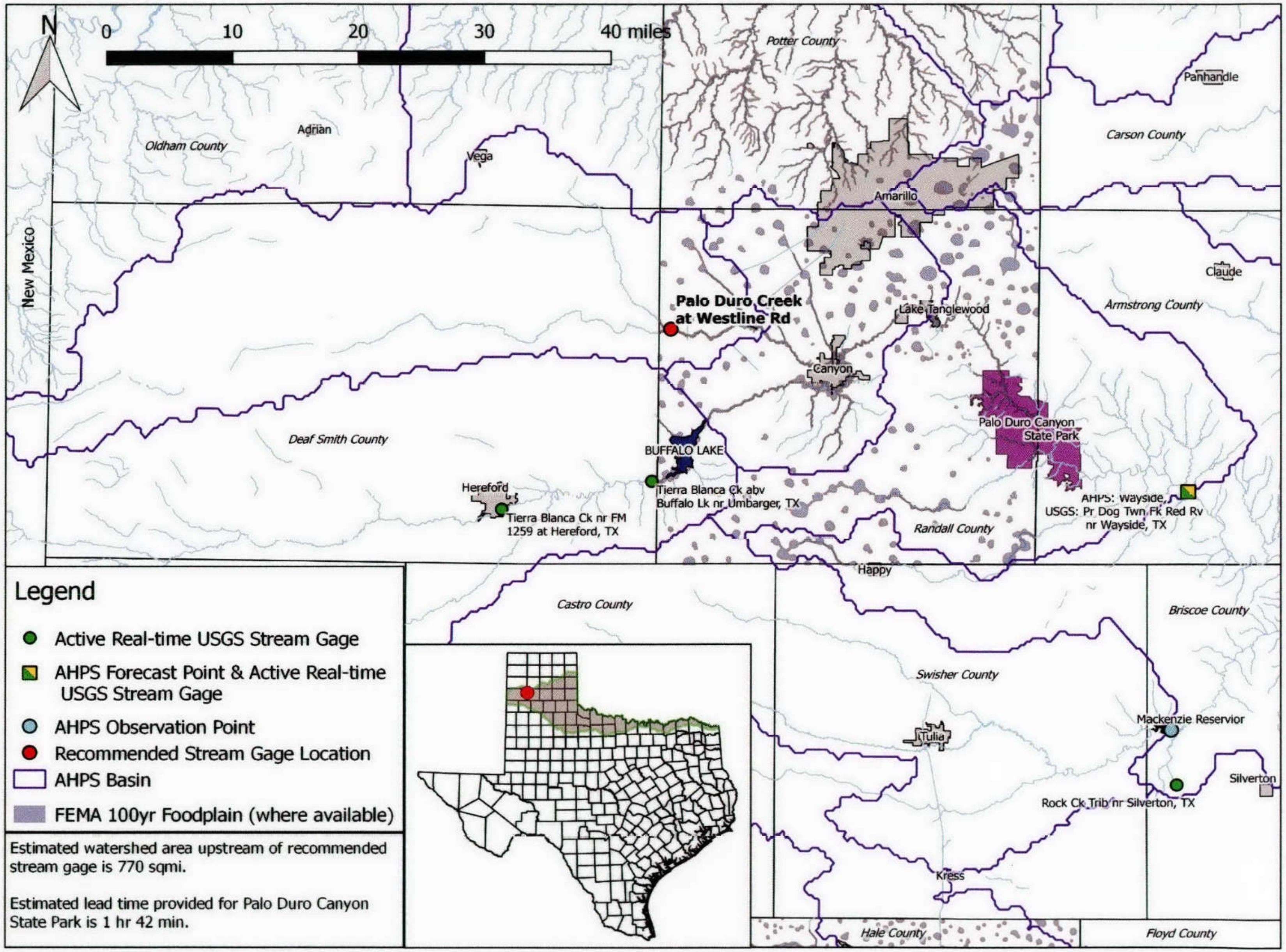
Rank #25: Neches River at FM 279, to provide flood forecasting for unincorporated Smith County.



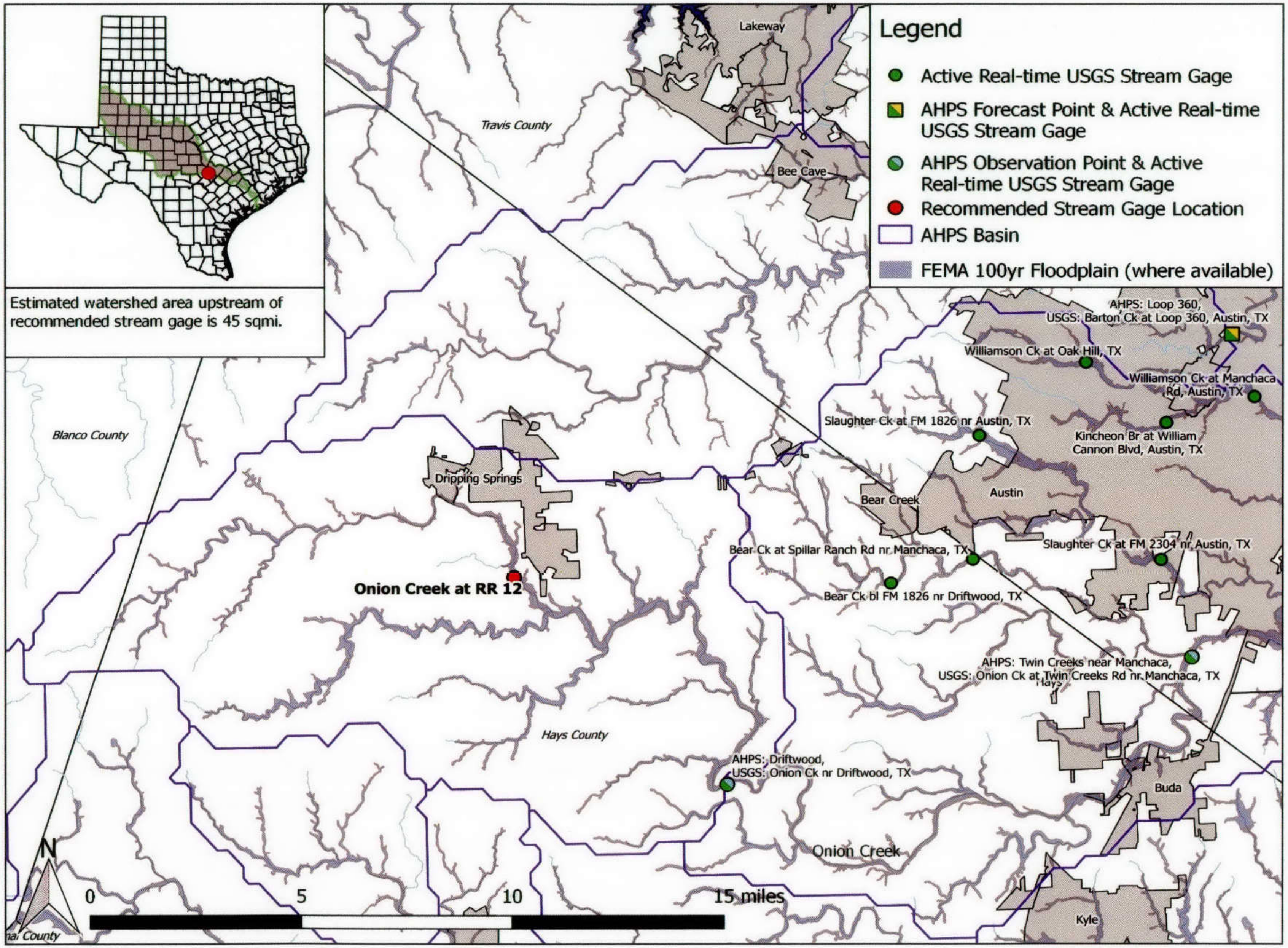
Rank #26: Oyster Creek at SH 6 in Sugarland, to provide flood forecasting for unincorporated Brazoria and Missouri Counties.



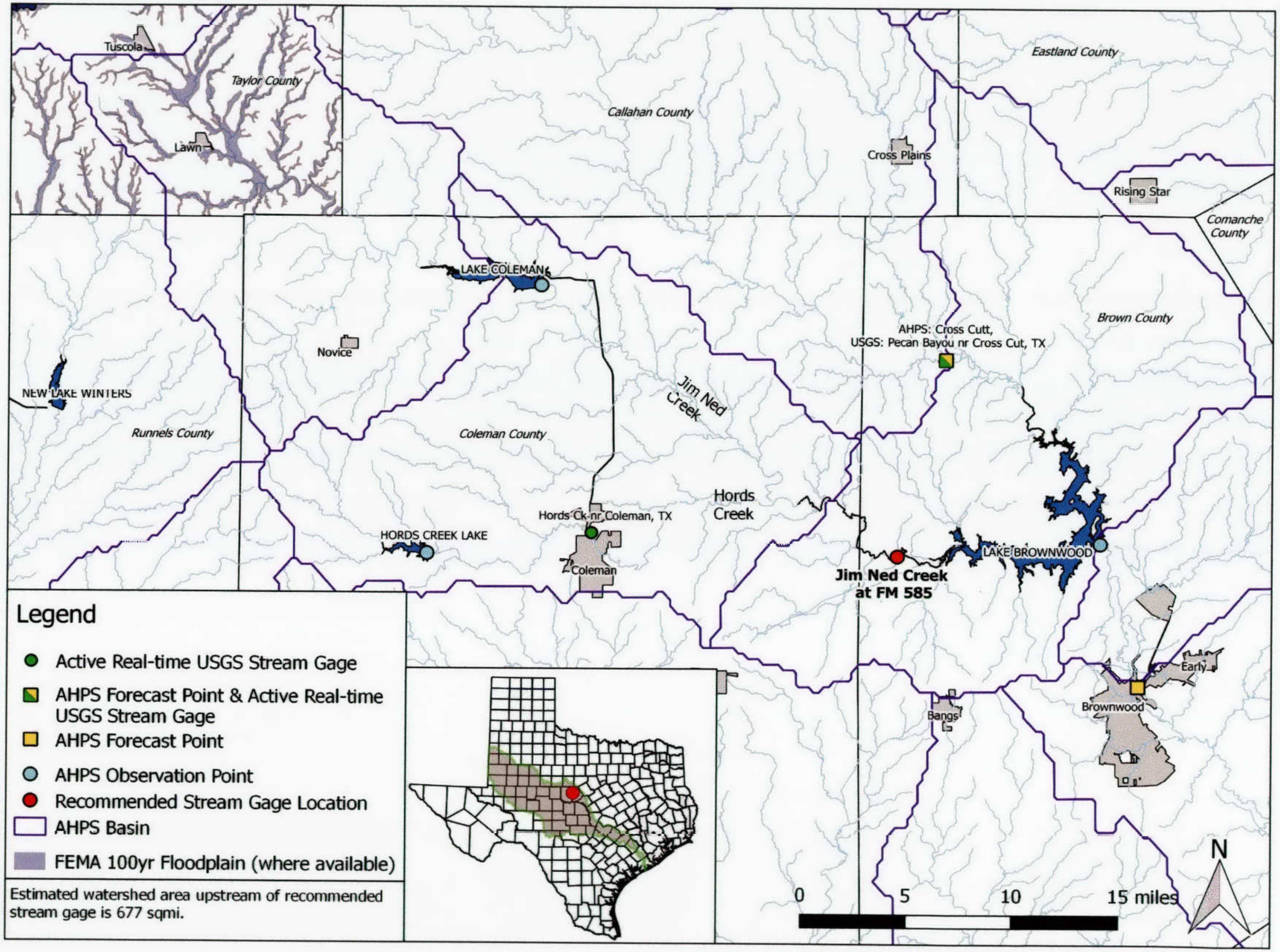
Rank #27: San Saba River at RM 864, to provide flood forecasting for unincorporated Menard County.



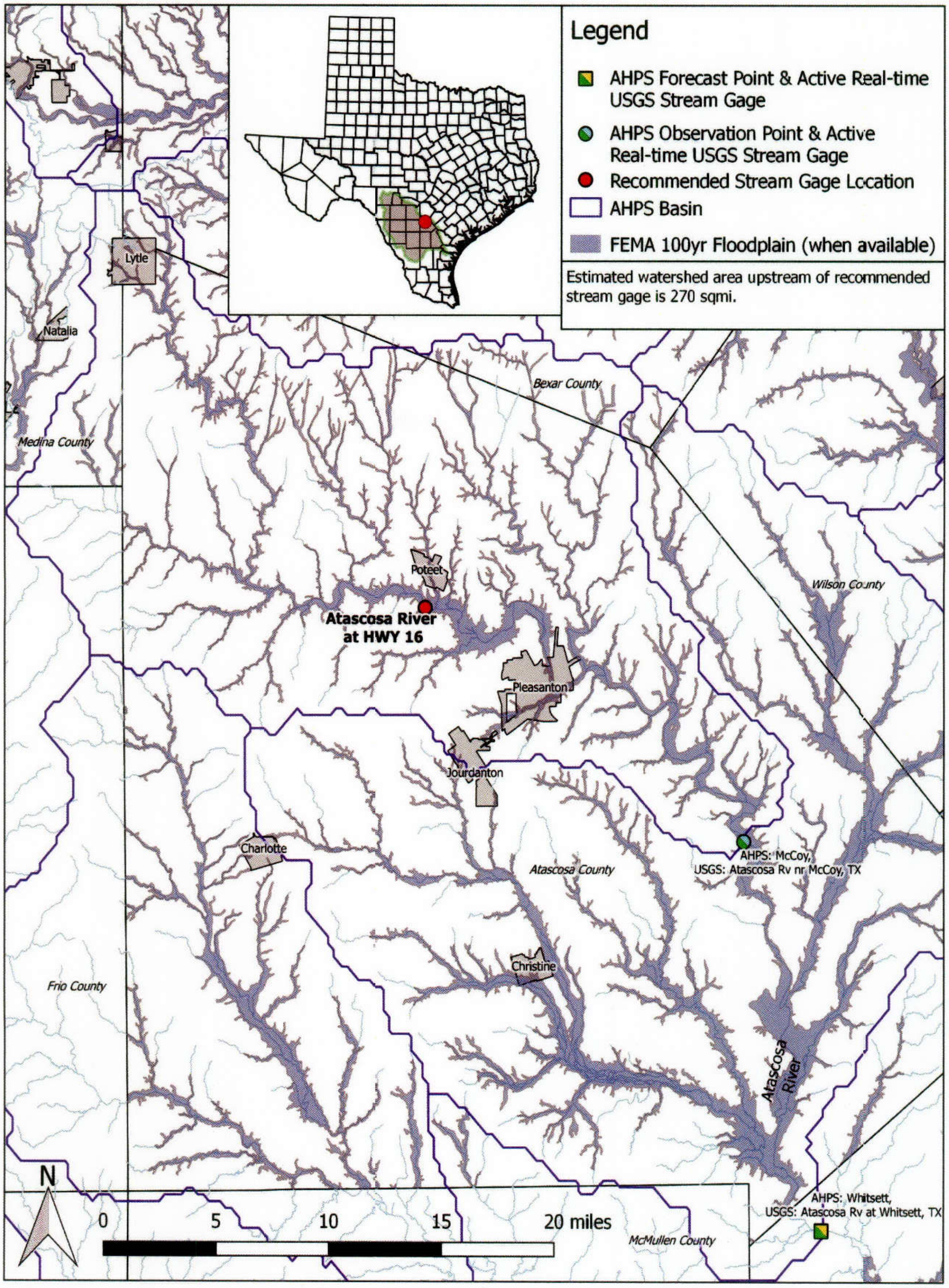
Rank #28: Palo Duro Creek at Westline Road, to provide flood forecasting for Palo Duro Canyon State Park.



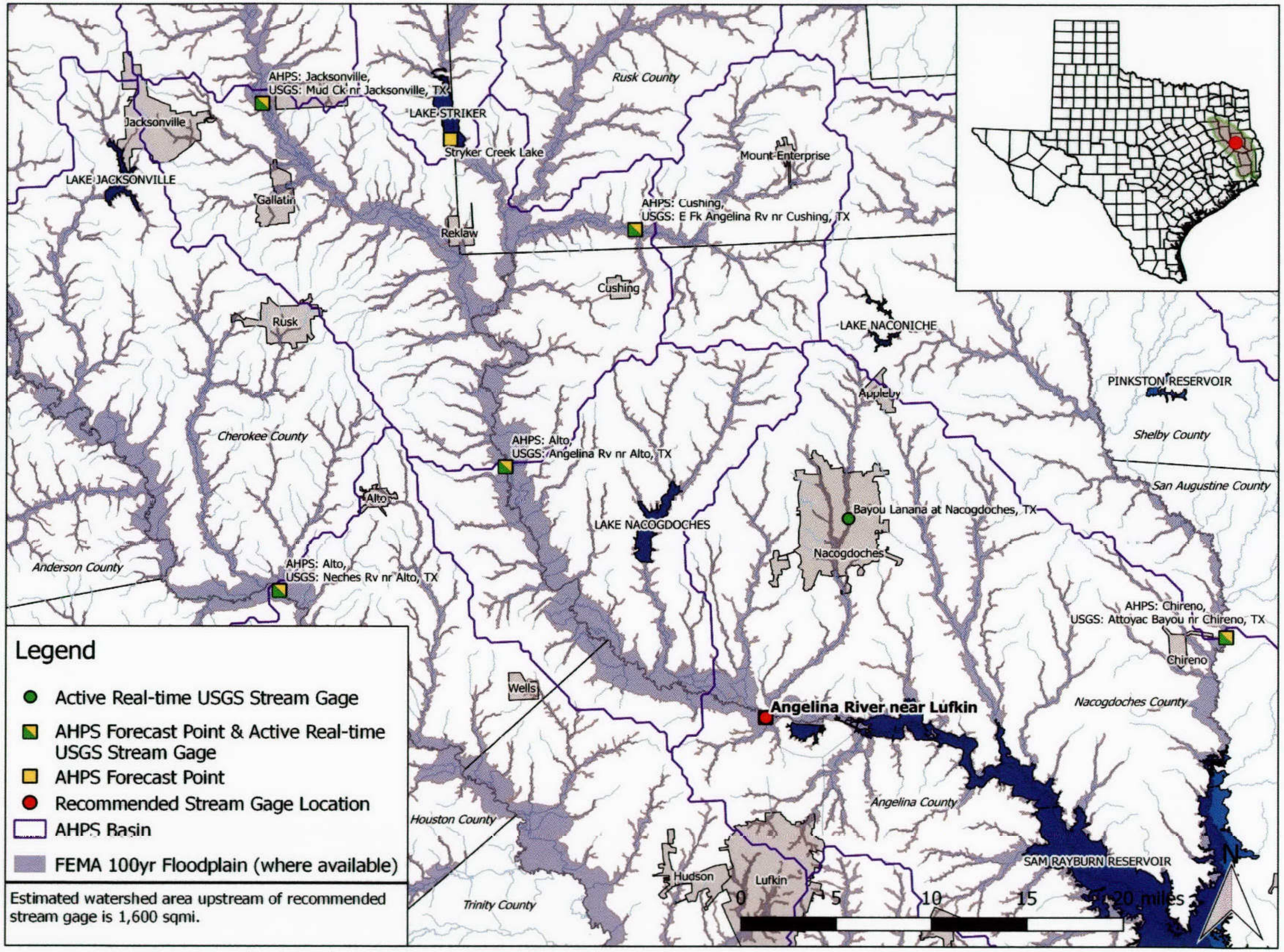
Rank #29: Onion Creek at RR 12.



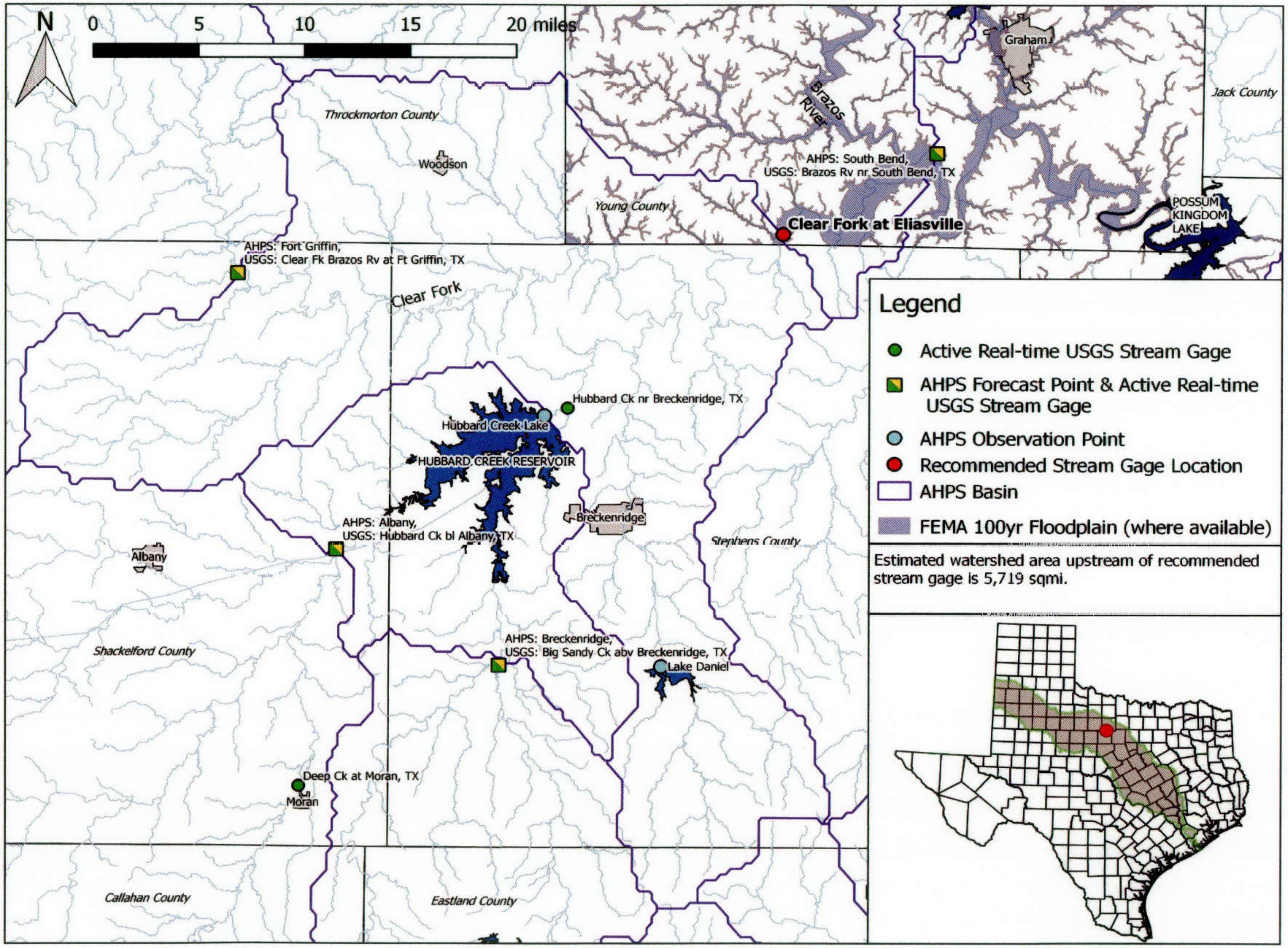
Rank #30: Jim Ned Creek at RM 585.



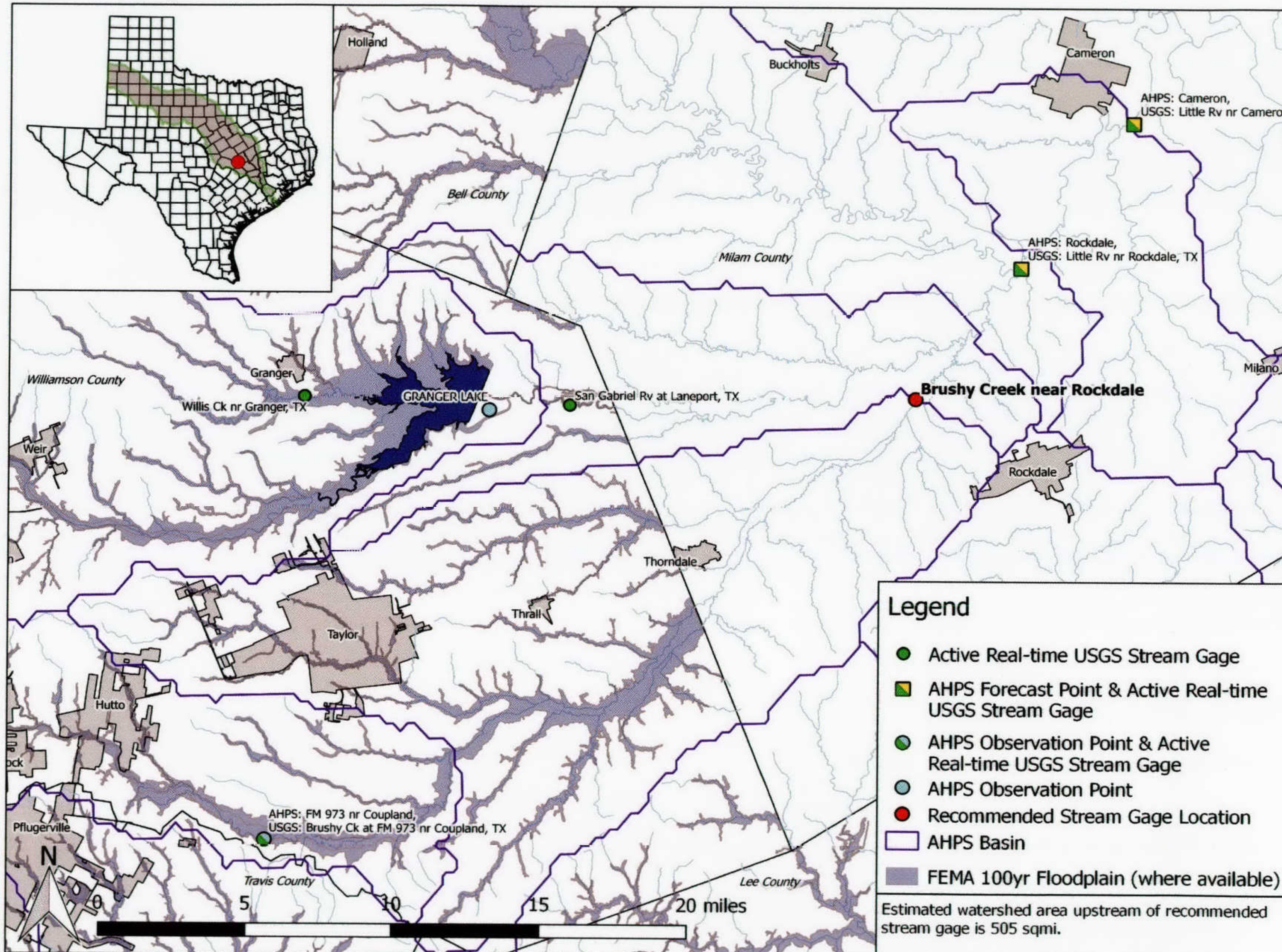
Rank #31: Atascosa River at HWY 16.



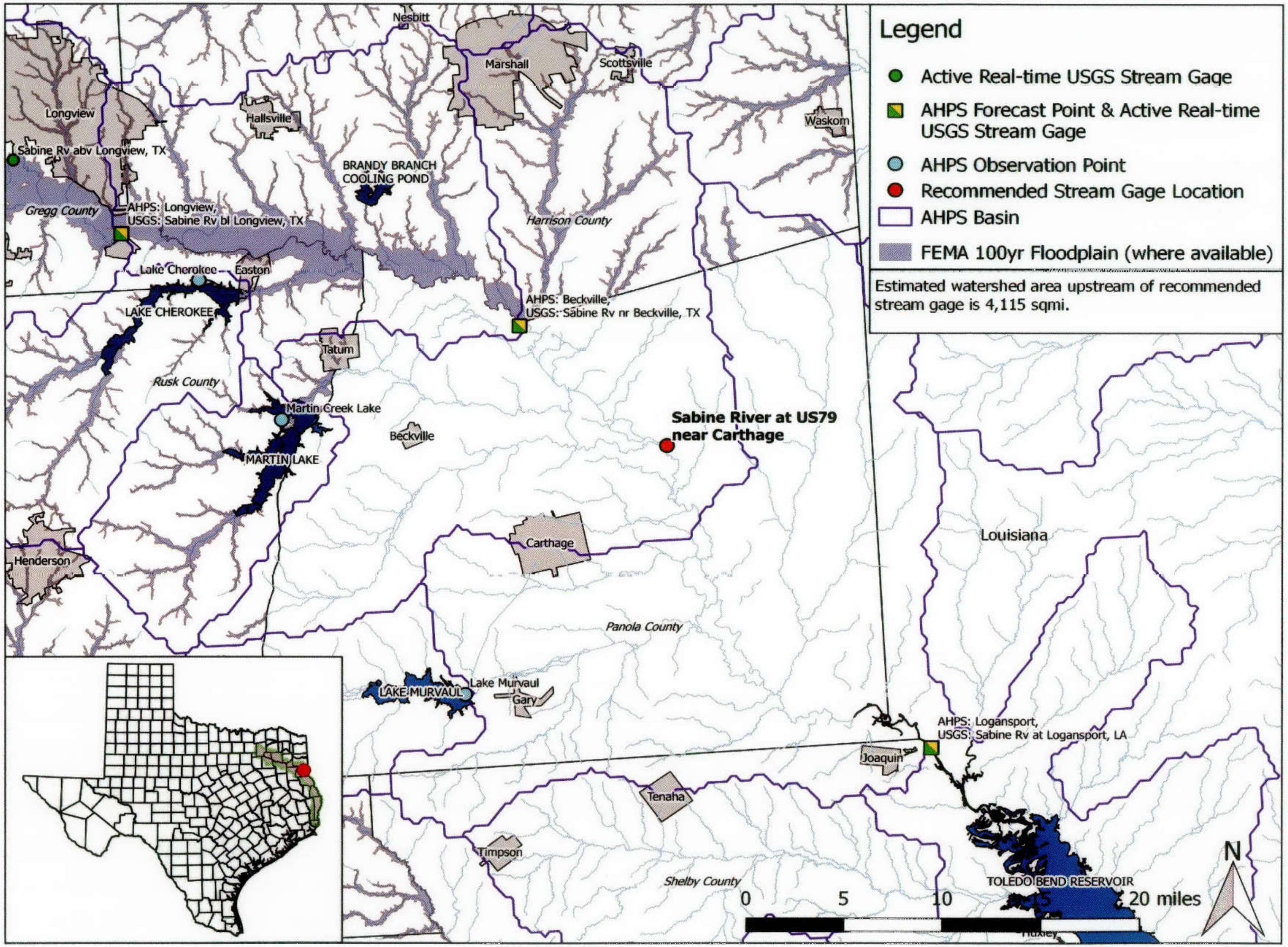
Rank #32: Angelina River near Lufkin.



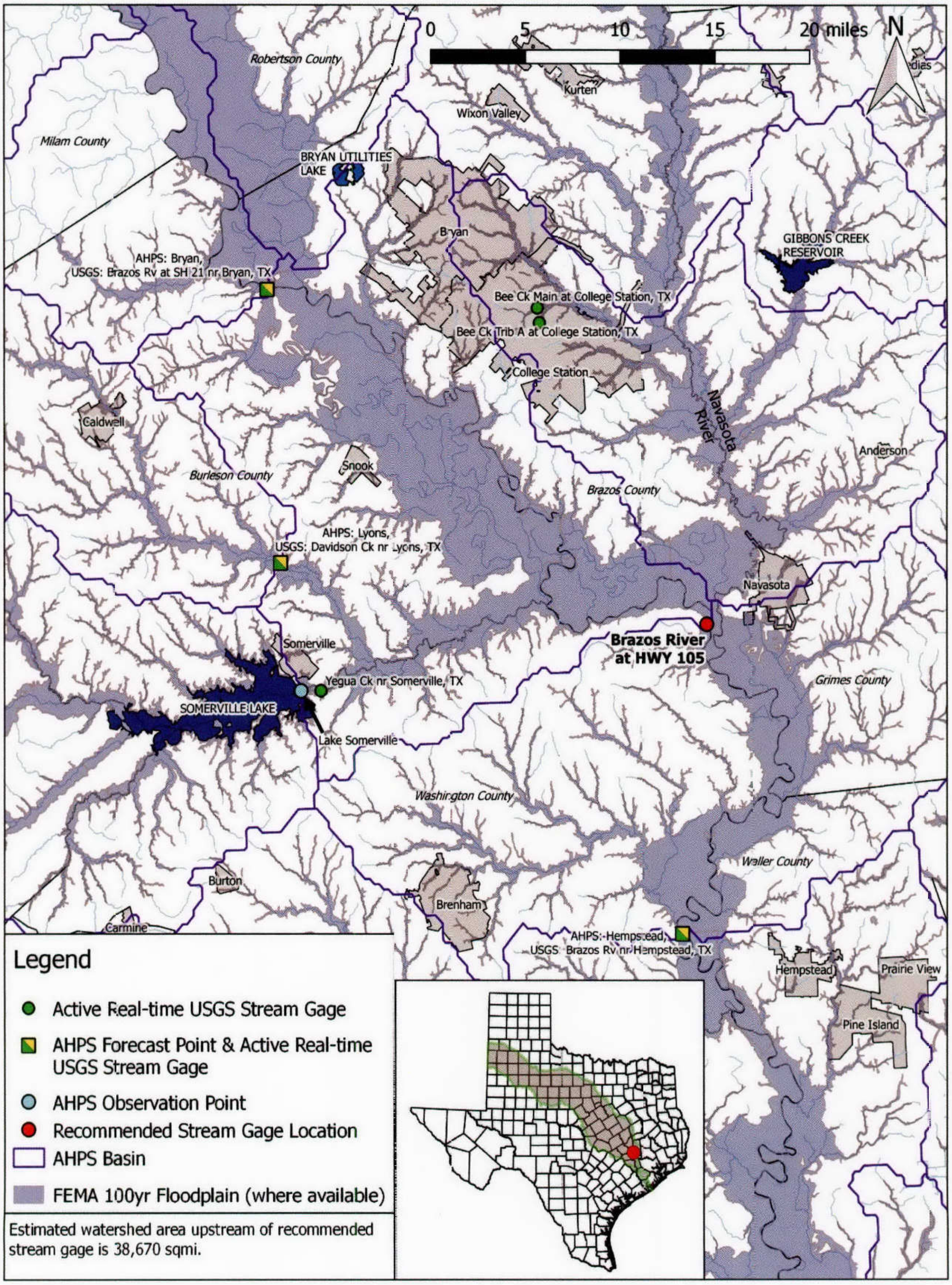
Rank #33: Clear Fork at Eliasville.



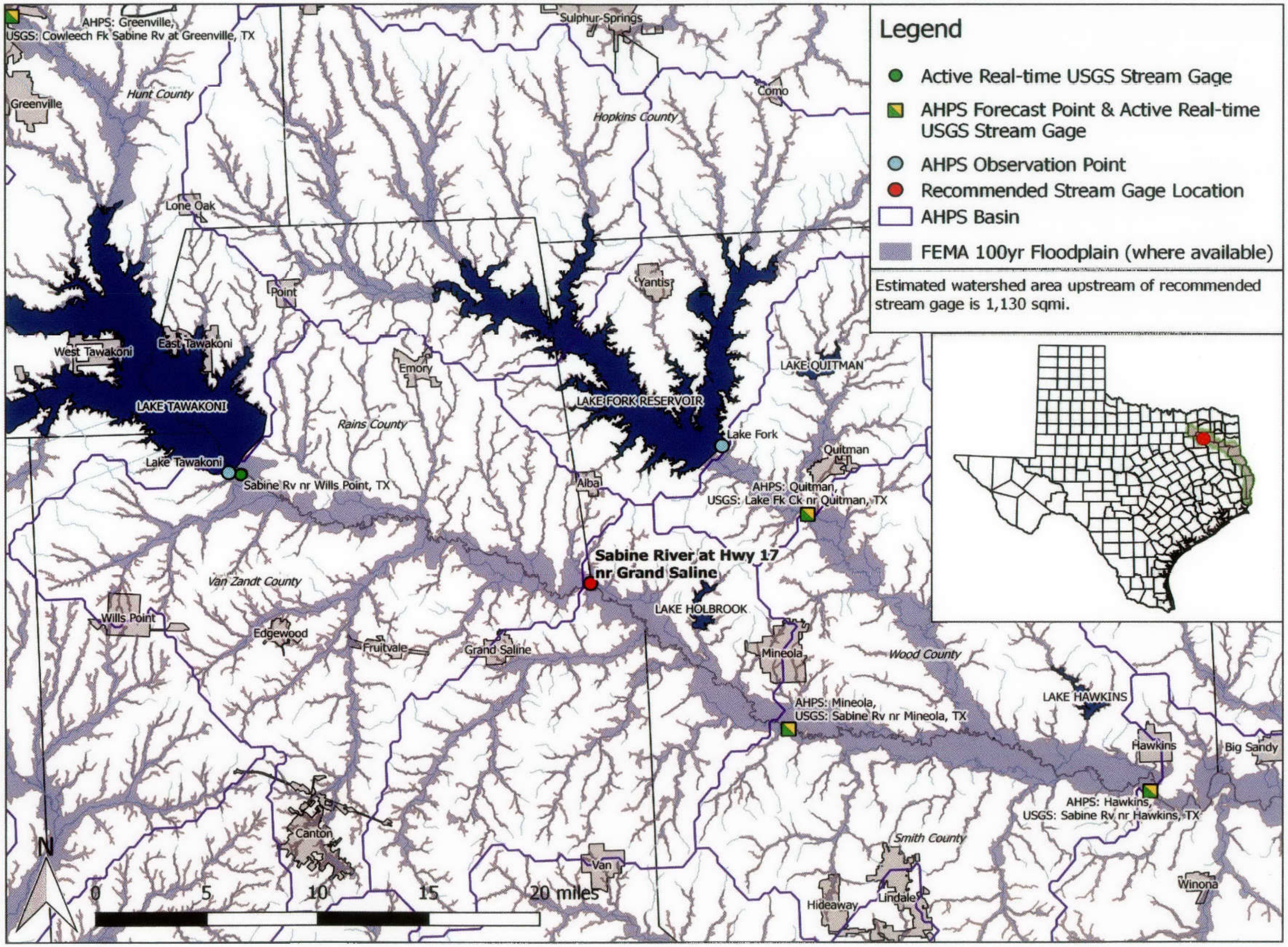
Rank #34: Brushy Creek near Rockdale.



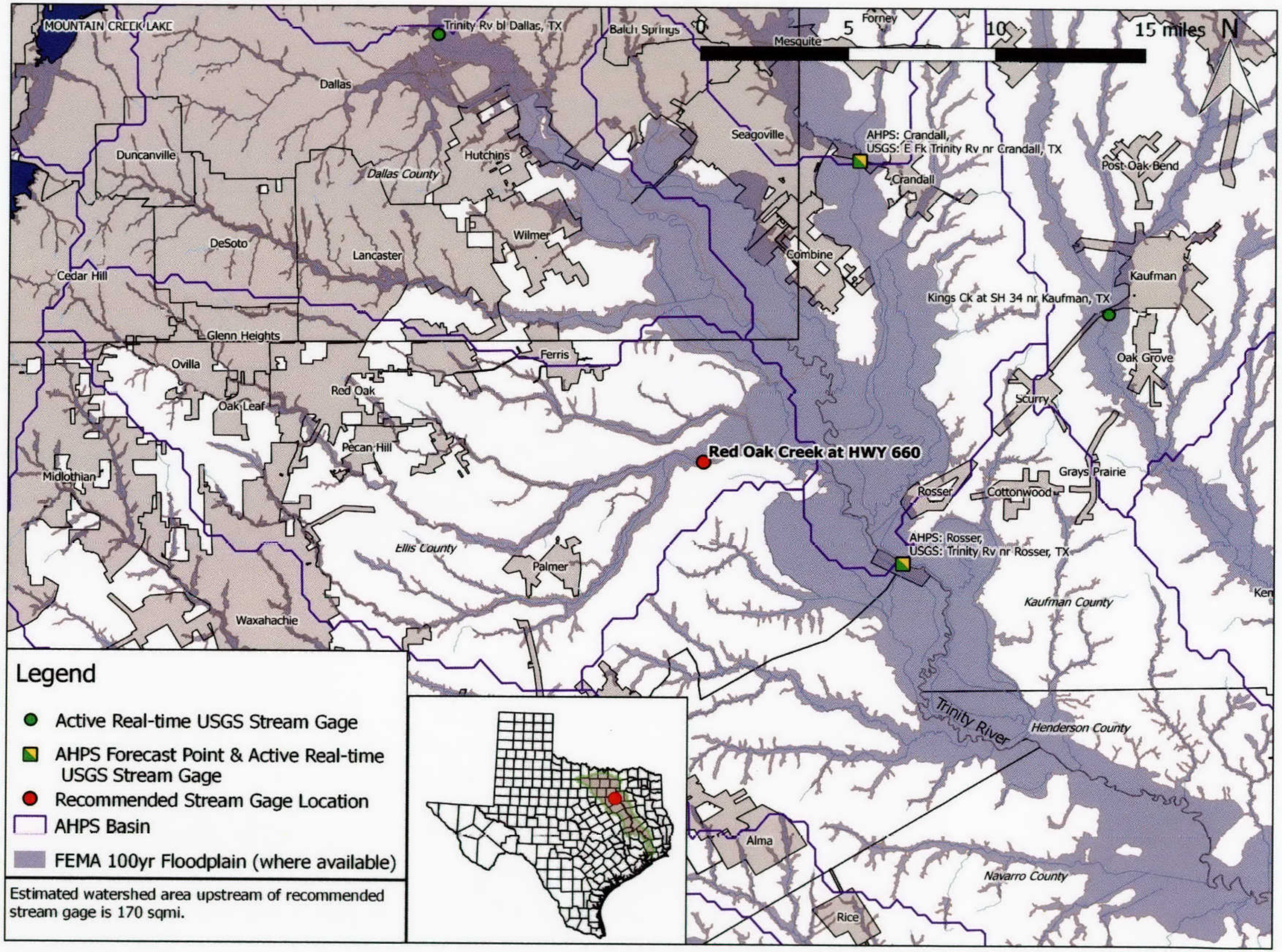
Rank #35: Sabine River at US 79 near Carthage.



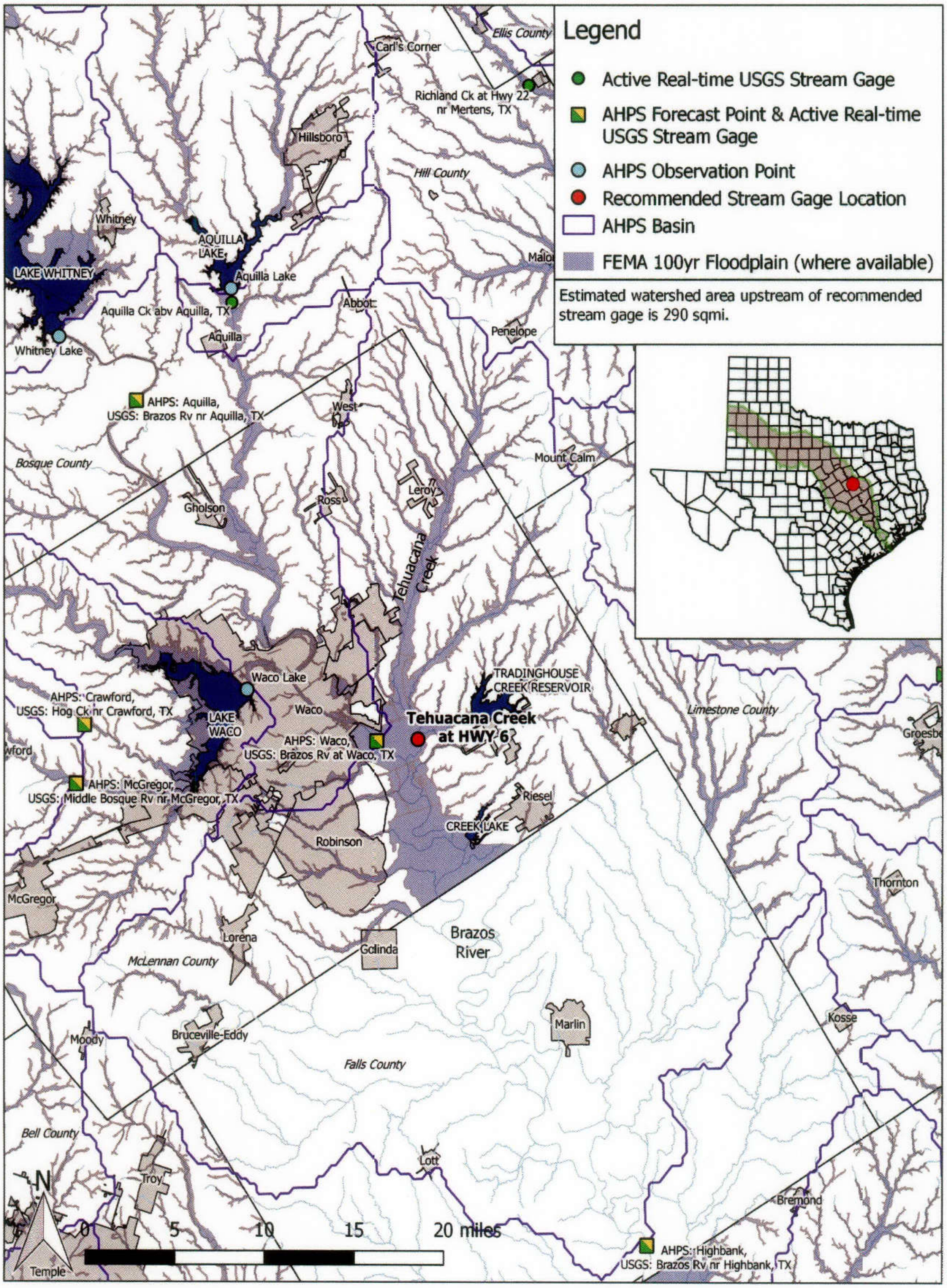
Rank #36: Brazos River at HWY 105.



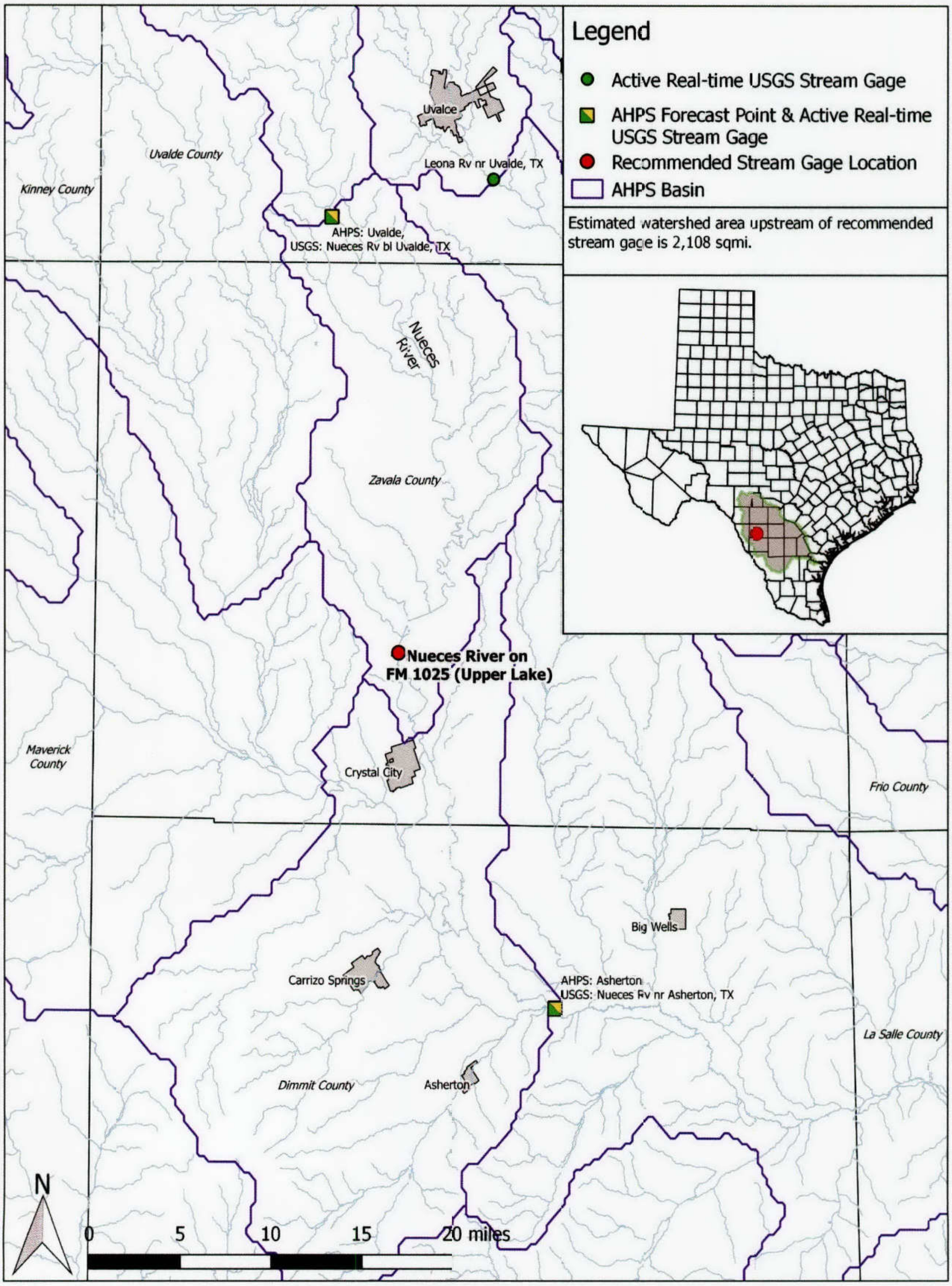
Rank #37: Sabine River at HWY 17 near Grand Saline.



Rank #38: Red Oak Creek at HWY 660.

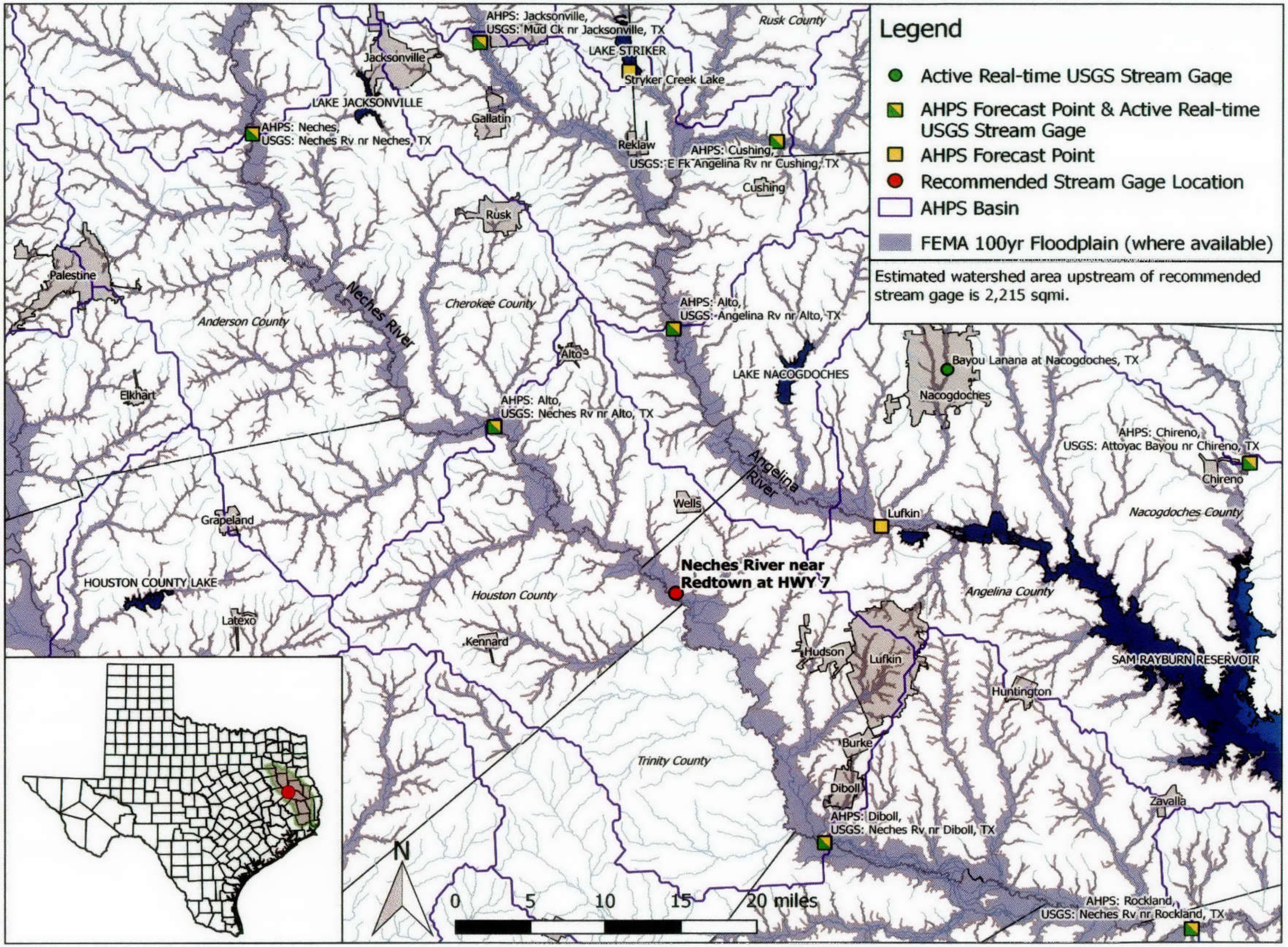


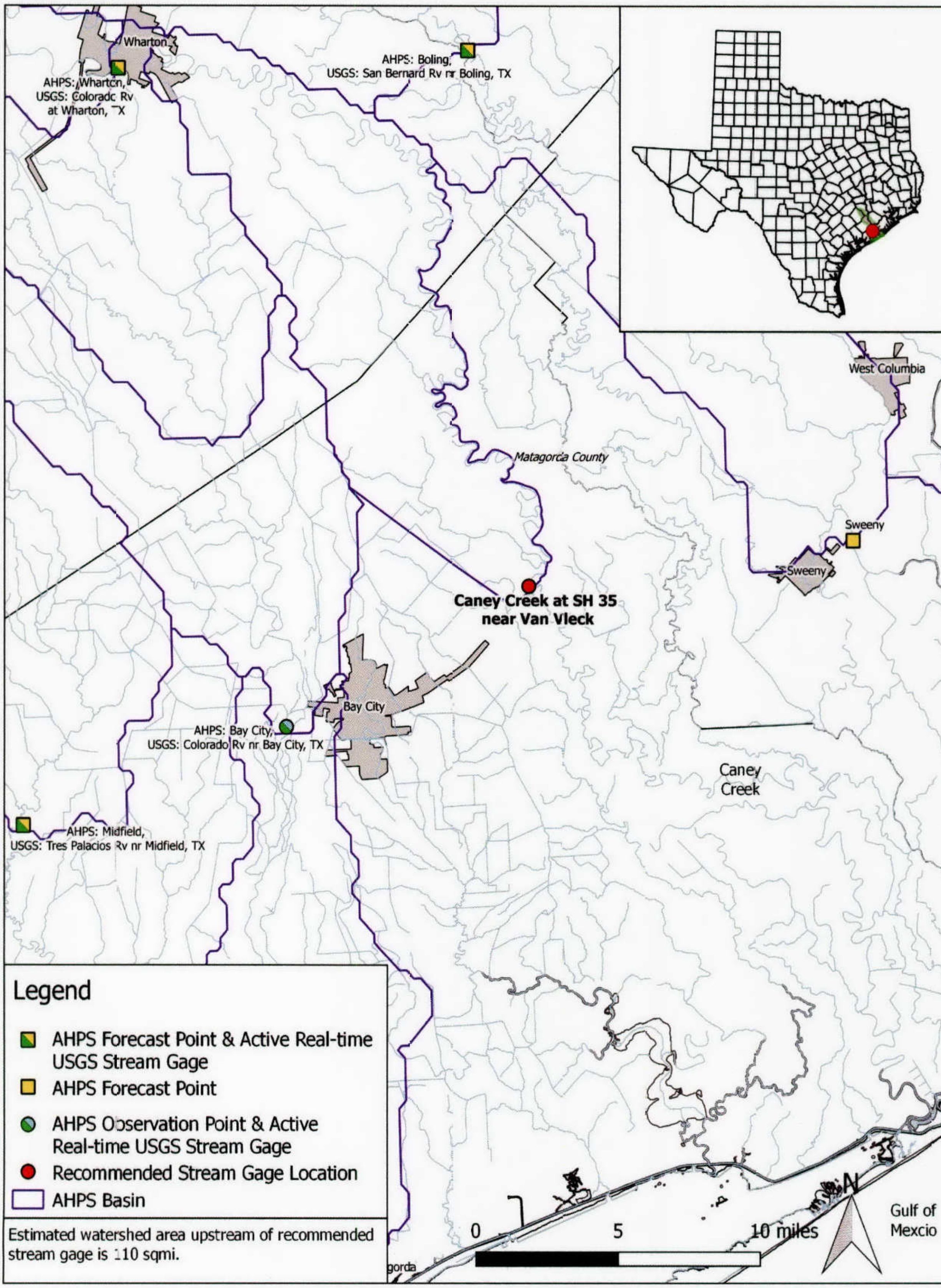
Rank #39: Tehuacana Creek at HWY 6.



Rank #40: Nueces River at FM 1025 (Upper Lake).

Rank #41: Neches River near Redtown at HWY 7.





Rank #42: Caney Creek at SH 35 near Van Vleck.

Appendix D: Stream gages suggested by other entities

ID	Description	Lat	Long	Entity & Entity's Priority	Status	Location recommended in Section 3
1001	Clear Fork Brazos @ Hawley	32.598056	-99.814722	NWS, 1	Installed	No
1002	Colorado River near Ira	32.54	-101.05	NWS, 1	Installed	No
1003	Neches River near Alto	31.585	-95.169167	NWS, 1	Installed	No
1004	Guadalupe River at Seguin	29.55	-97.97	NWS, 1	Installation pending	No
1005	San Diego River nr Alice	27.77	-98.08	NWS, 1	Installation pending	No
1006	Brazos River at West Columbia	29.144036	-95.606035	NWS, 1	Pending permanent status	No
1007	Pecan Bayou at Brownwood	31.731667	-98.973611	NWS, 1		Yes
1008	Angelina River near Lufkin	31.457222	-94.726111	NWS, 1		Yes
1009	Medina River @ La Coste	29.324152	-98.813169	NWS, 1	Installation pending	No
1010	Medina River @ Sommerset	29.2619	-98.5811	NWS, 1	Installation pending	No
1011	San Bernard near Sweeney	29.06	-95.67	NWS, 1	Installation pending	No
1141	Naples on the Sulphur River	33.25	-94.6199	NWS, 1	No longer being considered	No
1012	Clear Fork @ Eliasville	32.964167	-98.769167	NWS, 2		Yes
1013	Brushy Creek near Rockdale	30.693333	-97.0775	NWS, 2		Yes
1014	Palo Pinto Creek near Santo	32.6208	-98.18	NWS, 2		Yes
1015	Brazos River @ Valley Junction	30.826667	-96.6525	NWS, 2		No
1016	Gibbons Creek Reservoir	30.611811	-96.060489	NWS, 2		No
1017	Striker Lake	31.934121	-94.984281	NWS, 2	Installation pending	No
1018	Lake Cherokee	32.365782	-94.60489	NWS, 2	Installation pending	No
1019	San Gabriel Rv nr Rockdale	30.7275	-97.038611	NWS, 2		No

ID	Description	Lat	Long	Entity & Entity's Priority	Status	Location recommended in Section 3
1142	Brazos River nr Juliff	29.451667	-95.54	NWS, 2	No longer being considered	No
1143	Lampasas River @ Youngsport	30.951667	-97.706667	NWS, 2	No longer being considered	No
1144	White Rock Creek at Sceyne Rd	32.766261	-96.730939	NWS, 2	No longer being considered	No
1020	Guadalupe River at CR143 near Belmont	29.516206	-97.689791	NWS, 4	Installed	No
1021	Little Blanco River @ RM 32	30.020724	-98.330561	NWS, 4	Installed	No
1022	Blanco River @ Fischer Store Rd	30.020724	-98.330561	NWS, 4	Installed	No
1023	Guadalupe River at US183 nr Hochheim	29.3144	-97.3034	NWS, 4	Installed	No
1024	Sandies Creek at FM108 nr Smiley	29.260835	-97.558409	NWS, 4	Installed	No
1025	Peach Ck at US90 near Waelder	29.685804	-97.231278	NWS, 4	Installed	No
1026	Sandy Creek at E Hwy 97 near Waelder	29.62571	-97.320681	NWS, 4	Installation pending	No
1027	Little Brazos River @ FM 485 near Hearne	30.879534	-96.640254	NWS, 4		No
1028	Sabine River at US79 near Carthage	32.224784	-94.2259	NWS, 4		Yes
1029	Nolan Creek @ I-35 at Belton	31.051711	-97.457107	NWS, 4		Yes
1030	Jim Nedd Creek @ FM140	31.87928	-99.277889	NWS, 4		No
1031	Navasota R at Hwy 6	30.418865	-96.106294	NWS, 4		No
1032	Brazos R at Hwy 105	30.36152	-96.155493	NWS, 4		Yes
1033	Nueces River at George West	28.33	-98.09	NWS, 4		No
1034	Neches River near Rusk @ Hwy 294	31.62973	-95.285853	NWS, 4		No
1035	Piney Creek @ US59 near Corrigan	31.050254	-94.824381	NWS, 4		No
1036	Denton Creek @ FM51	33.32726	-97.523734	NWS, 4		No
1037	Trinity River @ Malloy Bridge Rd	32.596968	-96.587725	NWS, 4		No

ID	Description	Lat	Long	Entity & Entity's Priority	Status	Location recommended in Section 3
1038	Trinity River @ US287 near Cayuga	31.967258	-96.047171	NWS, 4	Installation pending	No
1039	Brazos River @ FM 979	30.979829	-96.758797	NWS, 4		No
1040	Guadalupe River at FM766	29.147085	-97.317656	NWS, 4		Yes
1041	Guadalupe River at Thomaston River Rd	28.974724	-97.187827	NWS, 4		No
1042	Nueces River @ FM 624	28.129666	-98.714222	NWS, 4		No
1043	Red River @ Hwy 78	33.753611	-98.196667	NWS, 4		No
1044	Red River @ Hwy 37	33.864722	-95.03111	NWS, 4		No
1045	Sabine River @ Hwy 17 nr Grand Saline	32.720363	-95.635017	NWS, 4		Yes
1046	Neches River near Lufkin @ Hwy 94	31.288762	-94.883881	NWS, 4		No
1047	Attoyac Bayou @ Hwy 7 near Martinsville	31.648388	-94.397534	NWS, 4		No
1048	Village Creek @ Hwy 287 near Village Mills	30.481384	-94.394752	NWS, 4		Yes
1049	Red Oak Creek @ Hwy 660	32.480875	-96.581267	NWS, 4		Yes
1050	Trinity River @ HWY 85	32.316568	-96.35937	NWS, 4		No
1051	Bedias Creek @ FM247	30.90563	-95.683384	NWS, 4		No
1052	Trinity River at FM 3478	30.925861	-95.528944	NWS, 4		No
1053	Brazos River @ Hwy 79	33.271635	-98.930828	NWS, 4		Yes
1054	Tehuacana Ck @ Hwy 6	31.535903	-97.032526	NWS, 4		Yes
1055	Lampasas River @ FM 1620	31.242034	-98.117467	NWS, 4		No
1056	San Gabriel River @ FM1660 at Jonah	30.635546	-97.54243	NWS, 4		No
1057	Lake Creek at Hwy 149	30.280421	-95.705329	NWS, 4		No
1058	WF San Jacinto at Hwy 242	30.210479	-95.397878	NWS, 4		No
1059	San Bernard River at I-10	29.748642	-96.296759	NWS, 4		Yes
1060	Rocky Creek at US 77	29.356435	-96.966844	NWS, 4		No
1061	Colorado River @ Regency Suspension Bridge	31.410467	-98.846233	NWS, 4		No

ID	Description	Lat	Long	Entity & Entity's Priority	Status	Location recommended in Section 3
1062	Geronimo Creek	29.599537	-97.939293	NWS, 4		Yes**
1063	York Creek @ FM20	29.721406	-97.841103	NWS, 4		No
1064	San Marcos River @ Ottine	29.592488	-97.587954	NWS, 4		No
1065	Frio River near Frio Town @ US57	28.983171	-99.23564	NWS, 4		No
1066	Frio River @ FM 140	28.938387	-99.178301	NWS, 4		No
1067	Leona River nr Dilley	28.792962	-99.241121	NWS, 4		No
1068	San Miguel River @ Hwy 85	28.801111	-98.895092	NWS, 4		No
1069	Nueces River @ Upper Lake	28.778629	-99.828327	NWS, 4		Yes
1070	Nueces River above Los Olmos Creek	28.138744	-99.020448	NWS, 4		No
1071	Nueces River @ FM 1042	28.42396	-98.284903	NWS, 4		No
1072	Village Creek @ Lumberton	30.285557	-94.192018	NWS, 4		No
1073	Medina River @ Rio Medina	29.442116	-98.896863	NWS, 4		No
1074	Caddo Ck nr Qunilan	32.936932	-96.114301	NWS, 4		No
1075	Mill Creek @ FM1925	32.747389	-95.777577	NWS, 4		No
1076	Sabine River near Tatum At Hwy43 bridge	32.370219	-94.45825	NWS, 4		No
1077	Socagee Ck @ Hwy 31	32.078711	-94.118354	NWS, 4		No
1078	Anacoco Lake	31.09375	-93.389333	NWS, 4		No
1079	Big Sandy Creek @ Hwy 87	31.207598	-93.751255	NWS, 4		No
1080	Housen Bayou @ Hwy 87	31.303454	-93.844464	NWS, 4		No
1081	Palo Gaucho Bayou at 87 Bridge	31.385996	-93.835713	NWS, 4		No
1082	Patroon Bayou @ 87 Bridge	31.617472	-93.983737	NWS, 4		No
1083	Patroon Bayou @ Reeves Rd	32.538016	-93.844971	NWS, 4		No
1084	Tenaha Creek @ Hwy 87	31.765657	-94.084205	NWS, 4		No
1085	Flat Fork Creek @ FM3267	31.855489	-94.035341	NWS, 4		No
1086	Bayou Castorat @ US84 bridge	31.97365	-93.970216	NWS, 4		No
1087	Clement Creek @ Hwy 191 bridge	31.916875	-93.856975	NWS, 4		No
1088	Bayou San Patricio @ Hwy 171	31.720314	-93.706273	NWS, 4		No

ID	Description	Lat	Long	Entity & Entity's Priority	Status	Location recommended in Section 3
1089	Bayou San Miguel @ Hwy 171 bridge	31.653623	-93.653034	NWS, 4		No
1090	Bayou Scie @ Hwy 191	31.620137	-93.65004	NWS, 4		No
1091	Neches River near Palestine @ US84	31.776524	-95.396754	NWS, 4		No
1092	Neches River near Redtown @Hwy7	31.396771	-94.965935	NWS, 4		Yes
1093	Angelina River near Cushing	31.823608	-94.946192	NWS, 4		Yes
1094	Lake Nacogdoches	31.588611	-94.825273	NWS, 4		No
1095	Neches River @ FM1013	30.680696	-94.091305	NWS, 4		No
1096	Clear Creek @ FM51	33.425376	-97.342661	NWS, 4		No
1097	Denton Creek @ US380	33.249027	-97.403851	NWS, 4		No
1098	Bear Creek at I-45	32.506051	-96.663084	NWS, 4		No
1099	Tenmile Creek @ I-45	32.557852	-96.663366	NWS, 4		No
1100	Richland Creek at I-45 near Richland	31.95006	-96.42183	NWS, 4		No
1101	Catfish Creek @ US287	31.881343	-95.869152	NWS, 4		No
1102	Upper Keechi Ck @ FM 542	31.405522	-95.764427	NWS, 4		No
1103	Hurricane Bayou @ FM2055 near Crockett	31.341924	-95.60617	NWS, 4		No
1104	Brazos River @ FM 712 nr Marlin	31.251467	-96.922148	NWS, 4		No
1105	Brazos River @ FM 485	30.865135	-96.695231	NWS, 4		No
1106	Brazos River nr Knox City	33.500426	-99.80215	NWS, 4		No
1107	Brazos River @ FM 143/Hwy 222	33.425894	-99.911327	NWS, 4		No
1108	Elm Creek @ I-20 near Abilene	32.478144	-99.78698	NWS, 4		Yes
1109	Brazos River @ US380 near Newcastle	33.176079	-98.755819	NWS, 4		No
1110	Tradinghouse Ck Reservoir	31.553235	-96.979459	NWS, 4		No
1111	Brazos River @ Hwy 7 above Deer Ck	31.288036	-96.968502	NWS, 4		No
1112	Big Creek @ Hwy 6	31.257073	-96.859966	NWS, 4		No
1113	Lake Creek near Dobbin	30.371472	-95.769126	NWS, 4		Yes
1114	San Bernard River @ Hwy 1093	29.622812	-96.146044	NWS, 4		No
1115	San Bernard River at Hwy 60 near Willis	29.602008	-96.089901	NWS, 4		No

ID	Description	Lat	Long	Entity & Entity's Priority	Status	Location recommended in Section 3
1116	West Bernard Creek at Hungerford	29.400755	-96.008833	NWS, 4		No
1117	San Bernard River at FM1301	29.160467	-95.765741	NWS, 4		No
1118	Mustang Creek @ FM1157	29.042465	-96.469802	NWS, 4		No
1119	Navidad River @ FM530	29.031505	-96.621202	NWS, 4		No
1120	Lavaca River @ FM 616 near Vanderbilt	28.832493	-96.577725	NWS, 4		No
1121	Concho River @ FM1692	31.542291	-100.17804	NWS, 4		No
1122	Lipan Creek @ FM380	31.501112	-100.08849	NWS, 4		No
1123	Dry Hollow Creek (Chandler Lake)	31.514572	-100.00865	NWS, 4		No
1124	Llano River @ Castell	30.703446	-98.958746	NWS, 4		No
1125	Pedernales River @ Hamilton Pool Rd	30.339948	-98.13915	NWS, 4		Yes
1126	Dry Creek @ Hwy 71	30.179619	-97.535169	NWS, 4		No
1127	Guadalupe River blw Seguin (SEGT2 replacement #2)	29.547277	-97.951622	NWS, 4	Installed	No
1128	Geronimo Creek	29.591044	-97.934954	NWS, 4		Yes**
1129	Geronimo Creek	29.591044	-97.934954	NWS, 4		Yes**
1130	York Creek @ Hwy 130	29.731892	-97.864197	NWS, 4		No
1131	Elm Creek at FM108	29.258152	-97.639445	NWS, 4		No
1132	San Geronimo Recharge Lake	29.534735	-98.807396	NWS, 4		No
1133	Medina River @ Castroville	29.355522	-98.872994	NWS, 4		No
1134	Medio Creek @ I-35 nr Von Ormy	29.298584	-98.62968	NWS, 4		No
1135	Frio River near Fowlertown Hwy 97	28.47212	-98.80482	NWS, 4		No
1136	San Miguel River @ Hwy 97	28.707836	-98.787783	NWS, 4		No
1137	Comanche Creek @ Hwy 83 @ Crystal City	29.661002	-99.842905	NWS, 4		No
1138	San Roque Creek @ FM133	28.332888	-99.574703	NWS, 4		No
1139	Los Olmos Creek @ Hwy 44 nr Encinal	28.000119	-99.149983	NWS, 4		No
1140	Black Creek @ Hwy 44	27.941993	-98.879682	NWS, 4		No

ID	Description	Lat	Long	Entity & Entity's Priority	Status	Location recommended in Section 3
1145	Little Brazos River @ Hwy 21 near Bryan	30.640889	-96.520903	NWS, 4	No longer being considered	No
1146	Colorado River @ Webberville Rd	30.229048	-97.518103	NWS, 4	No longer being considered	No
1147	Blanco River @ Blanco	30.092142	-98.423002	NWS, 4	No longer being considered	No
1148	Guadalupe River near Seguin (SEGT2 replacement)	29.541698	-97.96929	NWS, 4	No longer being considered	No
1149	Yegua Creek @ FM 50	30.368486	-96.343539	NWS, 4	No longer being considered	No
1150	Jim Nedd Creek @ Hwy 206	31.918874	-99.321929	NWS, 4	No longer being considered	No
1151	Nolan Creek at I-35 N. Frontage Rd. at Belton	31.051667	-97.456944	City of Belton		Yes
1152	Alternate Nolan Creek at HWY 317 at Belton	31.054794	-97.464392	City of Belton		No
1153	Alternate Nolan Creek at HWY 93 at Belton	31.058782	-97.46506	City of Belton		No
1154	Alternate Nolan Creek at Loop 121 at Belton	31.071165	-97.47624	City of Belton		No
1155	Atascosa River at FM 1333 nr Poteet	29.026447	-98.687325	Atascosa Co.		No
1156	Atascosa River at at HWY 16 at Poteet	29.012253	-98.576884	Atascosa Co.		Yes
1157	Tatum Lake	29.770598	-99.410621	Bandera Co.		No
1158	Garrison Lake	29.78098	-99.338366	Bandera Co.		No
1159	Krause Dam	29.686968	-98.287501	Comal Co.		No
1160	Vogel Dam	29.694456	-98.269631	Comal Co.		No
1161	Blieder's Creek Dam	29.739431	-98.156738	Comal Co.		No
1162	Eikel Blank Dam	29.650693	-98.277135	Comal Co.		No

ID	Description	Lat	Long	Entity & Entity's Priority	Status	Location recommended in Section 3
1163	Krueger Canyon Dam	29.668672	-98.20882	Comal Co.		No
1164	Elm Creek at Elm Creek Rd.	29.765044	-98.177364	Comal Co.		No
1165	Isaac Creek at River Oaks Dr	29.791995	-98.135526	Comal Co.		No
1166	Mountain Creek	29.838329	-98.177981	Comal Co.		No
1167	Onion Creek at RR 12	30.160699	-98.091313	Hays Co.		Yes
1168	South Onion Creek at RR 12	30.140224	-98.088356	Hays Co.		No
1169	Onion Creek at FM150	30.143574	-98.048993	Hays Co.		No
1170	Jim Nedd Creek at FM 585	31.828695	-99.170236	Brown Co. WID		Yes
1171	Lake Brazos at Franklin Ave.	31.560362	-97.125746	City of Waco		No
1172	Waco Creek	31.550068	-97.111901	City of Waco		No
1173	Oso Creek at Hwy 43	27.688843	-97.429341	City of Corpus Christi		No
1174	La Volla Creek at HWY 357 at Greenwood WWTP	27.721529	-97.457964	City of Corpus Christi		No
1175	Nueces River at Hwy 59	28.332955	-98.08617	City of Corpus Christi		Yes
1176	Trinity River at Highway 287	32.776557	-97.319489	TRWD		No
1177	West Fork Trinity River at CR 3250	33.179258	-97.672639	TRWD		No
1178	West Fork of Trinity River at CR 4757	33.034691	-97.534211	TRWD		No
1179	Big Sandy Creek at CR 1591	33.38526	-97.755768	TRWD		No
1180	Lake Brazos at the Franklin Avenue Bridge	31.560362	-97.125746	City of Waco		No
1181	Waco Creek	31.550068	-97.111901	City of Waco		No
** One of three recommended locations for Geronimo Creek						

Appendix E: List of Draft Final Report Comments

Overall, the report is well written and documents a research effort that achieved the objectives of the Scope of Work.

REQUIRED CHANGES

General Draft Final Report Comments:

1. Please add reference to TWDB Contract No. 1600012027 on cover of report.
2. Please correct the following typos (corrections in bold font):
    a. Page 1, 4th paragraph, 2nd sentence, "Arkansas-Red Basin (ARBRFC)" should be "Arkansas-Red Basin **RFC** (ARBRFC)."
    b. Page 13, Figure 2, "NFIP RPL Non-Mitigated Claims" should be "NFIP **RLP** Non-Mitigated Claims."
    c. Page 15, Table 2, "NFIP RPL Claims" should be "NFIP **RLP** Claims."
    d. Page 15, 2nd paragraph, 1st sentence, "*NFIP RPL Non-Mitigated Claims*" should be "*NFIP* ***RLP*** *Non-Mitigated Claims*."
    e. Page 16, 2nd paragraph, 1st sentence, "Repetitive Properly Loss" should be "Repetitive **Property** Loss."
    f. Page 20, 1st paragraph, 4th sentence, "community is not guarantee" should be "community is not **a** guarantee."
    g. Page 33, 1st paragraph, 1st sentence, "year 2,000 county population" should be "year **2000** county population."
    h. Page 33, 2nd paragraph, 1st sentence, "have not produce a list" should be "have not produce**d** a list."
3. To more accurately depict the activities of the River Forecast Centers, please make the following changes:
    a. Page 1, 5th paragraph, 2nd sentence, "HSAs are coincident" should be "HASs are **generally** coincident."
    b. Page 2, 1st paragraph, 1st sentence, "activities of the RFC center on flood warning and water management" should be "activities of the RFC center on **river forecasting for** flood warning and water management."
    c. Page 2, 1st paragraph, 2nd sentence, "products in support of WFOs and communication with these offices through HAS functions" should be "products **and coordination with WFOs in support of the WFO flash flood warning and river flood warning programs.**"
4. The definitions provided for Repetitive Loss Property and Severe Repetitive Loss Property on page 9 appear to be slightly different from those provided by FEMA's most recent Hazard Mitigation Assistance Guidance Document (page 116 of that document available at www.fema.gov/media-library-data/1424983165449-38f5dfc69c0bd4ea8a161e8bb7b79553/HMA_Guidance_022715_508.pdf). Please insure the definitions used are consistent with the most recent documentation or explain the difference.

5. There appear to be a couple of erroneous entries in Table 3 on page 17. For the second entry, the first forecast point downstream of Toledo Bend Dam is at Burkeville, not Deweyville as noted in the table. For the eighth entry, the first forecast point downstream of Grapevine Dam is Carrollton, not Fort Worth as noted in the table. Please double check these entries and correct if necessary.
6. The scope of work for this project related to rain gage locations mentions that the contractor will "seek locations near the geometric center of the watersheds of the communities prioritized." A quick review of prioritized stream gages in Table 5 did not identify any gage locations whose watersheds also correspond with locations of rain gage gaps shown in Figure 15. Nevertheless, for the sake of thoroughness, please document in the report that the geometric center of watersheds of prioritized stream gage locations was not a useful criteria for prioritization of rain gage locations.
7. The scope of work for this project related to rain gage locations mentions that the contractor will "identify existing weather stations that do not currently report in real time that offers the potential for network enhancement." There may be few if any such weather stations in the state. Nevertheless, for the sake of thoroughness, please document in the report that no such weather stations were identified.

SUGGESTED CHANGES

8. On page 1, 4th paragraph, 2nd sentence, the acronym "ARBRFC" is provided for the Arkansas-Red Basin River Forecast Center. However, the National Weather Service's own abbreviation for the Arkansas-Red Basin River Forecast Center is "ABRFC." To avoid confusion, please consider using the acronym already in use by the National Weather Service.
9. On page 5, 2nd paragraph, 3rd sentence makes reference to "near complete coverage" regarding the network of weather radars across the state. This could be considered a bit of an overstatement. Please consider modifying to something like "Fortunately there is a network of radars (NEXRAD) that provides coverage for most of the state, with gaps present at locations beyond the range of the network."
10. On page 34, 2nd paragraph, 2nd sentence the statement is made that if sites on the prioritized list prove unsuitable for stream flow monitoring, they should be skipped unless a suitable site can be found "no more than a river mile downstream and no more than two miles upstream." Recent experience of the Texas Water Development Board working with the US Geological Survey has been that it is sometimes possible to find alternative gaging sites capable of meeting the needs of the West Gulf River Forecast Center and local stakeholders outside the limited three river mile window mentioned in this report. Please consider recommending evaluation of the suitability of alternative sites based on criteria such as "consultation with USGS and the appropriate RFC" rather than a rule-of-thumb based on river miles.

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