Final Report: Karnes County Flood Protection Planning Study

Prepared For:

Karnes County, Texas

Prepared By:

Doucet, A Kleinfelder Company

Langford Community Management Services

In Association With:

Texas Water Development Board

San Antonio River Authority

City of Kenedy
City of Karnes City
City of Runge
City of Falls City

May 24, 2024

Texas Water Development Board Contract 40011

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    - Ron Branyon, P.E., CFM – HDR, Inc. – Technical Consultant
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Executive Summary

The Karnes County Flood Protection Planning Study (FPPS) provides flood hazard mitigation assessment and stormwater planning for high-priority watersheds affecting the County, including Ecleto Creek, Escondido Creek, Hondo Creek, Marcelinas Creek, Ojo De Agua Creek, and select tributaries to the Lower San Antonio River. Funding is provided, in part, through a grant from the Texas Water Development Board (TWDB) Flood Infrastructure Fund (FIF) Commitment No. G1001287. In addition to the TWDB grant, the study is sponsored by Karnes County, the City of Kenedy, the City of Karnes City, the City of Runge, the City of Falls City, and San Antonio River Authority (SARA). The key stakeholders and the percentage of funding provided are summarized below:

- Texas Water Development Board – 75%
- Karnes County – 10%
- San Antonio River Authority – 9%
- City of Kenedy – 1.5%
- City of Karnes City – 1.5%
- City of Runge – 1.5%
- City of Falls City – 1.5%

Through this FPPS, Karnes County sought to complete a detailed analysis of the study area to identify existing and future flood prone areas and develop a flood protection plan to mitigate flood problems. The study scope of work included the following items:

- Project management
- Collection and review of baseline information
- Assessment of environmental constraints
- Initial identification of flood problem areas
- Field survey and measurements
- Hydrologic modeling
- Hydraulic modeling
- Final identification of flood problem areas, establishment of flood protection criteria, and evaluation of flood mitigation alternatives
- Hydrologic and hydraulic analyses of flood mitigation alternatives
- Benefit-cost analysis of flood mitigation alternatives
- Flood early warning system and response planning
- Implementation and phasing plan
- Final report

To assess existing flood hazards within the County, new and updated hydrologic and hydraulic models were developed reflecting Atlas 14 rainfall data for approximately 523 square miles of drainage area and over 140 stream miles, as detailed in **Table ES-1** and shown in **Figure ES-1**. The 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual chance exceedance (5-, 10-, 25-, 50-, 100- and 500-year return period) storm events were analyzed. Hydrologic models were developed for each watershed using HEC-HMS v.4.9. Detailed 1D steady-state hydraulic models were developed to represent existing conditions on each study stream using HEC-RAS v.6.3.

Table ES-1. Study area summary by subwatershed.

Study Area	Watershed Drainage Area (sq mi)	Stream Name	Stream Code	Stream Miles	Bridges/ Culverts
Ecleto Creek Watershed	263.1	Dry Ecleto Creek	DEC	17.7	7
		Ecleto Creek	ECL	34.7	15
		Tributary 1 to Ecleto Creek	ECL_T1	2.9	3
		Unnamed Tributary 1 to Tributary 1 to Ecleto Creek	ECL_T1_1	1.2	6
		Unnamed Tributary 2 to Tributary 1 to Ecleto Creek	ECL_T1_2	0.89	1
		Tributary 2 to Ecleto Creek	ECL_T2	0.68	0
		Unnamed Tributary 1 to Tributary 2 to Ecleto Creek	ECL_T2_1	2.3	2
Escondido Creek Watershed	112.9	Escondido Creek	ESC	26.6	11
		Unnamed Tributary 2 to Nichols Creek	NIC_T2	0.43	4
		Unnamed Tributary 4 to Nichols Creek	NIC_T4	0.60	5
		Panther Creek	PAN	7.6	4
Hondo Creek Watershed	45.6	Hondo Creek	HON	16.92	9
Lower San Antonio River Tributaries	15.4	Tributary 147 to Lower San Antonio River	LSA_T147	6.67	5
		Unnamed Tributary 2 to Tributary 147 to Lower San Antonio River	LSA_T147_2	0.50	0
		Tributary 152 to Lower San Antonio River	LSA_T152	1.83	0
		Unnamed Tributary 1 to Tributary 152 to Lower San Antonio River	LSA_T152_1	0.72	0
Marcelinas Creek Watershed	10.1	Marcelinas Creek	MAR	5.62	2
Ojo De Agua Creek Watershed	75.5	Ojo De Agua Creek	OJO	10.00	6
		Tributary 10 to Ojo De Agua Creek	OJO_T10	1.55	2
		Tributary 8 to Ojo De Agua Creek	OJO_T8	0.68	0
TOTAL	**522.6**	---	**---**	**140.1**	**82**

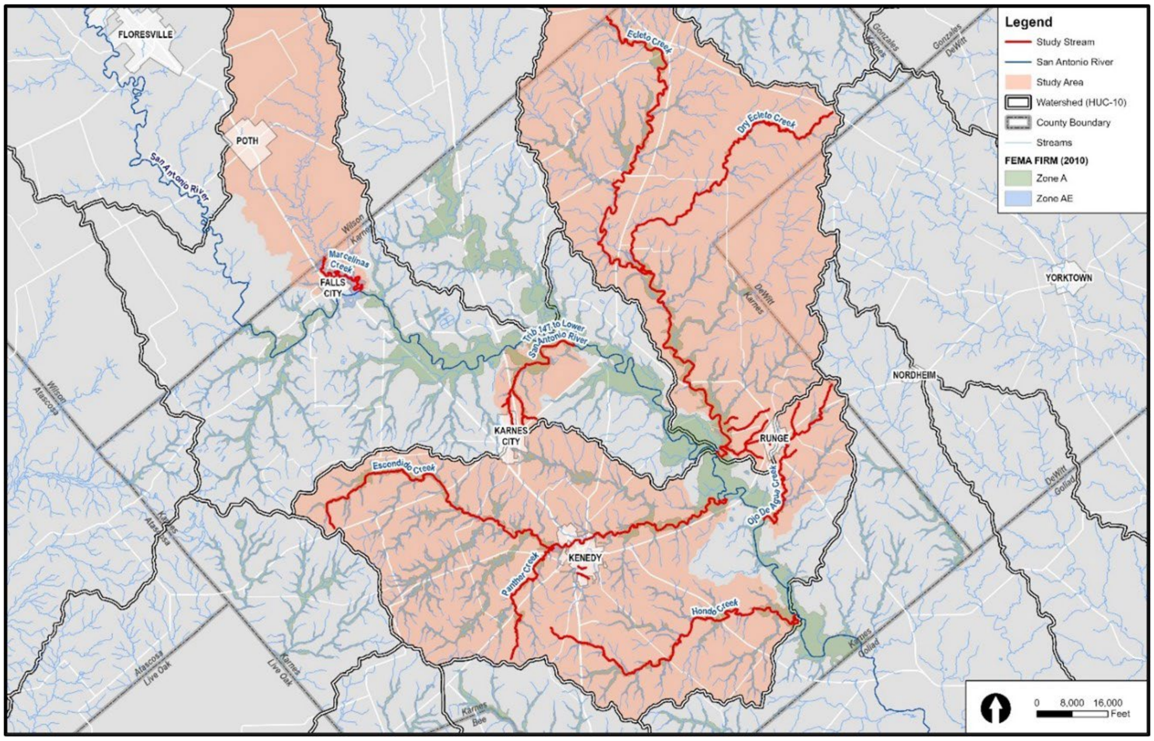

Figure ES-1. Project study area map.

Updated floodplain mapping for the 1% and 0.2% storm events was developed for the study reaches, which included a total of 20 streams and tributaries. While these updated models and floodplain boundaries will not supersede the effective FEMA data, communities within Karnes County will be able to use them as "best available data" for regulatory and planning purposes.

In addition to the modeling efforts, public outreach was an essential component of this study and was the primary source of information for identifying high-priority flood problem areas in Karnes County. This input was obtained through coordination with community officials, as well as three public meetings attended by residents with knowledge on flood prone areas.

The FPPS identified 15 recommended Flood Mitigation Projects (FMPs) throughout the study area, and 2D hydraulic models of these proposed projects were developed using HEC-RAS v.6.3. With a total of $111,427,541 in estimated construction costs, these recommended FMPs include upgrades to existing low-water crossings to improve their levels-of-service, as well as channel improvements to mitigate flooding of commercial and residential structures. Using criteria developed for the TWDB Regional Flood Planning efforts, an effort was made to prioritize the FMPs based on the severity of the flood hazards being addressed and the level of benefit they provide. In addition to the 15 FMPs, 9 other areas were recommended as Flood Management Evaluations (FMEs) for additional study and evaluation. This identification of projects and associated prioritization is intended to aid the stakeholders and communities in the selection of future flood hazard mitigation projects. A summary of the proposed flood mitigation projects and recommended evaluations is provided in **Table ES-2**.

Table ES-2. Summary of recommended Flood Mitigation Projects and Flood Management Evaluations.

Flood Problem Area Priority	Flood Problem Area Name	Description	Flood Mitigation Action Type	Estimated Cost
1	Drainage Improvements at CR 337 and CR 326 Near City of Runge	Elevate CR 337 and CR 326 and upgrade low water crossings to include box culverts and channel improvements. Channel improvements along CR 337 to improve level of service	Project	$6,773,000.00
2	City of Kenedy Drainage Improvements on Escondido Creek	Upgrade 5th Street culvert with additional boxes, roadway elevation, and channel modifications. Additional channel modifications through Kenedy to improve conveyance and reduce flooding of structures.	Project	$33,317,000.00
3	Nichols Creek Tributary 2 Drainage Improvements	Upgrade Escondido Street crossing with an additional box and upstream channel improvements	Project	$1,651,000.00
4	CR 302 Drainage Improvements at Ecleto Creek	Upgrade existing low water crossing to include roadway elevation, a new bridge structure, and channel improvements	Project	$15,261,000.00
5	CR 331 Drainage Improvements at Escondido Creek	Upgrade existing low water crossing to include roadway elevation, a new bridge structure, and channel improvements	Project	$4,865,554.00
6	CR 145 Drainage Improvements at Hondo Creek	Upgrade existing low water crossing to include roadway elevation, a new bridge structure, and channel improvements	Project	$3,688,372.00
7	CR 127 Drainage Improvements at Hondo Creek	Upgrade existing low water crossing to include roadway elevation, a new bridge structure, and channel improvements	Project	$8,992,000.00
8	CR 163 Drainage Improvements at Panther Creek	Elevate roadway and upgrade existing culvert structure to include box culverts and channel improvements	Project	$3,218,400.00
9	CR 325 Drainage Improvements at Ojo De Agua Creek	Upgrade CR 325 crossing with roadway elevation, bridge structure upgrades, and channel improvements	Project	$2,007,000.00
10	Nichols Creek Tributary 4 Drainage Improvements	Channel improvements upstream (east) of Escondido Street; lower existing pond bottom at Kenedy Retreat Apartments to increase capacity	Project	$1,441,000.00
11	CR 336 Drainage Improvements at Ecleto Creek Tributary	Upgrade CR 336 low water crossing to include a new bridge structure with roadway and channel improvements	Project	$2,859,756.00
12	CR 354 Drainage Improvements at Lower San Antonio Tributary 147	Elevate roadway and upgrade existing culvert structure with a new bridge structure and channel improvements	Project	$6,467,859.00
13	CR 294 Drainage Improvements at Dry Ecleto Creek	Upgrade CR 294 to include new bridge structure with roadway and channel improvements for 100 year roadway access	Project	$7,178,000.00

Table ES-2. Summary of recommended Flood Mitigation Projects and Flood Management Evaluations (continued).

Flood Problem Area Priority	Flood Problem Area Name	Description	Flood Mitigation Action Type	Estimated Cost
14	CR 262 Drainage Improvements at Ecleto Creek	Upgrade CR 262 to include roadway elevation, bridge expansion, and channel improvements	Project	$11,242,400.00
15	US 181 Drainage Improvements at Marcelinas Creek Trib	Upgrade US HWY 181 culvert crossing to include additional boxes and channel improvements to mitigate residential flooding south of the highway	Project	$2,465,200.00
16	CR 326B at Ecleto Creek	Evaluate upgrades to existing bridge with consideration of backwater from San Antonio River	Evaluation	$100,000.00
17	CR 237 at Marcelinas Creek	Evaluate upgrades to existing bridge with consideration of backwater from San Antonio River	Evaluation	$100,000.00
18	City of Kenedy Flooding on Escondido Creek Tributary	Evaluate alternatives to mitigate flooding within City of Kenedy commercial area along Escondido Creek tributary	Evaluation	$100,000.00
19	Falls City Flooding from San Antonio River	Evaluate alternatives to mitigate flooding from the San Antonio River affecting buildings in the City of Falls City	Evaluation	$100,000.00
20	San Antonio River Flooding on US 181	Evaluate alternatives to mitigate US 181 flooding from the San Antonio River and tributaries	Evaluation	$100,000.00
21	Cibolo Creek Flooding on SH 123	Evaluate alternatives to mitigate SH 123 flooding from Cibolo Creek	Evaluation	$100,000.00
22	San Antonio River Flooding on SH 80	Evaluate alternatives to mitigate SH 80 flooding from the San Antonio River and tributaries	Evaluation	$100,000.00
23	Localized Residential Flooding in City of Kenedy	Evaluate alternatives to mitigate localized residential flooding in the southern portion of the City of Kenedy	Evaluation	$100,000.00
24	San Antonio River Flooding on SH 72	Evaluate alternatives to mitigate SH 72 flooding from the San Antonio River and tributaries	Evaluation	$100,000.00
25	Karnes County FEWS	Evaluate upgrades to Flood Early Warning Systems	Evaluation	$100,000.00

Finally, Doucet staff contacted SARA to discuss their Predictive Flood Model (PFM) and its applicability in Karnes County's Flood Early Warning System (FEWS). While the existing warning system associated with the PFM is largely focused on Bexar County, the PFM currently provides gage-adjusted radar rainfall totals and forecasts for the entire San Antonio River Basin, including Karnes County. These forecast data are available to the County, as well as the municipalities within the County. The County has the option to approach SARA about expanding the network of precipitation and streamflow gages in Karnes County. This expansion will further refine the modeling results produced by the PFM, allowing the County to enhance its emergency planning and response capabilities. The Karnes County FEWS assessment was included as an FME as part of this study, as shown in **Table ES-2**.

1 Introduction

The Karnes County Flood Protection Planning Study (FPPS) provides flood hazard mitigation assessment and stormwater planning for high-priority watersheds affecting the County, including Ecleto Creek, Escondido Creek, Hondo Creek, Marcelinas Creek, Ojo De Agua Creek, and tributaries to the Lower San Antonio River.

1.1 Key stakeholders

The Karnes County FPPS was partially funded by Texas Water Development Board (TWDB) Flood Infrastructure Fund (FIF) Category 1 Commitment No. G1001287 with local sponsorship from Karnes County, the City of Kenedy, the City of Karnes City, the City of Runge, the City of Falls City, and San Antonio River Authority (SARA). The key stakeholders and the percentage of funding provided are summarized below:

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1.2 Description of project area

Covering a total project area of 522.6 square miles, this FPPS included the development of new hydrologic and hydraulic models for streams within the following HUC-10 basins in the Lower San Antonio River (LSAR) watershed:

- Ecleto Creek (HUC ID 1210030303)
- Hondo Creek-San Antonio River (HUC ID 1210030304)
- Marcelinas Creek-San Antonio River (HUC ID 1210030302)

The study area covers portions of Karnes County, Guadalupe County, Wilson County, and DeWitt County. Existing land uses largely consist of rural, undeveloped land with urbanized areas in the cities of Kenedy, Karnes City, Falls City, and Runge within Karnes County, as well as the City of Poth in Wilson County. New hydraulic models were developed for a total of 140.1 stream miles on twenty streams and tributaries within Karnes County. Please see **Figure 1-1** and **Table 1-1** for a summary of the study areas by subwatershed.

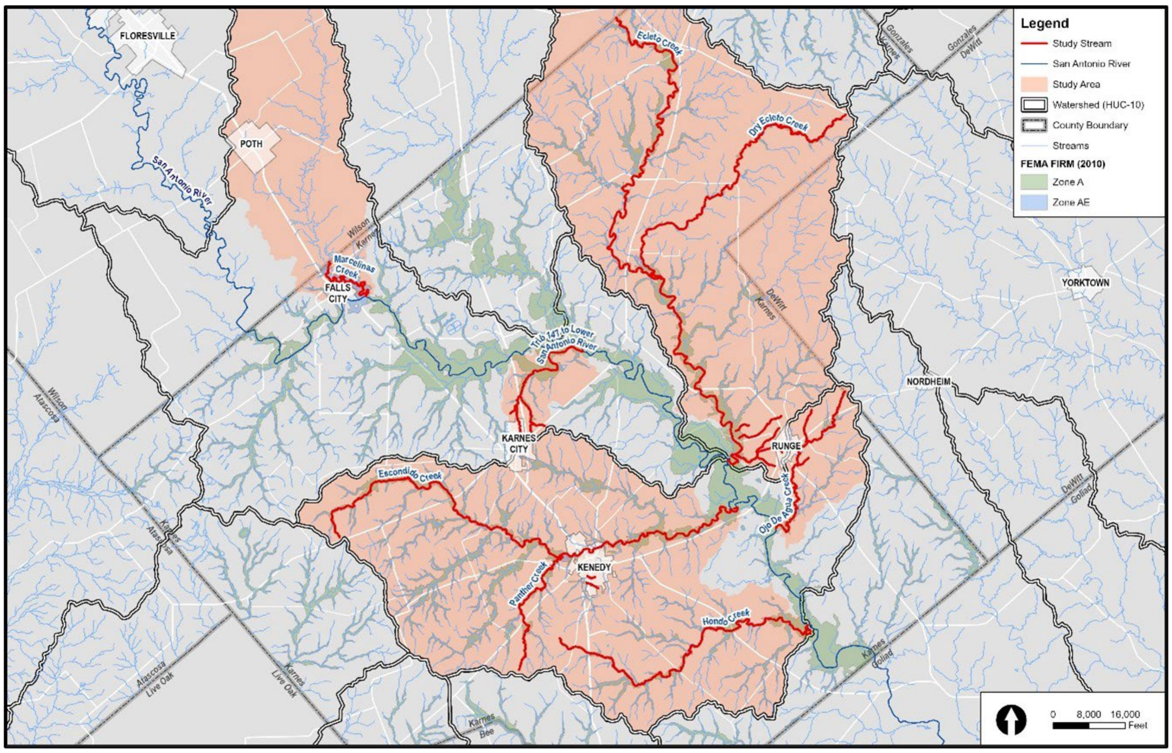

Figure 1-1. **Project study area map.**

Table 1-1. Study area summary by subwatershed.

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TOTAL	**522.6**	---	**---**	**140.1**	**82**

1.3 Description of project scope

Through this FPPS, Karnes County sought to complete a detailed analysis of the study area to identify existing and future flood prone areas and develop a flood protection plan to mitigate flood problems. The objective of the planning effort was to provide the participating communities with the following:

- An accurate assessment of the hydrologic and hydraulic conditions of the subject watersheds and streams
- A practical storm water management plan to address the critical flooding problems
- An important tool to manage growth and development.

A detailed description of the planning study scope of work is presented in the following sections.

1.3.1 Project management

A kick-off meeting with Karnes County, the TWDB project manager, and the representatives from the participating entities was held on October 6, 2021 to cover the following topics:

- Project communication & reporting responsibilities to establish the frequency and method of interfacing with the TWDB project manager, Karnes County project manager, and the representatives from the participating entities;
- Project milestones and schedule; and
- Project deliverables at each milestone.

During the course of the study, project progress reports were submitted to TWDB at a minimum interval of quarterly (once every 3 months). Project progress meetings were also conducted on a monthly basis. Meeting agendas included the following:

- Tasks accomplished since last meeting
- Discussion of issues discovered, if any
- Tasks to be performed
- Project schedule status
- Budget status

Three (3) public meetings were also conducted by the project team: one to solicit input on initial flood problem area identification, one following development of flood mitigation alternatives, and one upon development of the final report.

1.3.2 Collection and review of baseline information

The project team collected and reviewed previous drainage studies, FEMA Flood Insurance Study (FIS) and maps, FEMA LOMRs, master plans, drainage studies and reports, citizen drainage complaint reports, storm damage reports, field survey data, as-built information, and other relevant data within the planning area.

A base map was developed using the following information:

- Current FEMA FIS and Flood Insurance Rate Map (FIRM)
- Digital GIS data of parcels, zoning maps, current land use maps, and soils maps;
- As-builts drawings for channel and bridge/culvert improvements;
- Most current LiDAR topography; and

- Approved LOMRs since the 2010 FIRM update

1.3.3 Assessment of environmental constraints

This project included a record review and data research of Critical Environmental Features (CEF) within the study area. These features are generally defined as springs, bluffs, canyon rimrocks, caves, sinkholes & recharge features and wetlands.

This task did not include detailed field survey, investigation, and determination of CEFs, but rather established the framework for the requirements of environmental assessment during the implementation and final design phase of the flood mitigation measures.

1.3.4 Initial identification of flood problem areas

Based on the previous drainage studies, reports, and other baseline data, known flood problem areas were identified. Karnes County and the participating communities conducted a public meeting to solicit input on the drainage problem areas including the specifics and nature of the flooding.

1.3.5 Field survey and measurements

Karnes County utilized best available LiDAR data including 2018 USGS South Texas and 2019 USGS Hurricane datasets. In addition, this study included budget to obtain field survey and measurement data for critical regional detention facilities, bridge/culvert crossings, cross sections and finished floor elevations, as needed to support future Zone AE FIRM updates. Use of existing field survey data available from participating communities were incorporated where applicable.

1.3.6 Hydrologic modeling

Doucet developed GIS geo-referenced hydrologic models using the USACE HEC-HMS computer program, including the program's built-in geospatial tools. Hydrologic rainfall-runoff models were developed based on existing watershed conditions. The following information was incorporated into the HEC-HMS models:

- SCS flood control reservoirs and regional detention facilities;
- Other large scale storm water impoundment facilities (more than 20 acres in surface area).

The hydrologic model input parameters were developed based on the following approach.

- Terrain Processing – Karnes County utilized best available LiDAR data including 2018 USGS South Texas and 2019 USGS Hurricane datasets, ESRI ArcGIS Pro, and HEC-HMS tools to develop a digital terrain model (DTM) to support hydrologic model development.
- Rainfall data – A .dss file containing NOAA Atlas 14 precipitation hyetographs for Karnes, Wilson, and Goliad Counties was provided by SARA for use in this study. Hyetographs for the 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% storm events were applied as precipitation gages in the hydrologic models. This .dss file also contained hyetographs for various areal reduction thresholds ranging from no reduction (for drainage areas less than 10 square miles) up to 400 square miles.

- Drainage Area – Hydrologic subbasins were delineated using the DTM, ESRI ArcGIS Pro, and HEC-HMS tools.
- Runoff Loss Method – The NRCS Runoff Curve Number (CN) for each sub-basin was computed based on procedures outlined in the NRCS TR-55 publication. Land use designations within the study area were assigned based on the 2019 National Land Cover Database (NLCD). Using these land use designations, the existing condition CN for each sub-basin was computed using the values listed in Table 10 in the *SARB Regional Modeling Standards*. The latest NRCS Soil Survey Geographic (SSURGO) database for Karnes County and other Counties were used for hydrologic soil group determination. The average percent impervious value for each sub-basin was developed based on the 2019 NLCD impervious cover raster.
- Unit Hydrograph Method – The Snyder Unit Hydrograph method was used to develop runoff hydrographs within HEC-HMS. The Snyder Unit Hydrograph method is the primary method utilized by the Corps of Engineers Fort Worth District for the majority of hydrologic studies in the region. The Snyder method requires two parameters, the Snyder standard lag and the Snyder peaking coefficient (Cp). Snyder's lag values were developed using the USACE Fort Worth District Urbanization Curve methodology with HEC-HMS and ESRI ArcGIS Pro tools. Snyder peaking coefficients were developed based on previous studies within the region (e.g., 2005 USACE Study and 2007 Karnes County Map Modernization Study).
- Hydrograph Routing – For the study reaches and other reaches where existing hydraulic models were available, the Modified Puls routing method was used to account for peak flow and timing attenuation along the stream. For reaches without existing hydraulic models, the Muskingum-Cunge was applied for hydrograph routing.
- Model Calibration – Where USGS gauges existed, the hydrologic models were calibrated to peak discharges recorded during historic storm events.

1.3.7 Hydraulic modeling

Doucet developed GIS geo-referenced hydraulic models using the USACE HEC-RAS v.6.3 computer program, including the geospatial tools available in the HEC-RAS Mapper module. The HEC-RAS hydraulic models covered all the stream miles identified in **Table 1-1**. The hydraulic model input parameters and modeling procedures are presented as follows:

- Peak discharges from the HEC-HMS junctions were specified at the appropriate cross sections.
- Manning's roughness coefficients ("n") were established based on field reconnaissance, aerial photos and standard engineering reference tables or publications.
- Field survey and/or measurements were performed for major detention facilities and roadway crossings where no as-built information was available.
- Other HEC-RAS parameters, such as "ineffective flow areas", "expansion/contraction coefficients" and "bridge/culvert energy loss coefficients" were used as appropriate.

1.3.8 Final identification of flood problem areas, establishment of flood protection criteria, and evaluation of flood mitigation alternatives

Based on the collected baseline information and results of the hydraulic models, flood problem areas were identified and evaluated. Regional Flood Planning criteria from TWDB were used to assist in the evaluation and prioritization of flood problem areas. These factors included, but were not limited to:

- Number of affected structures with consideration of flood depth and frequency;
- Roadway overtopping with consideration of flood depth and frequency;
- Risk to life and safety;
- Availability of alternative evacuation routes; and
- Potential environmental constraints

For the flood problem areas identified, the structural flood mitigations measures like the following were evaluated for feasibility at each location:

- Detention/Retention Facilities;
- Channel Improvements using the Natural Channel Method;
- Roadway Bridge/Culvert Improvements;
- Levees/Berms/Floodwalls; and
- Combination of any of two or more of the above.

Non-structural solutions, such as the following, were also considered:

- Updates to the Karnes County and participating community's drainage criteria (if applicable) and existing land development ordinance if necessary;
- Buy-outs of the flooded properties;
- Installation of Early Flood Warning systems;
- Installation of flood warning signs and barricades at frequent inundated roadway crossings; and
- Develop public information publications describing flood risks and flood insurance.

1.3.9 Hydrologic and hydraulic analyses of flood mitigation alternatives

The flood mitigation alternatives were modeled using 2D HEC-RAS v.6.3 models for the various hypothetical flood events. Conceptual flood control measures were developed and added to the hydraulic models as appropriate to evaluate the flood mitigation potential.

Flood mitigation alternatives were evaluated not only at the problem area (to reduce the levels of flooding) but also upstream and downstream of the problem area to ensure no adverse hydrologic/hydraulic impacts at other locations in the watershed.

1.3.10 Benefit-cost analysis of flood mitigation alternatives

The flood mitigation alternatives identified by the study were evaluated and selected based on their cost-effectiveness and overall feasibility. Karnes County performed a benefit/cost analysis for each flood mitigation alternative following the TWDB Regional Flood Planning guidelines.

A public meeting was conducted to obtain citizen and stakeholder input on the proposed flood mitigation alternatives and the results of the benefit/cost analysis. To the extent possible, citizen and stakeholder concerns were incorporated.

1.3.11 Flood early warning system and response planning

The goal of the Flood Early Warning effort was to review existing gage and flood early warning equipment in-place, evaluate software and hardware required to develop and/or improve flood early warning system effectiveness, and coordinate with local participating entities on desired end products associated with Flood Early Warning. This effort included coordination with other outside entities involved in recent extreme floods, such as the San Antonio River Authority, to develop a list of "lessons learned" that can be applied to this watershed area.

1.3.12 Implementation and phasing plan

Based on input from the public meeting, a project implementation and phasing plan was developed. The implementation and phasing plan considered items such as funding sources, project location, project timing, community priorities, and benefit-cost ratio.

1.3.13 Final report

A draft final report summarizing the results of the hydrologic/hydraulic investigations, flood mitigation alternatives, benefit/cost analysis and stakeholder input was developed. The draft report included technical descriptions of hydrologic/hydraulic analyses, methodologies, assumptions and modeling notes as well as improvement alternative costs, easement requirements (if applicable), phasing and implementation plan, floodplain maps and other applicable exhibits.

A final public meeting was conducted to present the draft final report. Following the public meeting and incorporation of public input, the draft final report was submitted to TWDB for review. Upon addressing TWDB review comments, the final report was submitted to TWDB.

2 Project background

Damages sustained during significant flood events in recent decades, as well as the need for updated flood hazard data, led Karnes County to undertake this flood protection planning study. To create the framework for the study, relevant historical and technical data were acquired from various sources and reviewed. Some of these data, such as existing hydrologic and hydraulic models, were leveraged in this study where appropriate.

2.1 Need for project

Karnes County has been subject to extreme flooding including catastrophic events in September 1967 (Hurricane Beulah), August 1998 (Tropical Storm Charley), October 1998, July 2002, July 2003 (Hurricane Claudette), August 2007 (Tropical Storm Erin), and August 2017 (Hurricane Harvey) with extensive impacts to lives and property. Based on recorded historical flood occurrences within Karnes County and immediately surrounding areas, 26 recorded flooding events in a 21-year reporting period provides a probability of occurrence of at least 1 event per year (i.e., highly likely). Based on historical storm events by impact data provided by NOAA's National Climatic Data Center (NCDC), Karnes County is ranked in the top 20% of Texas counties. From 1996 to 2017, 96% of total hazard impacts in Karnes County have been due to hurricanes and flooding ($10M). Inadequate roadway drainage infrastructure at many stream crossings across the County result in roadway overtopping during frequent, light rainfall events, resulting in regular disturbances in emergency services availability (i.e., fire, medical, and law enforcement), school bus routes, and public access to homes and businesses.

As shown in **Figure 2-1**, the proximity of Karnes County to the Texas Coast makes this area vulnerable to flooding from hurricanes and hurricane-force winds that cause damage across large areas. This exposes all building, facilities, and populations within the County to the impact of a hurricane or tropical storm. Damage to towers, trees, and underground utility lines from uprooted trees and fallen poles can cause damage to utility infrastructure and cause considerable disruption. Debris such as small items left outside, signs, roofing materials, and trees can become extremely hazardous in hurricanes and tropical storms and strong winds can easily destroy poorly constructed buildings, barns and mobile homes. Hurricanes and tropical storms also produce large amounts of rain increasing the risk of flooding. This rain can overwhelm drainage systems as hurricanes or tropical storms that have weakened after making landfall can continue to drop significant quantities of water. The impacts to communities from a Category 5 storm can result in complete destruction of houses, commercial property, cropland resulting in large-scale economic impacts and population displacement.

Based on ACS 2016 data, housing within Karnes County includes 15% manufactured homes, which are more vulnerable to extreme flood events than site-built structures, and 63% of homes constructed prior to 1980. These structures are likely to have been built to lower or less stringent construction standards than newer construction and typically more susceptible to damages during significant events. In addition, manufactured and temporary housing is located sporadically throughout rural portions of the County, which are more prone to being isolated from essential needs and emergency services in the event of a disaster.

The City of Kenedy has a long history of flooding problems from Escondido Creek. Devastating floods occurred in 1935, 1942, 1960 and 1967. The 1960 flood was concentrated more on Nichols Creek than on Escondido Creek. The 1967 flood was a result of Hurricane Beulah and covered a large area. A disastrous storm occurred in the Escondido Creek watershed on August 30-31, 1981. The storm was centered just south of Karnes City or approximately 5 miles northeast of the City of Kenedy. Rainfall amounts over 16 inches were reported in slightly less than a 24-hour period. The most intense rainfall occurred between 6 p.m. on August 30 and 2 a.m. on August 31, 1981. Some local residents reported rainfall intensities up to six inches per hour during the latter portion of this time period.

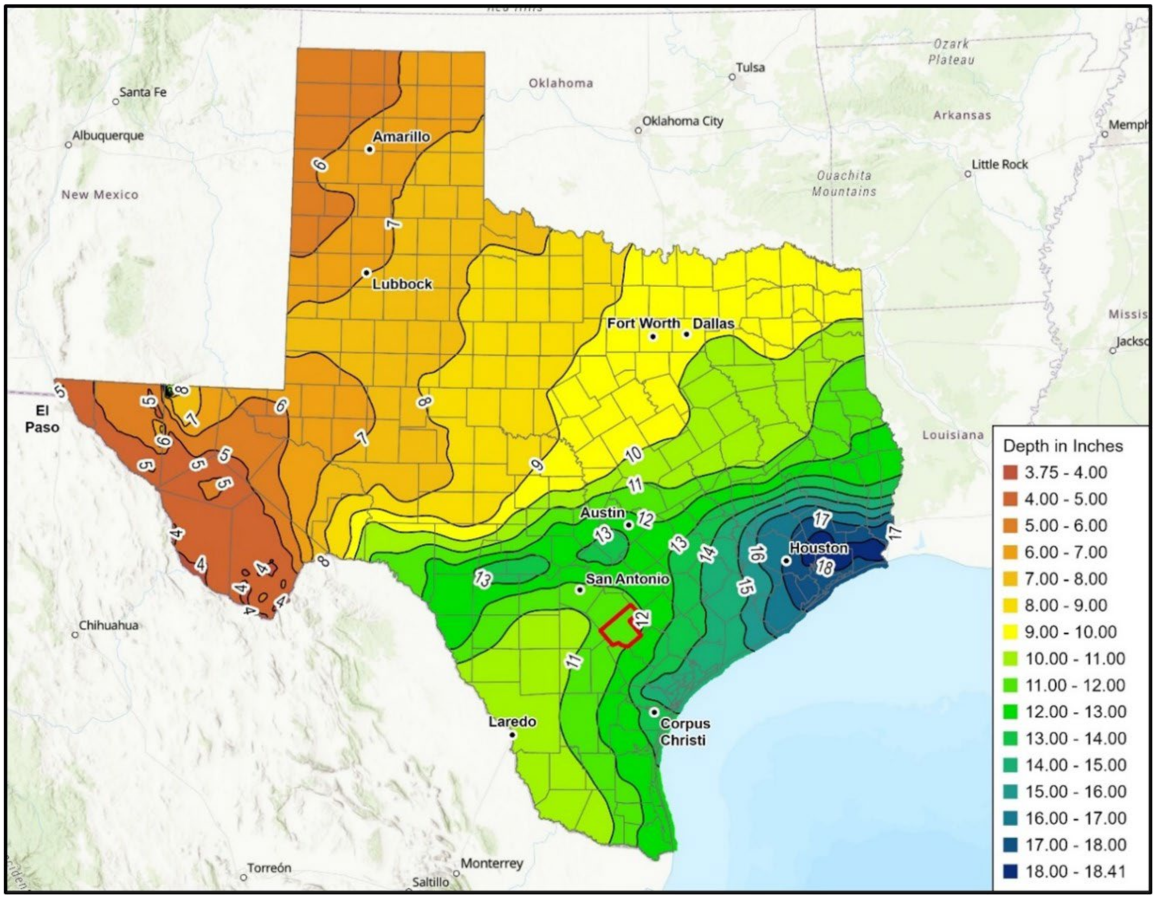

Figure 2-1. Atlas 14 100-year 24-hour precipitation depths in Inches – Karnes County shown in red.

The current Flood Insurance Rate Map (FIRM) for the watersheds within the planning area is over 10 years old and contains outdated and inaccurate peak discharges and base flood information. Although the FIRM was updated in October 2010, new hydrologic/hydraulic analyses were not performed for most of the proposed study area. In order to have an effective tool to manage quality and sustainable growth, it is important to prepare an updated and comprehensive drainage plan in the planning area.

2.2 Data collection

Relevant sources of information, such as previous drainage studies, topographic data, as-built plans, and citizen drainage complaint reports were collected and reviewed to develop a historical and technical understanding of the planning area. This section describes the baseline data collected during this FPPS.

2.2.1 Public meetings

Public input from residents and community officials was an important source of information for this FPPS. To solicit this input, three (3) public meetings were held during the course of the project. The intention of the first public meeting, which was held on March 17, 2022, was to ask for the public's knowledge and experience to identify and discuss known flood problem areas within Karnes County. The second public meeting was held on September 28, 2023, to present 1) revised floodplain mapping for the streams included in the study and 2) conceptual flood mitigation alternatives for high-priority flood problem areas. The third and final public meeting was held on March 13, 2024 to present and discuss final recommendations for flood mitigation solutions and community initiatives. Documents from the public meetings are included in **Appendix B**.

2.2.2 Topographic data

Preparation of the hydrologic and hydraulic analyses necessitated the acquisition of up-to-date topographic data. This information was needed to ensure the models accurately reflected existing terrain and hydraulic structures, such as bridge and culvert crossings.

LiDAR data

The following publicly available LiDAR datasets were obtained from the Texas Natural Resources Information System (TNRIS) to represent the topography throughout the study area:

- 2018 USGS South Texas LiDAR
    - Collected by Quantum Spatial between January 13, 2018 and February 23, 2018
    - Spatial Reference: NAD83(2011) / UTM zone 14N
- 2019 USGS Hurricane LiDAR
    - Collected by Fugro between January 4, 2019 and February 20, 2019
    - Spatial Reference: NAD83(2011) / UTM zone 14N

Field survey and measurements

In order to accurately represent existing bridge and culvert structures in the hydraulic models, field survey and measurement of the hydraulic structures on each study stream was conducted between August 1, 2022, and October 20, 2022. In addition to the field measurements, photographs of the upstream and downstream channels, the upstream and downstream faces, and the roadway centerline were taken for each hydraulic structure. These photographs, as well as detailed field measurement reports, are provided in **Appendix C**. Where possible, field data from previous studies were utilized in the hydraulic models and new field measurements were not taken. Per the Hydraulics TSDN for the SARA Karnes County Map Modernization Study (2007), bridge, culvert, and road crossing data were carried over from the HEC-RAS models developed by the USACE for the Lower San Antonio River Basin Feasibility Study in 2005. During the Map Modernization Study, additional survey data were incorporated into the Detailed studies on Escondido Creek, Ojo De Agua Creek, and Marcelinas Creek. No additional survey data were incorporated into the Enhanced Approximate studies.

2.2.3 Previous and ongoing drainage studies

Multiple previous and ongoing studies were utilized to obtain hydrologic and hydraulic modeling data, as well as historical flooding information. Where possible, drainage basin boundaries, hydrologic parameters, HEC-RAS cross-sections, and hydraulic structure data were leveraged from these other studies. Review of FEMA's Map Service Center website showed that only one LOMR has been approved in Karnes County since the 2010 FIRM update. This LOMR study, with an effective date of January 9, 2014, was not located on one of the scoped study streams for this FPPS, and the data was not incorporated into the analyses. **Table 2-1** provides a summary of the studies utilized in this FPPS.

Table 2-1. Previous and ongoing drainage studies in Karnes County.

Karnes County
Karnes County Multi-jurisdictional Wilson County Multi-jurisdictional Hazard Mitigation Action Plan - April 7, 2020
May/June/July 2021 Flood Damage Repair Cost Summary
Karnes County FY 19-20 KCRB Road Inventory Report Spreadsheet
Karnes County FY 20-21 KCRB Road Inventory Report Spreadsheet
CDBG-MIT Grant Application - September 2020
San Antonio River Authority (SARA)
Cooperating Technical Partners Flood Risk Project Mapping Activity Statement No. 11 - May 2015
MAS No. 11 - Lower San Antonio River Phase II, Texas - Hydrologic Report - March 2021
MAS No. 11 - Lower San Antonio River Phase II, Texas - Draft Hydraulic Report - October 2020
Holistic Watershed Master Plan for Karnes, Goliad, and Wilson Counties Summary Report - May 8, 2015
Hydrology Technical Support Data Notebook for Karnes County Map Modernization - June 2007
Hydraulics & Work Map Technical Support Data Notebook for Karnes County Map Modernization - Sept. 2007
Texas General Land Office (GLO)
Ongoing GLO Combined River Basin Flood Study - Western Region - Estimated completion Summer 2024

2.2.4 As-built plans

Where available, as-built plans for existing hydraulic structures on state and federal highways, farm-to-market roads, and county roads were obtained from TxDOT and used to develop hydraulic models for the study streams. These plans were dated as early as 1937 and as recent as 2019. A table summarizing the TxDOT as-builts utilized in this study is provided in **Appendix D**.

As-built documents and outfall rating curves for existing NRCS dams within the Escondido Creek watershed were obtained from the San Antonio River Authority. For the existing NRCS dams within the Ecleto Creek and Hondo Creek watersheds, a letter formally requesting as-built data was submitted to the Ecleto Watershed District and Hondo Watershed District. However, the request did not receive a response. As a result, reasonable assumptions were made to estimate the stage-storage-discharge relationships of the Ecleto Creek and Hondo Creek dams, as described in further detail in the Hydrologic Analysis section of this report. A table summarizing the inventory of as-builts for NRCS dams is provided in **Appendix D**.

3 Hydrologic analysis

Detailed, geo-referenced hydrologic rainfall-runoff models were prepared for each of the 6 study watersheds discussed in Section 3.1 using USACE HEC-HMS v.4.9. The following sections discuss the methodology and assumptions used to develop the models and input parameters.

3.1 Overview of watershed study areas

The hydrologic analysis for this FPPS included the development of new HEC-HMS hydrologic models for streams within the following HUC-10 basins in the Lower San Antonio River watershed:

- Ecleto Creek
- Hondo Creek-San Antonio River
- Marcelinas Creek-San Antonio River

The study area, covering a total of 522.6 square miles, was divided into 6 separate regions based on the mainstem stream within those regions (see **Figure 3-1**). For simplicity and consistency, each of the 6 regions was assigned a 3-character code for file naming and labeling purposes. **Table 3-1** lists the 6 study regions, their associated basin codes, and drainage areas. Additional information on each of the study regions is discussed in Section 3.1.1 through 3.1.6.

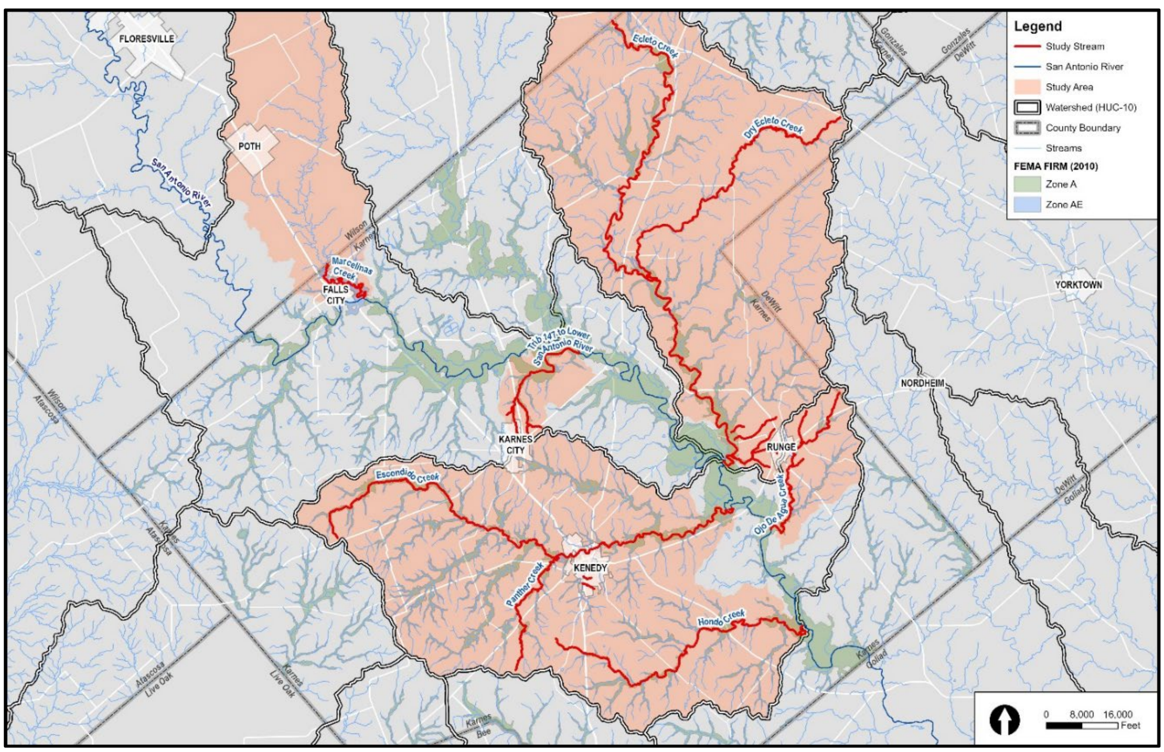

Figure 3-1. Project study area map.

Table 3-1. Hydrologic study regions and basin codes.

HUC-10	Hydrologic Study Region	Basin Code	Drainage Area (sq mi)
Ecleto Creek	Ecleto Creek Watershed	ECL	263.1
Hondo Creek-San Antonio River	Escondido Creek Watershed	ESC	112.9
	Hondo Creek Watershed	HON	45.6
	Ojo De Agua Creek Watershed	OJO	15.4
Marcelinas Creek-San Antonio River	Lower San Antonio River Tributaries	LSA	10.1
	Marcelinas Creek Watershed	MAR	75.5
		TOTAL	**522.6**

3.1.1 Ecleto Creek Watershed

Covering 263.1 square miles, the Ecleto Creek Watershed is the largest of the 6 regions analyzed in this FPPS. The upstream limits of the watershed lie within southern Guadalupe County. The basin extends south through Wilson County and into northern and eastern Karnes County and western De Witt County. The basin outlet lies at the confluence of Ecleto Creek and the Lower San Antonio River southwest of Runge. The land use within the watershed largely comprises undeveloped pasture, shrub/scrub, cropland, and oil and gas well pads, with Runge being the primary urban area within the basin. The most recent detailed hydrologic study of this watershed was the 2007 Karnes County Map Modernization Study, and the hydrologic parameters for the basins and routing reaches lying upstream of the Karnes County boundary were leveraged from that study.

3.1.2 Escondido Creek Watershed

The Escondido Creek Watershed covers 112.9 square miles and is entirely contained within the Karnes County limits. The upstream limits of the watershed lie in western Karnes County, and the basin flows east to the confluence with the Lower San Antonio River southwest of Runge. The City of Kenedy lies within the Escondido Creek Watershed, as does a portion of Karnes City. Outside of these urban areas, the land uses largely consist of undeveloped pasture, shrub/scrub, cropland, and oil and gas well pads. The most recent detailed hydrologic study of this watershed was the 2007 Karnes County Map Modernization Study, and portions of the hydrologic model parameters were leveraged from that study.

3.1.3 Hondo Creek Watershed

Lying in southern Karnes County, the Hondo Creek Watershed covers 45.6 square miles and shares a portion of its northern boundary with the Escondido Creek Watershed. The watershed drains from west to east, and the outfall lies at the confluence with the Lower San Antonio River. There are no urban areas within the drainage basin, and the primary land uses are undeveloped pasture and shrub/scrub. No detailed hydrologic models of the Hondo Creek Watershed were available, so a new hydrologic analysis was prepared.

3.1.4 Lower San Antonio River Tributaries

This FPPS includes the analysis of small tributaries to the Lower San Antonio River north of Karnes City. Covering 10.1 square miles, this study area is the smallest of the regions included in this analysis. The upstream limits of this basin lie within the northern portion of Karnes City, and the basin drains north to the Lower San Antonio River. Other than the urbanization within

Karnes City, the land uses in the basin largely consist of undeveloped pasture, shrub/scrub, cropland, and oil and gas well pads. No detailed hydrologic models of the Lower San Antonio River Tributaries were available, so a new hydrologic analysis was prepared.

3.1.5 Marcelinas Creek Watershed

The Marcelinas Creek Watershed covers 75.5 square miles, extending from north-central Wilson County south into Falls City in Karnes County, where it discharges into the Lower San Antonio River. Approximately 7% of the watershed area lies within the Karnes County limits. Other than Falls City, the only other urbanized area is the City of Poth in Wilson County. The primary land uses within the watershed are undeveloped pasture, shrub/scrub, and cropland. The most recent detailed hydrologic study of this watershed was the 2007 Karnes County Map Modernization Study, and the hydrologic parameters for the basins and routing reaches lying upstream of the Karnes County boundary were leveraged from that study.

3.1.6 Ojo De Agua Creek Watershed

The Ojo De Agua Creek Watershed covers 15.4 square miles in eastern Karnes County, with the most upstream limits lying in western De Witt County. Sharing a portion of its western boundary with the Ecleto Creek Watershed, the basin drains from northeast to southwest, where it discharges into the Lower San Antonio River south of Runge. Other than the urbanization in Runge, the primary land uses are undeveloped pasture, shrub/scrub, cropland, and oil and gas well pads. The most recent detailed hydrologic study of this watershed was the 2007 Karnes County Map Modernization Study, and portions of the hydrologic model parameters were leveraged from that study.

3.2 Hydrologic methodology and assumptions

Geo-referenced hydrologic rainfall-runoff models were prepared for each of the six (6) mainstem watersheds discussed in Section 3.1 using USACE HEC-HMS v.4.9. The models and input parameters were prepared in accordance with the *San Antonio River Basin (SARB) Regional Modeling Standards for Hydrology and Hydraulic Modeling* revised September 2013.

3.2.1 Data leveraged from previous studies

Where appropriate, drainage area boundaries and hydrologic model parameters were leveraged from the following previous studies:

- 2007 Karnes County Map Modernization Study
- Cooperating Technical Partners Flood Risk Project Mapping Activity Statement No. 11 – Lower San Antonio River Phase II, Texas
    - Hydrology – March 2021
    - Hydraulics – October 2020
- 2005 USACE Lower San Antonio River Basin Feasibility Study

3.2.2 Terrain processing

Best available LiDAR data, including 2018 USGS South Texas and 2019 USGS Hurricane LiDAR, were processed using ESRI ArcGIS Pro and HEC-HMS tools to develop a 3-meter digital terrain model (DTM) to support hydrologic model development.

3.2.3 Drainage area delineation

Hydrologic subbasins were delineated using the DTM, ESRI ArcGIS Pro, and HEC-HMS GIS tools. To ensure consistency in the peak time computation within the HEC-HMS model, the target subbasin size for rural areas was generally 5 to 8 square miles. The target sub-basin size for urban areas was generally 0.25 to 1.0 square mile. For sub-basins lying upstream of Karnes County within the Ecleto Creek and Marcelinas Creek watersheds, the sub-basin boundaries and hydrologic parameters were maintained from the effective 2007 Karnes County Map Modernization Study by SARA.

3.2.4 Precipitation

A .dss file containing NOAA Atlas 14 precipitation hyetographs for Karnes, Wilson, and Goliad Counties was provided by SARA for use in this study. Hyetographs for the 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% storm events were applied as precipitation gages in the hydrologic models. This .dss file also contained hyetographs for various areal reduction thresholds ranging from no reduction (for drainage areas less than 10 square miles) up to 400 square miles.

3.2.5 Infiltration losses

The NRCS Runoff Curve Number (CN) for each sub-basin was computed based on procedures outlined in the NRCS TR-55 publication. Land use designations within the study area were assigned based on the 2019 National Land Cover Database (NLCD). Using these land use designations, the existing condition CN for each sub-basin was computed using the values listed in Table 10 in the *SARB Regional Modeling Standards*. The latest NRCS Soil Survey Geographic (SSURGO) database for Karnes County and other Counties were used for hydrologic soil group determination. The average percent impervious value for each sub-basin was developed based on the 2019 NLCD impervious cover raster.

3.2.6 Unit hydrograph method

The Snyder Unit Hydrograph method was used to develop runoff hydrographs within HEC-HMS. The Snyder method requires two parameters, the Snyder standard lag and the Snyder peaking coefficient (Cp). Snyder's lag values were developed using the USACE Fort Worth District Urbanization Curve methodology with ESRI ArcGIS Pro and HEC-HMS GIS tools. The following equation was used to calculate the Snyder lag values:

$$\log(T_p) = 0.3833 \log\left(\frac{L \times L_{ca}}{\sqrt{S_{st}}}\right) + [Sd \times (\log(Ip_s) - \log(Ip_c)) + \log(Ip_c)] - (BW \times Urb)$$

Where:

Tp = Lag time in hours

L = Longest flow path in miles from the basin outlet to the upstream limit of the basin

L_{ca}	=	Distance in miles along the longest flow path from the basin outlet to a point nearest the basin centroid
S_{st}	=	Weighted slope in ft/mi along the longest flow path from 85% of the distance upstream of the outlet to 10% of the distance upstream of the outlet
Sd	=	Percent sand of the drainage basin expressed as a decimal
Ip_s	=	Calibration point for sand (1.81 according to the Fort Worth District Urbanization Curves)
Ip_c	=	Calibration point for clay (0.92 according to the Fort Worth District Urbanization Curves)
BW	=	Bandwidth (0.266 according to the Fort Worth District Urbanization Curves)
Urb	=	Percent urbanization of the drainage basin expressed as a decimal

Snyder peaking coefficients were maintained from previous studies within the region (e.g., 2005 USACE Study and 2007 Karnes County Map Modernization Study). The average percent sand values for each sub-basin were developed using a raster dataset for Texas obtained from the USACE. The percent urbanization values for each sub-basin were developed based on the 2019 NLCD land use designations and Table 1.15 in the *NCTOG iSWM Technical Manual - Hydrology*.

3.2.7 Hydrograph routing

For the study reaches where existing hydraulic models were available, the Modified Puls routing method was used to account for peak flow and timing attenuation along the streams. For reaches without existing hydraulic models, the Muskingum-Cunge 8-point cross-section method was applied for hydrograph routing. For reaches lying upstream of Karnes County within the Ecleto Creek and Marcelinas Creek watersheds, the routing parameters were maintained from the effective 2007 Karnes County Map Modernization Study by SARA. Where reaches were located upstream of an NRCS reservoir, the downstream end of the reach was placed where the elevation at the stream centerline equaled the crest elevation of the dam. This conservative approach was taken to avoid double-counting storage within the reservoirs. In a few cases, this approach resulted in subbasins with no reach segments.

3.2.8 NRCS reservoirs

Within the study area, there are 21 existing NRCS reservoirs: 3 within the Hondo Creek watershed, 5 within the Ecleto Creek watershed, and 13 within the Escondido Creek watershed. The effective Escondido Creek hydrologic model reflects the NRCS reservoirs, and the parameters were maintained for this FPPS. Updated rating curves for the Escondido Dams were provided by SARA and incorporated into the HEC-HMS model. As-built plans for those reservoirs were also obtained from SARA. The reservoirs within the Ecleto Creek and Hondo Creek reservoirs were not represented in the effective models for those watersheds. The Karnes County Watershed Districts were contacted to obtain as-built plans for these reservoirs. At the direction of the watershed districts, a letter formally requesting the as-built plans for the reservoirs in both the Ecleto Creek and Hondo Creek watersheds was provided. However, the request was not acknowledged and did not receive a response. In lieu of using as-built plans to define the reservoir parameters in the models, stage-storage relationships for each reservoir were developed using the project DTM. For each dam, primary outlet configurations were assumed based on the as-built plans for Escondido Creek reservoirs with similar contributing drainage areas.

3.2.9 Areal reduction

For drainage areas greater than 10 square miles, areal reduction factors were accounted for in the HEC-HMS model. The precipitation .dss file provided by SARA contains hyetographs for each storm event for areal reduction thresholds of 10, 12, 15, 20, 30, 50, 80, 150, 225, 350, and 400 square miles. Within each mainstem watershed hydrologic model, multiple simulations were created to calculate discharge rates for each of these areal reduction thresholds ranging from no reduction (10 square miles) up to the first threshold larger than the total contributing drainage area. Using a spreadsheet obtained from SARA, the areally-reduced discharge for each hydrologic element was interpolated from the discharge values associated with each areal reduction threshold.

3.3 Hydrologic model validation

For calibration purposes, there is only one USGS streamflow gage located within the study area. Gage 08186500 is located on Ecleto Creek near Runge, TX. Historical streamflow records were obtained for the period between 1903 and 2022. Using these records, a flood frequency analysis was carried out in HEC-SSP Version 2.1.1 using both Bulletin 17B and Bulletin 17C methodology. Model validation also included an analysis of historical precipitation radar and a comparison to the results of previous drainage studies.

3.3.1 USGS gage analysis – Bulletin 17B

The most extreme events in the streamflow record were associated with May 31, 1903 (71,000 cfs), August 31, 1952 (39,000 cfs), September 22, 1967 (58,400 cfs), and August 31, 1981 (74,000 cfs). In the Bulletin 17B analysis, these events were designated as “Historical” events. A weighted skew was applied, using a regional skew of -0.3 and regional skew mean square error (MSE) of 0.302 per the Bulletin 17B documentation. The resulting 1% annual exceedance discharge was about 30,000 cfs (see **Table 3-2** and **Figure 3-2**). The HEC-HMS discharge at junction C30601, which corresponds to the gage location, was about 29,000 cfs. These results agree well with the values reported in the 2007 Karnes County Map Modernization Hydrology TSDN, which reports a HEC-HMS generated flow of 24,728 for the 1% annual chance event, as well as a 1% flow of 27,000 cfs produced using 17B methodology in HEC-SSP.

Table 3-2. HEC-SSP Bulletin 17B flood frequency table for USGS gage 08186500 – weighted skew.

Percent Chance Exceedance	Computed Flow in cfs	0.05 Confidence Limit	0.95 Confidence Limit
0.2	60,846.7	126,742.3	35,436.7
0.5	41,412.4	80,406.7	25,315.1
1.0	30,278.0	55,581.7	19,231.5
2.0	21,600.5	37,380.4	14,277.2
5.0	13,129.7	20,911.0	9,166.8
10.0	8,510.0	12,680.2	6,196.2
20.0	5,088.8	7,084.2	3,851.7
50.0	1,966.4	2,550.6	1,513.5
80.0	792.8	1,048.5	568.3
90.0	501.4	686.2	338.4
95.0	346.3	490.9	221.0
99.0	176.6	269.5	100.8

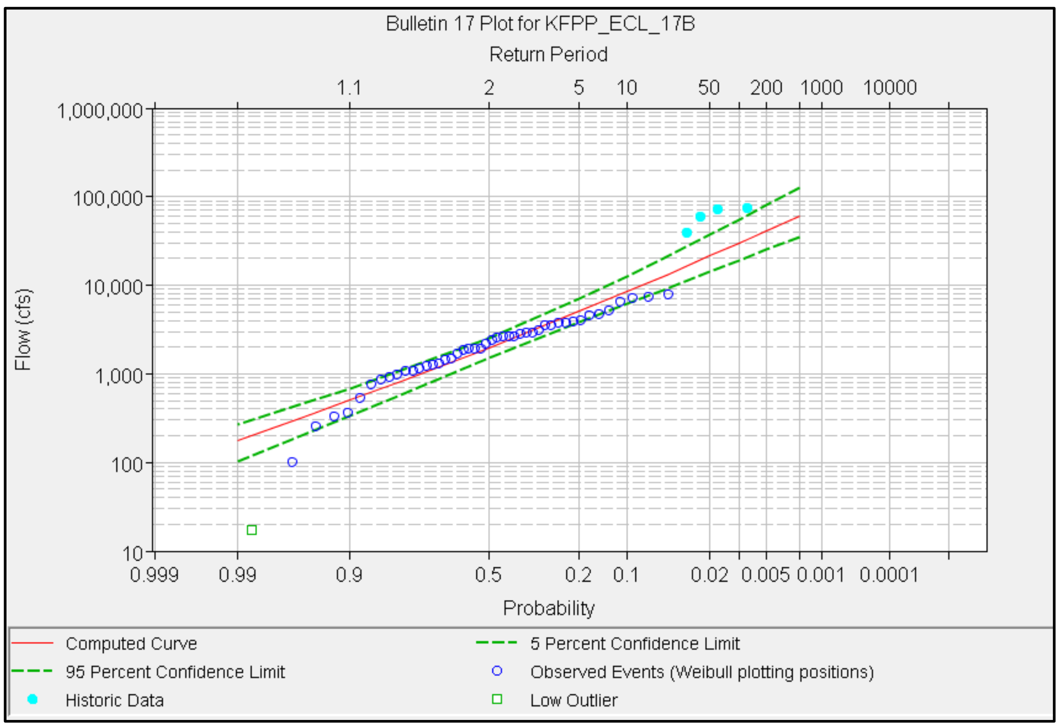

Figure 3-2. HEC-SSP Bulletin 17B flood frequency curve for USGS gage 08186500 – weighted skew.

3.3.2 USGS gage analysis – Bulletin 17C

The gage records included large gaps in the data, particularly between 1903 and the beginning of the systematic records in 1962. For the Bulletin 17C analysis, the records before 1962 were neglected. For comparison purposes, flood frequency curves were developed using both station skew and regional skew. Using station skew, the computed 1% annual chance discharge was about 58,500 cfs, approximately double the HEC-HMS generated flow of 29,000 cfs (See **Table 3-3** and **Figure 3-3**). The HEC-HMS discharge also lay outside the 95% confidence interval of the 17C analysis using station skew. The substantial differences between the station skew discharge and the findings of previous studies indicated the results using station skew were unreasonable. Therefore, based on the guidance and parameters discussed in Section 9 of the TxDOT Hydraulic Design Manual, an analysis using a regional skew of 0.0 and regional skew MSE of 0.123 was carried out. The resulting 1% annual chance discharge was about 42,000 cfs, approximately 45% higher than the HEC-HMS generated discharge of 29,000 cfs at the gage location (see **Table 3-4** and **Figure 3-4**). However, the modeled discharge for the 1% annual chance event was within the 95% confidence interval of the Bulletin 17C analysis.

Table 3-3. HEC-SSP Bulletin 17C flood frequency table for USGS gage 08186500 – station skew.

Percent Chance Exceedance	Computed Flow in cfs	0.05 Confidence Limit	0.95 Confidence Limit
0.2	164,492.3	1,232,088.1	68,765.1
0.5	92,352.6	419,031.3	44,472.1
1.0	58,493.6	188,266.8	31,123.2
2.0	36,232.9	86,378.8	21,131.5
5.0	18,361.5	32,335.5	11,895.4
10.0	10,429.3	15,962.5	7,173.2
20.0	5,511.5	7,830.4	3,894.3
50.0	1,869.6	2,521.3	1,356.6
80.0	754.4	995.8	568.2
90.0	500.9	649.7	340.4
95.0	368.7	501.9	224.7
99.0	223.4	387.6	104.0

Table 3-4. HEC-SSP Bulletin 17C flood frequency table for USGS gage 08186500 – regional skew.

Percent Chance Exceedance	Computed Flow in cfs	0.05 Confidence Limit	0.95 Confidence Limit
0.2	84,157.4	304,754.3	32,679.0
0.5	57,210.2	162,380.5	26,115.6
1.0	41,606.3	99,308.6	21,411.2
2.0	29,378.3	59,679.8	16,960.0
5.0	17,431.3	29,325.7	11,512.6
10.0	10,962.6	16,420.2	7,789.8
20.0	6,251.9	8,643.2	4,583.7
50.0	2,135.0	2,898.1	1,549.3
80.0	729.1	1,017.3	481.2
90.0	415.8	596.7	239.8
95.0	261.5	397.3	129.5
99.0	109.6	206.7	36.9

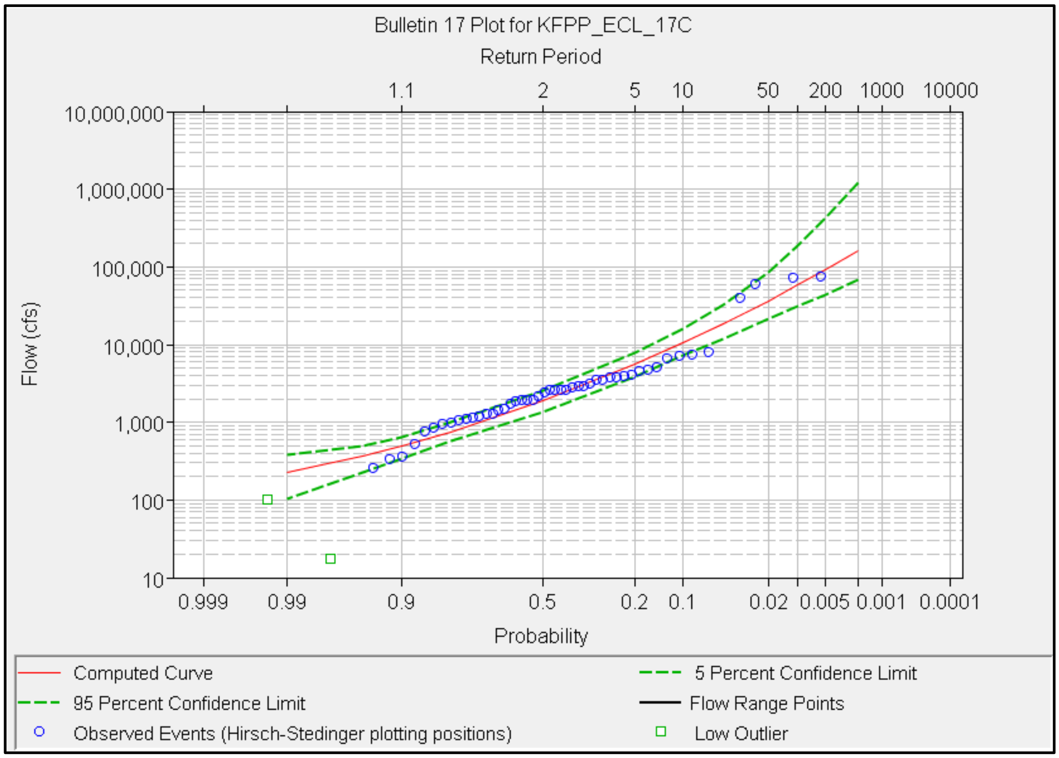

Figure 3-3. **HEC-SSP Bulletin 17C flood frequency curve for USGS gage 08186500 – station skew.**

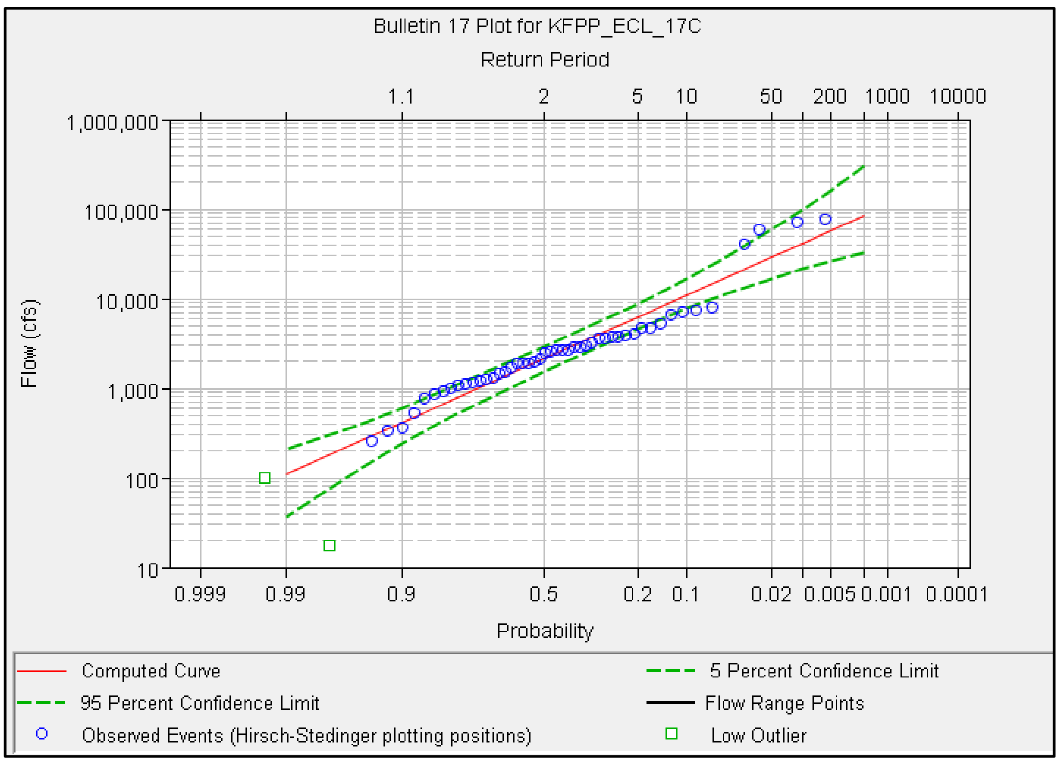

Figure 3-4. **HEC-SSP Bulletin 17C flood frequency curve for USGS gage 08186500 – regional skew.**

3.3.3 Historical precipitation radar analysis

Historical radar datasets were obtained for storm events in November 2002, March 2007, May 2015, and November 2018 for the purpose of comparing the model output to streamflow data observed at USGS gage 08186500 on Ecleto Creek. For storm events prior to 2012, Parameter-elevation Regressions on Independent Slopes Model (PRISM) precipitation rasters were downloaded from Oregon State University. These rasters have a grid cell size of 4,000 meters and a time step of 24 hours. For storm events after 2012, Multi-Radar Multi-Sensor Quantitative Precipitation Estimate (MRMS QPE) precipitation rasters were obtained from Iowa State University. These rasters have a grid cell size of 1,000 meters and a time step of 1 hour.

Using the Gridded Data Import Wizard in HEC-HMS, these raster datasets were imported into the model, clipped to the Ecleto Creek watershed boundary, and converted to .dss format, allowing for the creation of a Precipitation Gridset for each storm event. Meteorological models for each storm event were created using these Precipitation Gridsets. After applying a structured discretization grid with 2,000-meter cells to the Basin Model, simulations for each historical storm event were created and run. The simulated results at junction C30601 were compared to the instantaneous streamflow values observed at the USGS gage during each storm event. These comparisons are represented in **Figure 3-5, Figure 3-6, Figure 3-7, and Figure 3-8**.

Reviewing the comparisons of simulated results to observed discharges, it can be seen that the HEC-HMS results overestimated the peak discharge for the November 2002 storm by approximately 41%, and the time of peak was 90 minutes earlier than observed. However, for the March 2007 event, the magnitude of the HEC-HMS peak discharge was nearly identical to the observed peak discharge, although the time of peak occurred later than observed. The HEC-HMS model underestimated the peak discharges for the May 2015 and November 2018 events by 15% and 18%, respectively. The simulated time of peak for the May 2015 event occurred more than 6 hours earlier than observed, while the simulated time of peak for the November 2018 event was 90 minutes later than observed. When considering all of these events, on average, the modeled peak discharge was within 2% of the observed flow, and the time of peak was within 30 minutes of the observed peak (see **Table 3-5**).

Table 3-5. Summary of simulated and observed storm events.

Storm Event	Start	End	Observed Discharge (cfs)	Observed Volume (ac-ft)	Observed Time of Peak	Simulated Discharge (cfs)	Simulated Volume (ac-ft)	Simulated Time of Peak	Δ cfs	Δ %	Δ min	Δ ac-ft
Nov 2002	11/3/02 0:00	11/10/02 0:00	3,480	17,392	11/5/02 21:15	4,892	18,924	11/5/02 19:45	1,412	41%	-90	1,532
Mar 2007	3/12/07 0:00	3/19/07 0:00	6,500	22,773	3/14/07 9:45	6,510	18,943	3/14/07 14:00	10	0%	255	-3,830
May 2015	5/14/15 0:00	5/21/15 0:00	2,880	15,128	5/16/15 3:15	2,447	9,867	5/15/15 21:00	-433	-15%	-375	-5,261
Nov 2018	11/8/18 0:00	11/15/18 0:00	1,680	4,236	11/9/18 19:15	1,380	3,423	11/9/18 20:45	-300	-18%	90	-813
								Average	172	2%	-30	-2,093

*Observed parameters reflect data from USGS gage 08186500. Simulated parameters reflect results at HMS Node C30601.

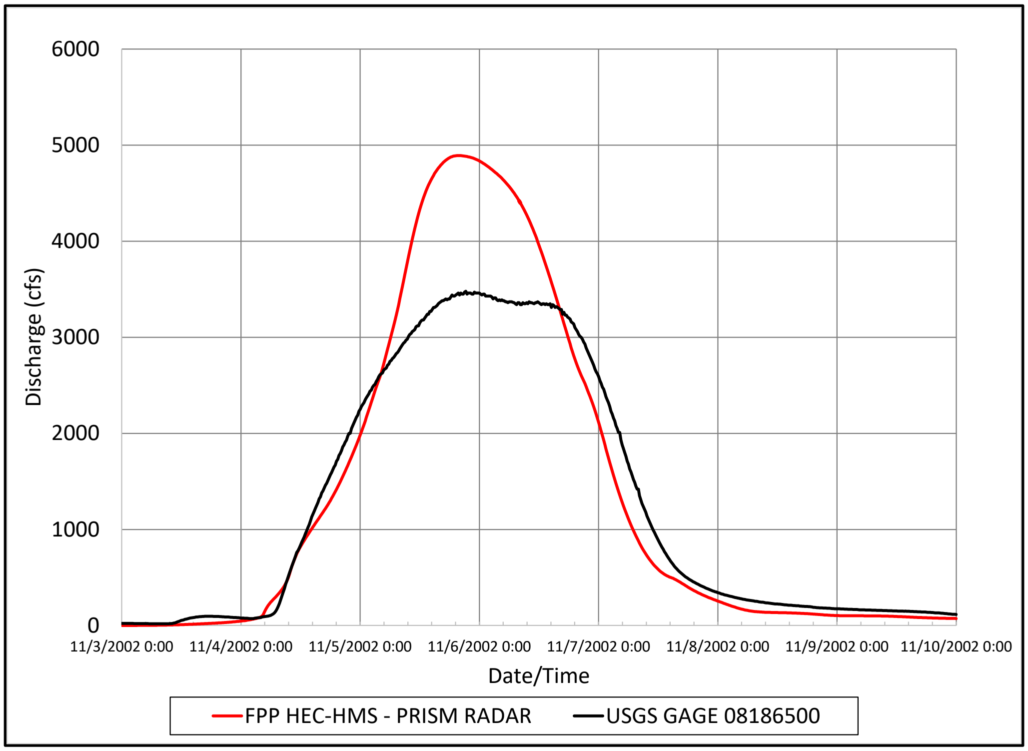

Figure 3-5. Simulated and observed flow comparison – November 2002.

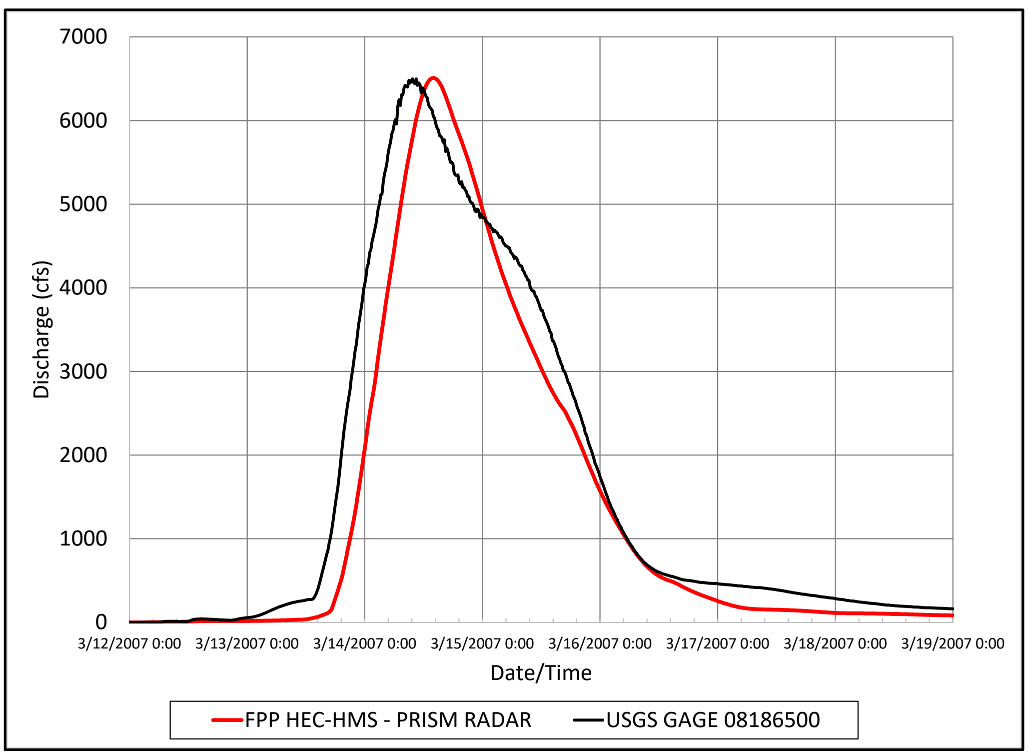

Figure 3-6. Simulated and observed flow comparison – March 2007.

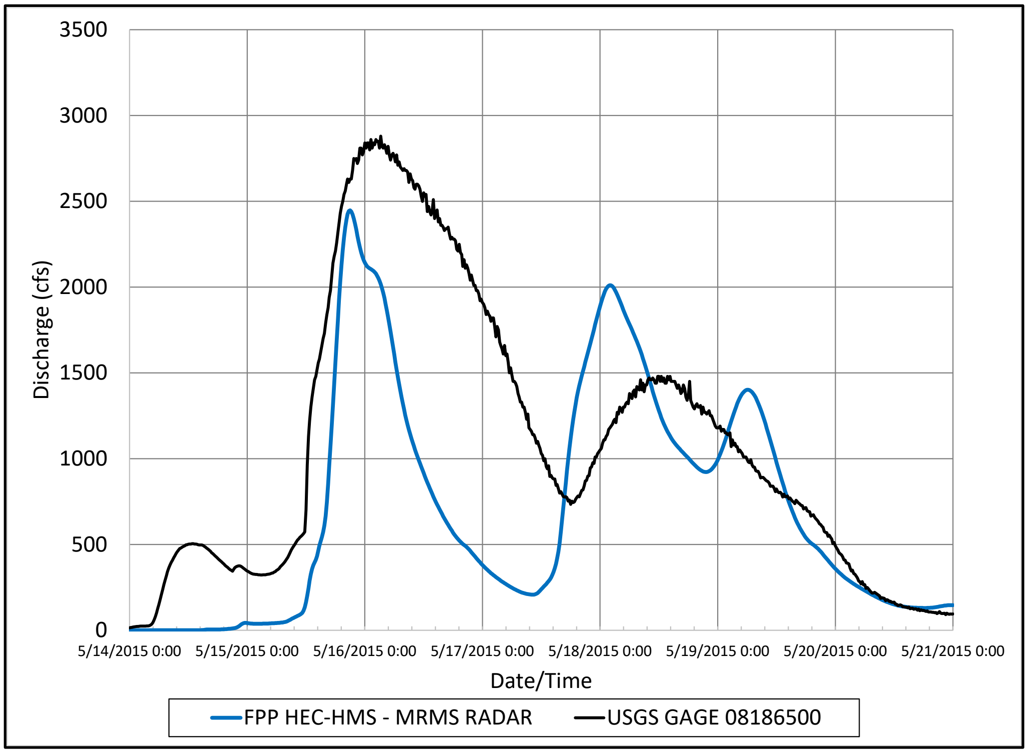

Figure 3-7. Simulated and observed flow comparison – May 2015.

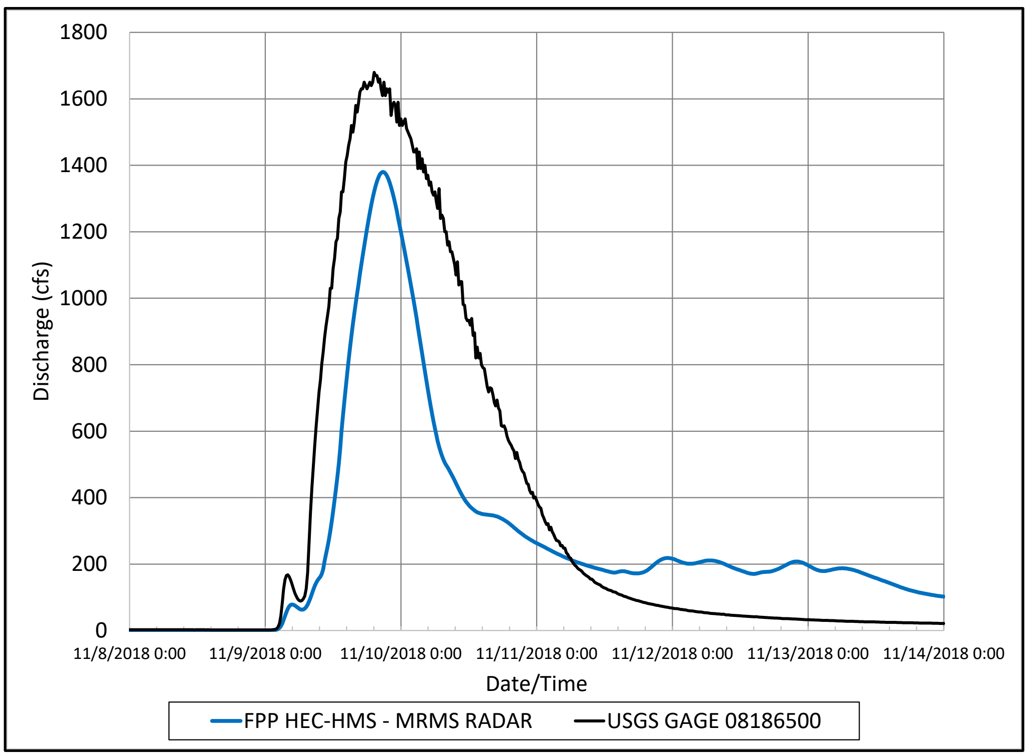

Figure 3-8. Simulated and observed flow comparison – November 2018.

3.3.4 Validation summary

Based upon the results of the flood frequency analyses in HEC-SSP, as well as the historical radar analysis in HEC-HMS, it was determined that maintaining the effective hydrologic parameters and methodology in the Ecleto Creek model produced a representative watershed model, and no calibration adjustments were made. For Marcelinas Creek, the majority of the hydrology model and parameters were maintained from the effective study, and no calibration adjustments were made. In the absence of stream gage records for use in calibration and validation in the other study watersheds, the initial hydrologic parameters calculated for this study were not adjusted since the methodology used in the effective study had been followed.

4 Hydraulic analysis

Detailed, geo-referenced 1D steady-state hydraulic models were developed for each study stream using USACE HEC-RAS v.6.3. These sections describe the methodology and assumptions used to develop the models based on existing watershed conditions.

4.1 Overview of study streams

Within the 6 study regions discussed in Section 3, this FPPS included the development of new HEC-RAS hydraulic models for 20 study streams for a total of 140.1 stream miles (see **Figure 4-1**). These new hydraulic models also included a total of 82 bridge and culvert structures. For simplicity and consistency, each study stream was assigned a stream code for file naming and labeling purposes. **Table 4-1** lists the streams included in the study and provides a summary of the stream codes, stream miles, and number of bridge and culvert structures on each stream.

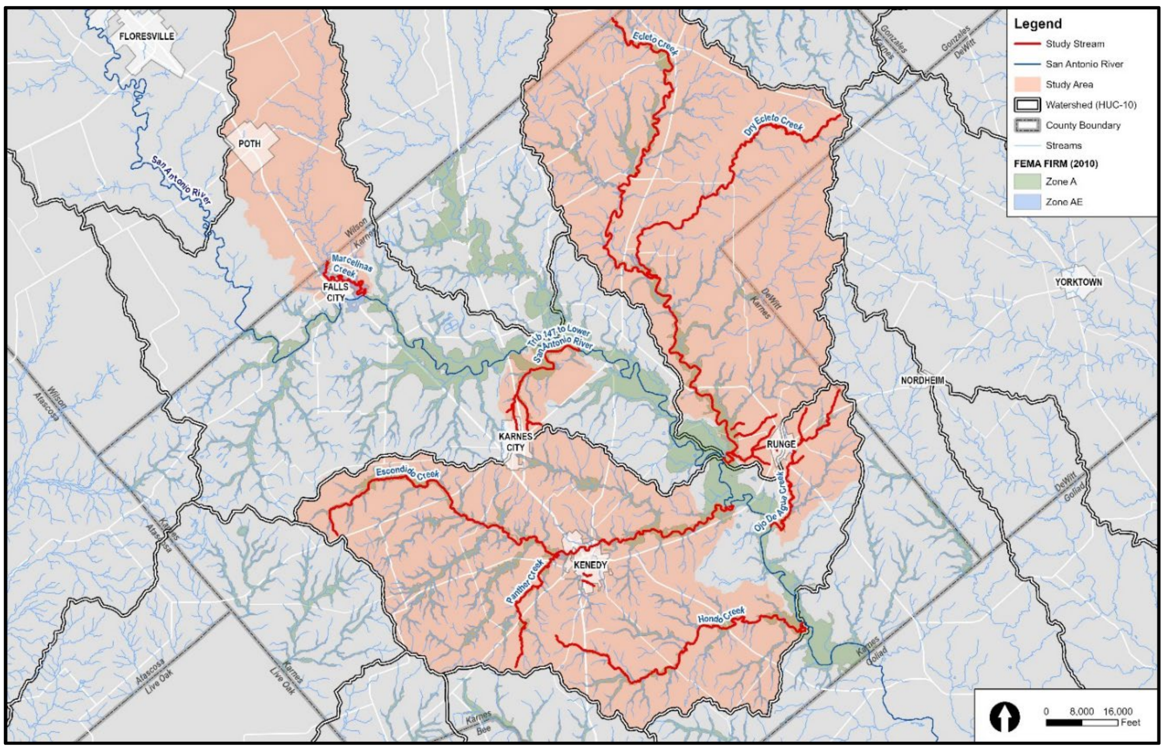

Figure 4-1. Project study area map.

Table 4-1. Summary of study streams.

Study Area	Stream Name	Stream Code	Stream Miles	Bridges/ Culverts
Ecleto Creek Watershed	Dry Ecleto Creek	DEC	17.7	7
	Ecleto Creek	ECL	34.7	15
	Tributary 1 to Ecleto Creek	ECL_T1	2.9	3
	Unnamed Tributary 1 to Tributary 1 to Ecleto Creek	ECL_T1_1	1.2	6
	Unnamed Tributary 2 to Tributary 1 to Ecleto Creek	ECL_T1_2	0.89	1
	Tributary 2 to Ecleto Creek	ECL_T2	0.68	0
	Unnamed Tributary 1 to Tributary 2 to Ecleto Creek	ECL_T2_1	2.3	2
Escondido Creek Watershed	Escondido Creek	ESC	26.6	11
	Unnamed Tributary 2 to Nichols Creek	NIC_T2	0.43	4
	Unnamed Tributary 4 to Nichols Creek	NIC_T4	0.60	5
	Panther Creek	PAN	7.6	4
Hondo Creek Watershed	Hondo Creek	HON	16.92	9
Lower San Antonio River Tributaries	Tributary 147 to Lower San Antonio River	LSA_T147	6.67	5
	Unnamed Tributary 2 to Tributary 147 to Lower San Antonio River	LSA_T147_2	0.50	0
	Tributary 152 to Lower San Antonio River	LSA_T152	1.83	0
	Unnamed Tributary 1 to Tributary 152 to Lower San Antonio River	LSA_T152_1	0.72	0
Marcelinas Creek Watershed	Marcelinas Creek	MAR	5.62	2
Ojo De Agua Creek Watershed	Ojo De Agua Creek	OJO	10.00	6
	Tributary 10 to Ojo De Agua Creek	OJO_T10	1.55	2
	Tributary 8 to Ojo De Agua Creek	OJO_T8	0.68	0
TOTAL	---	**---**	**140.1**	**82**

4.2 Hydraulic methodology and assumptions

These sections describe the methodology and assumptions used to develop the detailed 1D steady-state HEC-RAS v.6.3 models based on existing watershed conditions. The models were developed in accordance with the HEC-RAS guidance documents, standard modeling practices, and engineering judgment.

4.2.1 Data leveraged from previous studies

Where appropriate, existing hydraulic models, stream centerlines, cross-sections, and hydraulic structure data were leveraged from the following previous studies:

- SARA CTP Flood Risk Project MAS 11 (2021)
- Karnes County Map Modernization (2007)

4.2.2 Stream centerlines and cross-sections

Centerlines for each study stream were aligned with the natural channel bottom based on the project DEM with guidance from data leveraged from previous studies. Similarly, cross-sections were aligned along the stream centerline to be perpendicular to the direction of flow with guidance from data leveraged from previous studies. Cross-sections bounding hydraulic structures, such as bridges, culverts, and inline structures, were placed as directed in the HEC-RAS guidance manuals. In accordance with SARB Regional Modeling Standards, cross-sections were generally spaced no more than 500 feet apart in urban areas and no more than 1,000 feet apart in rural areas. In some cases involving the confluence of two study streams, where the water surface elevation is controlled by the receiving stream, cross-sections in the receiving stream model were extended across both streams. As a conservative measure, the combined flow from the confluence of both streams was used to set a flow change location at the upstream end of the portion of the model with the extended cross-sections (please refer to Section 4.3 for more detailed information on these cases).

4.2.3 Manning's roughness value estimation

Manning's roughness values were defined using the 2019 NLCD land cover classifications. The land use classifications were assigned the roughness values shown in **Table 4-2**, which were selected to comply with Table 15 in the SARB Regional Modeling Standards. Channel roughness values were refined to have a single value between the bank stations at each cross-section and generally ranged from 0.04 for grass-lined channels to 0.08 for dense vegetation. Overbank roughness values were simplified and refined where appropriate to minimize the total number of roughness values assigned to each cross-section.

Table 4-2. Manning's roughness values utilized in HEC-RAS models.

2019 NLCD Land Use Classification	2019 NLCD Gridcode	Manning's Roughness Value
Open Water	11	0.038
Developed, Open Space	21	0.040
Developed, Low Intensity	22	0.060
Developed, Medium Intensity	23	0.080
Developed, High Intensity	24	0.090
Barren Land Rock-Sand-Clay	31	0.025
Deciduous Forest	41	0.100
Evergreen Forest	42	0.090
Mixed Forest	43	0.100
Shrub-Scrub	52	0.085
Grassland-Herbaceous	71	0.038
Pasture-Hay	81	0.038
Cultivated Crops	82	0.035
Woody Wetlands	90	0.080
Emergent Herbaceous Wetlands	95	0.068

4.2.4 Hydraulic structures

To model existing bridge and culvert structures on each study stream, available as-built plans were obtained from TxDOT and Karnes County Road and Bridge Department for use in model development. Where as-built plans were not available, field measurements were collected and were used to develop the structure models. Shallow structures with less than 4 feet of depth between the roadway surface and channel bottom were considered to have little impact on the limits of flooding during the 1% and 0.2% storm events. For such structures, no field measurements were collected, and nominal pipe sizes were assumed during model development.

At bridge and culvert structures, 4 cross sections were used to model the contraction and expansion areas in the vicinity of the openings. The roadway deck geometry was based on the project DEM and adjusted as needed based on field measurements collected for the project. Contraction and expansion coefficients of 0.3 and 0.5, respectively, were applied at the 2 nearest cross-sections upstream of each structure and 1 cross-section downstream. Where railing was present, 100% blockage was assumed, and the full height and length of railing was incorporated into the roadway deck geometry.

The same approach to cross-section placement and contraction and expansion coefficients was also utilized for existing inline dams and berms with a vertical height of 4 feet or greater. In those instances, the dams were modeled as inline structures. Where the models included large NRCS dams, rating curves from the HEC-HMS model were used to define the discharge through the structure.

4.2.5 Peak discharge application locations

Peak discharges for points of interest along each study stream were derived from the areal reduction spreadsheets for each study watershed. These peak discharges were applied in the HEC-RAS models using the following approach:

- For headwater basins and at the downstream end of reach segments, flow changes were placed 1/3 to 1/2 the stream distance upstream of the basin outfall.
- At stream confluences, the flow changes were generally set one cross-section downstream of the junction. In some cases, involving the confluence of two study streams, where the water surface elevation is controlled by the receiving stream, cross-sections in the receiving stream model were extended across both streams. As a conservative measure, the combined flow from the confluence of both streams was used to set a flow change location at the upstream end of the portion of the model with the extended cross-sections (please refer to Section 4.3 for more detailed information on these cases).
- In instances where flows from HEC-HMS nodes were found to decrease in the downstream direction, the more conservative upstream flows were maintained in the HEC-RAS model. This step was taken to ensure that flows increased in the downstream direction. The only exceptions to this approach were flow changes representing peak discharge reduction at NRCS dam structures.
- The flow values used in the HEC-RAS models were derived from the areal reduction spreadsheets and rounded in accordance with Section 3.1.2 in the SARB Regional Modeling Standards.

4.3 Detailed hydraulic modeling considerations

In addition to the methodology described in Section 4.2, this section discusses stream-specific details, assumptions, and considerations where special conditions or challenges were encountered in the development of the hydraulic models.

4.3.1 Ecleto Creek

At the confluence of ECL and DEC, the floodplain is primarily controlled by ECL. Therefore, between RS 69584-75346 in the ECL model, the cross-sections were extended across both ECL and DEC. To be conservative, the combined discharge from the confluence of the two streams (HEC-HMS node C30410) was applied at RS 75346 to represent the total flow in both streams.

At the confluence of ECL, ECL_T2, and ECL_T2_1, the floodplain is primarily controlled by ECL. Therefore, between RS 9439-12778 in the ECL model, the cross-sections were extended across all three streams. To be conservative, the combined discharge from the confluence of these streams (HEC-HMS node C30606) was applied at RS 12778 to represent the total flow in all three streams. The structure at RS 10413 represents the bridge at CR 326 on ECL_T2. This structure was modeled in the ECL model using a multiple opening analysis, and the ECL mainstem was represented as a conveyance area.

4.3.2 Dry Ecleto Creek

At the confluence of ECL and DEC, the floodplain is primarily controlled by ECL. Therefore, between RS 69584-75346 in the ECL model, the cross-sections were extended across both ECL and DEC. The downstream end of the DEC model was set just upstream of this confluence.

4.3.3 Tributary 1 to Ecleto Creek

At the confluence of ECL_T1 and ECL_T1_1, the floodplain is primarily controlled by ECL_T1. To model this area, RS 6889-8304 within the ECL_T1 model were extended to cross both ECL_T1 and ECL_T1_1. To be conservative, the combined discharge from the confluence of these two streams (HEC-HMS node C30616A) was applied at RS 8304 to represent the total flow in both streams. Within this segment of the model, two culvert structures exist side-by-side at CR 337, separated by about 300 ft. One structure lies on ECL_T1, and the other is located on ECL_T1_1. Using the combined discharge, these two crossings were analyzed using a multiple opening analysis within the ECL_T1 model.

The flow applied at RS 15058 represents the headwater flow for the stream. Approximately 42% of basin 30612 drains to RS 15058, so the headwater flow was estimated as 42% of the total flow at HEC-HMS node C30612.

4.3.4 Unnamed Tributary 1 to Tributary 1 to Ecleto Creek

The structure at RS 2683 represents two consecutive driveway culverts. Due to their close proximity, these culverts were modeled as a single structure (assumed to be 24" CMP).

The flow applied at RS 6120 represents the headwater flow for the stream. Approximately 22% of basin 30613 drains to RS 6120, so the headwater flow was estimated as 22% of the total flow at HEC-HMS node C30613.

4.3.5 Unnamed Tributary 2 to Tributary 1 to Ecleto Creek

The flow applied at RS 4587 represents the headwater flow for the stream. Approximately 21% of basin 30616 drains to RS 4587, so the headwater flow was estimated as 21% of the total flow at HEC-HMS node C30616.

4.3.6 Tributary 2 to Ecleto Creek

At the confluence of ECL, ECL_T2, and ECL_T2_1, the floodplain is primarily controlled by ECL. Therefore, between RS 9439-12778 in the ECL model, the cross-sections were extended across all three streams. The downstream end of the ECL_T2 model was set just upstream of this confluence.

The flow applied at RS 3363 represents the headwater flow for the stream. Approximately 13% of basin 30610 drains to RS 3363, so the headwater flow was estimated as 13% of the total flow at HEC-HMS node C30610.

4.3.7 Escondido Creek

The flow applied at RS 29333 represents HEC-HMS element C3040301, which is the confluence of nodes C3040301A and C3040303. Typically, the flow from HMS element C3040301A would be applied 1/3 of the distance from the bottom of drainage area 3040301 (near RS 31726). In this case however, the flows at C3040301A were slightly lower than the next upstream node (C3040224). As a conservative measure, a flow change was not applied for C3040301A, and the higher upstream flows applied at RS 35798 were maintained down to the confluence represented at RS 29333.

4.3.8 Unnamed Tributary 2 to Nichols Creek

Due to the small size of the drainage area and stream segment, this stream was modeled by applying the total flow from HEC-HMS node C3040220 at the upstream cross-section (RS 2213).

4.3.9 Unnamed Tributary 4 to Nichols Creek

Due to the small size of the drainage area and stream segment, this stream was modeled by applying the total flow from HEC-HMS node C3040219 at the upstream cross-section (RS 3067).

Review of the area downstream of FM 239 (RS 611) indicates that an underground storm drain exists beneath the industrial facility structures. This storm drain was modeled in the 1D HEC-RAS model as a long culvert. In the absence of detailed site data, the culvert dimensions were inferred from the culvert structure on FM 239. The floodplain along the stream centerline is contained within the culvert structure with additional inundation areas shown in the overbanks. Due to the complexity of the drainage conditions, this particular area would benefit from a more detailed 2D analysis, which is beyond the scope of this FPPS.

4.3.10 Panther Creek

A rail height of 32" was assumed for the culvert structures at SH 72 (RS 25386).

The flow applied at RS 39968 represents the headwater flow for the stream. Approximately 13% of basin 3040206 drains to RS 39968, so the headwater flow was approximated as 13% of the total flow at HEC-HMS node C3040206.

4.3.11 Hondo Creek

HEC-HMS node C40517 is located approximately 1,300 feet downstream of node C40514. Due to this close proximity, the flow change applied at RS 30286 represents the more conservative flows from C40517 rather than C40514.

As-built plans for the NRCS Site 1 Reservoir were requested from the Hondo Creek Watershed District but were not received. As a result, the dam was modeled based on LiDAR data.

4.3.12 Tributary 147 to Lower San Antonio River

The flow applied at RS 32688 represents the headwater flow for the stream. Approximately 9% of basin 20604 drains to RS 32688, so the headwater flow was estimated as 9% of the total flow at HEC-HMS node C20604A.

4.3.13 Unnamed Tributary 2 to Tributary 147 to Lower San Antonio River

Due to the small size of the drainage area and stream segment, this stream was modeled by applying the total flow from HEC-HMS node C20605 at the upstream cross-section (RS 2424).

4.3.14 Tributary 152 to Lower San Antonio River

The flow applied at RS 9446 represents the headwater flow for the stream. Approximately 58% of basin 20601 drains to RS 9446, so the headwater flow was estimated as 58% of the total flow at HEC-HMS node C20601A.

4.3.15 Unnamed Tributary 1 to Tributary 152 to Lower San Antonio River

The flow applied at RS 2829 represents the headwater flow for the stream. Approximately 23% of basin 20602 drains to RS 2829, so the headwater flow was approximated as 23% of the total flow at HEC-HMS node C20602.

4.3.16 Marcelinas Creek

Bridge and culvert structure data were leveraged from the SARA 2007 Map Modernization Study.

Using the rounding guidance in Section 3.1.2 in the SARB Modeling Standards, the flows associated with HEC-HMS nodes C20256 and C20257 rounded to the same values. Therefore, the flows for C20256 were applied at RS 14028, and a flow change for C20257 was not included farther downstream to avoid redundancy.

4.3.17 Ojo De Agua Creek

Cross-sections and drainage structure data from the SARA DFIRM model were leveraged and updated with more recent topography and available as-built plans. Cross-section placement was adjusted as needed to represent updated topographic data.

The field sketch for CR 122/FM 885 (designated as crossing OJO_1000) shows 4 spans. The SARA DFIRM model, the TxDOT bridge inventory data, and site photos indicate there are 3 spans. Therefore, the bridge model was developed using 3 spans rather than 4.

At the confluence of OJO and OJO_T10, the floodplain is primarily controlled by OJO. To model this area, RS 31739-33569 within the OJO model were extended to cross both OJO and OJO_T10. To be conservative, the combined discharge from the confluence of these two streams (HEC-HMS node C40405) was applied at RS 33569 to represent the total flow in both streams. Within this segment of the model, two culvert structures exist side-by-side at FM 1020, separated by about 450 ft. One structure lies on OJO, and the other is located on OJO_T10. Using the combined discharge, these two crossings were analyzed using a multiple opening analysis within the OJO model.

4.3.18 Tributary 8 to Ojo De Agua Creek

The downstream normal depth slope of 0.0016 was determined using the average 1% energy grade slope between RS 26006 and 25593 in the OJO model. This section of the OJO model contains the confluence of OJO and OJO_T8 reflecting the downstream boundary condition.

The flow applied at RS 3460 represents the headwater flow for the stream. Approximately 41% of basin 40411 drains to RS 3460, so the headwater flow was approximated as 41% of the total flow at HEC-HMS node C40411.

4.3.19 Tributary 10 to Ojo De Agua Creek

The downstream normal depth slope of 0.0032 was determined using the average 1% energy grade slope between RS 31739 and 33569 in the OJO model. This portion of the OJO model contains the downstream end of OJO_T10 reflecting the downstream boundary condition.

The field sketch and photos for the CR 325A crossing (designated as OJO_T10_2000) indicated the presence of debris at the culvert inlet. The Manning's roughness value was increased to 0.1 at RS 512 to reflect the debris.

At the confluence of OJO and OJO_T10, the floodplain is primarily controlled by OJO. To model this area, RS 31739-33569 within the OJO model were extended to cross both OJO and OJO_T10. The downstream end of the OJO_T10 model was set just upstream of this confluence.

4.4 Model calibration

Calibration data, such as high-water marks or historical flooding data, were not available for the study streams. Due to this lack of available information, the hydraulic model parameters were not adjusted for calibration purposes.

4.5 Floodplain mapping

Using the results of the 1D HEC-RAS models, updated floodplain boundaries reflecting Atlas 14 precipitation data were developed for the 1% and 0.2% storm events. The raw inundation boundaries were exported from RAS Mapper into ArcGIS Pro and processed to produce cleaner datasets for use in the creation of floodplain maps. The processing tasks included the elimination of inundation areas and holes less than one acre in size. In addition, the inundation boundaries were simplified by removing vertices with a maximum horizontal offset of 3 feet. Updated floodplain maps for each study stream are provided in **Appendix A**.

5 Flood mitigation alternatives

Based on the collected baseline information and results of the hydraulic models, flood problem areas were identified and evaluated. These sections describe the selection and assessment of flood mitigation alternatives for high-priority flood hazard areas in the County.

5.1 Flood problem area identification

Flood problem areas were identified throughout Karnes County during the course of this FPPS. A complete list of these flood problem areas is provided in **Appendix K**. Many of these areas were identified as high-priority flood hazards by Karnes County officials and residents, as well as previous flood hazard studies, such as the Holistic Watershed Master Plan for Karnes, Goliad, and Wilson Counties. Other flood problem areas were identified based on the results of the 1D hydraulic analyses discussed in Section 4. Fifteen (15) high-priority flood problem areas located throughout Karnes County were selected to develop flood mitigation alternatives and are listed in **Table 5-1**.

Table 5-1. Karnes County Flood Mitigation Projects.

Project Identifier	Flood Mitigation Project Title
KC-1	CR 294 Drainage Improvements at Dry Ecleto Creek
KC-2	CR 302 Drainage Improvements at Ecleto Creek
KC-3	CR 262 Drainage Improvements at Ecleto Creek
KC-4	Drainage Improvements at CR 337 and CR 326 Near City of Runge
KC-5	CR 336 Drainage Improvements at Ecleto Creek Tributary
KC-6	CR 331 Drainage Improvements at Escondido Creek
KC-7	City of Kenedy Drainage Improvements on Escondido Creek*
KC-8	CR 127 Drainage Improvements at Hondo Creek
KC-9	CR 145 Drainage Improvements at Hondo Creek
KC-10	CR 354 Drainage Improvements at Lower San Antonio Tributary 147
KC-11	US 181 Drainage Improvements at Marcelinas Creek Trib*
KC-12	Nichols Creek Tributary 2 Drainage Improvements
KC-13	Nichols Creek Tributary 4 Drainage Improvements
KC-14	CR 325 Drainage Improvements at Ojo De Agua Creek
KC-15	CR 163 Drainage Improvements at Panther Creek

*Identified as a Damage Center in the Holistic Watershed Master Plan for Karnes, Goliad, and Wilson Counties

Alternatives analyses included conceptual design, hydrologic and hydraulic modeling, construction cost estimation, and benefit-cost analyses. Conceptual design and modeling of alternatives were performed using new, two-dimensional (2D) HEC-RAS version 6.3 hydraulic models for each flood problem area.

The primary objectives of the proposed mitigation alternatives were to remove existing structures from the 100-year floodplain and to improve the level-of-service of existing low water crossings. Conceptual designs were adjusted to ensure no negative impacts were created beyond the public right-of-way (ROW), project property, or easement, in accordance with TWDB Technical

Guidelines for Regional Flood Planning. The 15 recommended Flood Mitigation Projects (FMPs) discussed in this report were incorporated into the July 14, 2023 Amendment of the 2023 San Antonio Regional Flood Plan for Flood Planning Region 12.

In addition to the 15 FMPs listed in **Table 5-1**, ten (10) additional flood problem areas were identified as Flood Mitigation Evaluations (FMEs), where further analysis will be needed to define existing flood hazards and develop mitigation solutions. Many of these FMEs were previously identified as damage centers in the Holistic Watershed Master Plan for Karnes, Goliad, and Wilson Counties. These flood problem areas are listed in **Table 5-2** along with a brief description of the needed evaluations. As with the FMPs listed above, these FMEs were incorporated into the July 14, 2023 Amendment of the 2023 San Antonio Regional Flood Plan for Flood Planning Region 12. For more detailed summaries of the proposed FMEs and FMPs in accordance with Section 2.5 of *TWDB Technical Guidelines for Regional Flood Planning*, please see **Tables 5-3** and **5-4**. These tables have also been provided in **Appendix M**.

Table 5-2. Karnes County Flood Management Evaluations.

Flood Management Evaluation Name	Description of Evaluation Needed
CR 326B at Ecleto Creek	Evaluate upgrades to existing bridge with consideration of backwater from San Antonio River
City of Kenedy Flooding on Escondido Creek Tributary*	Evaluate alternatives to mitigate flooding within City of Kenedy commercial area along Escondido Creek tributary
CR 237 at Marcelinas Creek	Evaluate upgrades to existing bridge with consideration of backwater from San Antonio River
Falls City Flooding from San Antonio River*	Evaluate alternatives to mitigate flooding from the San Antonio River affecting buildings in the City of Falls City
San Antonio River Flooding on US 181*	Evaluate alternatives to mitigate US 181 flooding from the San Antonio River and tributaries
Cibolo Creek Flooding on SH 123*	Evaluate alternatives to mitigate SH 123 flooding from Cibolo Creek
San Antonio River Flooding on SH 80*	Evaluate alternatives to mitigate SH 80 flooding from the San Antonio River and tributaries
Localized Residential Flooding in City of Kenedy*	Evaluate alternatives to mitigate localized residential flooding in the southern portion of the City of Kenedy
San Antonio River Flooding on SH 72*	Evaluate alternatives to mitigate SH 72 flooding from the San Antonio River and tributaries
Karnes County FEWS	Evaluate upgrades to Flood Early Warning Systems

* Identified as a Damage Center in the Holistic Watershed Master Plan for Karnes, Goliad, and Wilson Counties

Table 5-3. Karnes County Flood Management Evaluations recommended by RFPG.

FME ID	FME Name	Description	Associated Goals	Counties	HUC8s	HUC12s	Watershed Name	FME Study Area (sqmi)	Flood Risk Type	Sponsor	Entities with Oversight	Emergency Need	Estimated Study Cost	RFPG Recommendation	Reason for Recommendation
121000175	CR 326B at Ecleto Creek	Evaluate upgrades to existing bridge with consideration of backwater from San Antonio River	12000030	Karnes	12100303	121003030306	12000016	0.11	Riverine	00000095	00000095, 00000255, 00000282, 00001006	Yes	$100,000	Yes	HDR Recommended
121000176	CR 237 at Marcelinas Creek	Evaluate upgrades to existing bridge with consideration of backwater from San Antonio River	12000030	Karnes	12100303	121003030204	12000027	0.02	Riverine	00000095	00000095, 00000255, 00000282, 12002974	Yes	$100,000	Yes	HDR Recommended
121000177	City of Kenedy Flooding on Escondido Creek Tributary	Evaluate alternatives to mitigate flooding within City of Kenedy commercial area along Escondido Creek tributary	12000026	Karnes	12100303	121003030402	12000021	0.28	Riverine	00000095	00000095, 00000255, 00000282, 00000519, 12002975	Yes	$100,000	Yes	HDR Recommended
121000178	Falls City Flooding from San Antonio River	Evaluate alternatives to mitigate flooding from the San Antonio River affecting buildings in the City of Falls City	12000026	Karnes	12100303	121003030204, 121003030202, 121003030205	12000027, 12000030, 12000034	0.70	Riverine	00000095	00000095, 00000255, 00000282, 12002974	Yes	$100,000	Yes	HDR Recommended
121000179	San Antonio River Flooding on US 181	Evaluate alternatives to mitigate US 181 flooding from the San Antonio River and tributaries	12000030	Karnes	12100303	121003030205	12000034	1.00	Riverine	00000095	00000095, 00000255, 00000282	Yes	$100,000	Yes	HDR Recommended
121000180	Cibolo Creek Flooding on SH 123	Evaluate alternatives to mitigate SH 123 flooding from Cibolo Creek	12000030	Karnes	12100304	121003040405	12000057	0.58	Riverine	00000095	00000095, 00000255, 00000282	Yes	$100,000	Yes	HDR Recommended
121000181	San Antonio River Flooding on SH 80	Evaluate alternatives to mitigate SH 80 flooding from the San Antonio River and tributaries	12000030	Karnes	12100303	121003030206	12000037	0.17	Riverine	00000095	00000095, 00000255, 00000282	Yes	$100,000	Yes	HDR Recommended

Table 5-3. Karnes County Flood Management Evaluations recommended by RFPG (continued).

FME ID	FME Name	Description	Associated Goals	Counties	HUC8s	HUC12s	Watershed Name	FME Study Area (sqmi)	Flood Risk Type	Sponsor	Entities with Oversight	Emergency Need	Estimated Study Cost	RFPG Recommendation	Reason for Recommendation
121000182	Localized Residential Flooding in City of Kenedy	Evaluate alternatives to mitigate localized residential flooding in the southern portion of the City of Kenedy	12000026	Karnes	12100303	121003030402	12000021	0.15	Local	00000095	00000095, 00000255, 00000282, 00000519, 12002975	Yes	$100,000	Yes	HDR Recommended
121000183	San Antonio River Flooding on SH 72	Evaluate alternatives to mitigate SH 72 flooding from the San Antonio River and tributaries	12000030	Karnes	12100303	121003030403, 121003030404	12000022, 12000023	0.38	Riverine	00000095	00000095, 00000255, 00000282, 00000519	Yes	$100,000	Yes	HDR Recommended
121000184	Karnes County FEWS	Flood Early Warning System	12000009	De Witt, Wilson, Goliad, Karnes	12100204, 12100303, 12100304, 12100202, 12100406, 12110110, 12110111		12000014, 12000016, 12000019, 12000020, 12000021, 12000022, 12000023, 12000024, 12000025, 12000026, 12000027, 12000030, 12000034, 12000037, 12000040, 12000041, 12000042, 12000043, 12000045, 12000052, 12000057, 12000070	751.06	Riverine	00000095	00000095, 00000099, 00000100, 00000255, 00000260, 00000264, 00000282, 00000290, 00000291, 00000519, 00000526, 00001006, 12002756, 12002757, 12002974, 12002975	Yes	$100,000	Yes	HDR Recommended

Table 5-4. Karnes County Flood Mitigation Projects recommended by RFPG.

FMP ID	FMP Name	Description	Associated Goals (ID)	Counties	HUC8s	HUC12s	Watershed Name	Project Type	Project Area (sqmi)	Flood Risk Type (Riverine, Coastal, Urban, Playa, Other)	Sponsor	Entities with Oversight	Emergency Need (Y/N)
123000066	CR 294 Drainage Improvements at Dry Ecleto Creek	Upgrade CR 294 to include new bridge structure with roadway and channel improvements for 100 year roadway access	12000031	Karnes	12100303	121003030304	Ecleto Creek	LWC upgrade	0.437	Riverine	00000095	00000095, 00000255, 00000282, 00001006	No
123000067	CR 302 Drainage Improvements at Ecleto Creek	Upgrade existing low water crossing to include roadway elevation, a new bridge structure, and channel improvements	12000031	Karnes	12100303	121003030305, 121003030304	Ecleto Creek	LWC upgrade	0.525	Riverine	00000095	00000095, 00000255, 00000282, 00001006	No
123000068	CR 262 Drainage Improvements at Ecleto Creek	Upgrade CR 262 to include roadway elevation, bridge expansion, and channel improvements	12000031	Karnes	12100303	121003030303	Ecleto Creek	LWC upgrade	0.570	Riverine	00000095	00000095, 00000255, 00000282, 00001006	No
123000069	Drainage Improvements at CR 337 and CR 326 Near City of Runge	Elevate CR 337 and CR 326 and upgrade low water crossings to include box culverts and channel improvements. Channel improvements along CR 337 to improve level of service	12000026, 12000031	Karnes	12100303	121003030306	Ecleto Creek	Comprehensive	0.227	Riverine	00000095	00000095, 00000255, 00000282, 00001006, 12002757	Yes
123000070	CR 336 Drainage Improvements at Ecleto Creek Tributary	Upgrade CR 336 low water crossing to include a new bridge structure with roadway and channel improvements	12000031	Karnes	12100303	121003030306	Ecleto Creek	LWC upgrade	0.029	Riverine	00000095	00000095, 00000255, 00000282, 00001006	No
123000071	CR 331 Drainage Improvements at Escondido Creek	Upgrade existing low water crossing to include roadway elevation, a new bridge structure, and channel improvements	12000031	Karnes	12100303	121003030403	Escondido Creek	LWC upgrade	0.084	Riverine	00000095	00000095, 00000255, 00000282, 00000519	No
123000072	City of Kenedy Drainage Improvements on Escondido Creek	Upgrade 5th Street culvert with additional boxes, roadway elevation, and channel modifications. Additional channel modifications through Kenedy to improve conveyance and reduce flooding of structures.	12000026, 12000031	Karnes	12100303	121003030402	Escondido Creek	Comprehensive	0.340	Riverine	00000095	00000095, 00000255, 00000282, 00000519, 12002975	Yes
123000073	CR 127 Drainage Improvements at Hondo Creek	Upgrade existing low water crossing to include roadway elevation, a new bridge structure, and channel improvements	12000031	Karnes	12100303	121003030405	Hondo Creek	LWC upgrade	0.323	Riverine	00000095	00000095, 00000255, 00000282, 00000526	No

Table 5-4. Karnes County Flood Mitigation Projects recommended by RFPG (continued).

FMP ID	FMP Name	Description	Associated Goals (ID)	Counties	HUC8s	HUC12s	Watershed Name	Project Type	Project Area (sqmi)	Flood Risk Type (Riverine, Coastal, Urban, Playa, Other)	Sponsor	Entities with Oversight	Emergency Need (Y/N)
123000074	CR 145 Drainage Improvements at Hondo Creek	Upgrade existing low water crossing to include roadway elevation, a new bridge structure, and channel improvements	12000031	Karnes	12100303	121003030405	Hondo Creek	LWC upgrade	0.080	Riverine	00000095	00000095, 00000255, 00000282, 00000526	No
123000075	CR 354 Drainage Improvements at Lower San Antonio Tributary 147	Elevate roadway and upgrade existing culvert structure with a new bridge structure and channel improvements	12000031	Karnes	12100303	121003030206	Lower San Antonio River	LWC upgrade	0.260	Riverine	00000095	00000095, 00000255, 00000282	No
123000076	US 181 Drainage Improvements at Marcelinas Creek Trib	Upgrade US HWY 181 culvert crossing to include additional boxes and channel improvements to mitigate residential flooding south of the highway	12000026, 12000031	Karnes	12100303	121003030204	Marcelinas Creek	Comprehensive	0.124	Riverine	00000095	00000095, 00000255, 00000282, 12002974	Yes
123000077	Nichols Creek Tributary 2 Drainage Improvements	Upgrade Escondido Street crossing with an additional box and upstream channel improvements	12000026, 12000031	Karnes	12100303	121003030402	Escondido Creek	LWC upgrade	0.020	Riverine	00000095	00000095, 00000255, 00000282, 00000519, 12002975	No
123000078	Nichols Creek Tributary 4 Drainage Improvements	Channel improvements upstream (east) of Escondido Street; lower existing pond bottom at Kenedy Retreat Apartments to increase capacity	12000026	Karnes	12100303	121003030402	Escondido Creek	LWC upgrade	0.026	Riverine	00000095	00000095, 00000255, 00000282, 00000519, 12002975	No
123000079	CR 325 Drainage Improvements at Ojo De Agua Creek	Upgrade CR 325 crossing with roadway elevation, bridge structure upgrades, and channel improvements	12000031	Karnes	12100303	121003030404	Ojo De Agua Creek	LWC upgrade	0.047	Riverine	00000095	00000095, 00000255, 00000282	No
123000080	CR 163 Drainage Improvements at Panther Creek	Elevate roadway and upgrade existing culvert structure to include box culverts and channel improvements	12000031	Karnes	12100303	121003030402	Escondido Creek	LWC upgrade	0.090924	Riverine	00000095	00000095, 00000255, 00000282, 00000519	No

Table 5-4. Karnes County Flood Mitigation Projects recommended by RFPG (continued).

FMP ID	FMP Name	Estimated Project Cost ($)	Potential Funding Sources and Amount	Cost/ Structure removed	Percent Nature- based Solution (by cost)	Negative Impact (Y/N)	Negative Impact Mitigation (Y/N)	Water Supply Benefit (Y/N)	Benefit-Cost Ratio	Social Vulnerability Index (SVI)	RFPG Recommendation	Reason for Recommendation
123000066	CR 294 Drainage Improvements at Dry Ecleto Creek	$7,178,000	None	-	0.05	No	No	No	0.3	0.0831	Yes	HDR Recommended
123000067	CR 302 Drainage Improvements at Ecleto Creek	$15,261,000	None	-	0.05	No	No	No	0.7	0.504	Yes	HDR Recommended
123000068	CR 262 Drainage Improvements at Ecleto Creek	$11,242,400	None	-	0.05	No	No	No	0.1	0.0831	Yes	HDR Recommended
123000069	Drainage Improvements at CR 337 and CR 326 Near City of Runge	$6,773,000	None	$6,773,000	0.05	No	No	No	0.0	0.504	Yes	HDR Recommended
123000070	CR 336 Drainage Improvements at Ecleto Creek Tributary	$2,859,756	None	-	0.05	No	No	No	0.0	0.504	Yes	HDR Recommended
123000071	CR 331 Drainage Improvements at Escondido Creek	$4,865,554	None	-	0.05	No	No	No	0.4	0.736	Yes	HDR Recommended
123000072	City of Kenedy Drainage Improvements on Escondido Creek	$33,317,000	None	$594,946	0.05	No	No	No	0.1	0.736	Yes	HDR Recommended
123000073	CR 127 Drainage Improvements at Hondo Creek	$8,992,000	None	-	0.05	No	No	No	0.2	0.736	Yes	HDR Recommended
123000074	CR 145 Drainage Improvements at Hondo Creek	$3,688,372	None	-	0.05	No	No	No	0.3	0.736	Yes	HDR Recommended

Table 5-4. Karnes County Flood Mitigation Projects recommended by RFPG (continued).

FMP ID	FMP Name	Estimated Project Cost ($)	Potential Funding Sources and Amount	Cost/ Structure removed	Percent Nature- based Solution (by cost)	Negative Impact (Y/N)	Negative Impact Mitigation (Y/N)	Water Supply Benefit (Y/N)	Benefit-Cost Ratio	Social Vulnerability Index (SVI)	RFPG Recommendation	Reason for Recommendation
123000075	CR 354 Drainage Improvements at Lower San Antonio Tributary 147	$6,467,859	None	-	0.05	No	No	No	0.0	0.916	Yes	HDR Recommended
123000076	US 181 Drainage Improvements at Marcelinas Creek Trib	$2,465,200	None	$1,232,600	0.05	No	No	No	0.1	0.083	Yes	HDR Recommended
123000077	Nichols Creek Tributary 2 Drainage Improvements	$1,651,000	None	$1,651,000	0.05	No	No	No	1.6	0.736	Yes	HDR Recommended
123000078	Nichols Creek Tributary 4 Drainage Improvements	$1,441,000	None	-	0.05	No	No	No	1.8	0.736	Yes	HDR Recommended
123000079	CR 325 Drainage Improvements at Ojo De Agua Creek	$2,007,000	None	-	0.05	No	No	No	0.0	0.504	Yes	HDR Recommended
123000080	CR 163 Drainage Improvements at Panther Creek	$3,218,400	None	-	0.05	No	No	No	0.2	0.7358	Yes	HDR Recommended

5.2 Modeling analysis and methodology

To analyze potential mitigation solutions for the 15 FMPs identified in this study, 2D unsteady-state models were prepared in HEC-RAS version 6.3. This approach was taken to streamline the modeling process by eliminating intermediate steps requiring reach routing updates in the hydrologic (HEC-HMS) models to account for proposed channel modifications. In general, the 2D mesh for each study area was defined using a 50 ft x 50 ft grid with some modifications made as necessary around breaklines representing high points and 2D connections representing culvert or bridge structures.

The upstream and internal boundary conditions for the models were defined using flow hydrographs extracted from the HEC-HMS models. To define the downstream boundary conditions, normal depth slopes were estimated using the DTM developed for this FPPS from publicly available LiDAR data. The only exception to this downstream boundary condition approach was for CR 163 @ Panther Creek (Project KC-15), which is located just upstream of existing NRCS Dam Site 13. For that model, the rating curve for the dam structure was obtained from the HEC-HMS model and used to define the downstream boundary condition for the 2D HEC-RAS model.

Land cover classifications were assigned using the 2019 National Land Cover Database, and Manning's roughness values for each classification were obtained from Table 2.1 in the HEC-RAS 2D Modeling User's Manual. The terrain modification tools within RAS Mapper were utilized to represent proposed channel improvements within the project area. In areas representing proposed excavation, a Manning's roughness value of 0.04 was generally used.

The flood mitigation alternatives were modeled for various hypothetical flood events following TWDB Regional Flood Planning guidelines. Existing and proposed conditions for low-water crossings were generally assessed for the 2-, 10-, and 100-year storm events. In cases where there were no existing damages in the 2-year storm, the 10-, 25-, and 100-year storm events were used for the analyses.

In general, the mitigation improvements proposed for each project were designed to remove existing structures from the 100-year floodplain and to improve the level-of-service of existing low water crossings. Where channel improvements are proposed, channel benching was preliminarily designed to preserve the existing natural channel in an effort to minimize impacts to jurisdictional Waters of the US. A Manning's roughness value of 0.04 was generally assigned within areas of proposed excavation under the assumption that they would not be regularly maintained. Channel improvement projects will include nature-based solution (NBS) elements including riparian habitat restoration to enhance bank stability and water quality. Specific details for each improvement project are provided in Section 5.3.

5.3 Proposed flood mitigation projects

This section provides details on the following items for each of the 15 proposed FMPs:

- The existing conditions flood risk
- The proposed improvements
- The flood mitigation benefits of the project

5.3.1 Project KC-1 – CR 294 drainage improvements at Dry Ecleto Creek

The CR 294 low water crossing at Dry Ecleto Creek was identified by Karnes County as a high priority flood problem area. Based on preliminary modeling results, under existing conditions, the 2-year depth of flooding at the low water crossing is 9.5 feet, and the roadway is impassible for nearly 37 hours. During the 100-year event, the depth increases to 18.5 feet, making the roadway impassible for 48.5 hours. Please see **Figure 5-1A** for a view of the study area.

The proposed project for CR 294 was developed to improve the level-of-service for the roadway to accommodate daily traffic and emergency services. The proposed improvements include elevating the roadway to approximately 304.5 feet NAVD88, installing a 100-ft bridge, and approximately 1,600 linear feet of trapezoidal channel improvements with a bottom width of 100 feet and side slopes of 4:1. Please see **Figure 5-1B** for a depiction of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a 100-year level-of-service for the roadway and no overtopping. This reduction in depth makes the roadways passable during the 100-year event, whereas the roadway is impassable for 48.5 hours under existing conditions. Please see **Figure 5-1C** for a depiction of the 100-year flood risk reduction.

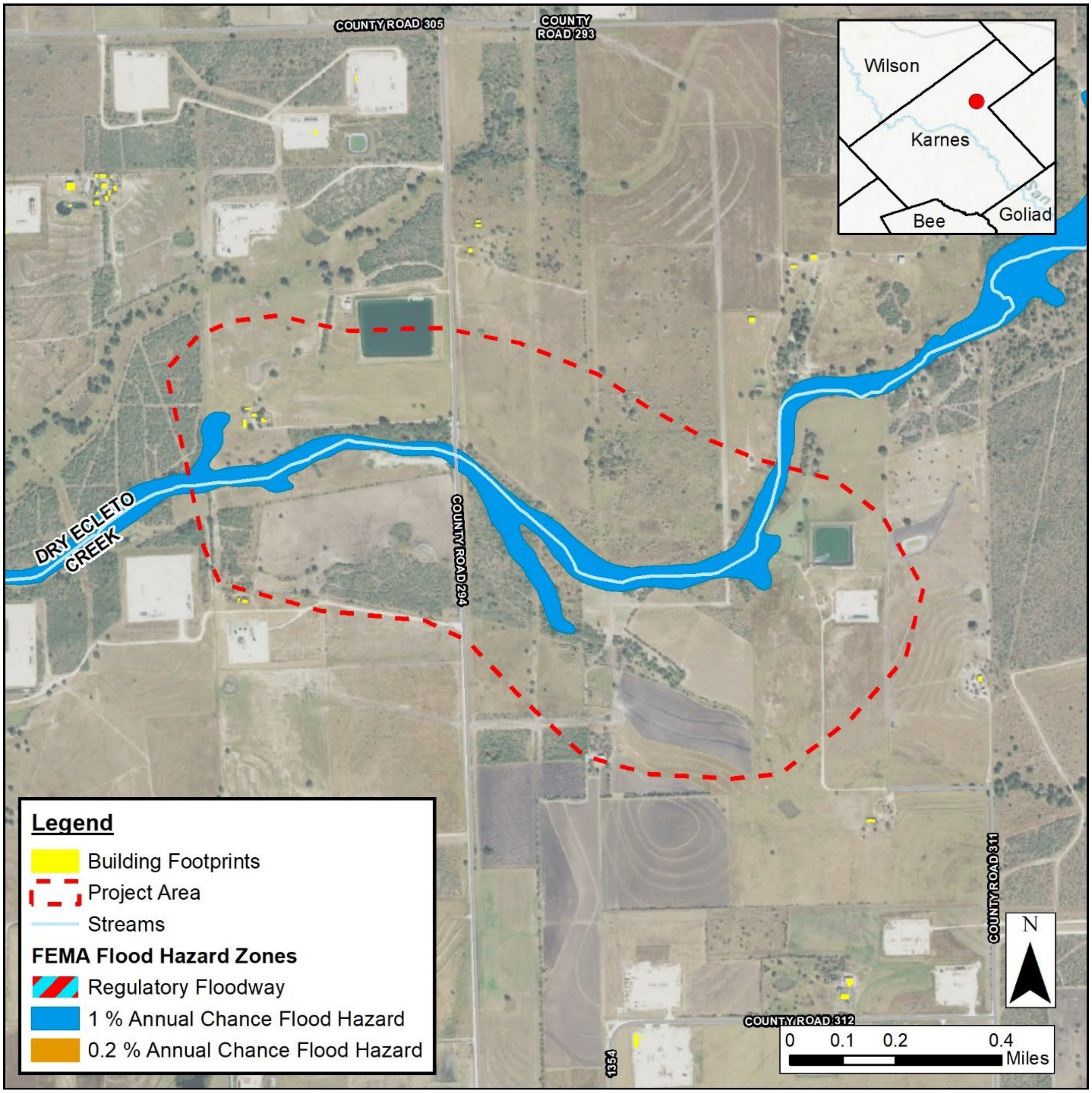

Figure 5-1A Project KC-1 study area location.

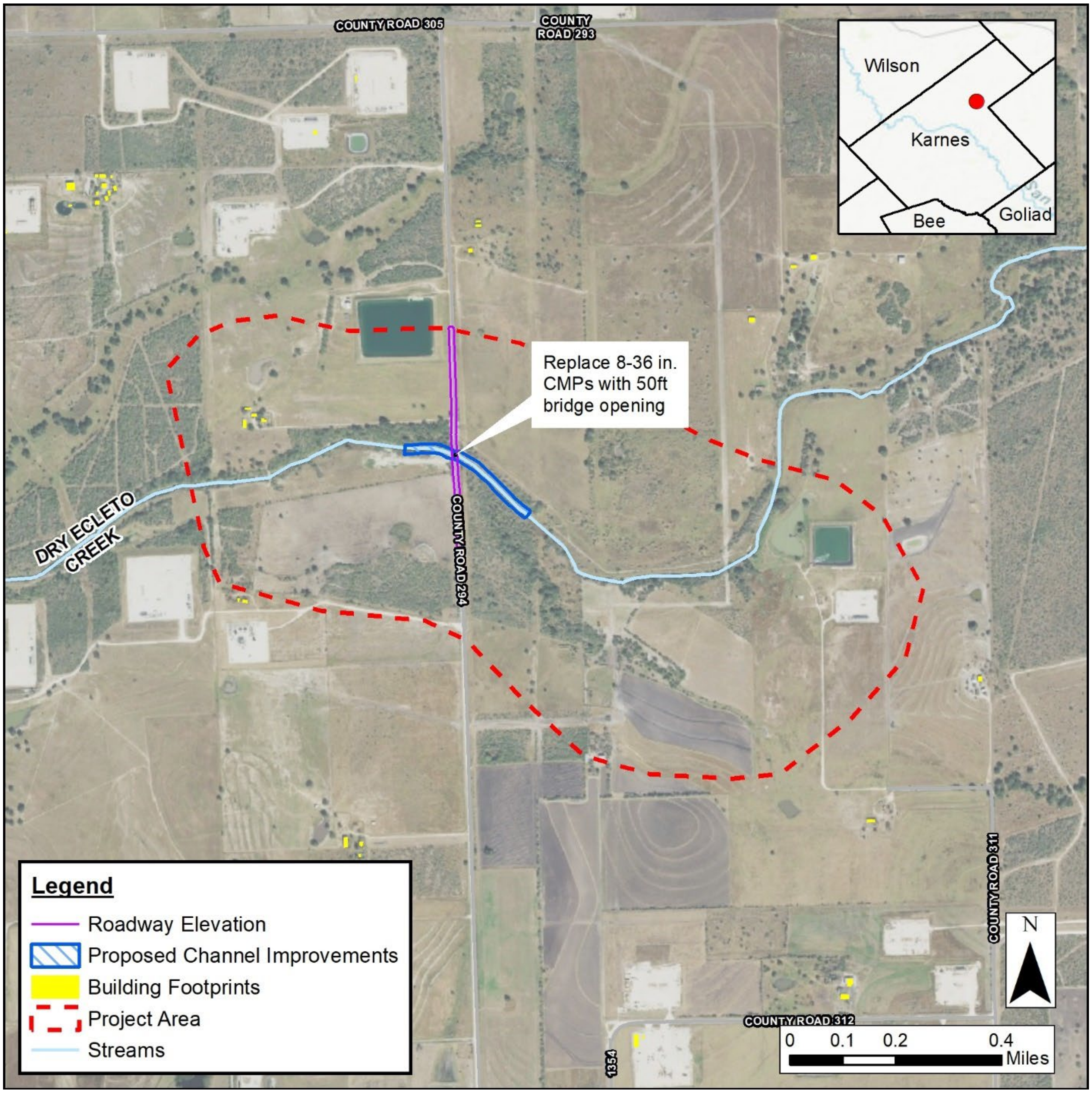

Figure 5-1B Project KC-1 proposed improvements.

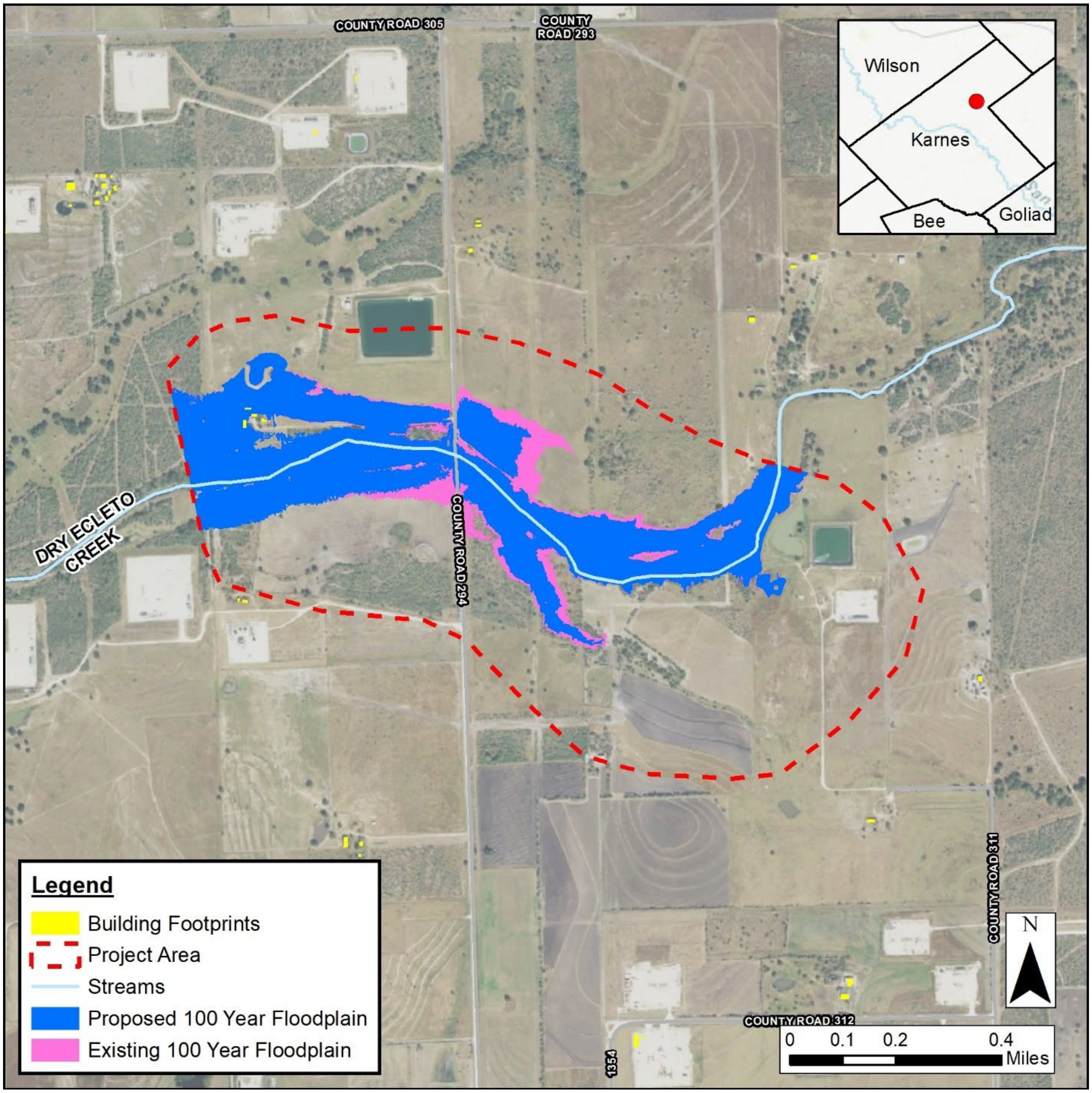

Figure 5-1C Project KC-1 flood risk reduction for the 100-year event.

5.3.2 Project KC-2 – CR 302 drainage improvements at Ecleto Creek

The CR 302 low water crossing at Ecleto Creek was identified by Karnes County as a high priority flood problem area. Based on preliminary modeling results, under existing conditions, the 2-year depth of flooding is 11.2 feet, and the roadway is impassible for an estimated 6 days. During the 100-year event, the depth increases to 20.7 feet, making the roadway impassible for an estimated 7 days. Please see **Figure 5-2A** for a view of the study area.

The proposed project for CR 302 was developed to improve the level-of-service for the roadway to accommodate daily traffic and emergency services. The proposed improvements include elevating the roadway to approximately 259 feet NAVD88 through to 261 feet NAVD88 across the channel opening, installing a 300-foot-long bridge, 1,600 linear feet of trapezoidal channel improvements with a bottom width of 150 feet and 4:1 side slopes, and 1,000 linear feet of trapezoidal channel improvements with a bottom width of 100 feet and 4:1 side slopes. Please see **Figure 5-2B** for a depiction of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a 100-year level-of-service for the roadway and no overtopping. This reduction in depth makes the roadway passable during the 100-year event, whereas the roadway is impassable for an estimated 7 days under existing conditions. Please see **Figure 5-2C** for a depiction of the 100-year flood risk reduction.

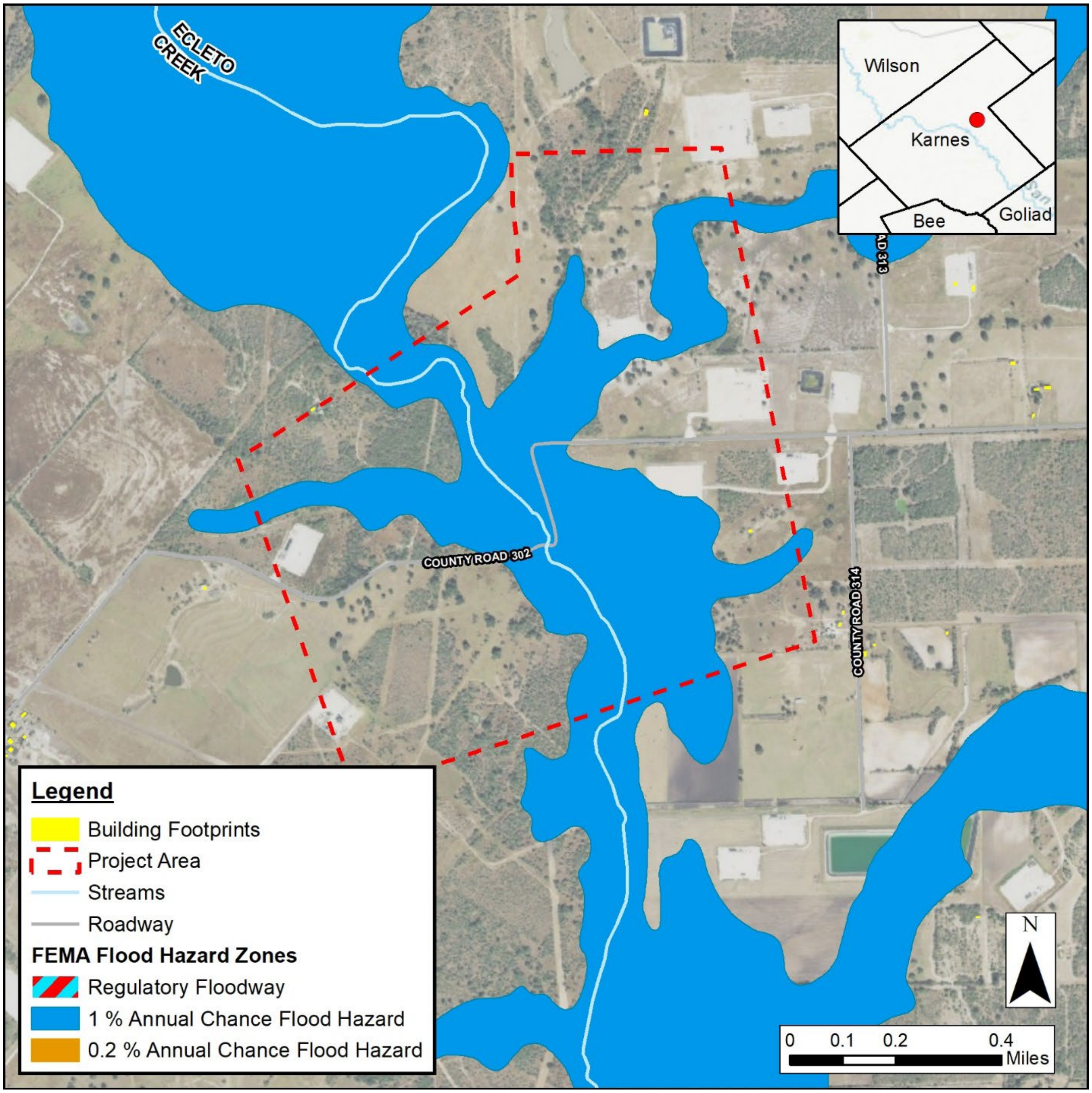

Figure 5-2A Project KC-2 study area location.

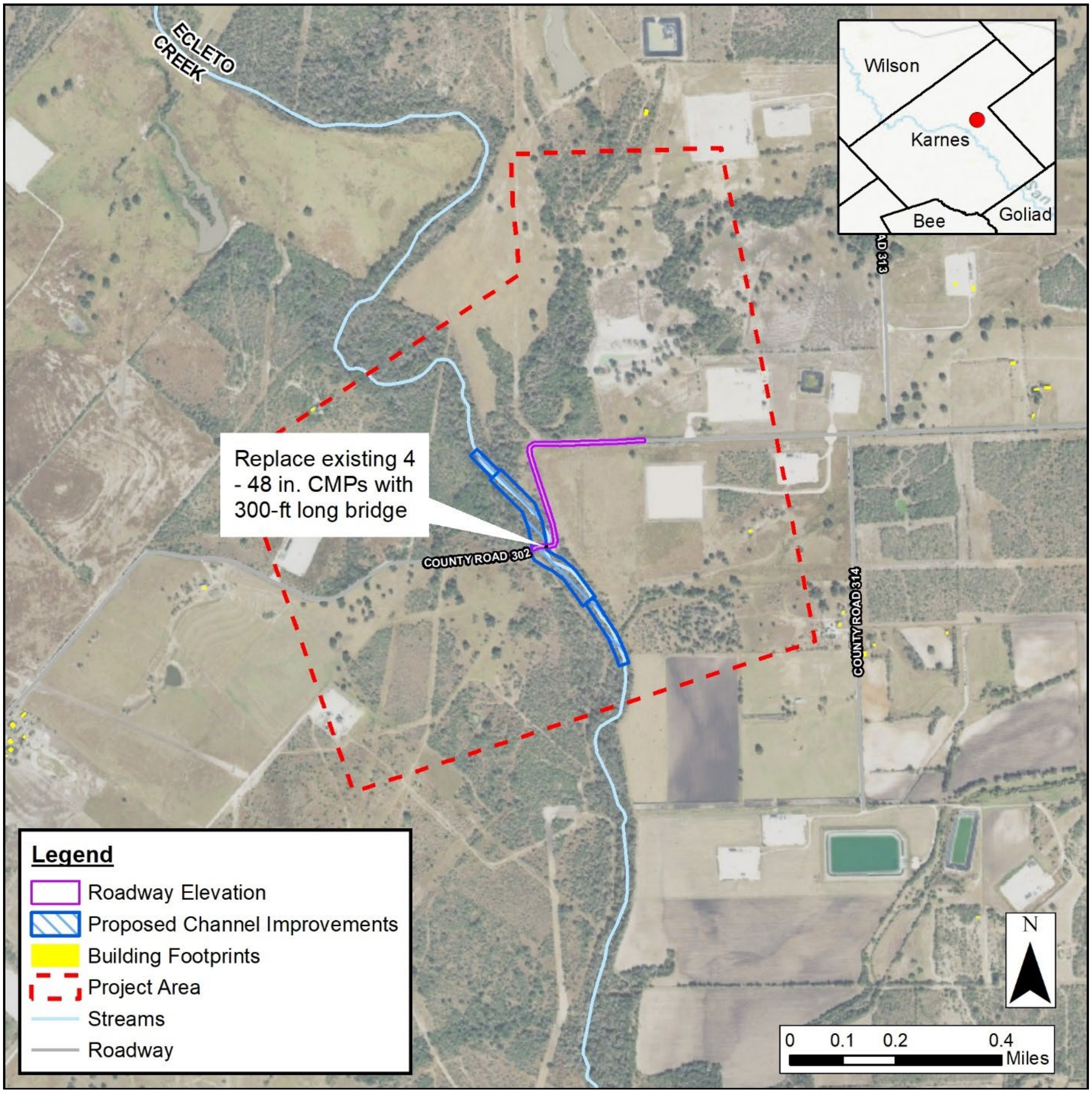

Figure 5-2B Project KC-2 proposed improvements.

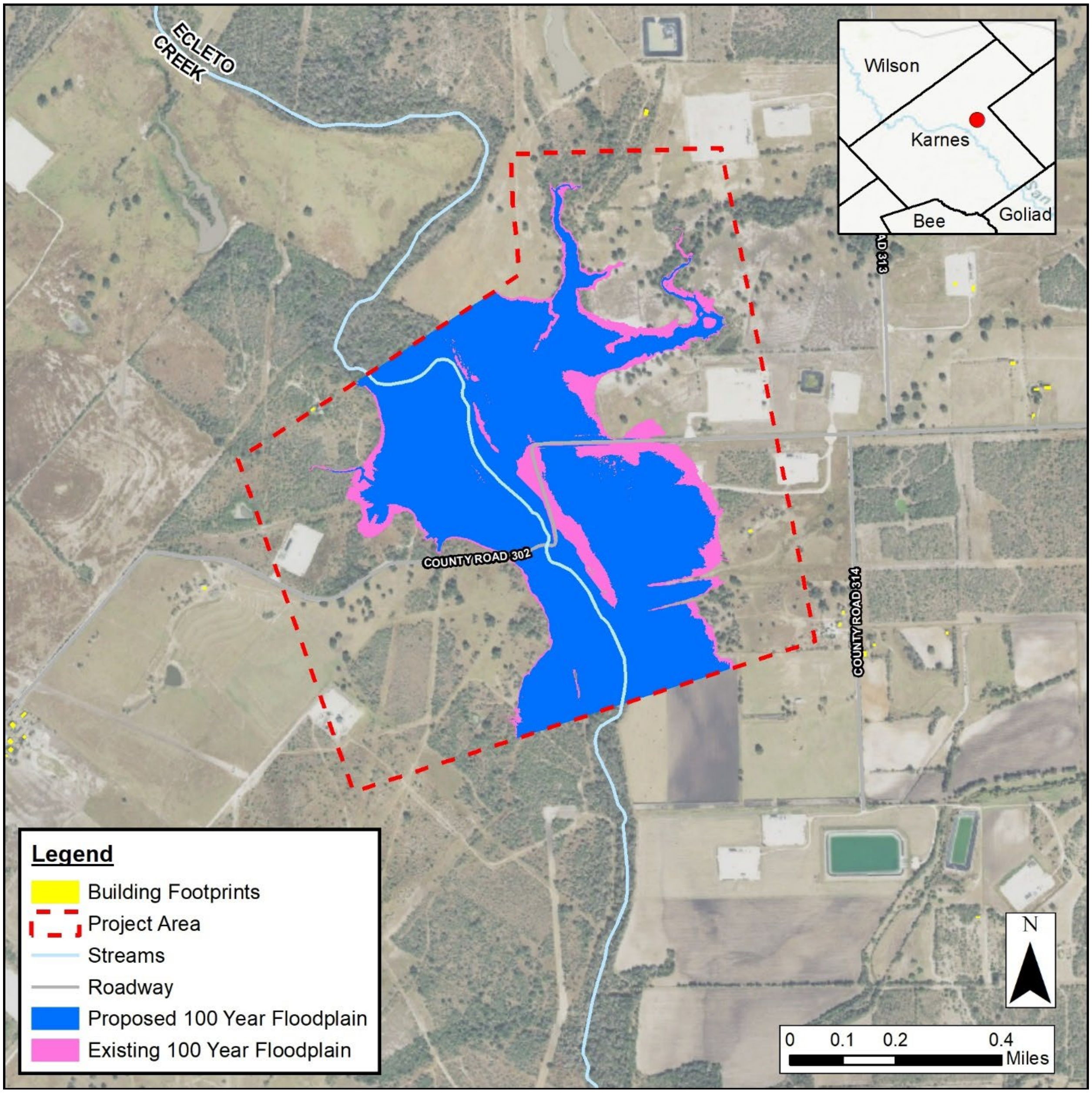

Figure 5-2C Project KC-2 flood risk reduction for the 100-year event.

5.3.3 Project KC-3 – CR 262 drainage improvements at Ecleto Creek

The CR 262 low water crossing at Ecleto Creek was identified by Karnes County as a high priority flood problem area. Under existing conditions, the max depth for the 2-year storm at the low water crossing is about 9 inches, and the roadway is impassable for nearly 7 hours. During the 100-year event the depth increases to 59 inches, and the road is impassable for nearly 36 hours. Please see **Figure 5-3A** for a view of the study area.

The proposed project for CR 262 was developed to improve the level-of-service for daily traffic and emergency services. The proposed improvements include elevating the roadway approximately 2 feet, upgrading the bridge to have an opening of 300 feet, and approximately 1,500 linear feet of trapezoidal channel improvements with a bottom width of 282 feet and side slopes of 4:1. Please see **Figure 5-3B** for a depiction of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a 2-year level-of-service for the roadway by reducing the maximum depth of flooding to be less than 6 inches. Please see **Figure 5-3C** for a depiction of the 100-year flood risk reduction.

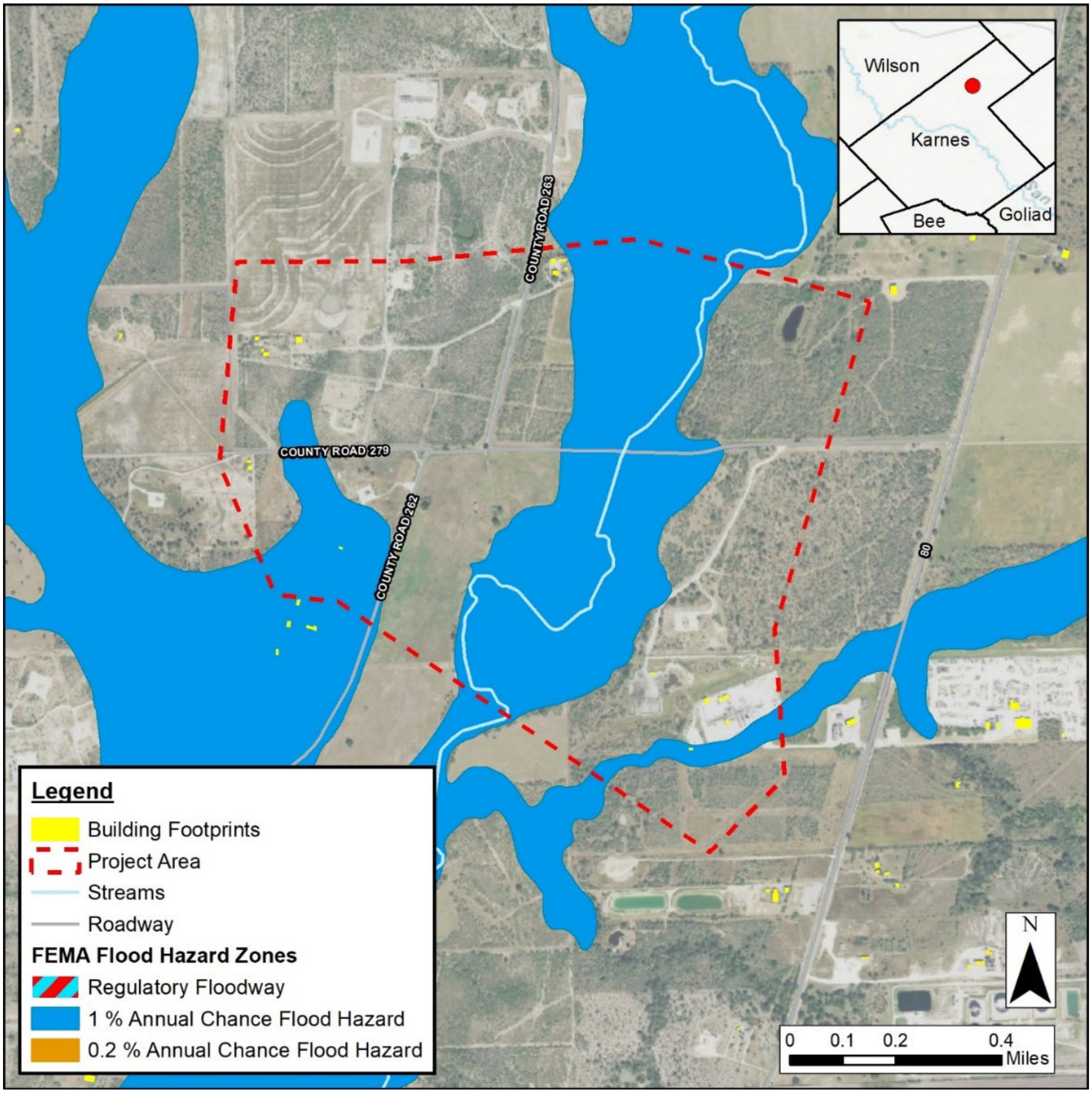

Figure 5-3A Project KC-3 study area location.

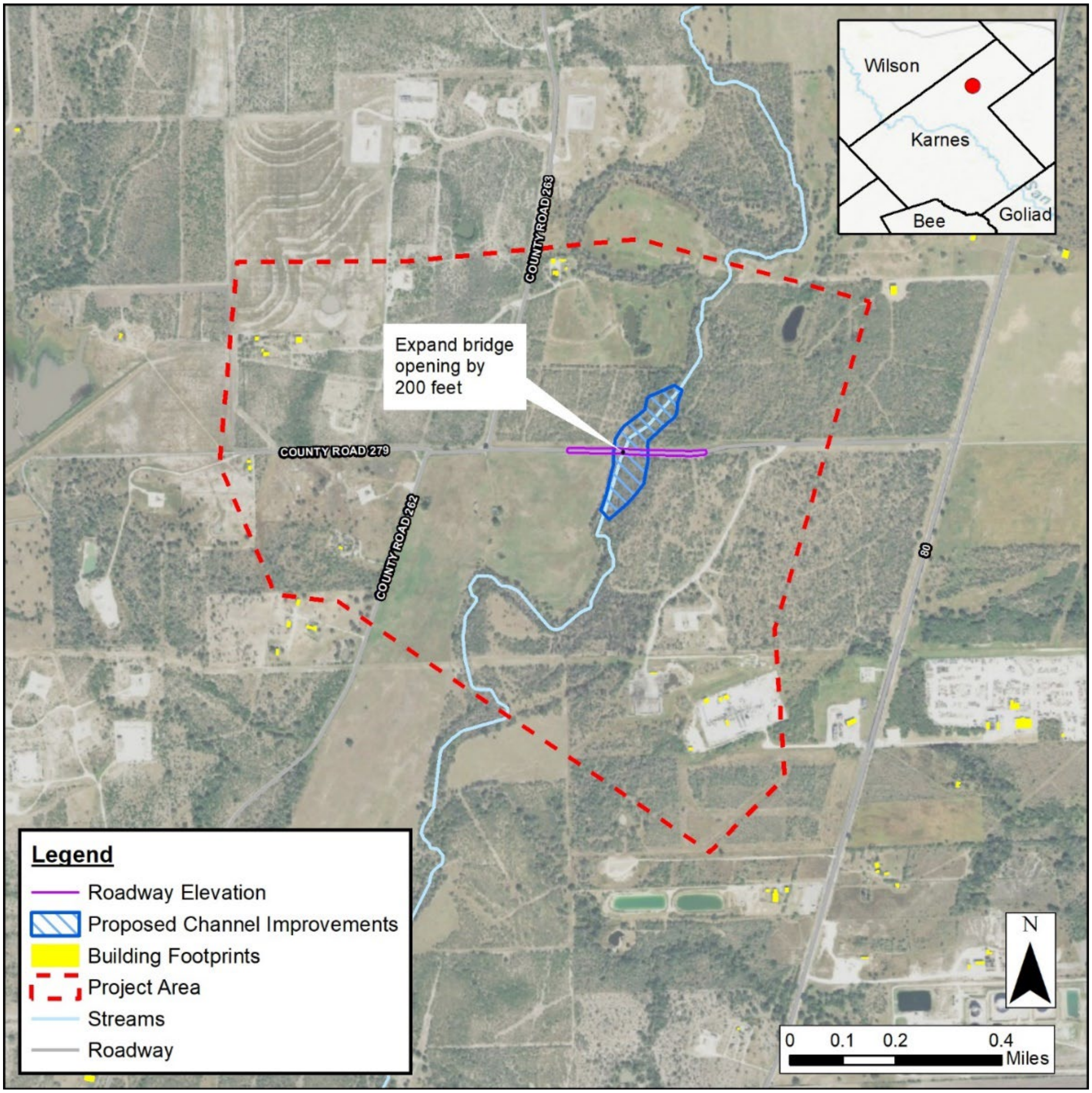

Figure 5-3B Project KC-3 proposed improvements.

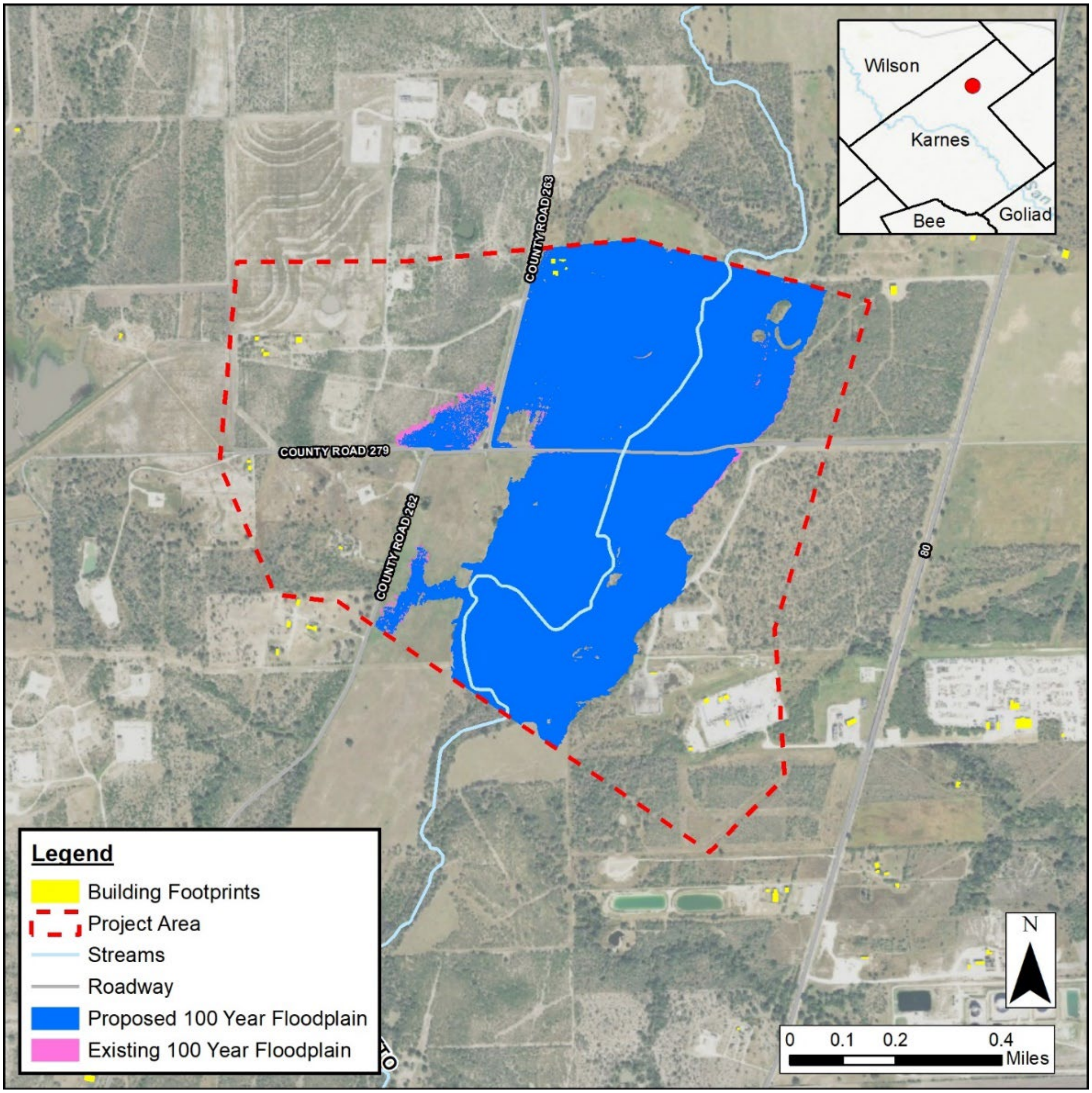

Figure 5-3C Project KC-3 flood risk reduction for the 100-year event.

5.3.4 Project KC-4 – drainage improvements at CR 337 and CR 326 near City of Runge

During a public meeting in March of 2022, the area near the intersection of CR 337 and CR 326 was identified by Karnes County residents as a high priority flood problem area. This site is located at the main outfall from the City of Runge and receives runoff that is conveyed to two small tributaries to Ecleto Creek. Under existing conditions, shallow flooding affects natural gas equipment at a Marathon Oil well pad on the north side of CR 337. This equipment was represented as a commercial structure in the benefit-cost analysis for this project. Existing low water crossings on CR 337 and CR 326 are flooded to depths of 22 inches and 14 inches, respectively, making the crossings impassable for over three hours during the 100-year event. In addition to the flooding at the existing low water crossings, stormwater is conveyed in roadside ditches parallel to CR 337, leading to additional roadway flooding during the 100-year event. Approximately 0.23 miles of CR 337 is flooded by 6 inches or more, causing that portion of the roadway to be impassable for over 2 hours. It should be noted that CR 337 is a dead-end street with no available detour during a storm event. Please see **Figure 5-4A** for a view of the study area.

The proposed project at CR 337 and CR 326 was developed to improve the level-of-service for daily traffic and emergency services and to reduce flooding at commercial and residential structures in the area. The project involves upgrading two existing low water crossings on CR 337 located approximately 300 feet apart. The western crossing will be upgraded from 2 – 36-inch CMPs to 4 – 10 ft x 4 ft box culverts, and the eastern crossing will be upgraded from 2 – 48-inch CMPs to 2 – 10 ft x 4 ft box culverts. In addition, the roadway will be elevated by approximately 3.40 feet at the crossings to prevent overtopping. Channel improvements are proposed at the western crossing with a 50-foot bottom width and 4:1 side slopes. On CR 326, an existing culvert structure on the north side of the intersection with CR 337 will be upgraded from 2 – 24-inch CMPs to 2 – 5 ft x 3 ft box culverts. The roadway will be elevated approximately 1 foot to mitigate overtopping. An existing roadside ditch lies along the north side of CR 337 to convey runoff from the existing CR 326 culvert structure through a series of private driveway culverts toward the Ecleto Creek tributaries. This existing ditch will be regraded to improve conveyance, and two of the existing driveway culverts will be upgraded to 5 ft x 2 ft box culverts. There is also a prominent existing flow path along the south side of CR 337; however, the majority of runoff is directed into the northern ditch, leading to flooding of structures. One of the goals of this project is to direct flow into the southern flow path to relieve flooding on CR 337 and structures north of the roadway. To accomplish this goal, a new 4 – 5 ft x 4 ft box culvert structure is proposed on CR 326 on the south side of the intersection with CR 337. In addition, ditch improvements and a 6.5 ac-ft storage area are proposed on the east side of CR 326 to facilitate conveyance on both sides of CR 337 rather than primarily the north side. The southern ditch will also be improved with a trapezoidal channel section with a 50-foot bottom width and 4:1 side slopes. Please see **Figure 5-4B** for a depiction of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a 100-year level-of-service for CR 337 with no overtopping. The roadway becomes passable during the 100-year event, whereas it is impassable for over 3 hours under existing conditions. On CR 326, the proposed improvements allow for at least a 10-year level of service with less than 6 inches of flooding. During the 100-year event, the depth of flooding is reduced from 14 inches to 8 inches, reducing the amount of time the roadway is impassable from 3.67 hours to 0.33 hours. The natural gas equipment located on the Marathon Oil well pad is removed from 100-year flooding. Please see **Figure 5-4C** for a depiction of the 100-year flood risk reduction.

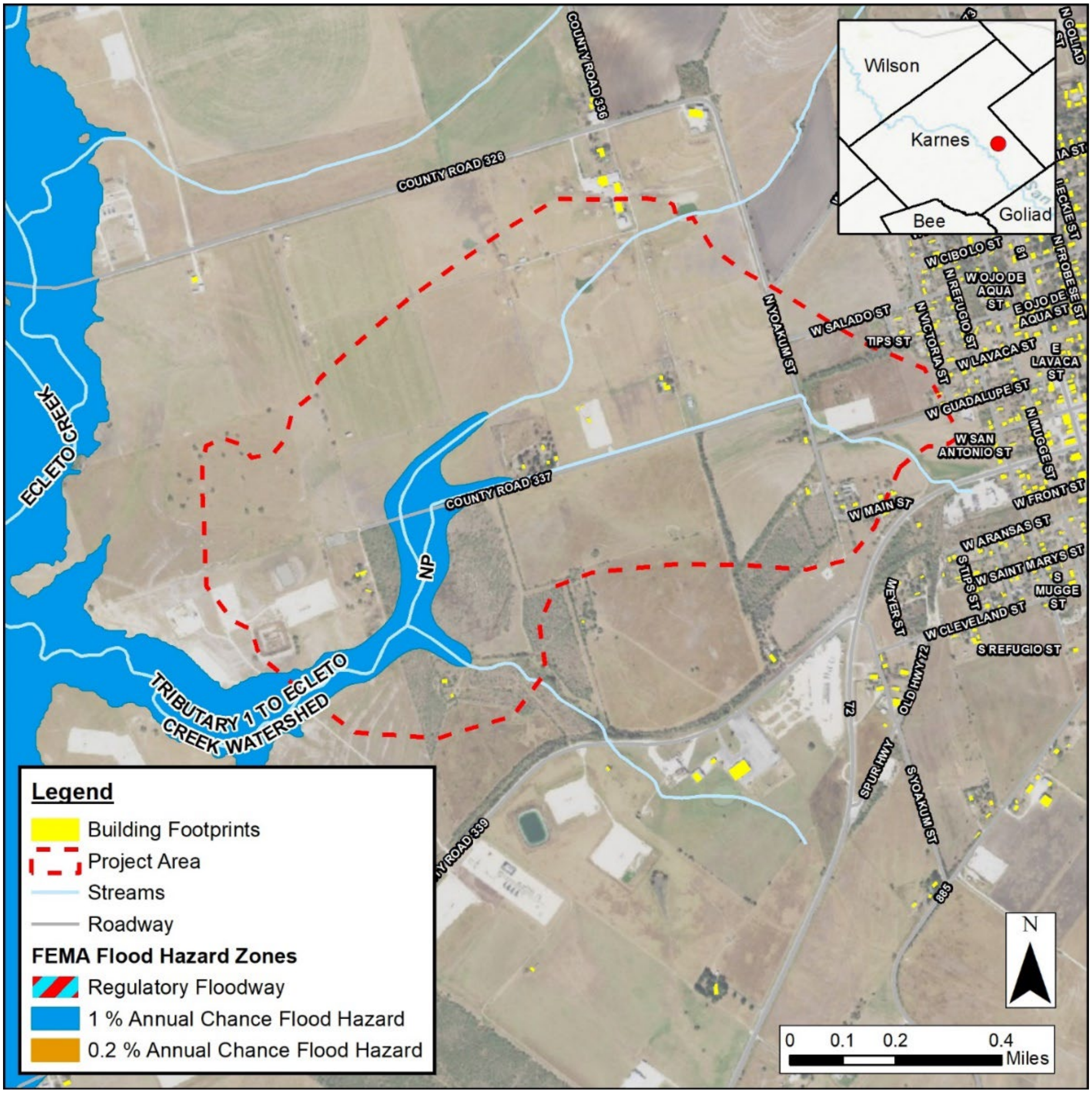

Figure 5-4A **Project KC-4 study area location.**

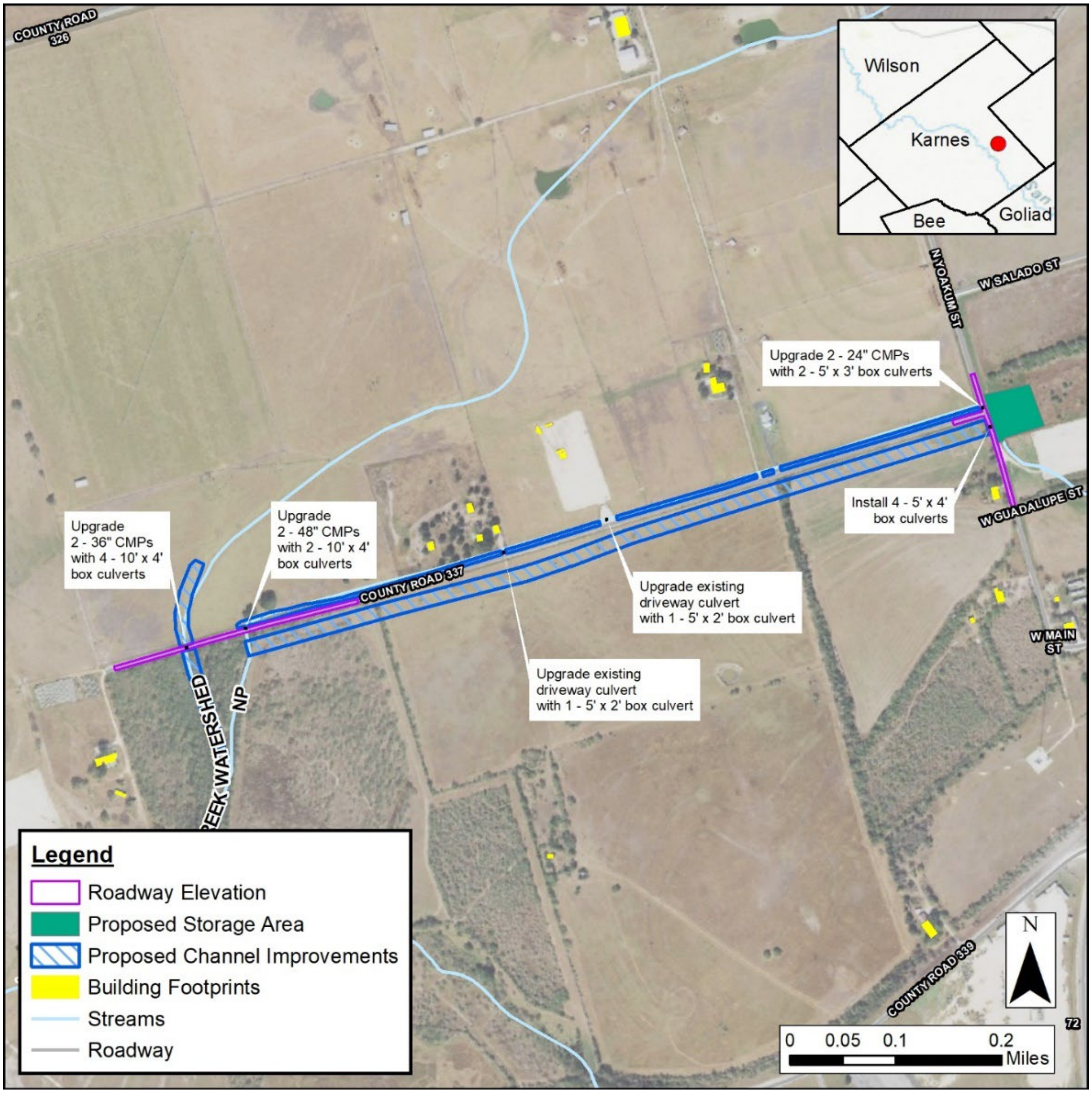

Figure 5-4B Project KC-4 proposed improvements.

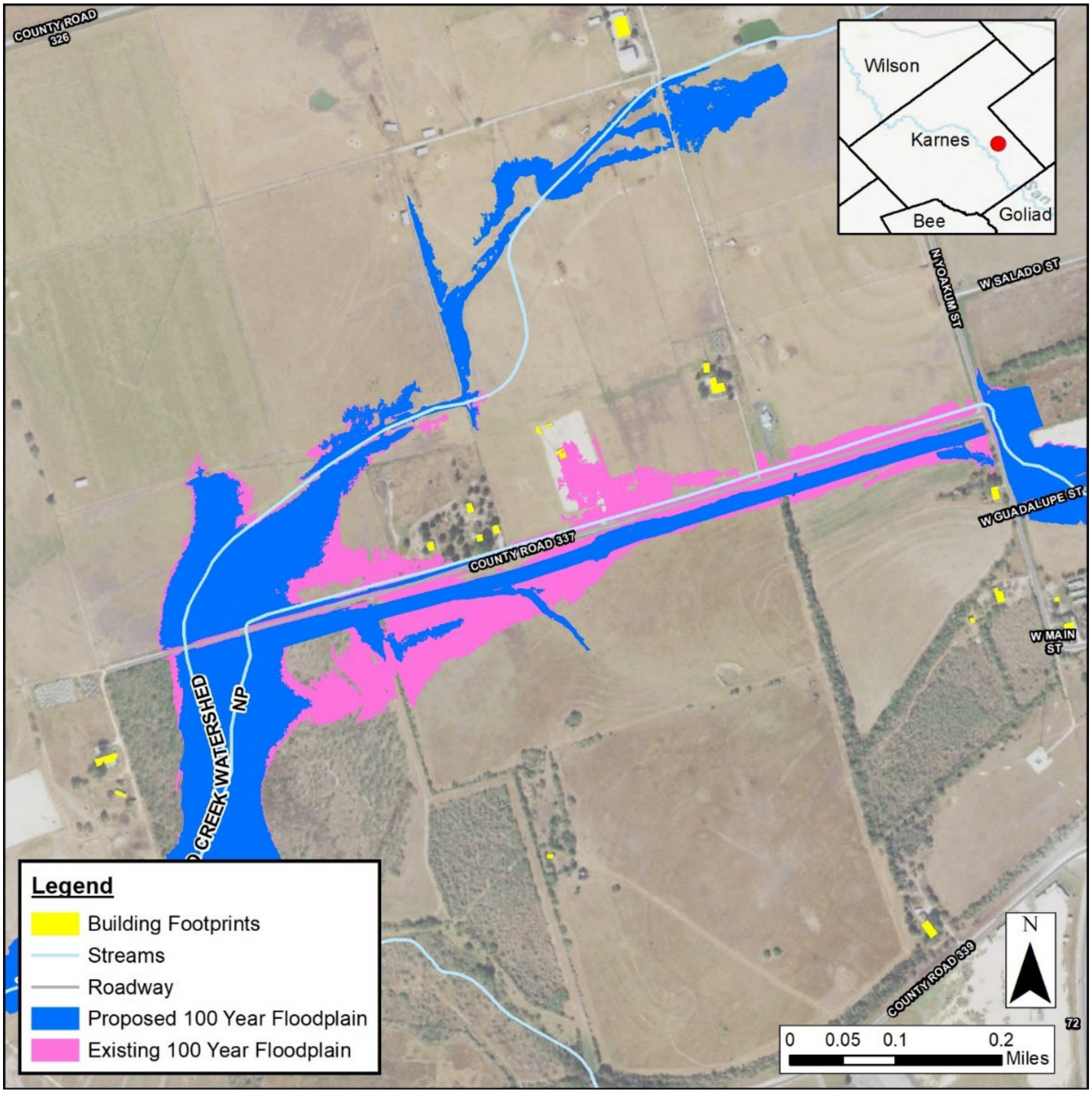

Figure 5-4C Project KC-4 flood risk reduction for the 100-year event.

5.3.5 Project KC-5 – CR 336 drainage improvements at Escondido Creek

The CR 335 low water crossing at Tributary 1 To Ecleto Creek Tributary 2 was identified by Karnes County as a high priority flood problem area. Based on preliminary modeling results, under existing conditions, the 2-year depth of flooding at the low water crossing is 12 inches, and the roadway is impassible for 2.67 hours. During the 100-year event, the depth increases to 24 inches, making the roadway impassible for 5.33 hours. Please see **Figure 5-5A** for a view of the study area.

The proposed project for CR 336 was developed to improve the level-of-service for the roadway to accommodate daily traffic and emergency services. The proposed improvements include elevating the roadway to 278 feet NAVD88, installing a 50 ft wide bridge, and approximately 700 linear feet of trapezoidal channel improvements with a bottom width of 100 feet and side slopes of 4:1. Please see **Figure 5-5B** for a depiction of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a 100-year level-of-service for the roadway and no overtopping This reduction in depth makes the roadways passable during the 100-year event, whereas the roadway is impassable for 5.33 hours under existing conditions. Please see **Figure 5-5C** for a depiction of the 100-year flood risk reduction.

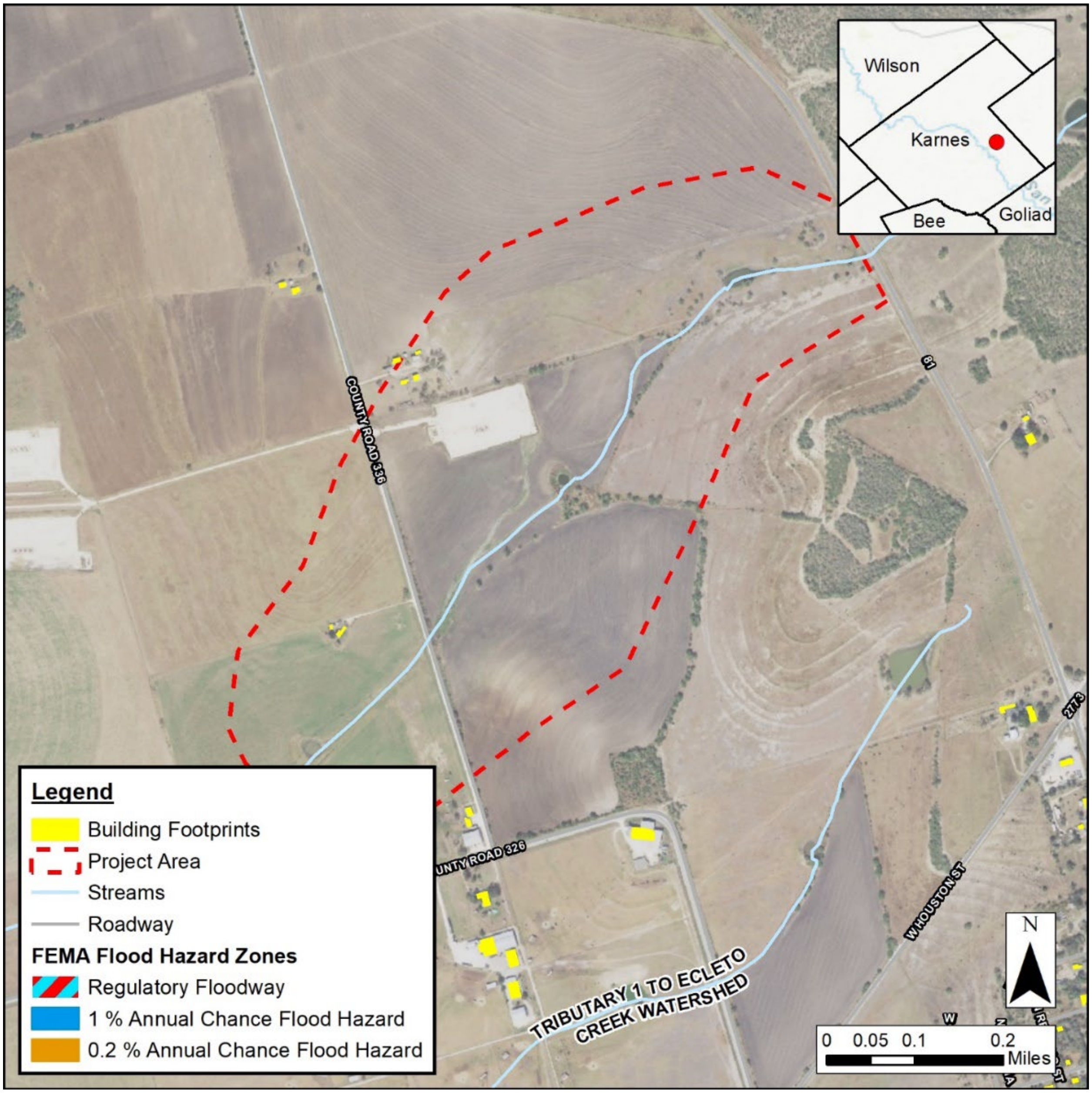

Figure 5-5A Project KC-5 study area location.

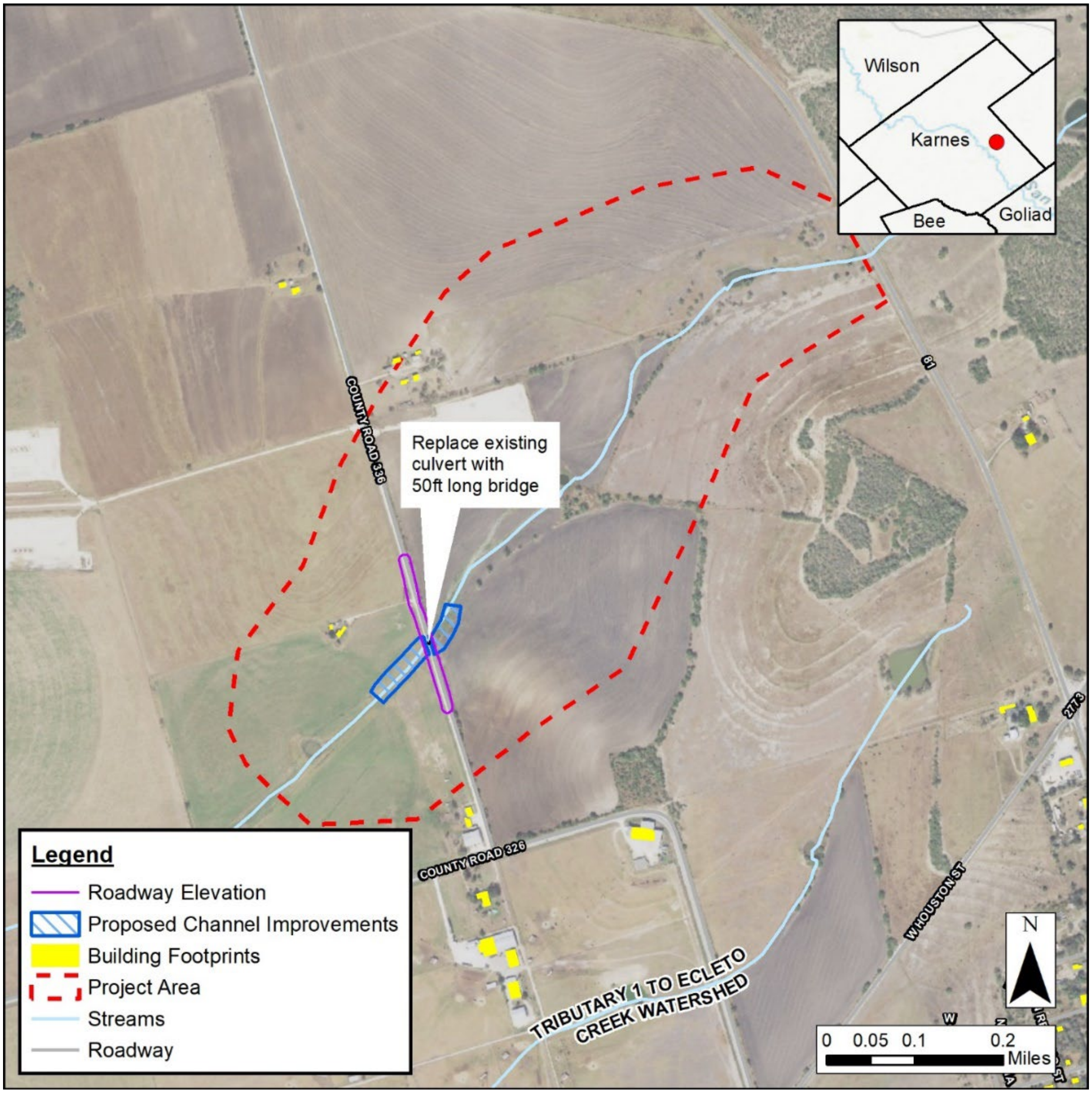

Figure 5-5B Project KC-5 proposed improvements.

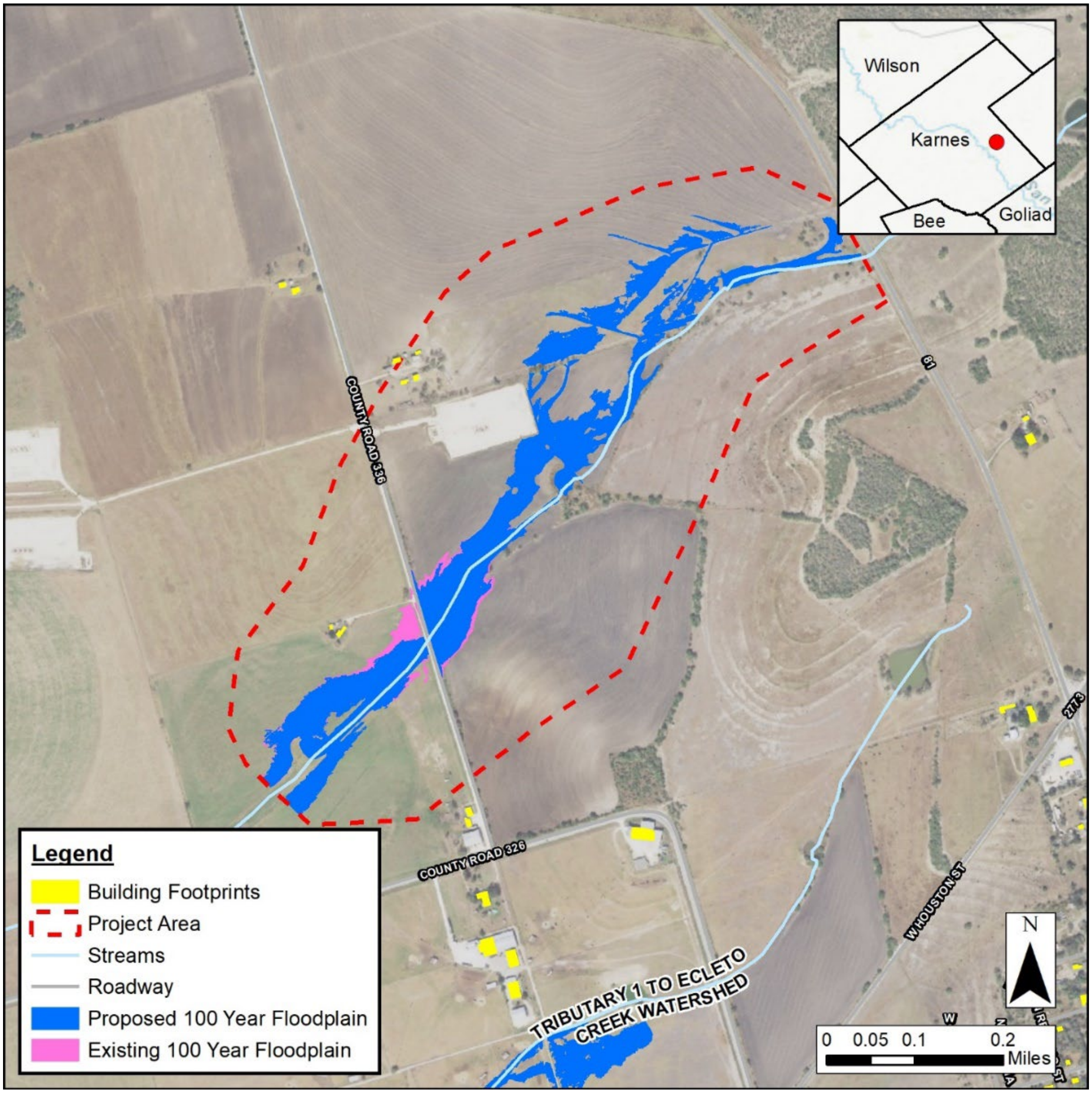

Figure 5-5C Project KC-5 flood risk reduction for the 100-year event.

5.3.6 Project KC-6 – CR 331 drainage improvements at Escondido Creek

The CR 331 low water crossing on Escondido Creek was identified by Karnes County as a high priority flood problem area. Preliminary modeling results show the roadway has less than a 2-year level-of-service under existing conditions with a maximum 2-year flooding depth of 49 inches (4.1 feet). This depth of flooding causes the crossing to be impassable for nearly 29 hours. During the 100-year storm event, the maximum depth of roadway flooding is 138 inches (11.5 feet), making the crossing impassable for at least 3 days. Please see **Figure 5-6A** for a view of the study area.

The goal of the mitigation project for CR 331 is to improve the level-of-service for the roadway to accommodate daily traffic and emergency services. The proposed improvements include elevating the roadway by approximately 6 feet, replacing the existing 2 – 84-inch CMPs with a 150-foot-long bridge, and approximately 1,300 linear feet of trapezoidal channel improvements with a 200-foot bottom width and 4:1 side slopes. Please see **Figure 5-6B** for a depiction of the proposed improvements.

Preliminary modeling results show the proposed improvements at CR 331 result in a 2-year level-of-service for the roadway. During the 2-year event, the maximum depth of roadway flooding is reduced from 49 inches (4.1 feet) to 0. During the 100-year event, the maximum depth of roadway flooding is reduced from 138 inches (11.5 feet) to 64 inches (5.3 feet). Under existing conditions, the roadway is impassable for multiple days during a 100-year event. However, the reduction in roadway flooding reduces the length of time the roadway is impassable to under 16 hours. Please see **Figure 5-6C** for a depiction of the 100-year flood risk reduction.

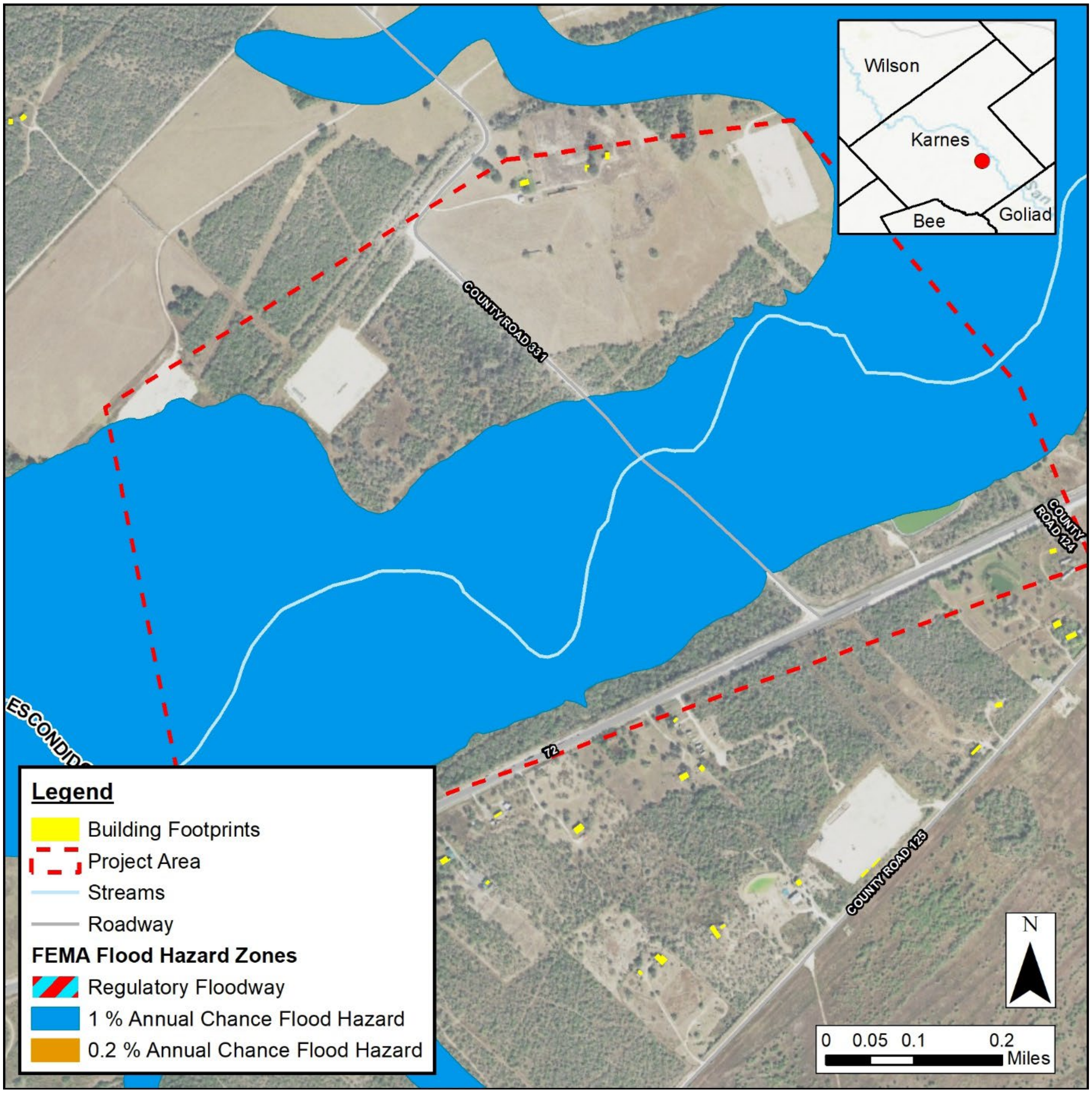

Figure 5-6A Project KC-6 study area location.

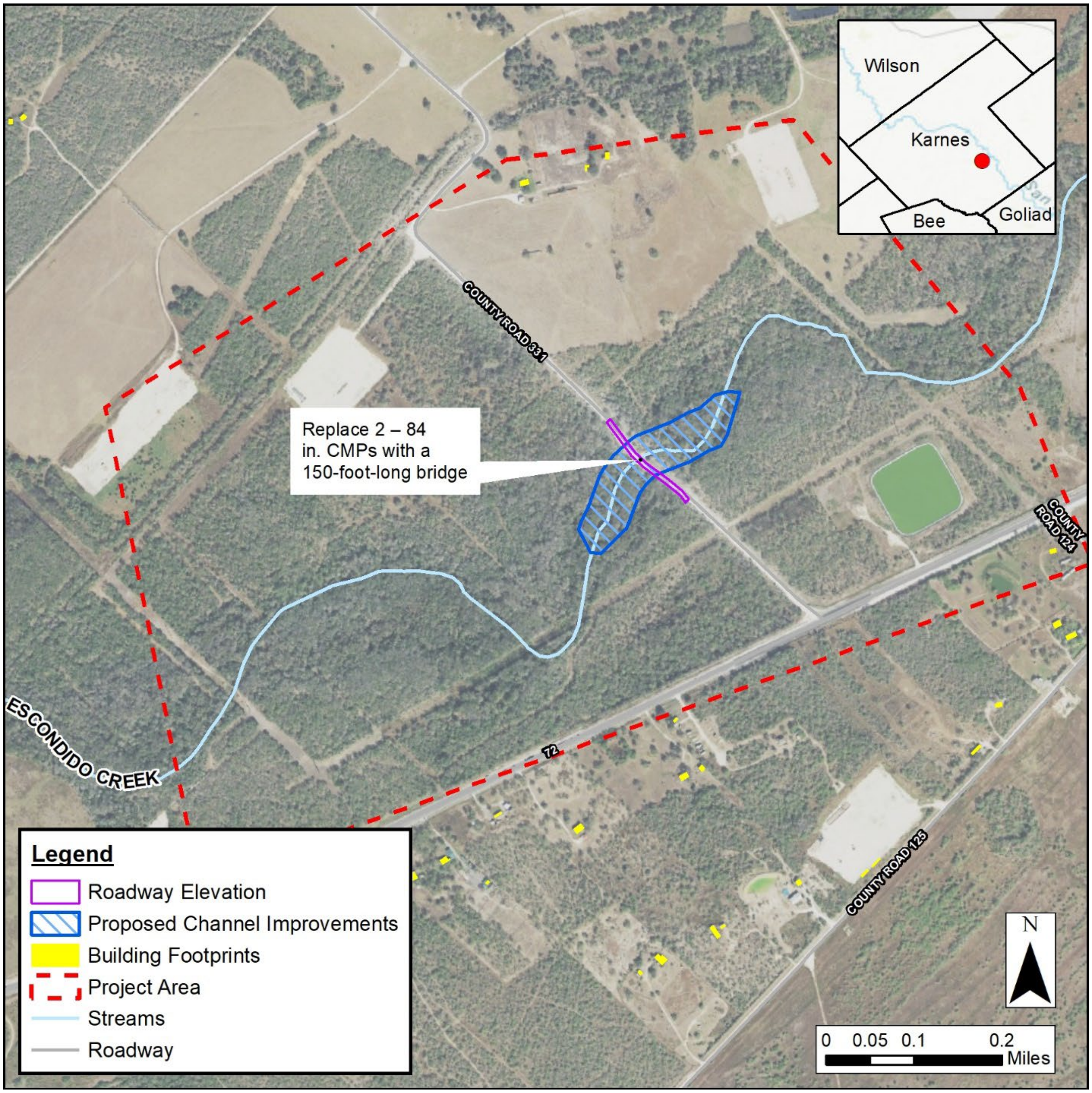

Figure 5-6B Project KC-6 proposed improvements.

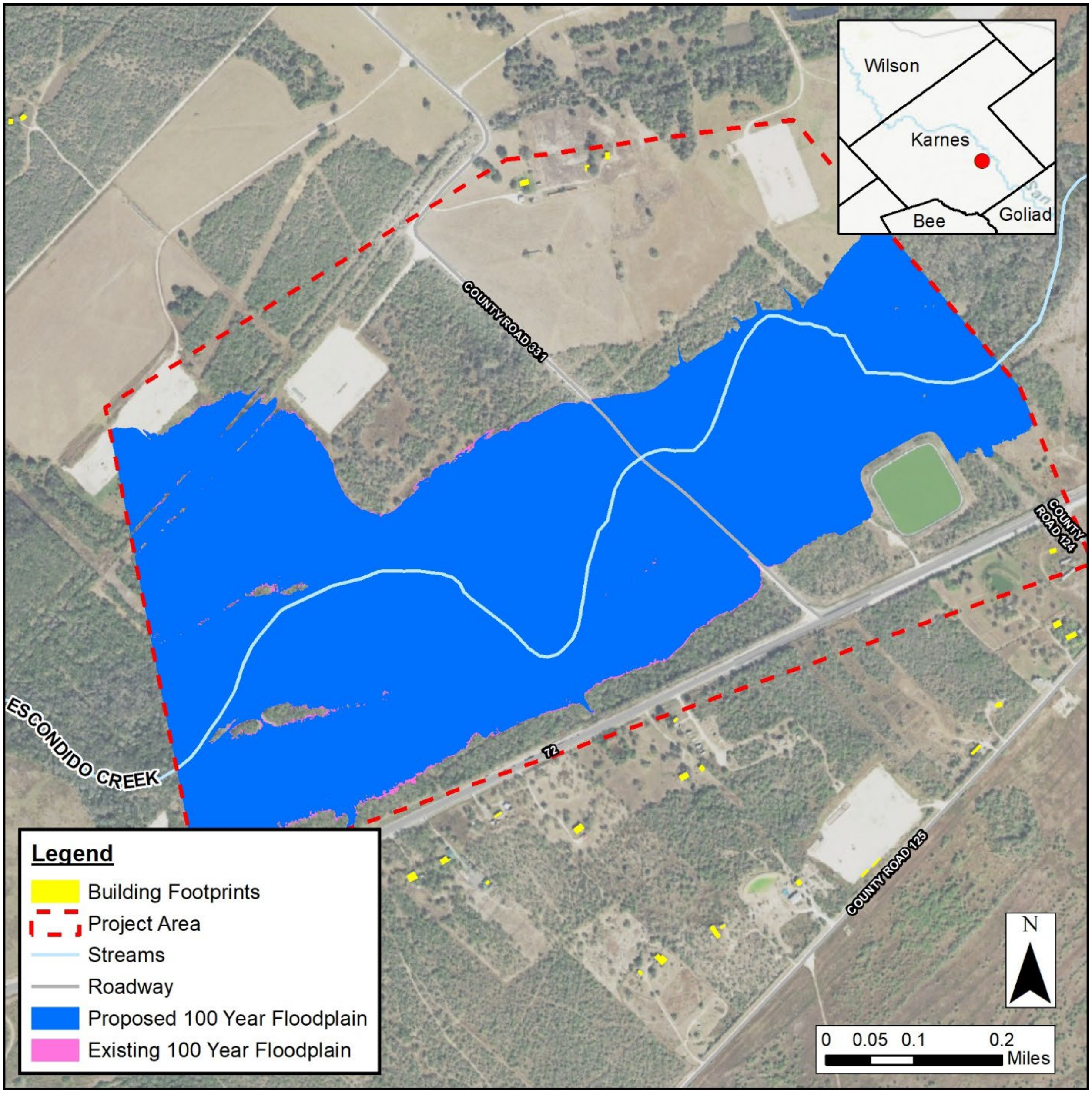

Figure 5-6C Project KC-6 flood risk reduction for the 100-year event.

5.3.7 Project KC-7 – City of Kenedy drainage improvements on Escondido Creek

Residential and commercial flooding hazards within the City of Kenedy on Escondido Creek were identified as a flood damage center in the Holistic Watershed Master Plan for Wilson, Karnes, and Goliad Counties. During the 100-year event, 78 structures are flooded under existing conditions, including 73 residential structures. North 5th Street was also specifically identified as a flood hazard in the Holistic Watershed Master Plan. Based on preliminary modeling results, under existing conditions, the 100-year depth of flooding at the low water crossing is approximately 1.86 feet, making the roadway impassible for 6.2 hours. During the 100-year flood event, approximately 2.52 miles of roadway within the city are impassible, with an average flooding depth of 1.64 feet. Dailey Road reaches a maximum depth of 2.65 ft and is impassable for over 3 days. Please see **Figure 5-7A** for a view of the study area and affected structures.

The proposed project for the City of Kenedy was developed to improve the level-of- service for the roadways to accommodate daily traffic and emergency services and to mitigate flooding of residential and commercial structures. As shown in **Figure 5-7B**, the proposed improvements include:

- Elevating North 5th street by approximately 5 feet at most
- Channel improvements to 2 low water crossings on North 5th Street (south of Escondido Creek)
- Approximately 230 linear feet of channel improvements downstream of North 5th Street along Escondido Creek, with a bottom width of 100 feet with 4:1 side slopes
- Approximately 250 linear feet of trapezoidal channel improvements, upstream of North 5th Street along Escondido Creek, with a bottom width of 50 feet and 4:1 side slopes
- Approximately 580 linear feet of trapezoidal channel improvements, downstream of the bridge crossing at Old Helena Road along Escondido Creek, with a bottom width of 50 feet and 4:1 side slope.
- Widening of approximately 1,980 linear feet of Escondido Creek upstream of Old Helena Road, following natural grade
- Removal of 780 linear feet of existing berm from an abandoned roadway or railroad on the north of Escondido Creek upstream of Old Helena Road.
- Creation of a 432 ft long trapezoidal berm to the south of Escondido Creek, North of E Daily Street, with a 15-foot top width and 4:1 side slopes
- Proposed storage volume downstream of the confluence of Nichols Creek and Escondido Creek

Based on the preliminary modeling results, the proposed improvements result in a 100-year level-of-service for the North 5th Street roadway. During the 100-year event, 56 structures are removed from the floodplain, including 54 residential structures. The length of roadway with more than 6 inches of flooding is reduced from 2.52 miles to 1.03 miles, with an average flooding depth of 1.03 feet. With the proposed improvements, Dailey Road has a 100-year level-of-service. Please see **Figure 5-7C** for a depiction of the 100-year flood risk reduction.

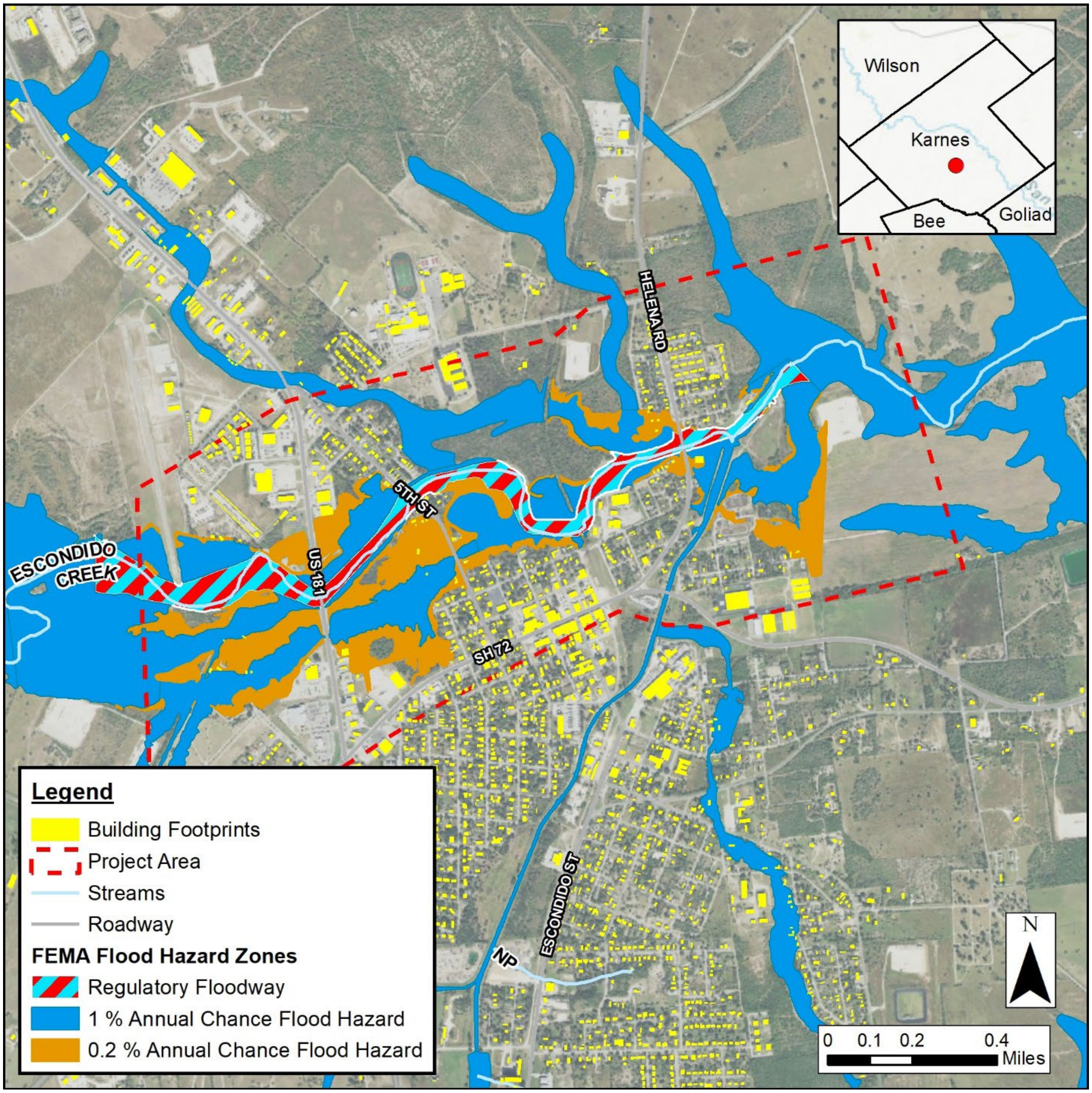

Figure 5-7A Project KC-7 study area location.

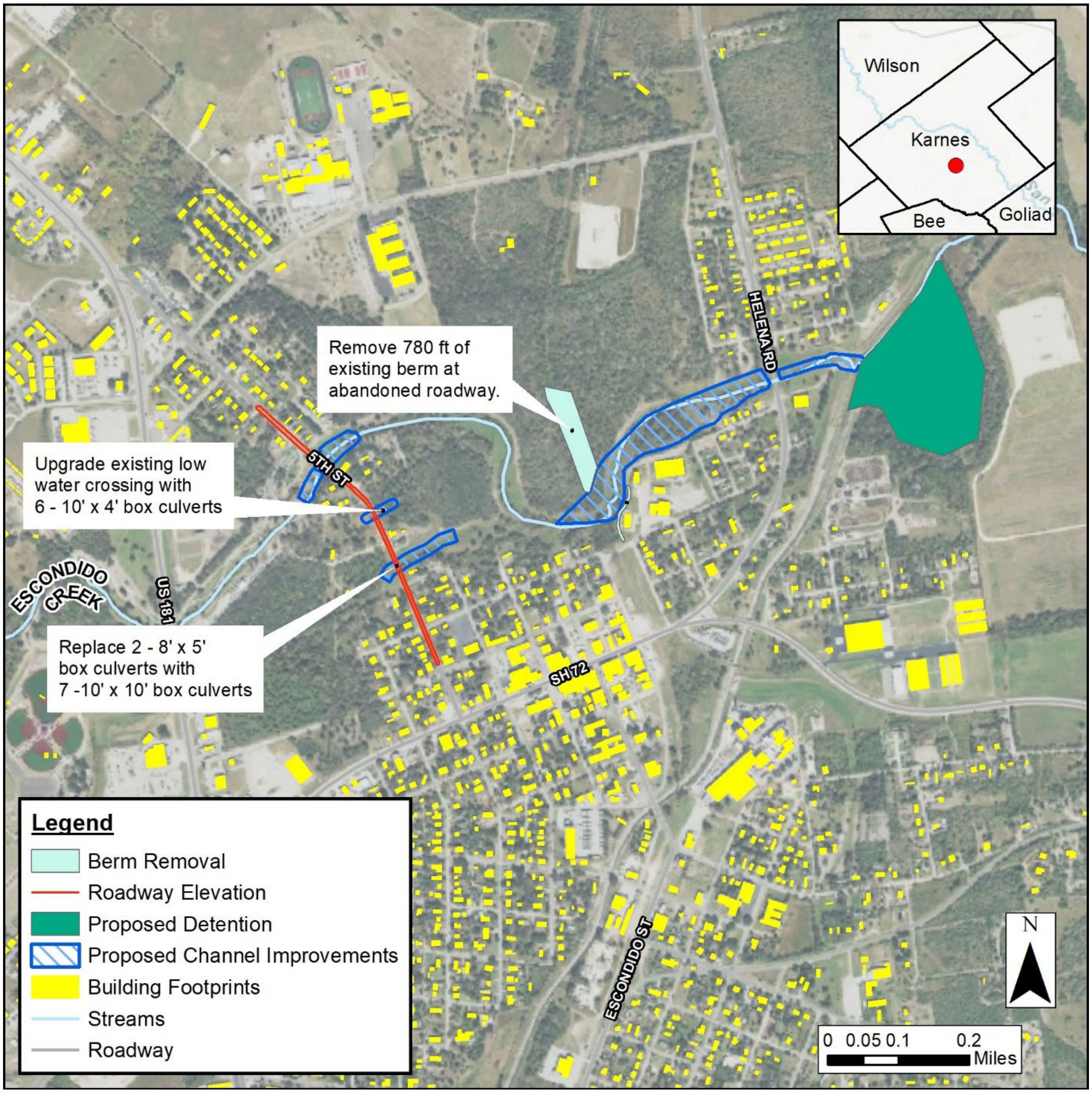

Figure 5-7B Project KC-7 proposed improvements.

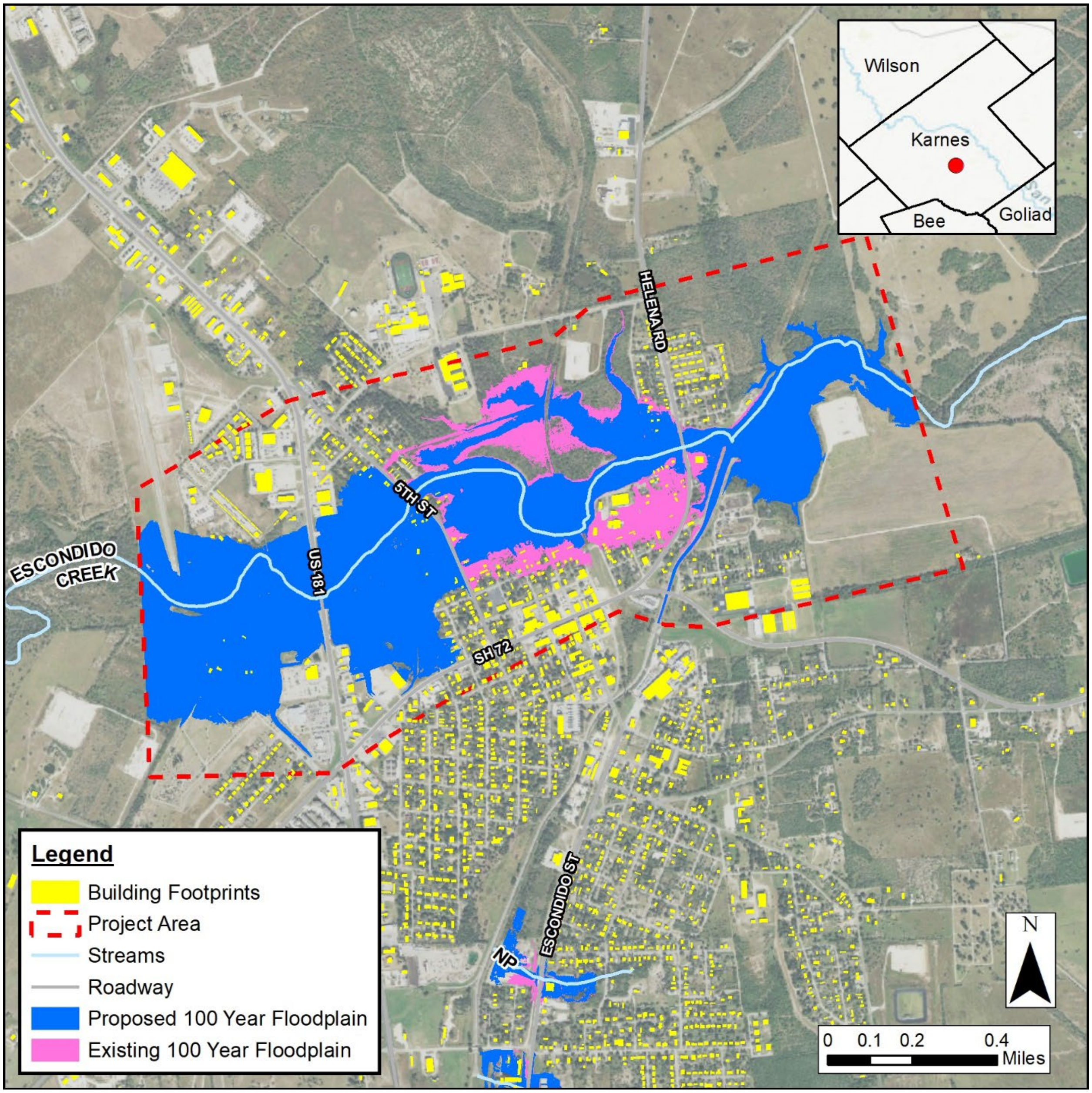

Figure 5-7C Project KC-7 flood risk reduction for the 100-year event.

5.3.8 Project KC-8 – CR 127 drainage improvements at Hondo Creek

The CR 127 low water crossing at Hondo Creek was identified by Karnes County as a high priority flood problem area. Based on preliminary modeling results, under existing conditions, the 2-year depth of flooding is approximately 7.3 feet, and the roadway is impassible for over 28 hours. During the 100-year event, the depth increases to 15.7 feet, making the roadway impassible for 46 hours. Please see **Figure 5-8A** for a view of the study area.

The proposed project for CR 127 was developed to improve the level-of-service for the roadway to accommodate daily traffic and emergency services. The proposed improvements include elevating the roadway to approximately 220 feet NAVD88, installing a 100-ft wide bridge, and 1,652 linear feet of trapezoidal channel improvements with a bottom width of 100 feet and side slopes of 4:1. Please see **Figure 5-8B** for a view of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a 100-year level-of-service for the roadway and no overtopping. This reduction in depth makes the roadway passable during the 100-year event, whereas the roadway is impassable for approximately 46 hours under existing conditions. Please see **Figure 5-8C** for a depiction of the 100-year flood risk reduction.

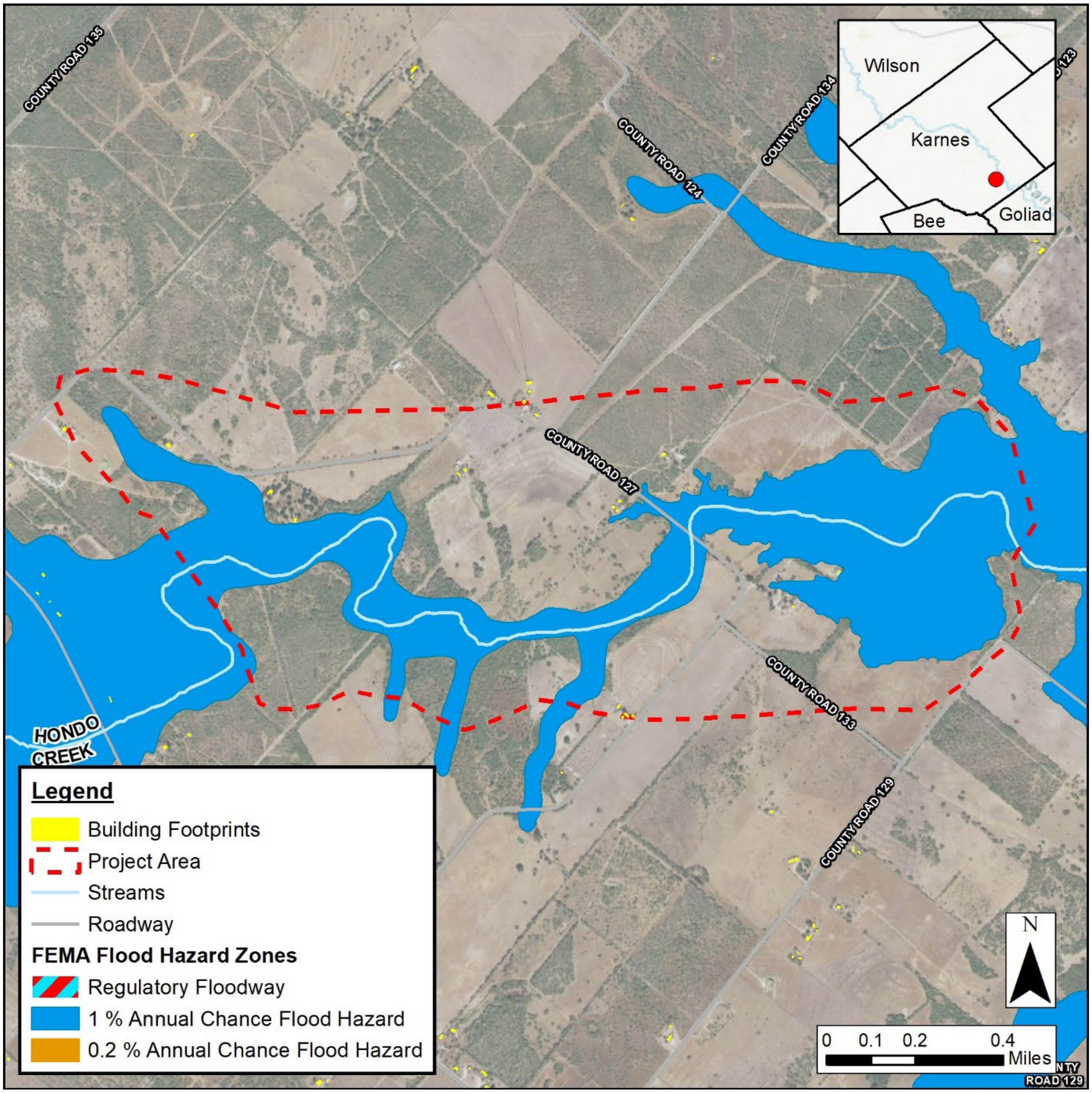

Figure 5-8A Project KC-8 study area location.

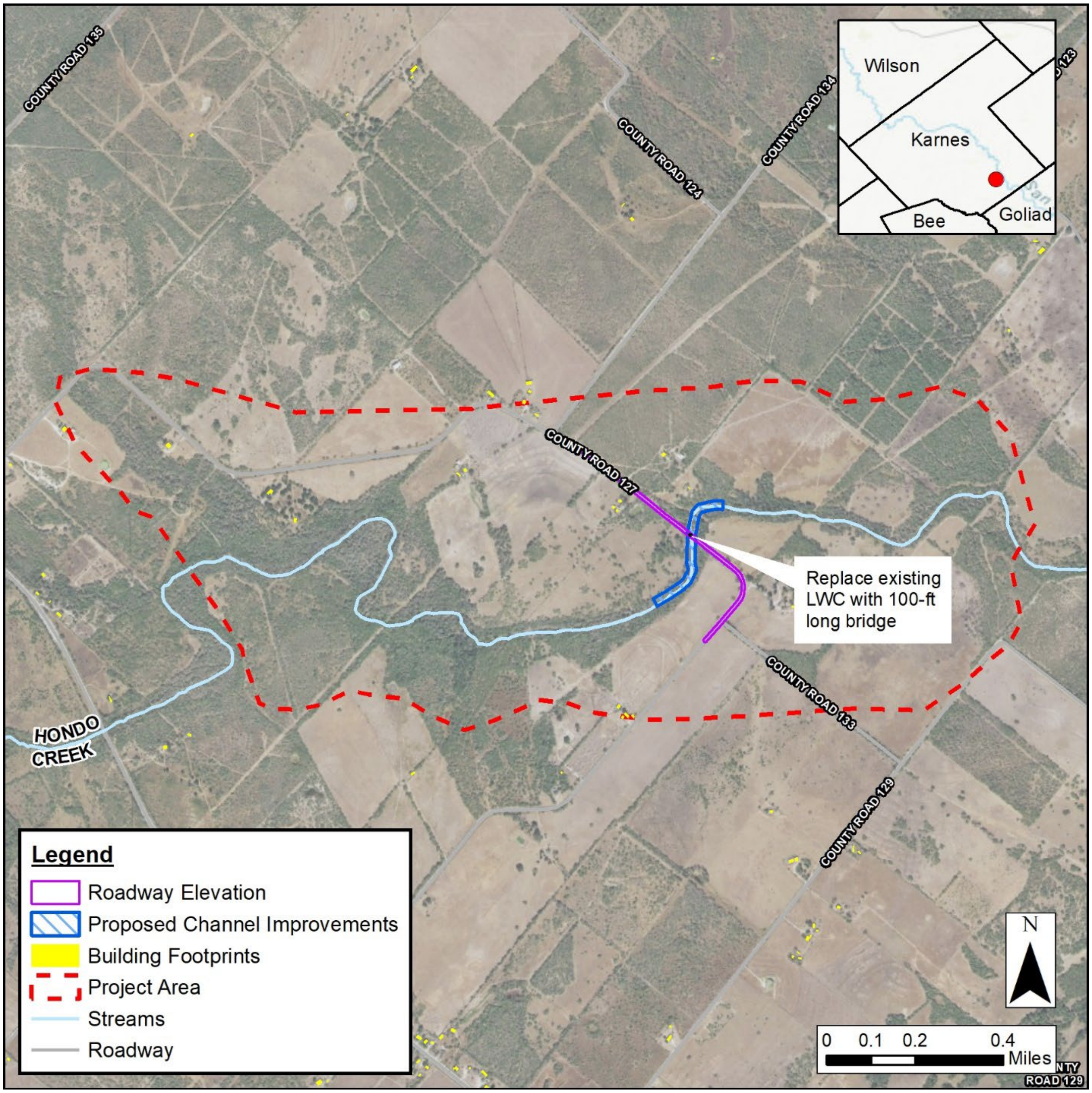

Figure 5-8B Project KC-8 proposed improvements.

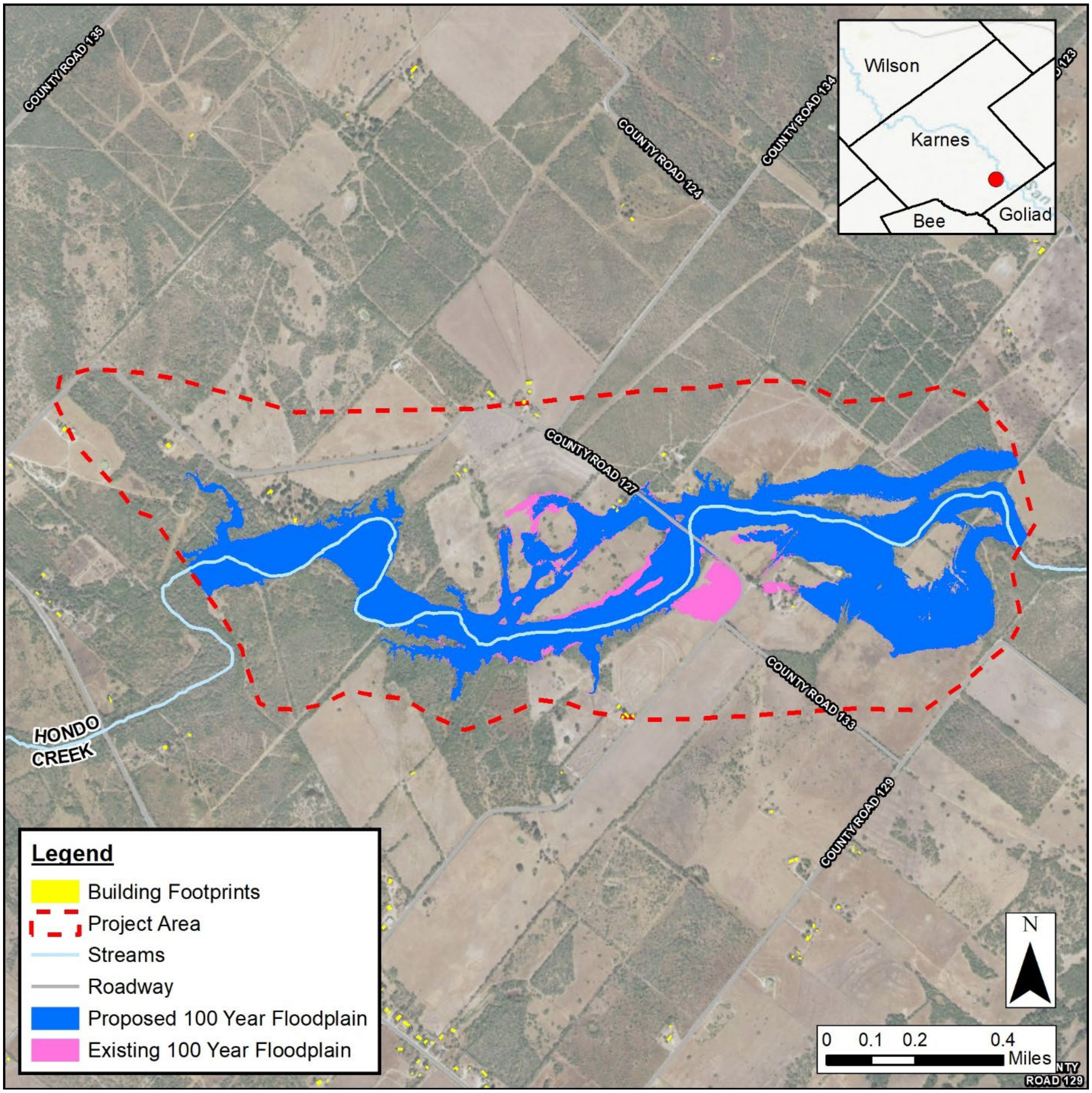

Figure 5-8C Project KC-8 flood risk reduction for the 100-year event.

5.3.9 Project KC-9 – CR 145 drainage improvements at Hondo Creek

The CR 145 low water crossing at Hondo Creek was identified by Karnes County as a high priority flood problem area. Based on preliminary modeling results, under existing conditions, the 2-year depth of flooding is 6 inches, and the roadway is impassible for about 40 minutes. During the 100-year event, the depth increases to 12.6 feet, making the roadway impassible for several days. This magnitude of flooding is largely due to the presence of NRCS Dam Site 1 downstream of the crossing. Please see **Figure 5-9A** for a view of the study area.

The proposed project for CR 145 on Hondo Creek was developed to improve the level-of-service for daily traffic and emergency services. The proposed improvements include elevating the roadway approximately 5.2 feet, upgrading the existing 80-foot bridge structure with a 170-foot-long bridge, and approximately 670 linear feet of channel improvements with a bottom width of 100 feet and 4:1 side slopes. Please see **Figure 5-9B** for a view of the proposed improvements.

Preliminary modeling results show the proposed improvements allow for a 10-year level-of-service for CR 145. During the 10-year storm event, the maximum roadway flooding depth is reduced from 58 inches (4.85 feet) to 0. This reduction in depth makes the roadway passable for the duration of the 10-year event, whereas it is impassable for several days under existing conditions. The proposed improvements reduce the maximum 100-year depth of flooding from 151 inches (12.6 feet) to 89 inches (7.41 feet), which also reduces the length of time the roadway is impassable by an estimated 5 days. Please see **Figure 5-9C** for a depiction of the 100-year flood risk reduction.

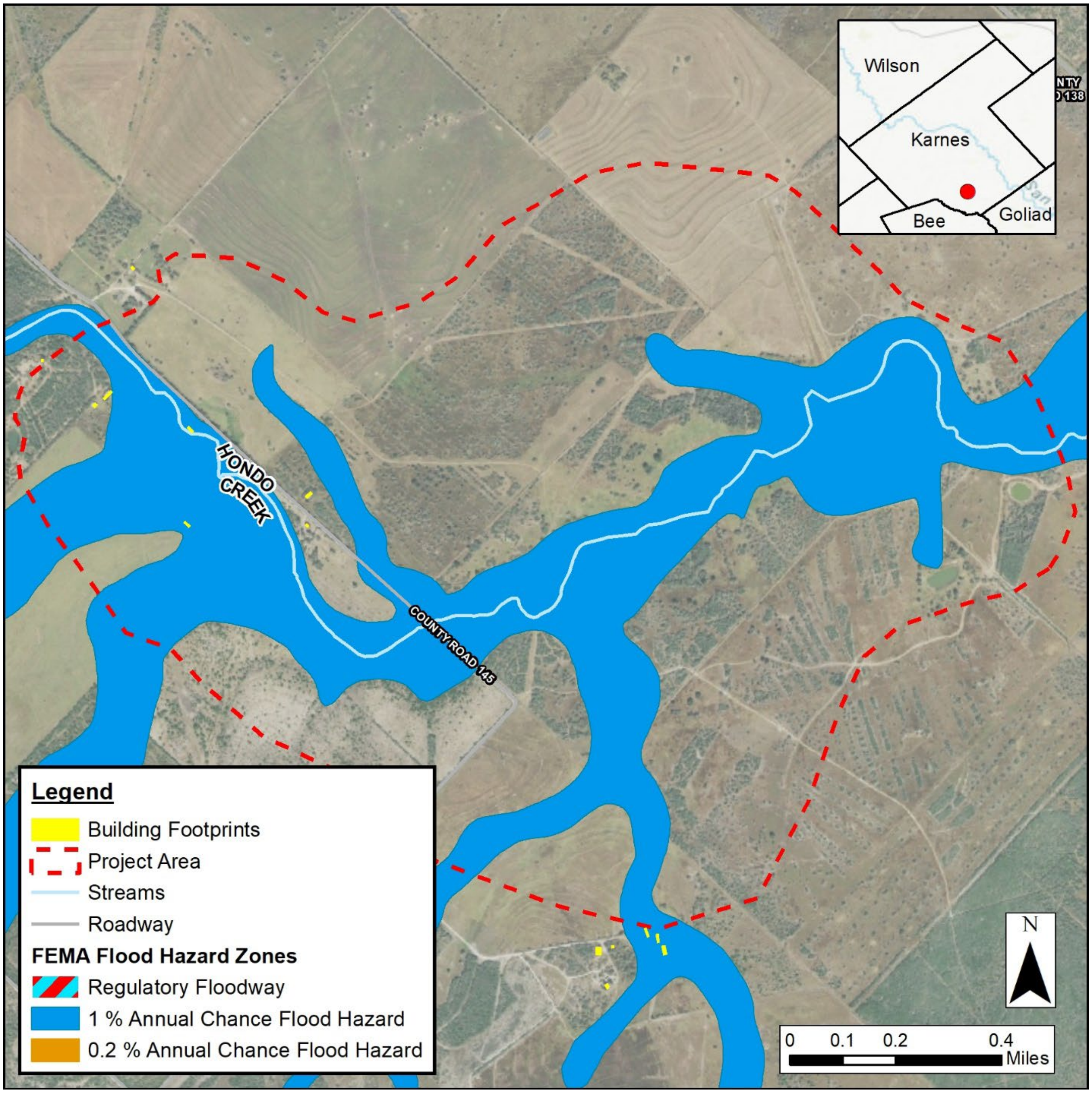

Figure 5-9A Project KC-9 study area location.

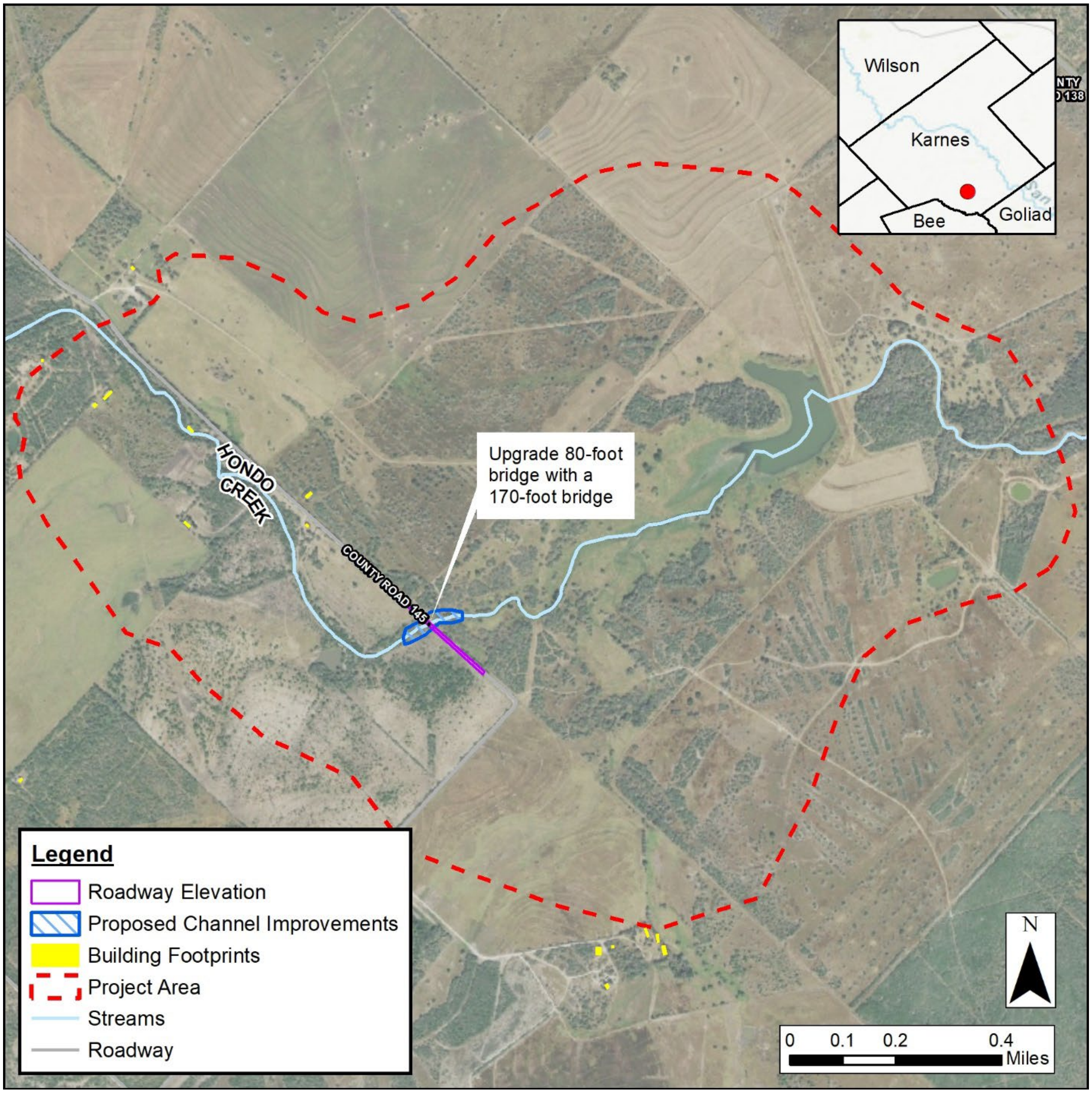

Figure 5-9B Project KC-9 proposed improvements.

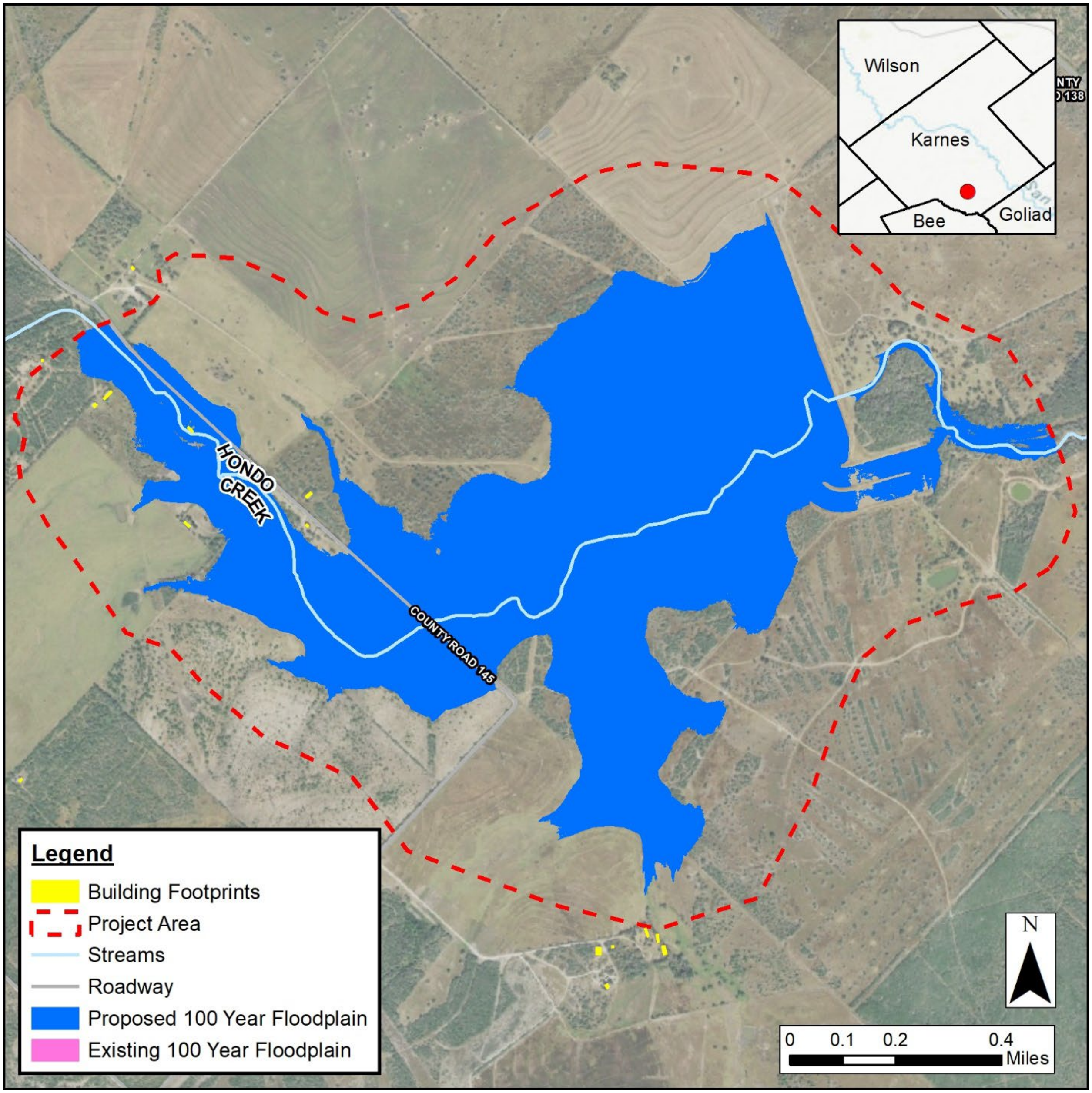

Figure 5-9C Project KC-9 flood risk reduction for the 100-year event.

5.3.10 Project KC-10 – CR 354 drainage improvements at Lower San Antonio Tributary 147

The CR 354 low water crossing at Lower San Antonio River Tributary 147 was identified by Karnes County as a high priority flood problem area. Under existing conditions, the 10- year depth of flooding at the low water crossing is 6 inches, and the roadway is impassable for nearly 2 hours. During the 100-year event, the depth increases to 10 inches making the roadway impassable for nearly 6 hours. Please see **Figure 5-10A** for a view of the study area.

The proposed project for CR 354 was developed to improve the level-of-service for daily traffic and emergency services. The proposed improvements include elevating the roadway approximately 2 feet for about 2,500 linear feet and adding a 100-foot-long bridge at the crossing. The proposed upstream channelization is approximately 1,200 linear feet and includes a channel bottom width of 150 feet and side slopes of 4:1. The proposed downstream channelization is about 1,000 linear feet and includes a channel bottom width of 250 feet and 4:1 side slopes. Please see **Figure 5-10B** for a view of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a 100-year level-of-service for the roadway by reducing the maximum depth to be less than 6 inches. Please see **Figure 5-10C** for a depiction of the 100-year flood risk reduction.

Figure 5-10A Project KC-10 study area location.

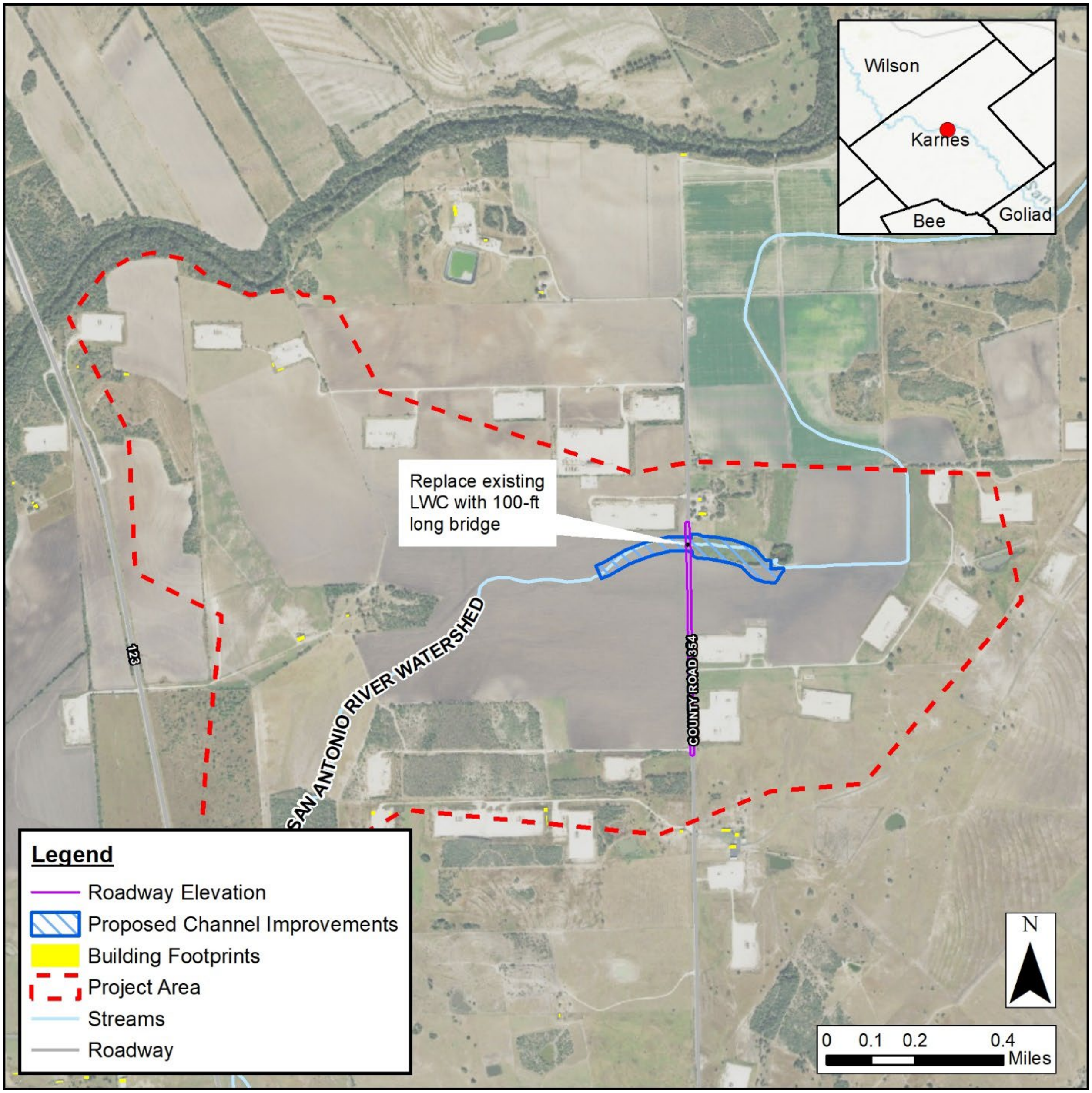

Figure 5-10B Project KC-10 proposed improvements.

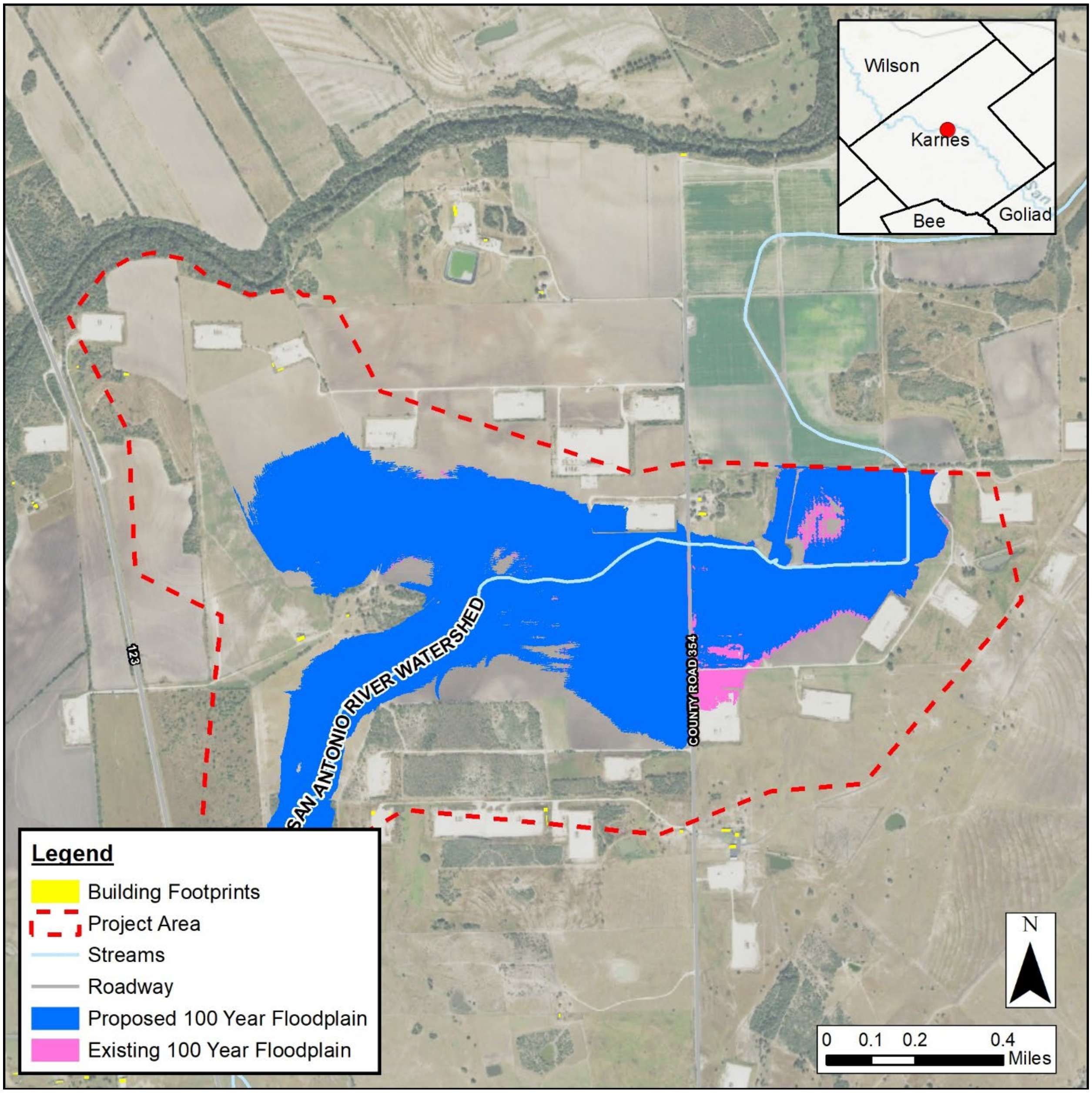

Figure 5-10C Project KC-10 flood risk reduction for the 100-year event.

5.3.11 Project KC-11 – US 181 drainage improvements at Marcelinas Creek Trib

The flood problem area at Marcelinas Creek was identified as a damage center in the Holistic Watershed Master Plan for Karnes, Goliad, and Wilson Counties. Under existing conditions, the 10-year event floods two (2) residential structures, with flooding depths of 2 and 6 inches. During the 100-year event, the number of flooded residential structures increases to six (6), with flooding depths ranging from 1 inch to 21 inches. Please see **Figure 5-11A** for a view of the study area.

The purpose of this proposed project is to mitigate flooding of residential and commercial structures south of US 181. The proposed improvements include installing two additional 5 ft x 5 ft box culverts to the original 4- 5 ft x 5 ft culverts at US 181, adding approximately 1,200 linear feet of trapezoidal channel improvements with a bottom width of 150 feet and side slopes of 4:1 upstream of the US 181 culverts, and approximately 500 linear feet of trapezoidal channel improvements with a bottom width of 50 feet and side slopes of 4:1 downstream of the US 181 culverts. Please see **Figure 5-11B** for a depiction of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a reduction of flooded structures from six (6) structures to four (4) structures during the 100-year event. Furthermore, the depth of flooding at one structure is reduced from 21 inches to 8 inches. Please see **Figure 5-11C** for a depiction of the 100-year flood risk reduction.

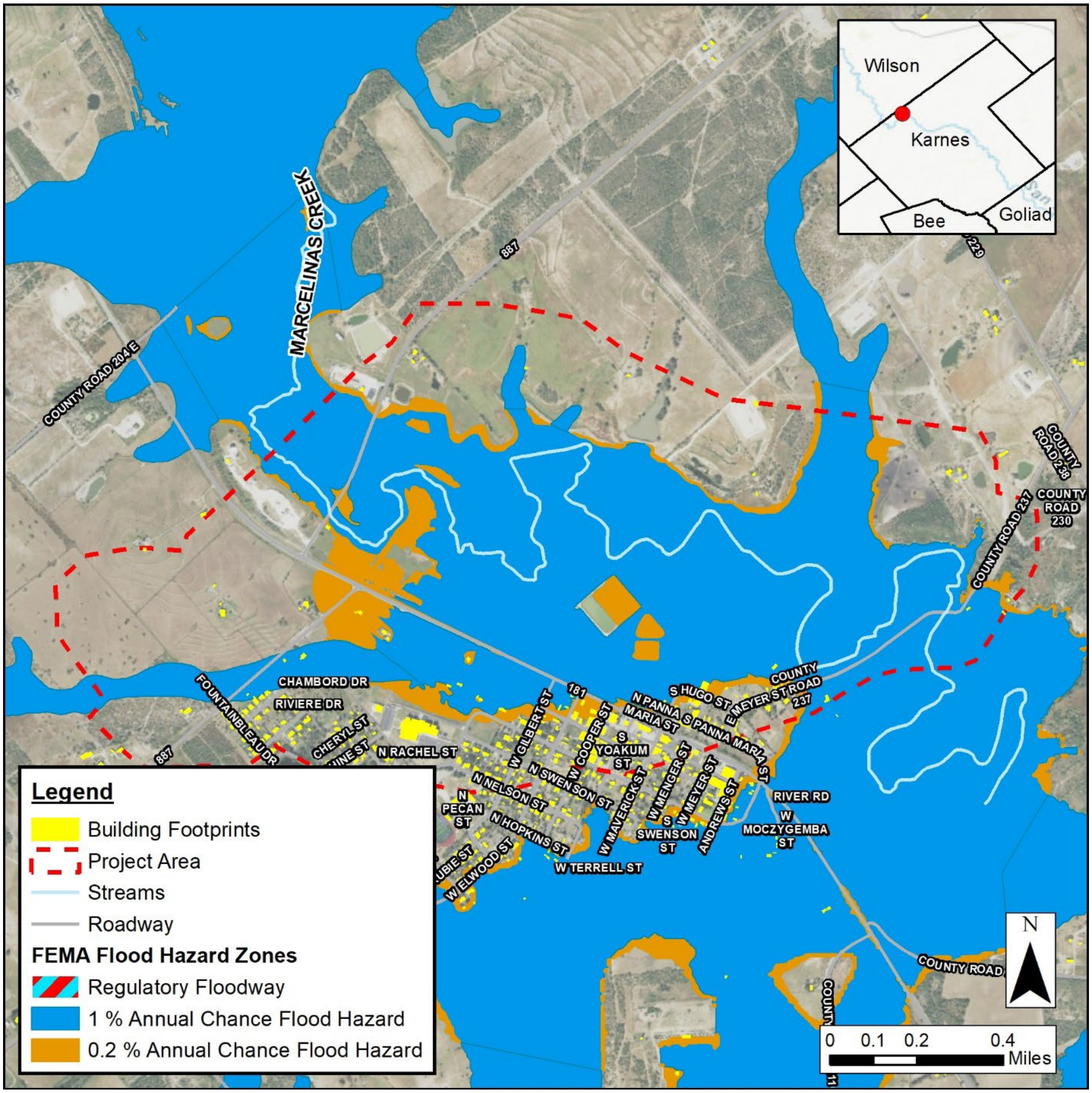

Figure 5-11A Project KC-11 study area location.

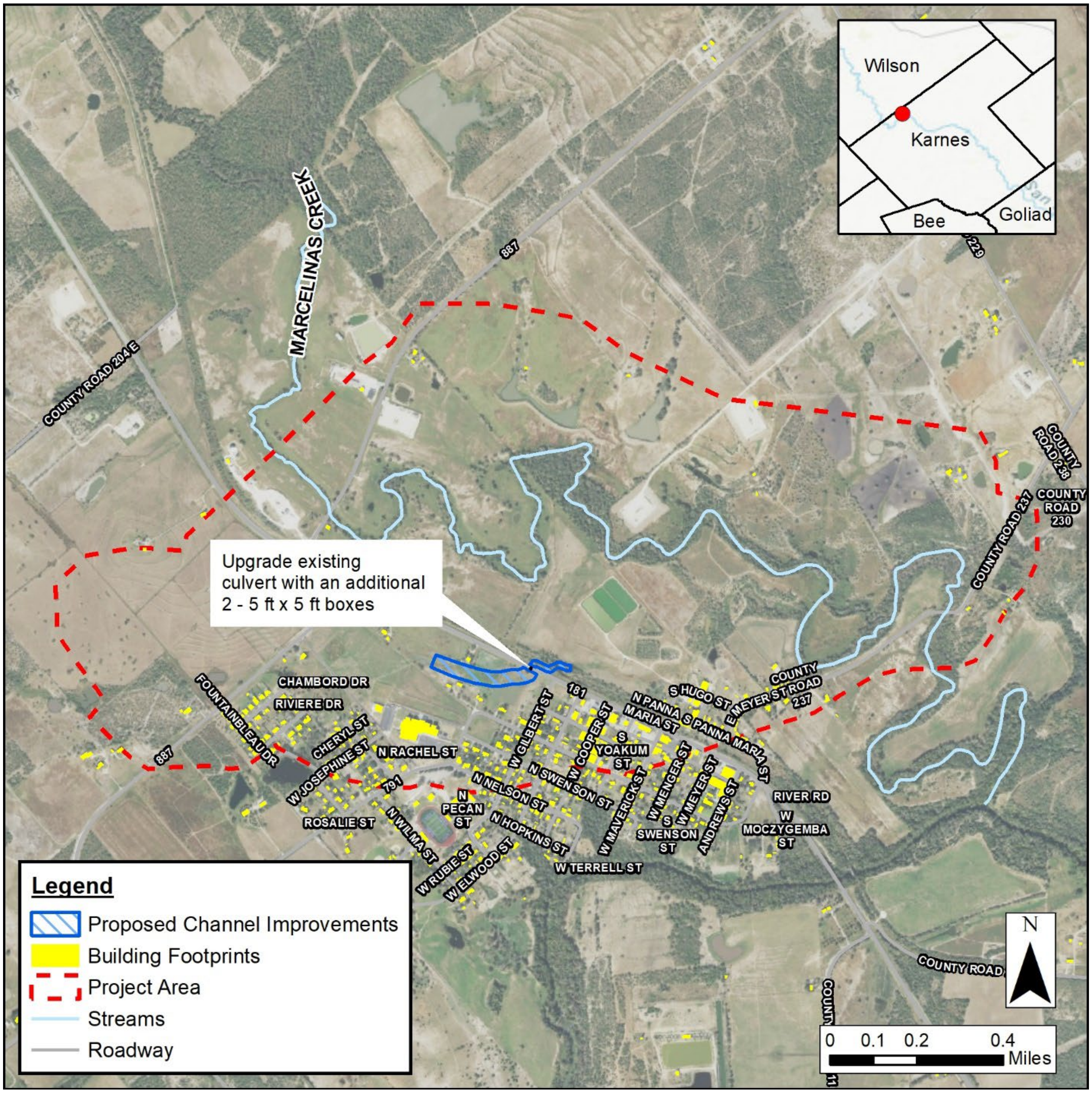

Figure 5-11B Project KC-11 proposed improvements.

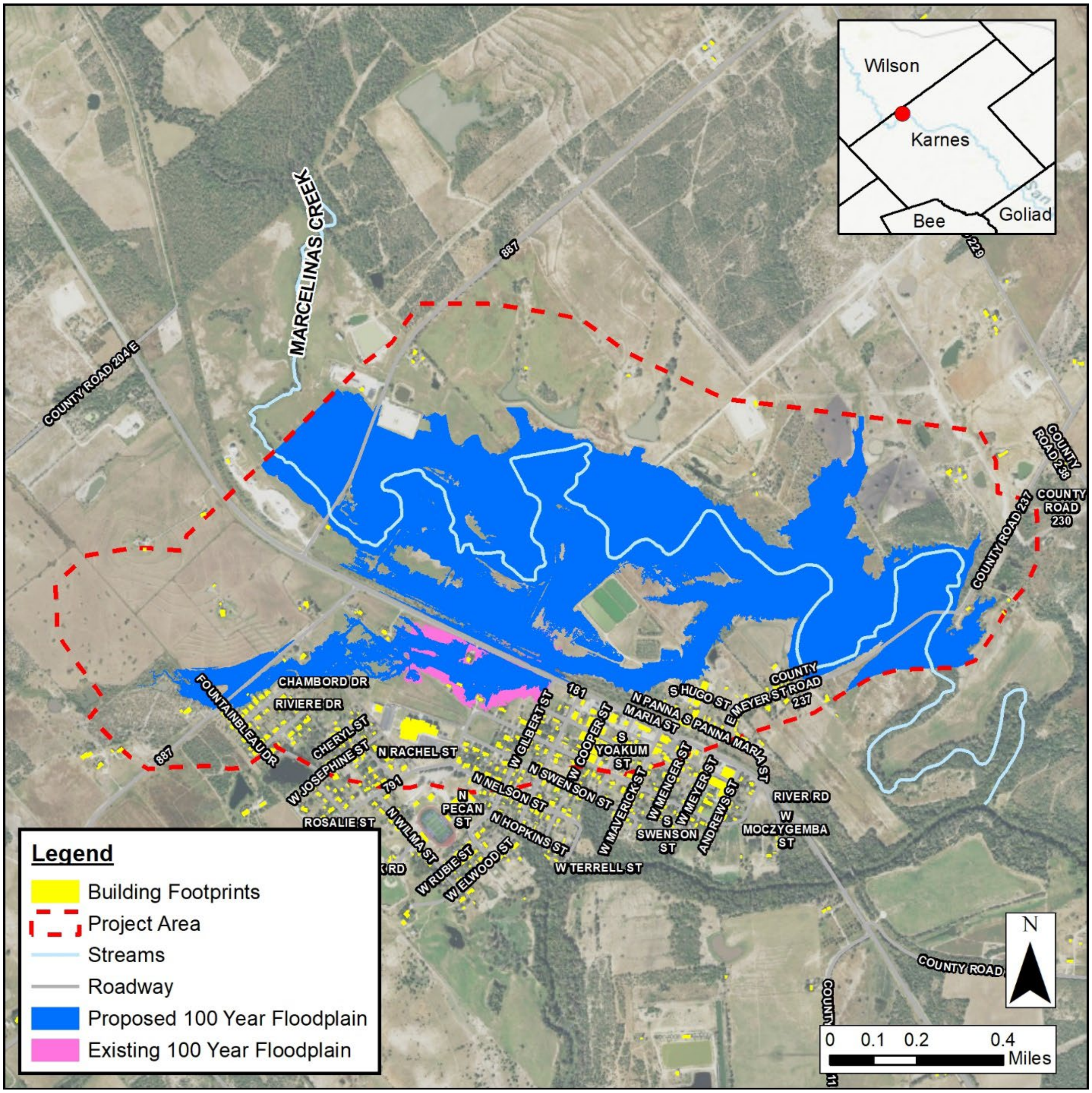

Figure 5-11C Project KC-11 flood risk reduction for the 100-year event.

5.3.12 Project KC-12 – Nichols Creek Tributary 2 drainage improvements

The Escondido Street low water crossing at Nichols Creek Tributary 2 was identified as a flood problem area based on the results of the 1D hydraulic modeling analysis. The results of preliminary 2D modeling show the 100-year depth of flooding at the low water crossing is 18 inches under existing conditions, and the roadway is impassible for approximately 6.4 hours. During the 100-year event, one (1) residential structure and two (2) commercial structures are flooded. Please see **Figure 5-12A** for a view of the study area.

The proposed project for Nichols Creek Tributary 2 was developed to improve the level-of-service for the roadway to accommodate daily traffic and emergency services and to mitigate flooding at commercial structures. As shown in **Figure 5-12B**, the proposed improvements include:

- 530 linear feet of trapezoidal channel improvements at the Escondido Street crossing
- Upgrade existing box culvert structure immediately downstream of Escondido Road with 2 – 4 ft x 4 ft boxes
- Install an additional 4 ft x 4 ft box at the Escondido Street Crossing

Based on the preliminary modeling results, the proposed project results in an improvement of the 100-year flooding on the roadway, with the flooding depth being reduced from 16 inches to 7 inches and the duration of flooding being reduced from 6.4 hours to 0.9 hours. Under proposed conditions, one (1) residential structure is removed from the 100-year floodplain, and flooding is reduced at two (2) commercial structures. Please see **Figure 5-12C** for a depiction of the 100-year flood risk reduction.

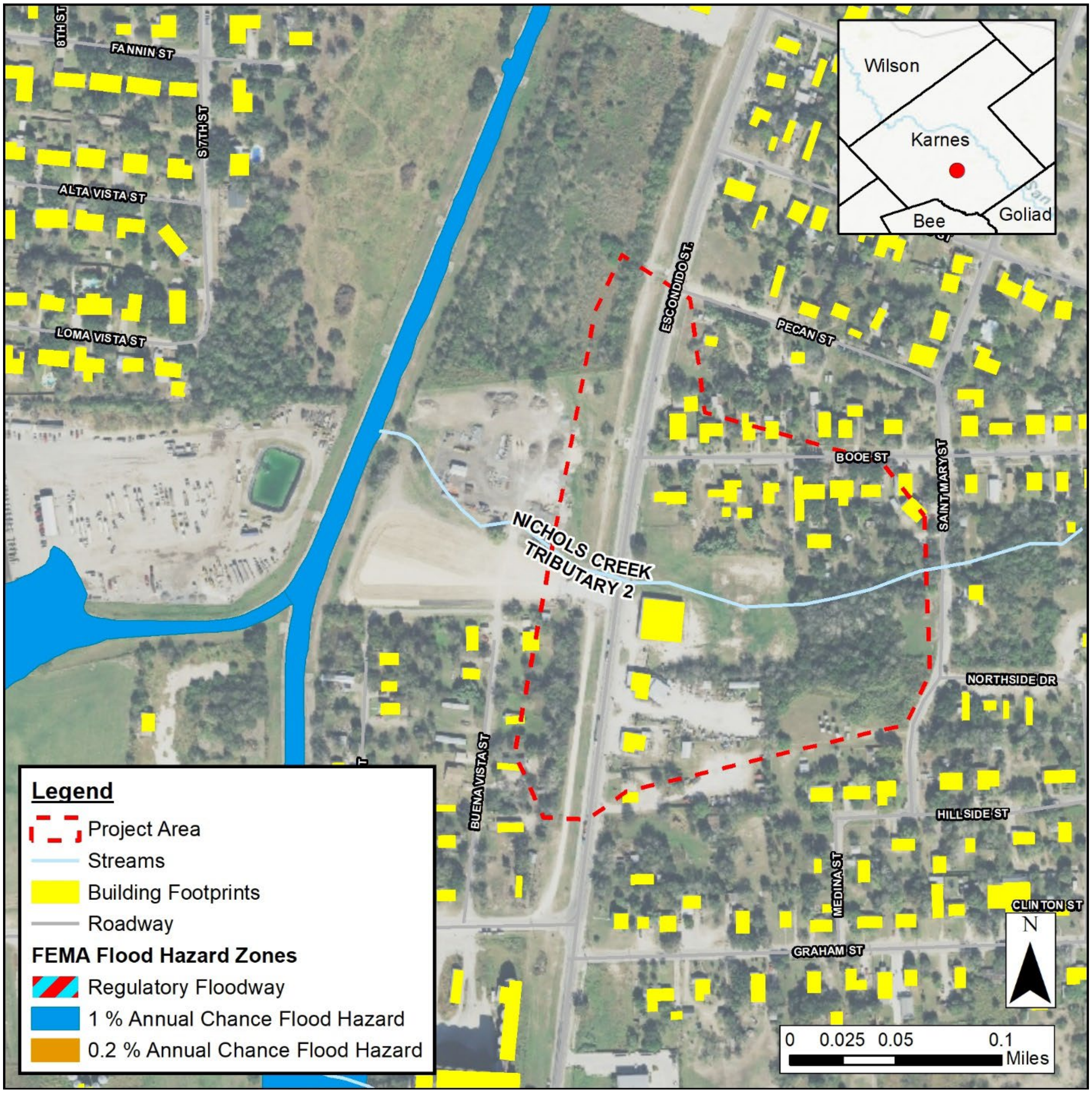

Figure 5-12A Project KC-12 study area location.

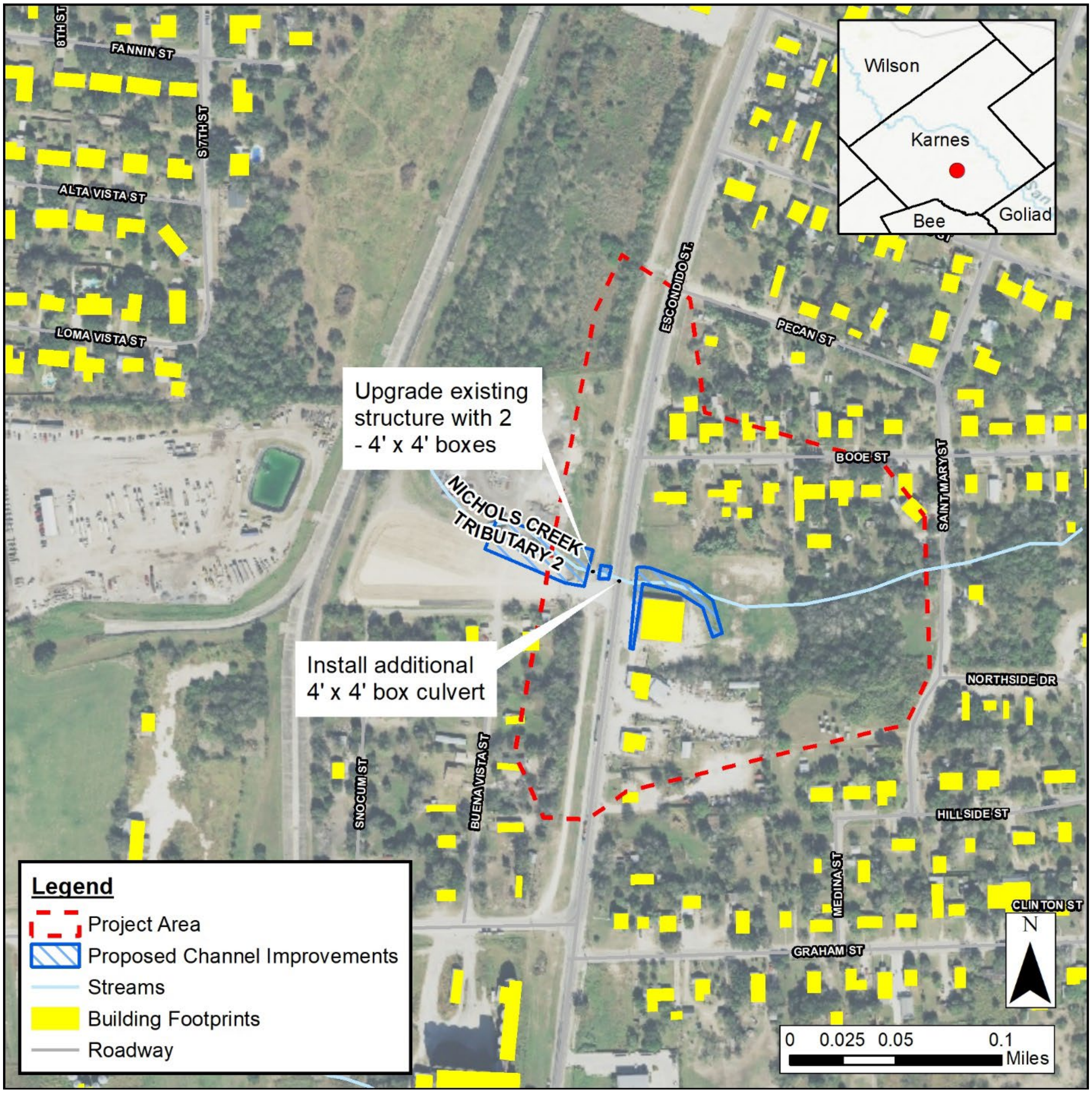

Figure 5-12B Project KC-12 proposed improvements.

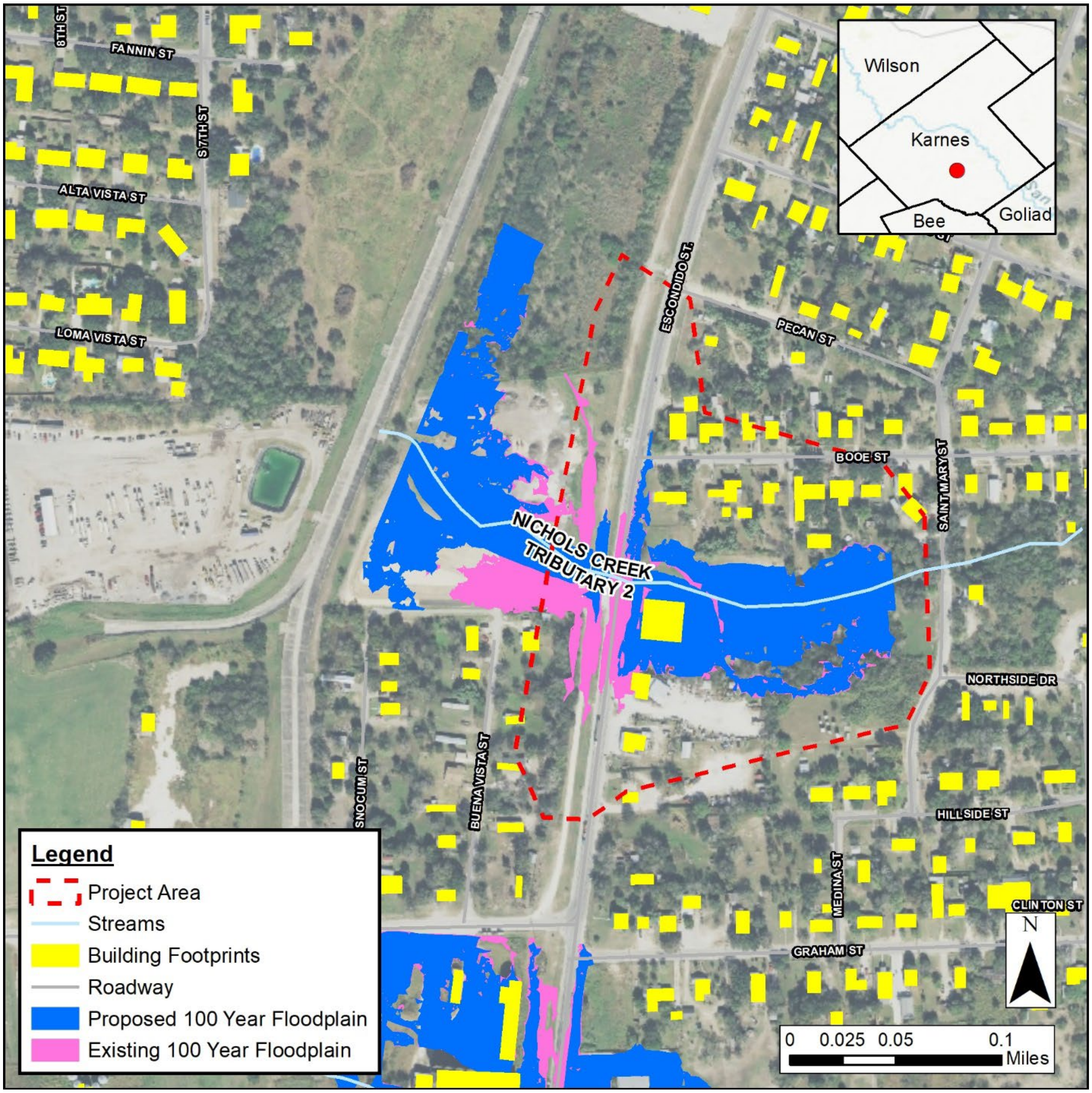

Figure 5-12C Project KC-12 flood risk reduction for the 100-year event.

5.3.13 Project KC-13 – Nichols Creek Tributary 4 drainage improvements

The Escondido Street low water crossing at Nichols Creek Tributary 4 was identified as a flood problem area based on the results of the 1D hydraulic modeling analysis. The results of preliminary 2D modeling show the 100-year depth of flooding at the low water crossing is 18 inches under existing conditions, and the roadway is impassible for nearly 2 hours. During the 100-year event, six (6) commercial structures are flooded at depths ranging from 5 inches to 36 inches. Please see **Figure 5-13A** for a view of the study area.

The proposed project for Nichols Creek Tributary 4 was developed to improve the level-of-service for the roadway to accommodate daily traffic and emergency services and to mitigate flooding at commercial structures. As shown in **Figure 5-13B**, the proposed improvements include:

- Elevating Escondido Street by approximately 0.20 feet
- 152 linear feet of trapezoidal channel improvements at the Escondido Street crossing, with a bottom width of 15 ft and 4:1 side slopes
- 231 linear feet of trapezoidal channel improvements east of the Kenedy Retreat Apartment Complex, with a bottom width of 20 feet and 3:1 side slopes
- Lower the bottom of the existing detention basin at the Kenedy Retreat Apartment Complex to increase storage capacity
- Replace existing 6 ft x 4 ft box culvert with 2 – 10 ft x 4 ft boxes at the Escondido Creek crossing.

Based on the preliminary modeling results, the proposed project results in a 100-year level-of-service for the roadway with no overtopping. This reduction in depth makes the roadway passable during the 100-year event, whereas the roadway is impassable for nearly 2 hours under existing conditions. Under proposed conditions, no structures are removed from the 100-year floodplain; however, flooding depths are reduced at four (4) structures. Please see **Figure 5-13C** for a depiction of the 100-year flood risk reduction.

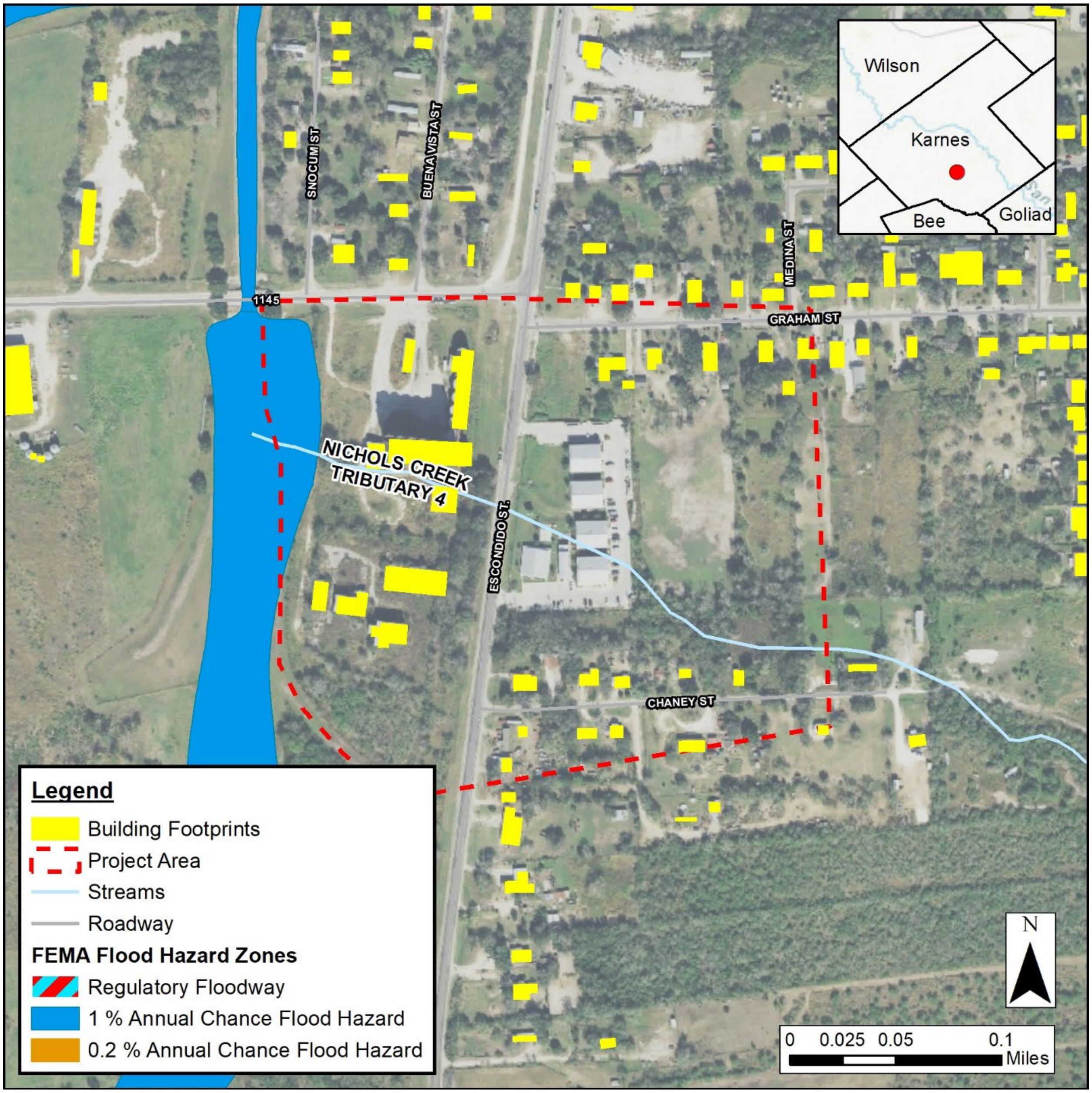

Figure 5-13A Project KC-13 study area location.

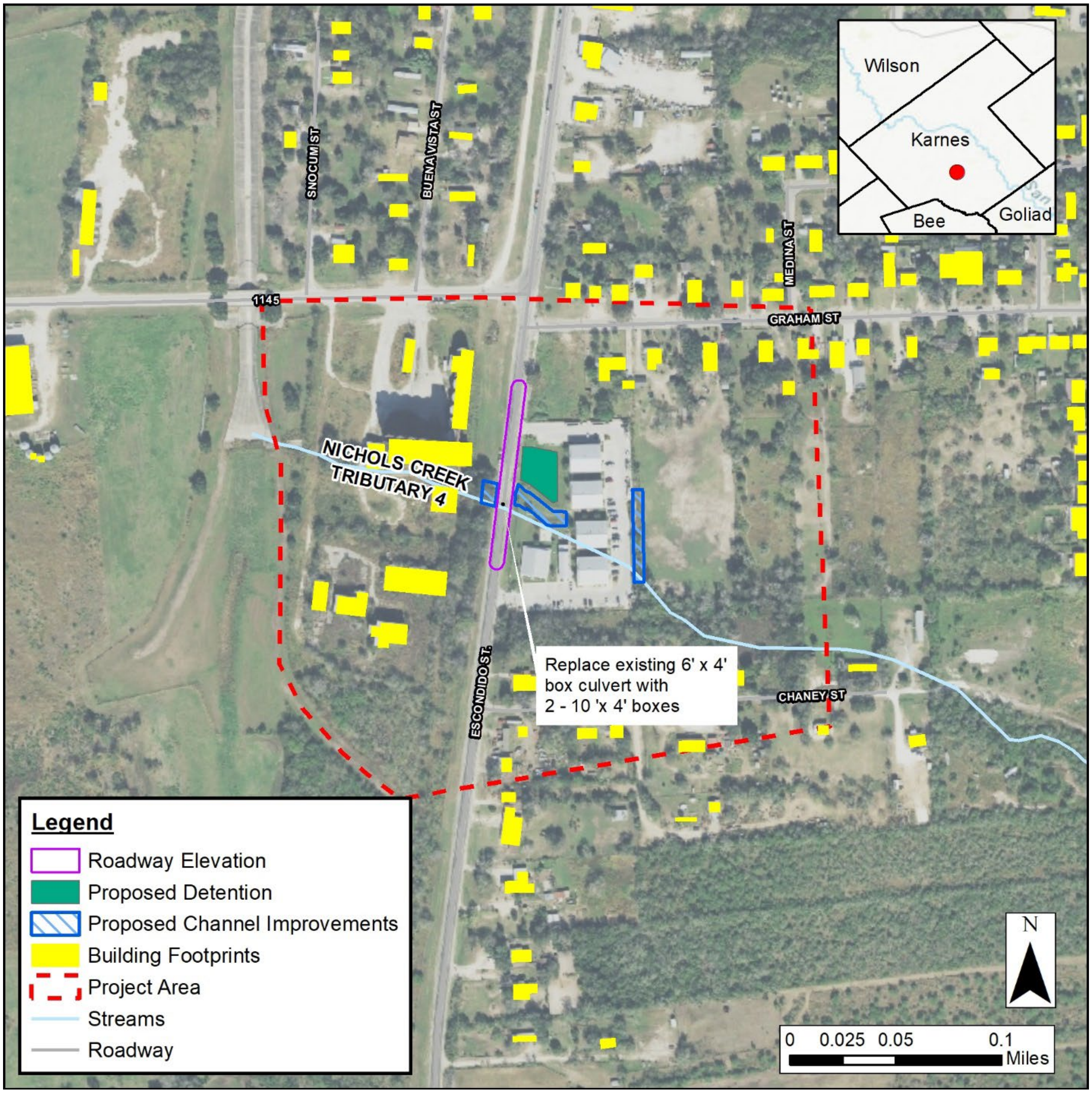

Figure 5-13B Project KC-13 proposed improvements.

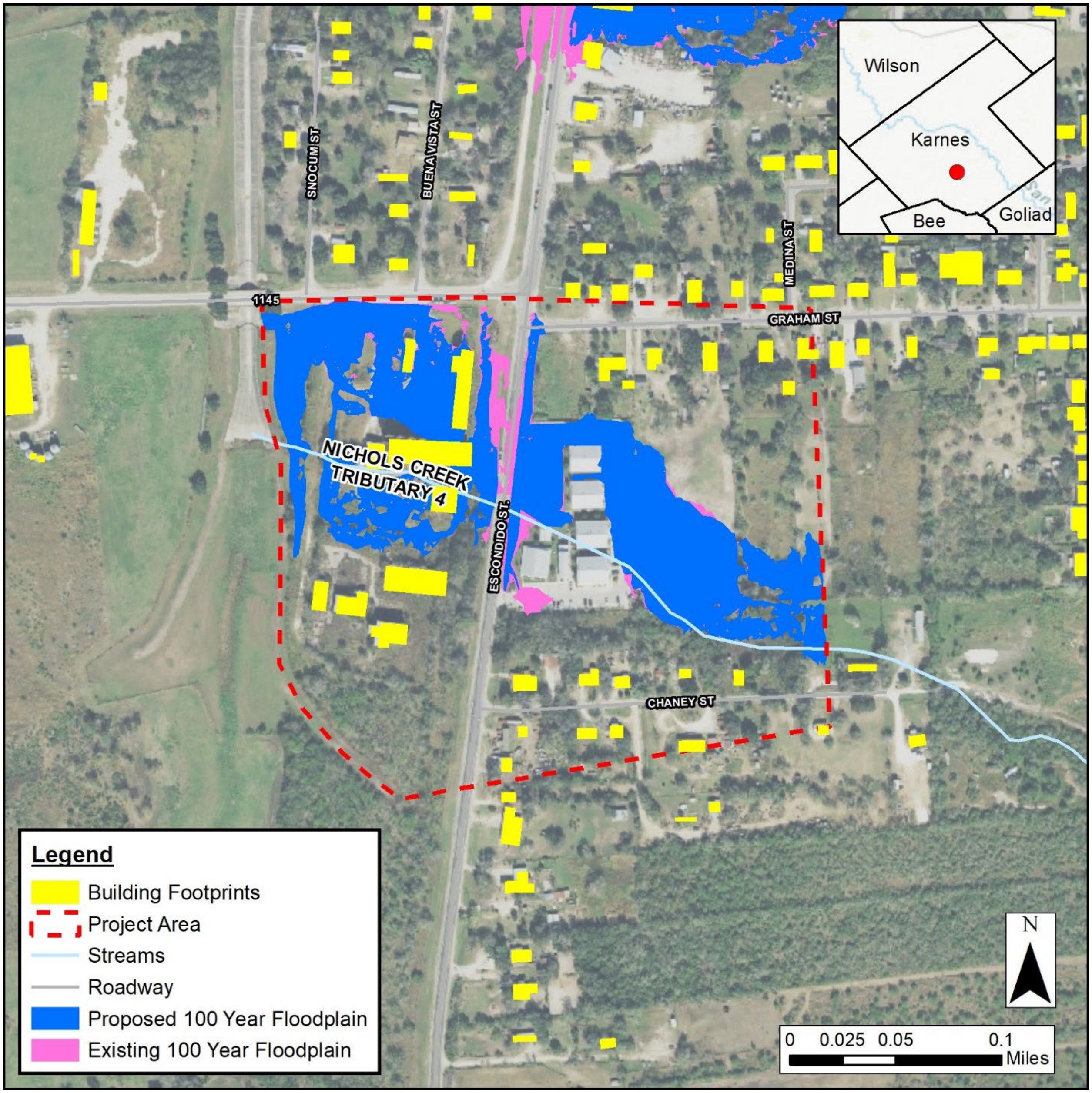

Figure 5-13C Project KC-13 flood risk reduction for the 100-year event.

5.3.14 Project KC-14 – CR 325 drainage improvements at Ojo De Agua Creek

The CR 325 low water crossing at Ojo de Agua Creek was identified by Karnes County as a high priority flood problem area. Based on preliminary modeling results, under existing conditions, the 100-year depth of flooding is 2.2 feet, making the roadway impassible for over 7 hours. Please see **Figure 5-14A** for a view of the study area.

The proposed project for CR 325 was developed to improve the level-of-service for the roadway to accommodate daily traffic and emergency services. The proposed improvements include elevating the roadway to approximately 310 feet NAVD88, installing 70 ft long bridge, 20 ft wide bridge, and 291 linear feet of trapezoidal channel improvements with a bottom width of 100 feet and side slopes of 3:1. Please see **Figure 5-14B** for a depiction of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a 100-year level-of-service for the roadway and no overtopping. This reduction in depth makes the roadway passable during the 100-year event, whereas the roadway is impassable for over 7 hours under existing conditions. Please see **Figure 5-14C** for a depiction of the 100-year flood risk reduction.

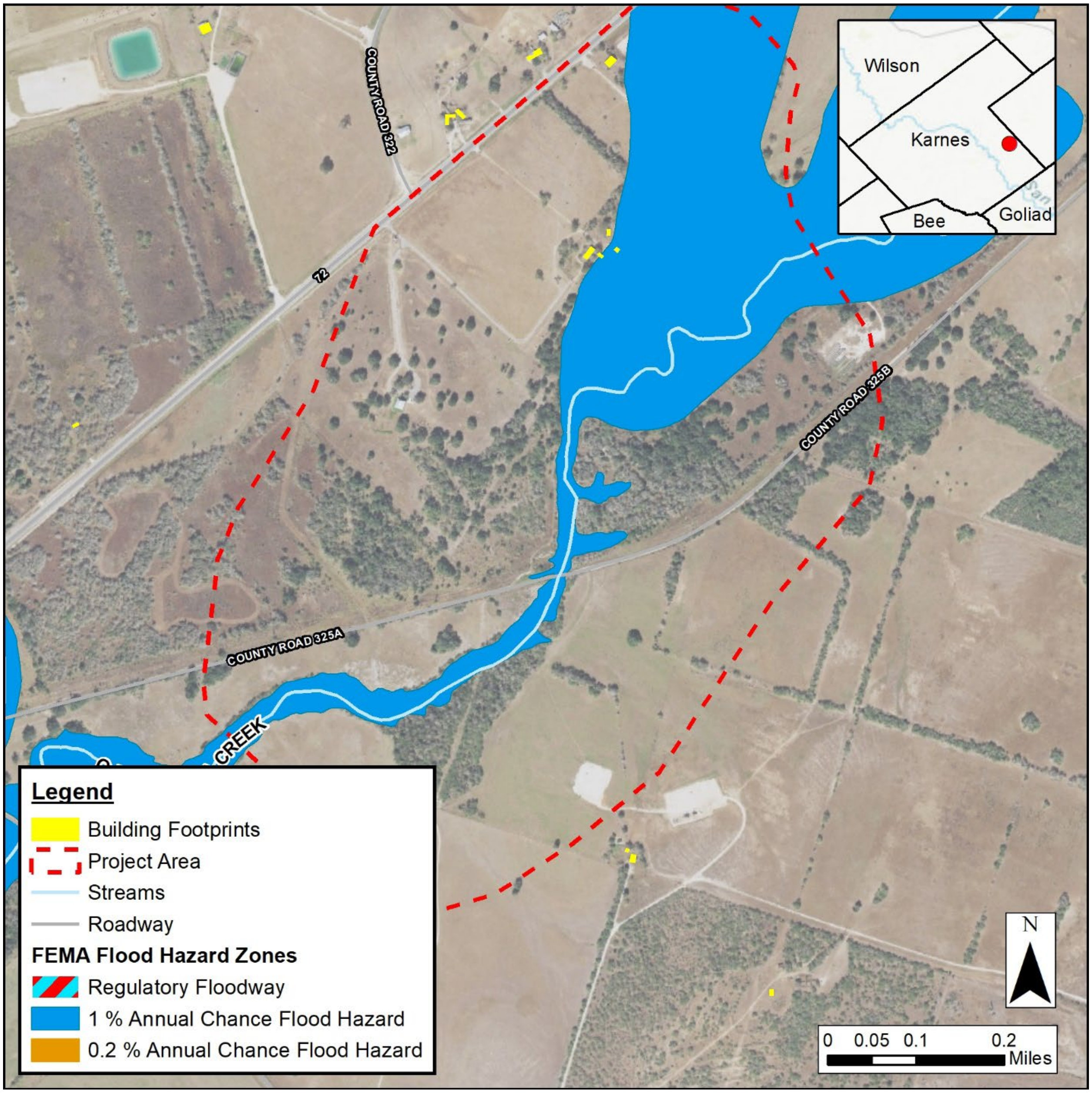

Figure 5-14A Project KC-14 study area location.

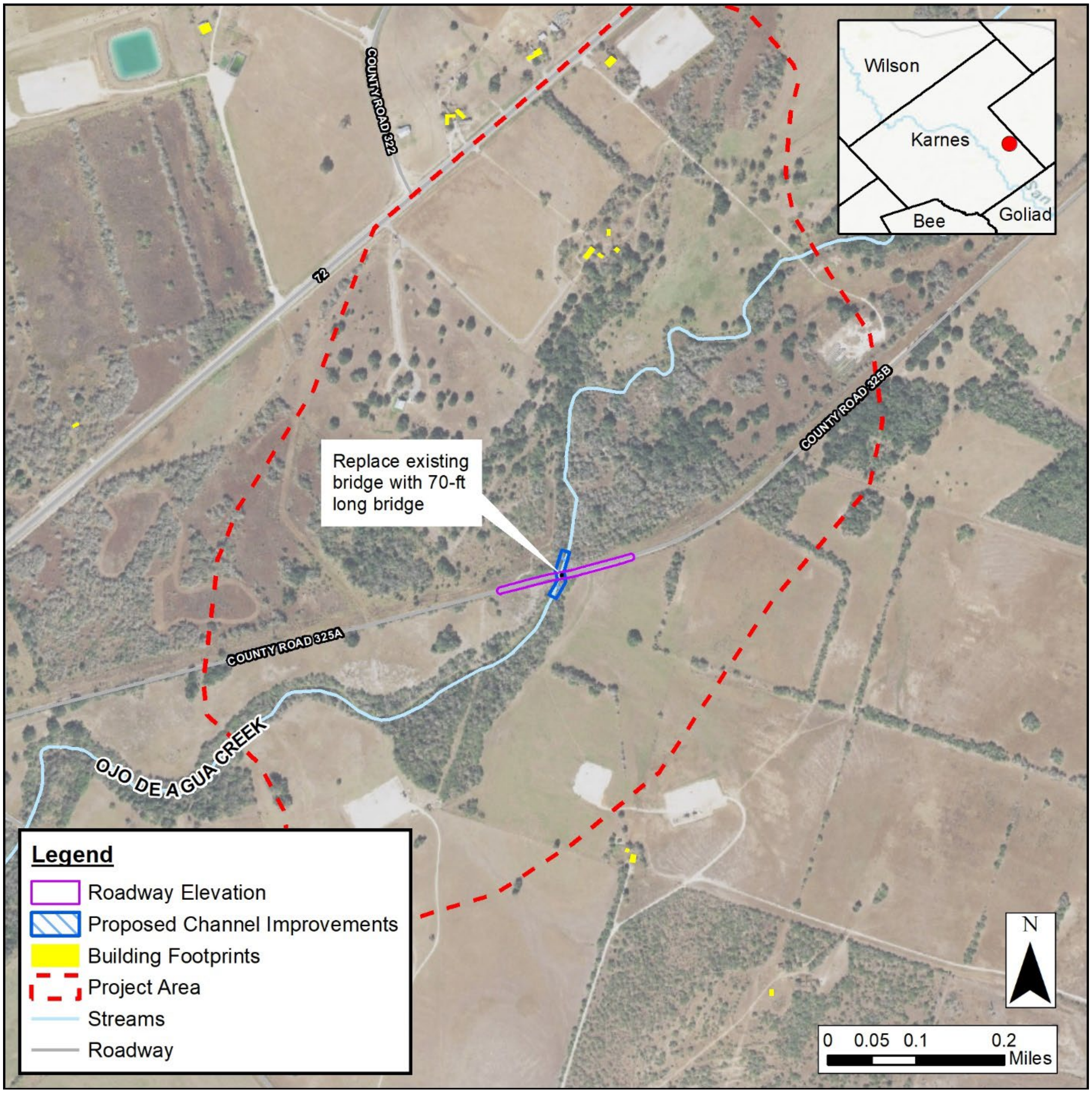

Figure 5-14B Project KC-14 proposed improvements.

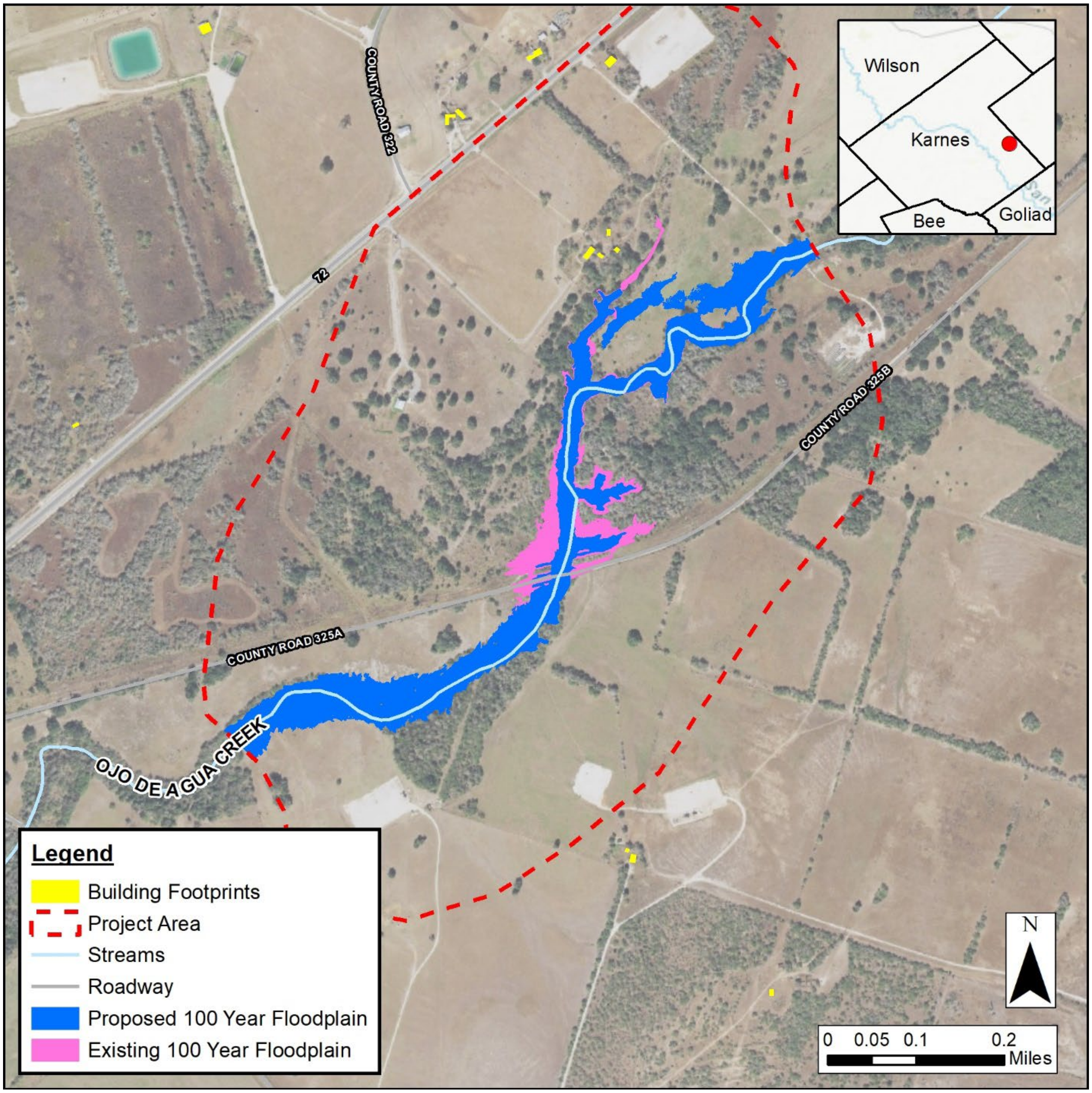

Figure 5-14C Project KC-14 flood risk reduction for the 100-year event.

5.3.15 Project KC-15 – CR 163 drainage improvements at Panther Creek

The CR 163 low water crossing at Panther Creek was identified by Karnes County as a high priority flood problem area. Under existing conditions, the 2-year depth of flooding at the low water crossing is 8 inches, and the roadway is impassable for nearly 2 hours. During the 100-year storm event, the depth increases to 93 inches, causing the roadway to be impassable for nearly a whole week. This magnitude of flooding is largely due to the presence of NRCS Dam Site 13 downstream of the crossing. Please see **Figure 5-15A** for a view of the study area.

The proposed project for CR 163 was developed to improve the level-of-service of the roadway for daily traffic and emergency services. The proposed improvements include elevating the roadway about 3 feet for approximately 850 linear feet, installing 4 – 10 ft x 6 ft box culverts, and approximately 1,400 linear feet of trapezoidal channel improvements with a bottom width of 100 feet and 4:1 side slopes. Please see **Figure 5-15B** for a depiction of the proposed improvements.

Based on the preliminary modeling results, the proposed improvements result in a 10-year level-of-service for the roadway by reducing the maximum depth of flooding to be less than 6 inches. With the proposed improvements, flood waters do not overtop the roadway during the 2- or 10-year event. Please see **Figure 5-15C** for a depiction of the 100-year flood risk reduction.

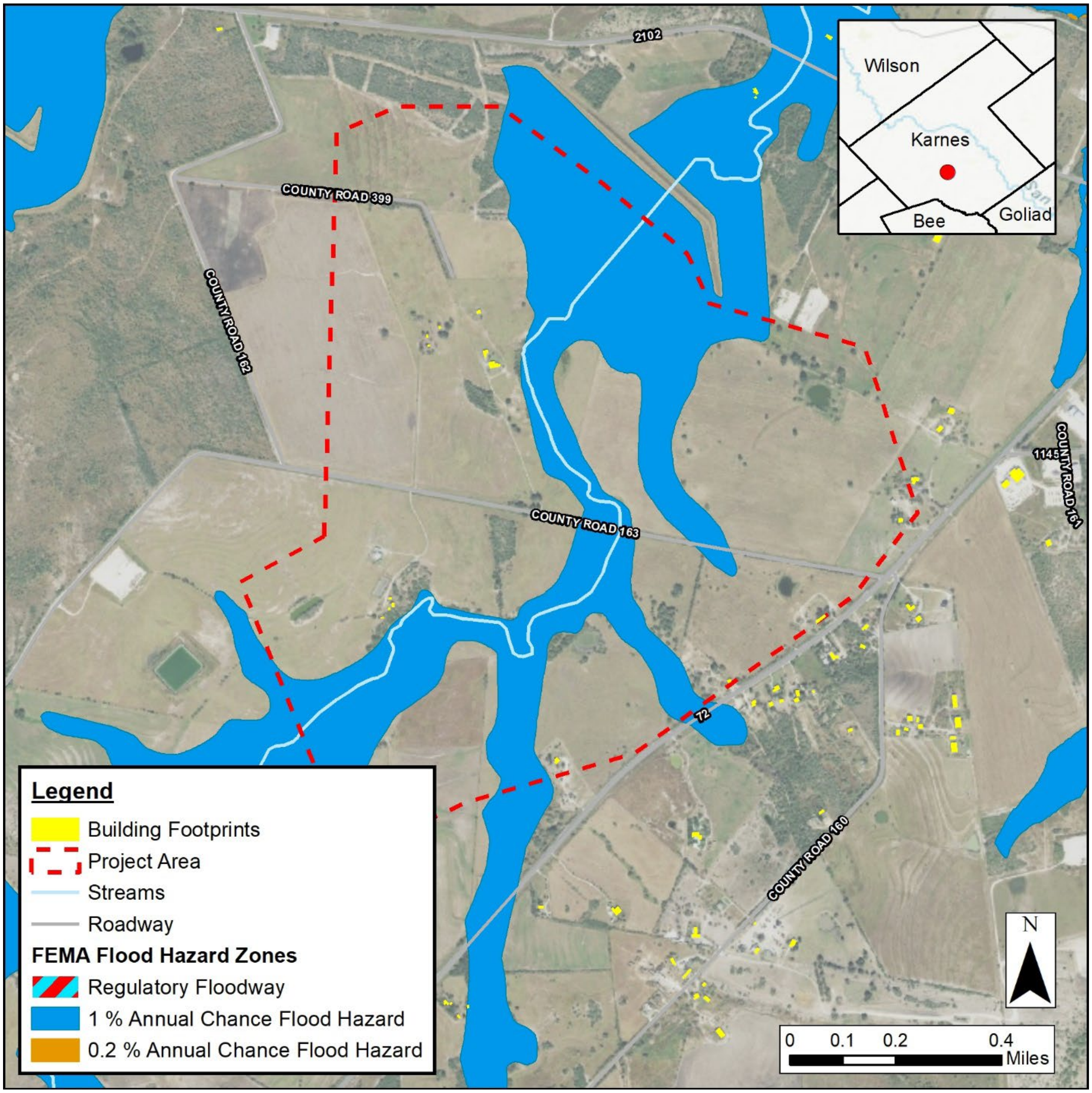

Figure 5-15A Project KC-15 study area location.

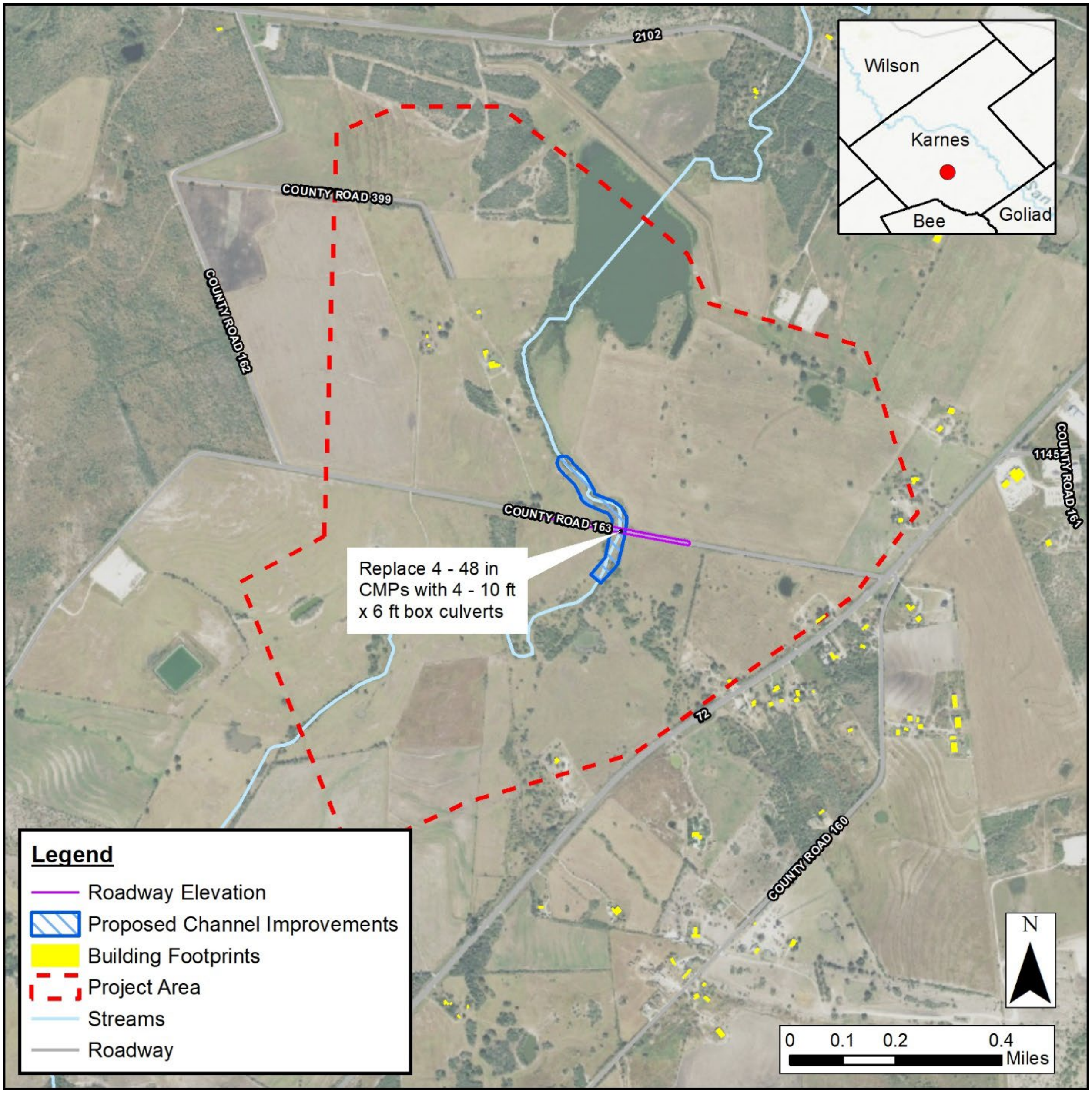

Figure 5-15B Project KC-15 proposed improvements.

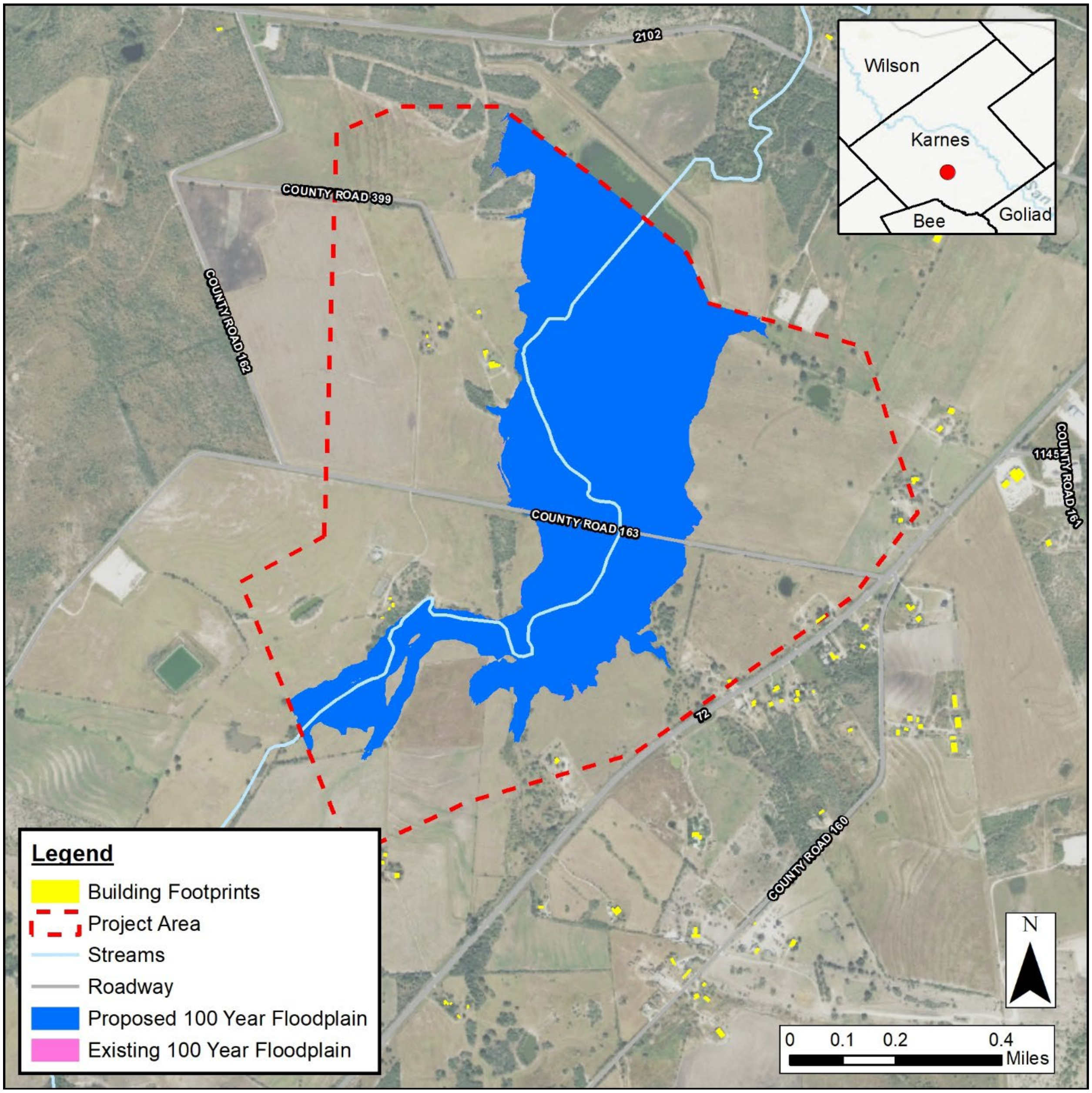

Figure 5-15C Project KC-15 flood risk reduction for the 100-year event.

5.4 Estimate of probable cost

An opinion of probable cost was prepared for each of the proposed projects based on local and TxDOT average low bid tabulations. **Table 5-5** summarizes the total estimated cost for each project, including construction, engineering, easement acquisition, and permitting. The construction costs include a 25% contingency to account for uncertainties in the preliminary design and analysis. Itemized construction cost estimates for each project are provided in **Appendix L**.

Table 5-5. Karnes County Flood Mitigation Projects – total cost estimates.

Project Identifier	Flood Mitigation Project Title	Total Estimated Cost
KC-1	CR 294 Drainage Improvements at Dry Ecleto Creek	$7,178,000
KC-2	CR 302 Drainage Improvements at Ecleto Creek	$15,261,000
KC-3	CR 262 Drainage Improvements at Ecleto Creek	$11,242,400
KC-4	Drainage Improvements at CR 337 and CR 326 Near City of Runge	$6,773,000
KC-5	CR 336 Drainage Improvements at Ecleto Creek Tributary	$2,859,756
KC-6	CR 331 Drainage Improvements at Escondido Creek	$4,865,554
KC-7	City of Kenedy Drainage Improvements on Escondido Creek	$33,317,000
KC-8	CR 127 Drainage Improvements at Hondo Creek	$8,992,000
KC-9	CR 145 Drainage Improvements at Hondo Creek	$3,688,372
KC-10	CR 354 Drainage Improvements at Lower San Antonio Tributary 147	$6,467,859
KC-11	US 181 Drainage Improvements at Marcelinas Creek Trib	$2,465,200
KC-12	Nichols Creek Tributary 2 Drainage Improvements	$1,651,000
KC-13	Nichols Creek Tributary 4 Drainage Improvements	$1,441,000
KC-14	CR 325 Drainage Improvements at Ojo De Agua Creek	$2,007,000
KC-15	CR 163 Drainage Improvements at Panther Creek	$3,218,400

5.5 Project constraints

An environmental constraints table including data regarding endangered species, historic preservation, and wetlands has been prepared for the 15 FMPs and is provided in **Appendix N**. Each of these projects will likely require local permitting and stormwater pollution prevention plans (SWPPP), as well as additional permitting with regulatory agencies, including those listed below:

- Federal Emergency Management Agency (FEMA)
- U.S. Army Corps of Engineers (USACE)
- U.S. Fish and Wildlife Services (USFWS)
- Texas Commission on Environmental Quality (TCEQ)
- Texas Historical Commission

Due to the rural location of many of the project sites, oil and gas pipeline data were reviewed on the Railroad Commission of Texas website. Drainage improvements were preliminarily designed to avoid conflicts with oil and gas infrastructure as much as possible. However, any conflicts will need to be verified and addressed during final design. Similarly, the locations of existing utilities (water, gas, sewer, electrical, and telecommunications) were preliminarily identified and noted based on aerial imagery reflecting manholes, lift stations, power poles, valves, pedestals, etc. For projects where potential utility conflicts were evident, the construction cost estimates were adjusted to account for utility relocation. Any utility conflicts will need to be verified and addressed during final design.

5.6 Benefit-cost analysis

The benefit-cost analysis (BCA) for each of these FMPs was prepared using the TWDB BCA Input Workbook version 1.2 and the FEMA BCA Toolkit version 6.0. A project life of 30 years was assumed for these analyses. Existing and proposed damages for low-water crossings were generally quantified for the 2-, 10-, and 100-year storm events. In cases where there were no existing damages in the 2-year storm, the 10-, 25-, and 100-year storm events were used for the BCA. The BCAs for each FMP are summarized in **Table 5-6** below. The BCA worksheets for each project are provided in **Appendix L**.

Table 5-6. Karnes County Flood Mitigation Projects – benefit-cost analysis summary.

Project ID	Flood Mitigation Project Title	Benefit Categories	Storm Events Analyzed	Final BCR
KC-1	CR 294 Drainage Improvements at Dry Ecleto Creek	Low Water Crossing	2-, 10-, 100-year	0.3
KC-2	CR 302 Drainage Improvements at Ecleto Creek	Low Water Crossing	2-, 10-, 100-year	0.7
KC-3	CR 262 Drainage Improvements at Ecleto Creek	Low Water Crossing	2-, 10-, 100-year	0.1
KC-4	Drainage Improvements at CR 337 and CR 326 Near City of Runge	Residential Structures, Commercial Structures, Flooded Streets, and Low Water Crossing	2-, 10-, 100-year	0.0
KC-5	CR 336 Drainage Improvements at Ecleto Creek Tributary	Low Water Crossing	10-, 25-, 100-year	0.0
KC-6	CR 331 Drainage Improvements at Escondido Creek	Low Water Crossing	2-, 10-, 100-year	0.4
KC-7	City of Kenedy Drainage Improvements on Escondido Creek	Residential Structures, Commercial Structures, Flooded Streets, and Low Water Crossing	10-, 25-, 100-year	0.1
KC-8	CR 127 Drainage Improvements at Hondo Creek	Low Water Crossing	2-, 10-, 100-year	0.2
KC-9	CR 145 Drainage Improvements at Hondo Creek	Low Water Crossing	2-, 10-, 100-year	0.3
KC-10	CR 354 Drainage Improvements at Lower San Antonio Tributary 147	Low Water Crossing	2-, 10-, 100-year	0.0
KC-11	US 181 Drainage Improvements at Marcelinas Creek Trib	Residential Structures and Commercial Structures	2-, 10-, 100-year	0.1
KC-12	Nichols Creek Tributary 2 Drainage Improvements	Commercial Structures and Low Water Crossing	2-, 10-, 100-year	1.6
KC-13	Nichols Creek Tributary 4 Drainage Improvements	Commercial Structures and Low Water Crossing	2-, 10-, 100-year	1.8
KC-14	CR 325 Drainage Improvements at Ojo De Agua Creek	Low Water Crossing	100-year	0.0
KC-15	CR 163 Drainage Improvements at Panther Creek	Low Water Crossing	2-, 10-, 100-year	0.2

5.7 No negative impact

In accordance with the *TWDB Technical Guidelines for Regional Flood Planning*, “No Negative Impact means that a project will not increase flood risk of surrounding properties. Using best available data, the increase in flood risk must be measured by the 100-year frequency storm event water surface elevation and peak discharge. It is recommended that no rise in water surface elevation or discharge should be permissible, and that the analysis extent must be vast enough to prove proposed project conditions are equal to or less than existing conditions.”

Based on the preliminary modeling for the 15 FMPs described in this memorandum, the following statements are valid:

- Stormwater does not increase inundation in areas beyond the public right-of-way, project property, or easement.
- Stormwater does not increase inundation of storm drainage networks, channels, and roadways beyond design capacity.

The *TWDB Technical Guidelines for Regional Flood Planning* state, “Maximum increase of 2D Water Surface Elevations must round to 0.3 feet (< 0.35 ft) measured at each computational cell.” Any localized rises greater than 0.35 feet evident in the preliminary modeling will likely be resolved with further refinements during final design, or the rises will be entirely contained within the public right-of-way, project property, or easement.

This report is prepared to serve as certification of no negative impact for the 15 FMPs discussed herein. As the projects are advanced, the impact analyses should be updated to reflect final design and confirm no negative impacts. A no negative impact determination table in accordance with the *TWDB Technical Guidelines for Regional Flood Planning* is provided in **Table 5-7** and has also been included in **Appendix M**.

Table 5-7. Karnes County Flood Mitigation Projects – no negative impact determination.

FMP ID	FMP Name	FMP Meets ALL No Negative Impacts Requirements from Exhibit C Section 3.6.A (Yes/ No)	Negative Impact Description	Planning Level Mitigation Plan (Yes/ No)	Mitigation Plan Description	No Negative Impact Determination (Yes/No)	Basis of No Negative Impact Determination (Model, Study, Engineering Judgement)	Model ID	Model Name	Model Submitted
123000066	CR 294 Drainage Improvements at Dry Ecleto Creek	Yes	None	No	NA	Yes	Model and Study	120000000049	CR 294 Drainage Improvements at Dry Ecleto Creek	Yes
123000067	CR 302 Drainage Improvements at Ecleto Creek	Yes	None	No	NA	Yes	Model and Study	120000000050	CR 302 Drainage Improvements at Ecleto Creek	Yes
123000068	CR 262 Drainage Improvements at Ecleto Creek	Yes	None	No	NA	Yes	Model and Study	120000000051	CR 262 Drainage Improvements at Ecleto Creek	Yes
123000069	Drainage Improvements at CR 337 and CR 326 Near City of Runge	Yes	None	No	NA	Yes	Model and Study	120000000052	Drainage Improvements at CR 337 and CR 326 Near City of Runge	Yes
123000070	CR 336 Drainage Improvements at Ecleto Creek Tributary	Yes	None	No	NA	Yes	Model and Study	120000000053	CR 336 Drainage Improvements at Ecleto Creek Tributary	Yes
123000071	CR 331 Drainage Improvements at Escondido Creek	Yes	None	No	NA	Yes	Model and Study	120000000054	CR 331 Drainage Improvements at Escondido Creek	Yes
123000072	City of Kenedy Drainage Improvements on Escondido Creek	Yes	None	No	NA	Yes	Model and Study	120000000055	City of Kenedy Drainage Improvements on Escondido Creek	Yes
123000073	CR 127 Drainage Improvements at Hondo Creek	Yes	None	No	NA	Yes	Model and Study	120000000056	CR 127 Drainage Improvements at Hondo Creek	Yes
123000074	CR 145 Drainage Improvements at Hondo Creek	Yes	None	No	NA	Yes	Model and Study	120000000057	CR 145 Drainage Improvements at Hondo Creek	Yes
123000075	CR 354 Drainage Improvements at Lower San Antonio Tributary 147	Yes	None	No	NA	Yes	Model and Study	120000000058	CR 354 Drainage Improvements at Lower San Antonio Tributary 147	Yes
123000076	US 181 Drainage Improvements at Marcelinas Creek Trib	Yes	None	No	NA	Yes	Model and Study	120000000059	US 181 Drainage Improvements at Marcelinas Creek Trib	Yes
123000077	Nichols Creek Tributary 2 Drainage Improvements	Yes	None	No	NA	Yes	Model and Study	120000000060	Nichols Creek Tributary 2 Drainage Improvements	Yes
123000078	Nichols Creek Tributary 4 Drainage Improvements	Yes	None	No	NA	Yes	Model and Study	120000000061	Nichols Creek Tributary 4 Drainage Improvements	Yes

Table 5-7. Karnes County Flood Mitigation Projects – no negative impact determination (continued).

FMP ID	FMP Name	FMP Meets ALL No Negative Impacts Requirements from Exhibit C Section 3.6.A (Yes/ No)	Negative Impact Description	Planning Level Mitigation Plan (Yes/ No)	Mitigation Plan Description	No Negative Impact Determination (Yes/No)	Basis of No Negative Impact Determination (Model, Study, Engineering Judgement)	Model ID	Model Name	Model Submitted
123000079	CR 325 Drainage Improvements at Ojo De Agua Creek	Yes	None	No	NA	Yes	Model and Study	120000000062	CR 325 Drainage Improvements at Ojo De Agua Creek	Yes
123000080	CR 163 Drainage Improvements at Panther Creek	Yes	None	No	NA	Yes	Model and Study	120000000063	CR 163 Drainage Improvements at Panther Creek	Yes

5.8 Flood early warning system

A Flood Early Warning System (FEWS) is the implementation of tools, data, and communication procedures to provide communities with advance notice of a potentially dangerous storm event. It requires the coordination of multiple entities to operate the proper equipment, gather pertinent data, and communicate with the public in a timely, efficient manner.

The San Antonio River Authority (SARA) utilizes a Predictive Flood Model (PFM), which is a continuous simulation software that has the ability to produce estimates of stream flow, depth, velocity, and maximum flood inundation within an inundation grid. The PFM develops these forecasts utilizing NexRAD weather and rainfall estimates, as well as data collected from an extensive network of precipitation and streamflow gages. This network of gages includes those installed at the 13 NRCS dams within the Escondido Creek watershed.

While the existing warning system associated with the PFM is largely focused on Bexar County, the PFM currently provides gage-adjusted radar rainfall totals and forecasts for the entire San Antonio River Basin, including Karnes County. These forecast data are available to the County, as well as the municipalities within the County. Karnes County should ensure this valuable information is being utilized by emergency response staff to monitor forecasted precipitation totals and provide notification to the public if dangerous conditions are predicted. While SARA does not currently have plans to expand the existing gage network, the County should consider approaching SARA about the installation and implementation of additional precipitation and streamflow gages within the County. The existing gage network is currently maintained by one person, with an annual planning budget of $5,000 per gage. If additional gages are installed in Karnes County, discussions will need to be held with SARA to determine which party will be responsible for maintenance of the new gages. For more information on the available precipitation forecast data and to discuss potential expansion of the gage network in Karnes County, it is recommended that the County contact SARA engineer Wayne Tschirhart, who coordinates the predictive modeling and warning system efforts.

At the second public meeting for this FPPS, held on September 28, 2023, Karnes County expressed the intention to expand their FEWS with advance flood warning sensors at low-water crossings. At the time of the meeting, the County’s list of planned sensor locations included 35 low-water crossings on county roads with a history of flooding problems.

5.9 Recommendations

To reduce risk to life and property at known flood problem areas in the community, it is recommended that Karnes County implement the fifteen (15) proposed flood mitigation construction projects discussed in this section. In addition, it is recommended that further analysis be carried out for the 10 flood mitigation evaluations listed in **Table 5-2**, which will help identify the extent of flood risk at those locations and provide alternatives for future flood mitigation projects. Finally, it is recommended that Karnes County take advantage of the precipitation forecast data made available by SARA through its Predictive Flood Model (PFM). The County should also approach SARA about expanding the network of precipitation and streamflow gages in Karnes County, which will further refine the modeling results produced by the PFM. This valuable information will be vital in developing the County’s Flood Early Warning System to protect the life and property of Karnes County residents.

6 Implementation and phasing plan

Based on input from the public meetings, a project implementation and phasing plan was developed. The implementation and phasing plan considered items such as project prioritization, funding sources, project duration, easement requirements, environmental impact of the proposed improvements, and benefit/cost ratio.

6.1 Project prioritization

To aid Karnes County in prioritizing the potential projects, the FMPs were ranked according to the Regional Flood Planning Group criteria and scores listed in **Table 6-1**. For each category, the projects received a score between 0 and 10. The project rankings are shown in **Table 6-2**, which were determined by summing the total score for all the categories. In cases where projects received the same score, those with a higher BCR were assigned a higher ranking.

Table 6-1. TWDB regional flood planning project scoring criteria.

Scoring Categories	Scoring Metrics	Score
Severity - Pre-Project Average Depth of Flooding (100-Year)	Baseline average flood depth > 3.5 ft	10
	Baseline average flood depth > 2 ft	8
	Baseline average flood depth > 1 ft	6
	Baseline average flood depth > 0.5 ft	4
	Baseline average flood depth < 0.5 ft	2
Severity - Community Need	>75% of project community affected (by population)	10
	50%-75% of project community affected	7
	25%-50% of project community affected	4
	<25% of project community affected	1
Flood Risk Reduction	Reduced risk to >75% of structures in floodplain	10
	Reduced risk to <75% of structures in floodplain	7
	Reduced risk to <50% of structures in floodplain	4
	Reduced risk to <10% of structures in floodplain	1
	Reduced risk to 0 structures in floodplain	0
Flood Damage Reduction	Flood damage reduction >95%	10
	Flood damage reduction > 75%	8
	Flood damage reduction > 50%	6
	Flood damage reduction > 25%	4
	Flood damage reduction < 25%	2
Critical Facilities Damage Reduction	Reduced risk for >75% of critical facilities in floodplain	10
	Reduced risk for <75% of critical facilities in floodplain	7
	Reduced risk for <50% of critical facilities in floodplain	4
	Reduced risk for <10% of critical facilities in floodplain	1
	Reduced risk for 0 structures in floodplain	0
Life and Safety	Life/injury risk percentage >50%	10
	Life/injury risk percentage >40%	8
	Life/injury risk percentage >30%	6
	Life/injury risk percentage >20%	4
	Life/injury risk percentage <20%	2
Water Supply	Involves directly increasing water supply availability and connection to user	10
	Directly benefits water availability in aquifer but no direct connection to user	7
	Indirectly benefits water availability (e.g., recharges aquifers naturally more)	4
	No impact on water supply	0

Table 6-1. TWDB regional flood planning project scoring criteria (continued).

Scoring Categories	Scoring Metrics	Score
Social Vulnerability	SVI between 0.75-1.00 (high vulnerability)	10
	SVI between 0.5-0.75 (moderate to high vulnerability)	7
	SVI between 0.25-0.5 (low to moderate vulnerability)	4
	SVI between 0.01-0.25 (low vulnerability)	1
Nature-Based Solutions	>75% of the project cost is nature-based	10
	> 50% of the project cost is nature-based	7
	>25% of the project cost is nature-based	4
	<25% of the project cost is nature-based	1
Multiple Benefits	Project delivers benefits in 4 or more wider benefit categories	10
	Project delivers benefits in 3 wider benefit categories	7
	Project delivers benefits in 2 wider benefit categories	4
	Project delivers benefits in only 1 wider benefit category	1
	Project does not deliver any wider benefits	0
Operations and Maintenance	Project will have low operation and maintenance requirements	10
	Project will have regular operation and maintenance requirements	7
	Project will have high operation and maintenance requirements	4
	Project will have extensive operation and maintenance requirements	1
Regulatory Obstacles	Project has few administrative and regulatory requirements	10
	Project has a typical number of administrative and regulatory requirements	6
	Project has a high number of administrative and regulatory requirements	2
Environmental Benefit	Project will deliver a high level of environmental benefits	10
	Project will deliver a moderate level of environmental benefits	6
	Project will deliver a low level of environmental benefits	3
	Project does not provide any environmental benefits	0
Environmental Impact	Project has no adverse environmental impacts	10
	Project will have adverse impacts in 1 environmental category	6
	Project will have adverse impacts in 2-3 environmental categories	3
	Project will have adverse impacts in 4+ environmental categories	0
Mobility	Project protects major and minor access routes and emergency service access	10
	Project protects all major access routes and all emergency service access	7
	Project protects some major access routes and most emergency service access	4
	Project provides no change to major, minor, or emergency access routes	0

Table 6-2. Karnes County flood mitigation project ranking.

Rank	Project Identifier	Flood Mitigation Project Title	Score	BCR
1	KC-4	Drainage Improvements at CR 337 and CR 326 Near City of Runge	79	0.0
2	KC-7	City of Kenedy Drainage Improvements on Escondido Creek	72	0.1
3	KC-12	Nichols Creek Tributary 2 Drainage Improvements	70	1.6
4	KC-2	CR 302 Drainage Improvements at Ecleto Creek	61	0.7
5	KC-6	CR 331 Drainage Improvements at Escondido Creek	61	0.4
6	KC-9	CR 145 Drainage Improvements at Hondo Creek	61	0.3
7	KC-8	CR 127 Drainage Improvements at Hondo Creek	61	0.2
8	KC-15	CR 163 Drainage Improvements at Panther Creek	61	0.2
9	KC-14	CR 325 Drainage Improvements at Ojo De Agua Creek	61	0.0
10	KC-13	Nichols Creek Tributary 4 Drainage Improvements	59	1.8
11	KC-5	CR 336 Drainage Improvements at Ecleto Creek Tributary	59	0.0
12	KC-10	CR 354 Drainage Improvements at Lower San Antonio Tributary 147	56	0.0
13	KC-1	CR 294 Drainage Improvements at Dry Ecleto Creek	55	0.3
14	KC-3	CR 262 Drainage Improvements at Ecleto Creek	55	0.1
15	KC-11	US 181 Drainage Improvements at Marcelinas Creek Trib	55	0.1

6.2 Construction phasing

The phasing of construction on these fifteen (15) projects will likely be driven primarily by public input, right-of-way and easement acquisition timeframes, and funding availability. In general, construction phasing should move from downstream to upstream; however, the projects presented here are not dependent on one another, which will allow the County to construct them in any order.

6.3 Funding sources

This section provides a brief summary of state and federal grant programs and other sources that may provide partial or full funding for planning, design, permitting, and construction activities related to the FMPs and FMEs recommended as part of this FPPS.

Municipal Funding Sources

- Capital Improvements Plan (CIP)
- Drainage Utility Fees
- General Fund
- General Obligations Bond (GO)
- Revenue Bond
- Special Assessment Bond
- Tax Increment Financing

State Funding Sources

- TWDB
    - Regional Flood Plan / Flood Infrastructure Fund
    - State Flood Plan / Flood Infrastructure Fund
    - Clean Water State Revolving Fund
    - Research and Planning Fund Grants
    - State Participation and Storage Acquisition Program
    - FEMA Cooperating Technical Partner (CTP) Program

- General Land Office (GLO)
    - Community Development Block Grant (CDBG) Program
        - Disaster Recovery (DR)
        - Mitigation (MIT)
- Texas Commission on Environmental Quality (TCEQ)
    - Texas Clean Rivers Program

Federal Funding Sources

- Federal Emergency Management Agency (FEMA)
    - Flood Hazard Mapping Program
    - Flood Mitigation Assistance (FMA) Grants
    - Hazard Mitigation Grant Program (HMGP)
    - Pre-Disaster Mitigation (PDM) Grant Program
- U.S. Department of Housing and Urban Development (HUD)
    - Disaster Relief/Urgent Needs Fund of Texas
    - Community Development Block Grant (CDBG) Program
- National Resources Conservation Service (NRCS)
    - Watershed Protection and Flood Prevention Program
    - Watershed Surveys and Planning
    - Wetland Reserve Program
    - Emergency Watershed Protection Program
- U.S. Army Corps of Engineers (USACE)
    - Emergency Advance Measures for Flood Prevention
    - Emergency Rehabilitation of Flood Control Works
    - Emergency Streambank and Shoreline Protection
    - Floodplain Management Services
    - Nonstructural Alternatives to Structural Rehabilitation of Damaged Flood Control Works
    - Planning Assistance to States
    - Small Flood Control Projects

7 References

Pape-Dawson Engineers, Inc. 2007. "Karnes County Map Modernization – Hydrology Technical Support Data Notebook." Prepared for San Antonio River Authority.

Pape-Dawson Engineers, Inc. 2007. "Karnes County Map Modernization – Hydraulics & Work Map Technical Support Data Notebook." Prepared for San Antonio River Authority

URS Corporation. 2015. "Holistic Watershed Master Plan for Karnes, Goliad, and Wilson Counties – Summary Report." Prepared for San Antonio River Authority.

AECOM & Halff Associates, Inc. 2021. "Lower San Antonio River Phase II, Texas – Contract Mapping Activity Statement (MAS) #11." Prepared for San Antonio River Authority and FEMA.

Langford Community Management Services and Rojas Planning. 2020. "Karnes/Wilson County Multi-jurisdictional Hazard Mitigation Action Plan." Prepared for Karnes County and Wilson County.

U.S. Army Corps of Engineers. 1968. "Report on Hurricane 'Beulah' – 8-21 September 1967."

San Antonio River Authority. 2013. "San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling – Revision September 2013."

Texas Water Development Board. 2021. "Exhibit C – Technical Guidelines for Regional Flood Planning."

Texas Water Development Board. 2021. "Exhibit D – Data Submittal Guidelines for Regional Flood Planning."

Paul Rodman, U.S. Army Corps of Engineers. October 1977. "Effects of Urbanization on Various Frequency Peak Discharges."

Thomas Nelson, U.S. Army Corps of Engineers. September 1970. "Synthetic Unit Hydrograph Relationships, Trinity River Tributaries, Fort Worth-Dallas Urban Area."

North Central Texas Council of Governments. Revised September 2014. "iSWM Technical Manual – Hydrology."

Natural Resources Conservation Service. June 1986. "Technical Release 55 – Urban Hydrology for Small Watersheds."