Spring Creek Flood Update Study

Flood Infrastructure Fund Category 1

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1 Executive summary

1.1 Study overview

This Spring Creek Flood Update Study was sponsored by Waller County and funded through the Texas Water Development Board (TWDB) Flood Infrastructure Fund (FIF) as a Category 1 study. Category 1 studies are intended to develop flood risk information for regions with outdated or inaccurate data and identify potential flood risk mitigation solutions to reduce flood risk within the study area.

This study was completed in accordance with TWDB guidelines to ensure their eligibility for FIF funding and evaluate projects for inclusion in the San Jacinto River Regional Flood Plan. The key stakeholder for the study is Waller County. Coordination with other stakeholders such as the TWDB and the San Jacinto Regional Flood Planning Group (RFPG - Region 6) was also completed.

Analysis performed as part of this study focused on two main goals:

1) providing more accurate flood risk data and mapping for four tributaries of Spring Creek within Waller County
2) identifying high flood risk areas and recommending projects to mitigate this risk

The study area encompasses both the potion of the Threemile Creek-Brushy Creek and Birch Creek-Walnut Creek subwatersheds located within Waller County. These subwatersheds are part of the Spring Creek watershed and are all contained within HUC10 1204010202 as shown in Figure 1-1. Project Study Area below.

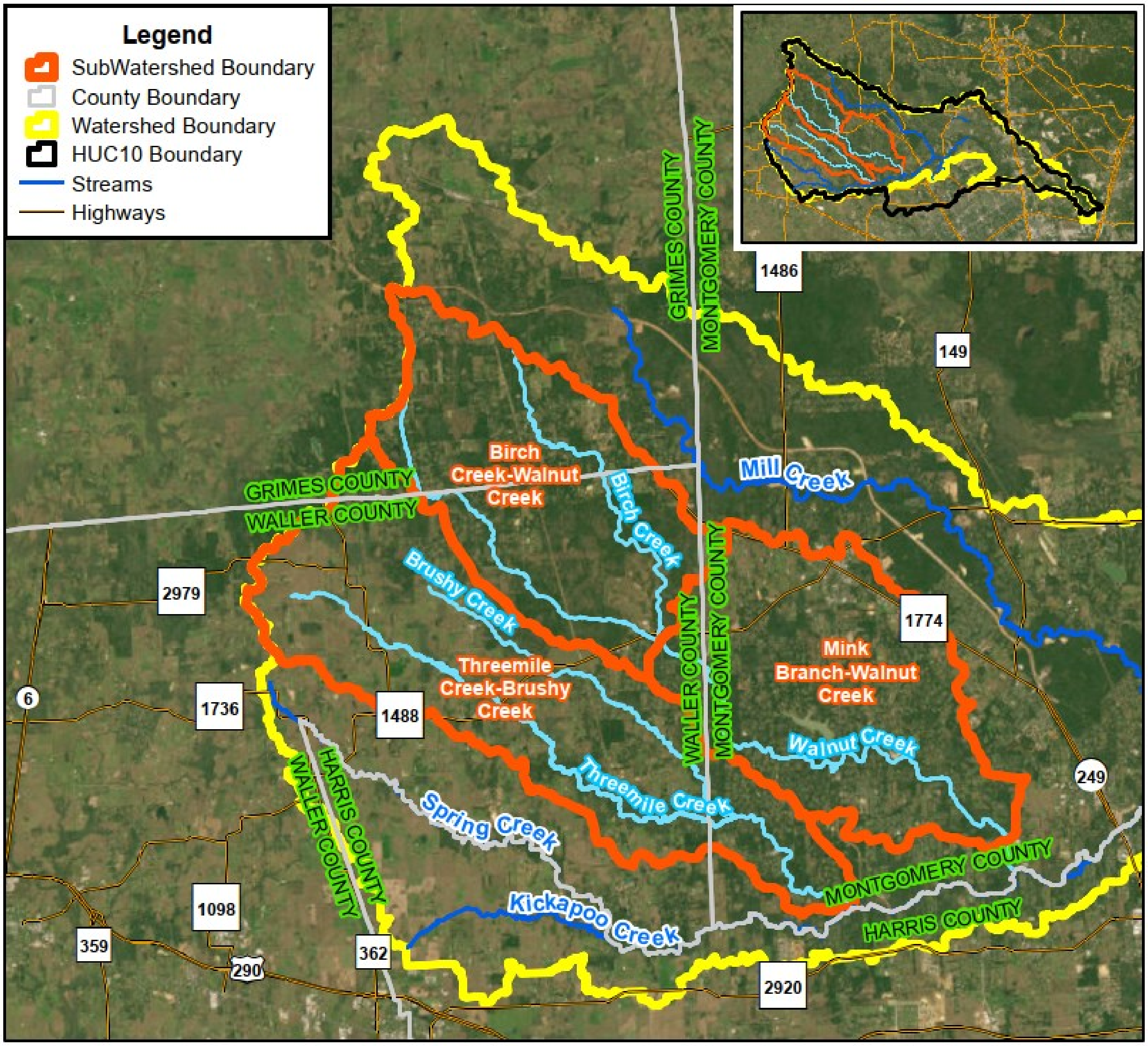

Figure 1-1. Project Study Area

To evaluate current flood risk within the study area, previous hydrologic and hydraulic modeling was leveraged that reflected 2018 HGAC lidar, 2018 HGAC land use, and Atlas 14 rainfall data. These leveraged models were subsequently updated within HEC-HMS (version 4.3) and HEC-RAS (version 6.2.0) to represent current drainage patterns and to develop updated inundation mapping and flood risk assessment for the study area. Existing condition results were compared to FEMA Flood Insurance Study flows and water surface elevations where possible. The updated inundation mapping was used to evaluate flood risk from the four studied tributaries of Spring Creek within Waller County. Structures, roads, and critical facilities at risk were determined. This analysis is summarized in Table 1-1 and Table 1-2 and shown in Exhibits 14 through 20.

Table 1-1. Summary of Existing 10-year Flood Risk.

Stream	Agricultural Areas at Risk (ac)	Structures at Risk	Inundated Roadway (mi)	Critical Facilities at Risk
	10% AEP	10% AEP	10% AEP	10% AEP
Threemile Creek	852.96	37	3.4	0
Brushy Creek	462.57	56	2.9	0
Walnut Creek	80.8	15	2.4	0
Birch Creek	5.19	0	0.03	0

Table 1-2. Summary of Existing 100-year Flood Risk.

Stream	Agricultural Areas at Risk (ac)	Structures at Risk	Inundated Roadway (mi)	Critical Facilities at Risk
	1% AEP	1% AEP	1% AEP	1% AEP
Threemile Creek	1,149.30	106	6.52	0
Brushy Creek	656.47	175	6.90	0
Walnut Creek	122.6	52	3.72	0
Birch Creek	13.7	1	0.18	0

Recommended flood risk solutions were vetted to adhere to Technical Guidelines for Regional Flood Planning Exhibit C including ensuring no negative impact is created by the proposed projects and quantifying the benefits provided by the projects using the outlined flood risk reduction metrics, benefit-cost analysis process, and cost estimation considerations.

1.2 Study recommendations

Areas with relatively high flood risk in the Spring Creek watershed through Waller County were identified as problem areas for additional assessment. Potential flood risk reduction alternatives were developed and evaluated using detailed modeling to determine recommended projects that address existing flood risk through reduced structural and roadway flooding. A summary of the recommended projects is provided in Table 1-3.

Table 1-3. Summary of Recommended Projects.

ID	Project	Brief Description	Summary of Benefits	Estimated Cost	BCR
PA2	N Reids Prairie and Kyle Road Improvements	Replacement of existing culverts with a bridge and raising the roadway.	LOS increased to 100-year and 4 structures benefitted in the 100-year event	$4,347,000	0.1*
PA3	Riley Road Improvements	Replacement of existing structures with bridge and raising the roadway.	LOS increased to 100-year and 2 structures benefitted in the 100-year event	$4,018,500	0.1*
PA4	Channel Extension at N Reids Prairie Road	Construction of a channel to convey overland flows upstream N Reids Prairie Road and Brushy Creek.	47 structures benefitted and 16 structures reduced in the 100-year event	$34,920,281	0.2

*The project will provide mobility benefits. However, there are limited monetary benefits associated with increases in mobility.

The implementation of these projects would provide mobility benefits as well as a reduction in structural flood risk. However, funding for the design and construction of these projects is limited and the entire process from project planning to full implementation can take years to complete. While the County is encouraged to begin seeking funding for the recommended projects as soon as possible, non-structural and flood response recommendations may be implemented in the short term to provide more immediate mitigation of flood risk.

A voluntary buyout program for structures in the 10-year floodplain is one of the non-structural recommendations. This solution would provide an immediate reduction in the population at frequent flood risk from the Threemile Creek, Brushy Creek, and Walnut Creek.

Drainage criteria updates could also be implemented by Waller County in the short term. Although this solution would not provide direct flood risk reduction to locations that already experience flooding, it would assist in addressing the potential for additional flood risk.

The structural and non-structural solution recommendations and guidance outlined within the Flood Protection Plan are all aimed at providing Waller County with the tools to identify and mitigate current flood risk within the County and prevent the creation of new flood risk.

2 Introduction and background

The upper Spring Creek watershed through Waller County is experiencing rapid growth in a historically rural area. This watershed is susceptible to flooding due to limited creek capacity, low water crossings, and flat terrain. This area experienced severe flooding most recently during the Memorial Day (April 2016) and Hurricane Harvey (2017) storm events, as shown in Figure 2-1. Waller County recognized the importance of assessing existing flood risk within the watershed to generate information that can be leveraged to better understand and regulate future growth as well as identify projects that can be implemented to reduce flooding for existing residents.

Figure 2-1. Roadway Flooding in Waller County (April 2016)

This project is funded by a grant from the Flood Infrastructure Fund (FIF), administered by the Texas Water Development Board (TWDB) as authorized by the 86th Texas Legislature and approved by Texas voters by a constitutional amendment in November 2019. This study was funded under FIF Category 1, Flood Protection Planning for Watersheds, on September 1, 2021, and is scheduled to be completed on September 30, 2023. The Spring Creek Flood Update Study is a joint venture from both the TWDB and Waller County with the goal of understanding existing flood risk in the Spring Creek watershed within Waller County as well as recommending four mitigation solutions for flood prone areas.

2.1 Study area

Spring Creek serves as the boundary between Waller and Harris County, as well as between Montgomery and Harris County. It is approximately 80 miles long with a contributing area of approximately 400 square miles. There are four main tributaries that run through Waller County, initiating in Grimes and Waller County then ultimately contributing to Spring Creek. These primary tributaries are Threemile Creek, Brushy Creek, Birch Creek, and Walnut Creek. With a combined drainage area of about 102 square miles, the tributaries include flows from parts of Waller, Grimes, and Montgomery counties. The full extents of the study area can be seen in Exhibit 1. Figure 2-2 also shows the areas of the hydrologic and detailed modeling, which includes the HUC-10s listed below in Table 2-1.

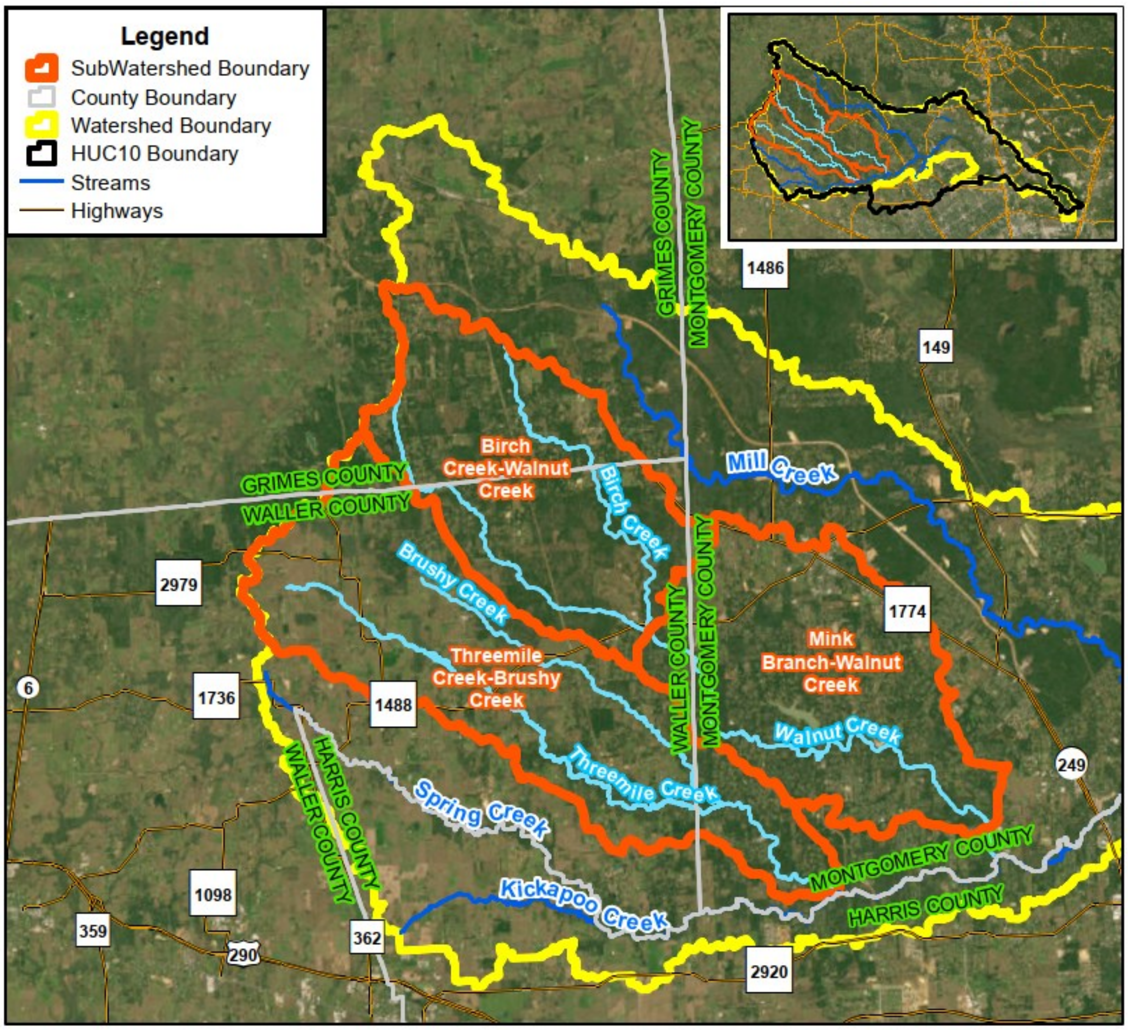

Figure 2-2. Project Study Area

Table 2-1. Detailed Study Area HUC-10s.

HUC-10 Number	HUC-10 Watershed Name	Subwatershed Name
1204010202	Spring Creek	Threemile Creek
1204010202	Spring Creek	Brushy Creek
1204010202	Spring Creek	Walnut Creek
1204010202	Spring Creek	Birch Creek

The Spring Creek watershed within Waller County is predominately rural with primarily agricultural land use. According to U.S. Census Bureau, the population of Waller County increased from 43,205 in 2010 to 56,794 in 2020 (an increase of approximately 32%). Furthermore, the County population is projected to increase roughly 9% between 2020 and 2022.

FM 1488 bisects the study area serving as a major east-west thoroughfare between Waller and Montgomery counties. The roadway is currently being expanded from two lanes to four lanes. The portion of the watershed downstream of FM 1488 consists of both forested and agricultural undeveloped areas as well as large lot residential developments along the Waller and Montgomery County boundary that extend all the way to the Spring Creek mainstem.

The topography within Waller County is relatively flat which contributes to existing flooding and results in widespread, shallow ponding. Runoff generally flows from northwest to southeast. Primary channels within Waller County are relatively shallow and remain in a natural state with overgrown vegetation.

The Spring Creek watershed has a long and well-documented history of flooding dating back to the 1970s and has experienced several significant flooding events, including the October 1994 storm, Tropical Storm Allison, Hurricane Ike, and Hurricane Harvey. Flood risk reduction along the Spring Creek tributaries within Waller County has become a priority as the County continues to urbanize. The key stakeholder for the study is Waller County. Additionally, coordination with other stakeholders such as the TWDB and the San Jacinto RFPG (Region 6) was also completed.

2.2 Study goals

The study goals are listed below:

- Assess existing flood risk within the study area by developing updated modeling.
- Evaluate flood protection criteria by reviewing the existing inundation mapping for the 2-year, 5-year, 10-year, 25-year, 50-year, 100-year, and 500-year frequency events.
- Identify flood prone areas and develop flood risk reduction alternatives for these areas.
- Develop recommendations for structural flooding and roadway flooding reduction solutions.
- Outline an implementation and phasing plan for recommended flood risk reduction solutions.

2.3 Previous studies

There are three major previous studies relevant to the Spring Creek tributaries within Waller County that were reviewed and leveraged to complete this study. The previous studies are discussed below.

2.3.1 *FEMA Flood Insurance Study*

The existing floodplains for the study area are based on the FEMA 2009 Flood Insurance Study (FIS). The study used regression equations to develop discharges for the 10-, 50-, 100-, and 500-year storm events and HEC-2 to develop water surface elevation profiles for each stream. The FEMA floodplains for the study area are shown in Figure 2-3 and Exhibit 2.

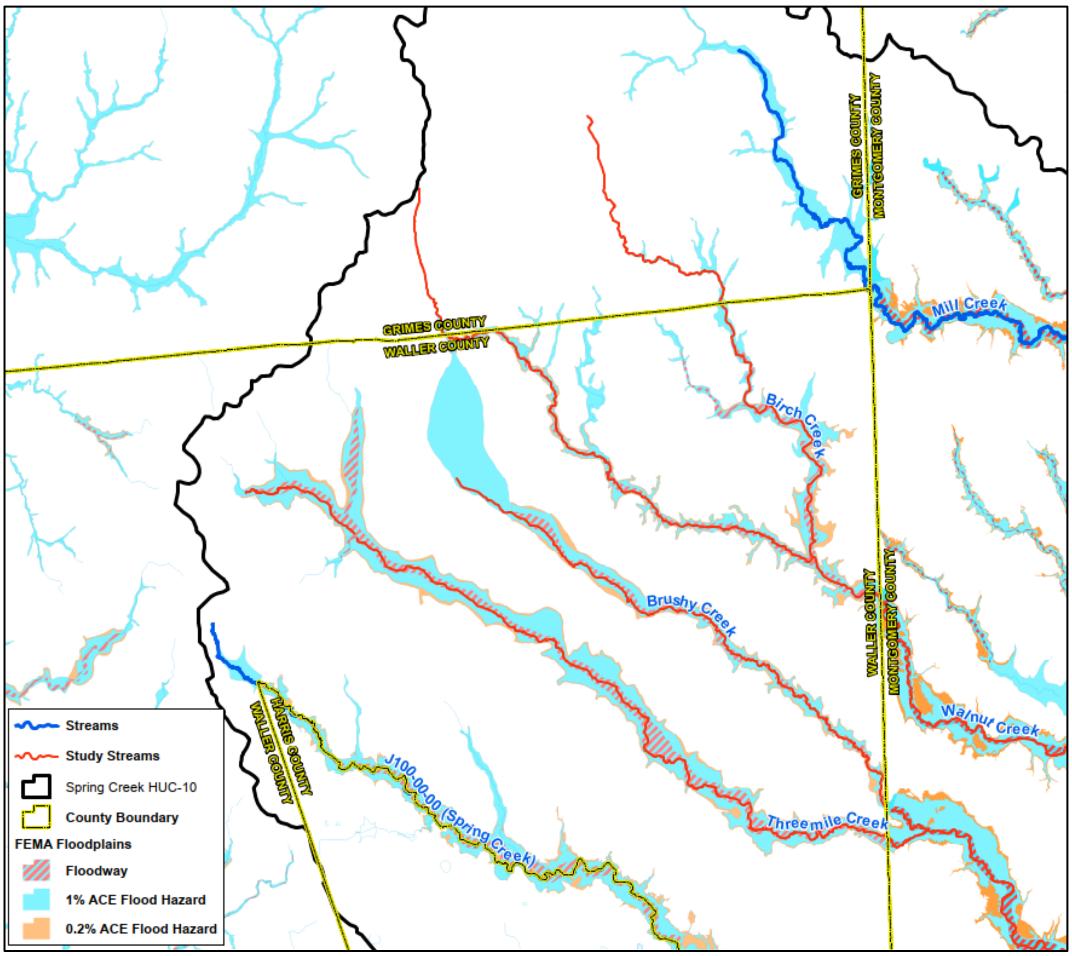

Figure 2-3. Study Area FEMA Floodplain Extents

2.3.2 *HCFCD MAAPnext Project*

The Modeling Assessment & Awareness Project (MAAPnext) led by the Harris County Flood Control District (HCFCD) in partnership with FEMA involved the development of new modeling and updated floodplain mapping for Harris County's 22 major watersheds, which includes the Spring Creek watershed. The models incorporated most current terrain and rainfall data and utilized new hydrologic and hydraulic modeling methodologies to create the most accurate representation of flood risk in the region. The flow in Spring Creek originates from tributaries in Montgomery, Waller, and Grimes Counties. A total of 13 tributaries were studied in the Spring Creek model, including Threemile Creek and Walnut Creek in Waller County. This study leveraged the following models and supporting documentation:

- HEC-RAS (v5.0.7) model for Walnut and Threemile Creeks
- HEC-HMS (v4.3) model for the Spring Creek Watershed

2.3.3 *Robinhood Bridge Impact Analysis*

In 2019, Halff completed an analysis of the Robinhood Bridge across Brushy Creek. The hydraulic models from this study were referenced and utilized where applicable in the Brushy Creek model development.

2.4 Data collection

The data collection effort involved requesting, organizing, and reviewing available information needed to complete the existing flood hazard assessment and development of flood risk reduction alternatives. Collected data included terrain data, existing hydrologic and hydraulics models, Atlas 14 rainfall data, historical flooding complaints, structure inventory data, field survey data, and field reconnaissance information. Table 2-2 below provides a summary of the data collected, including data source and purpose in this study.

Table 2-2. Summary of Data Collection.

Data	Source	Purpose
2018 LiDAR	Houston-Galveston Area Council (HGAC)	Drainage area delineation and hydraulic model development
Field Survey	Halff	Hydraulic structure measurements
Site Reconnaissance Information	Halff	Confirmation of existing hydraulic structures in flood prone areas
Spring Creek MAAPnext Hydrologic Model (HEC-HMS v4.3)	HCFCD	Hydrologic analysis for watershed

Data	Source	Purpose
Spring Creek MAAPnext Hydraulic Model (HEC-RAS v5.0.7)	HCFCD	Hydraulic analysis for Threemile Creek and Walnut Creek
Atlas 14 Precipitation Data	HCFCD White Paper: *Rainfall Depths and Intensities in Harris County*	Rainfall depth-duration data for hydrologic analysis
2018 Land Use	Houston-Galveston Area Council (HGAC)	Hydraulic model Manning's n values
Structural Inventory Data	TWDB	Structural flooding determination

2.4.1 *Field survey*

Field survey is critical for documenting structures such as bridges and culverts to accurately represent them in hydraulic models. Field survey involves collecting measurements about various characteristics of structures, including bridge opening dimensions and culvert size/length, which govern their hydraulic capacity. Elevations, dimensions, and materials were noted for each structure and photographs were taken to document each structure's location. A total of 26 structures were field surveyed as listed in Table 2-3 with field survey locations shown on Exhibit 3. Some of the surveyed structures are located in areas that were modeled in 2D and not using a detailed 1D channel; therefore, these structures were not included in the hydraulic model.

Table 2-3. Summary of Structure Survey Locations.

Stream	Location	Structure Type	Modeled
Threemile Creek	Robinson Road	Bridge	No
	Howell Road	Bridge	No
	FM 362	Bridge	No
	Bridge Scroggins Ln Crossing	Culvert	Yes
	Bowler Rd Crossing	Bridge	Yes
	FM 1488 Crossing	Bridge	Yes
	Kickapoo Crossing	Bridge	Yes
	Joseph Rd Crossing	Bridge	Yes
	Macedonia Rd Crossing	Bridge	Yes
	Creek Bend Rd Crossing	Bridge	Yes
	Clear Creek Rd Crossing	Bridge	Yes
Brushy Creek	Bowler Rd Crossing	Culvert	Yes
	FM 1488 Crossing	Bridge	Yes

Stream	Location	Structure Type	Modeled
	Rice Rd Crossing	Bridge	Yes
	Joseph Rd	Bridge	Yes
	Robin Hood Ln Crossing	Culvert	Yes
Walnut Creek	Kyle Dr Crossing	Culvert	Yes
	Riley Rd Crossing	Bridge	Yes
	Riley Rd Crossing	Culvert	Yes
	Riley Rd Crossing	Culvert	No
	FM 1488 Crossing	Bridge	Yes
	Joseph Rd. Crossing	Bridge	Yes
Birch Creek	Riley Rd Crossing	Culvert	No
	Riley Rd Crossing	Bridge	No
	Private Road	Private	No
	FM 1488 Crossing	Bridge	Yes

The horizontal position of all the survey data was referenced to the Texas State Plane Coordinate System, South Central Zone (4204), North American Datum: NAD 83(2011) Epoch 2010.00. Data positions are Grid Values in U.S. Survey Feet. Elevations are referenced to the North American Vertical Datum of 1988 (NAVD88).

2.4.2 *Site reconnaissance visit*

A site reconnaissance visit was conducted for the crossings of N Reids Prairie Road, Kyle Drive, and Riley Road with Walnut Creek to verify the existing structure conditions and to identify any constraints for proposed alternatives. The existing structures are shown below in Figure 2-4 and Figure 2-5.

Figure 2-4. Existing culverts at N Reids Prairie Road (left) and Kyle Road (right) and Walnut Creek

Figure 2-5. Existing bridge at Riley Road and Walnut Creek

2.5 Coordination and public meetings

An initial coordination meeting was held with Waller County in November 2021 to discuss study expectations, define schedule, project deliverables and feedback on the flood risk areas. Two public meetings were held during the study to communicate information about study progress and collect input from stakeholders and the public. Notices were posted in the Waller Times at least 2 weeks before the meetings were to take places for all public meetings. Additionally, physical notices of upcoming meetings were posted to bulletin boards within the Waller County courthouse and on their website.

Table 2-4 provides a list of meetings conducted, including meeting date and location**.** Figure 2-6Figure 2-6. Public Meeting #2 at Field Store Community Center below shows the project presentation and interactive exhibits stations from Public Meeting #2.

The first public meeting was held April 27th, 2022. This meeting provided the public with an overview of the study scope, goals, and initial progress on model development. Although several members of the public attended, there were no comments received.

The second public meeting was held on May 24th, 2023. This meeting reiterated the goals and scope of the study and presented the identification of flood prone areas as well as preliminary flood mitigation alternatives. Several members attended the meeting and provided feedback on historical flooding, flooding impacts to the community, and the identified areas of high flood risk.

Table 2-4. Summary of Meetings

Meeting Type	Date	Location
Initial Kickoff	2nd November 2021	Waller County, TX
Public Meeting #1	27th April 2022	Commissioners Court, Waller, TX
Public Meeting #2	24th May 2023	Field Store Community Center, Waller, TX

Figure 2-6. Public Meeting #2 at Field Store Community Center

3 Existing hydrology

A hydrologic analysis was conducted to determine peak discharge rates and generate flow hydrographs for subbasins to be applied to the updated existing hydraulic model. Previous study data was utilized as a starting point with modifications completed as appropriate based on a review of terrain data and aerial imagery. HEC-HMS (version 4.3) was used to model the transformation of rainfall into runoff.

3.1 Subbasin delineation

Previously delineated subbasins were reviewed for consistency with the 2018 terrain dataset and 2023 aerial imagery, and generally were determined to be adequate for the purpose of this study. Several subbasins along Brushy and Walnut Creek near the Waller County boundary with Grimes County were further subdivided. A total of 42 subbasins were included in the hydrologic model, with varying sizes of 1.2 to 4 square miles. Figure 3-1 and Exhibit 4 shows the existing conditions subbasins for the study area.

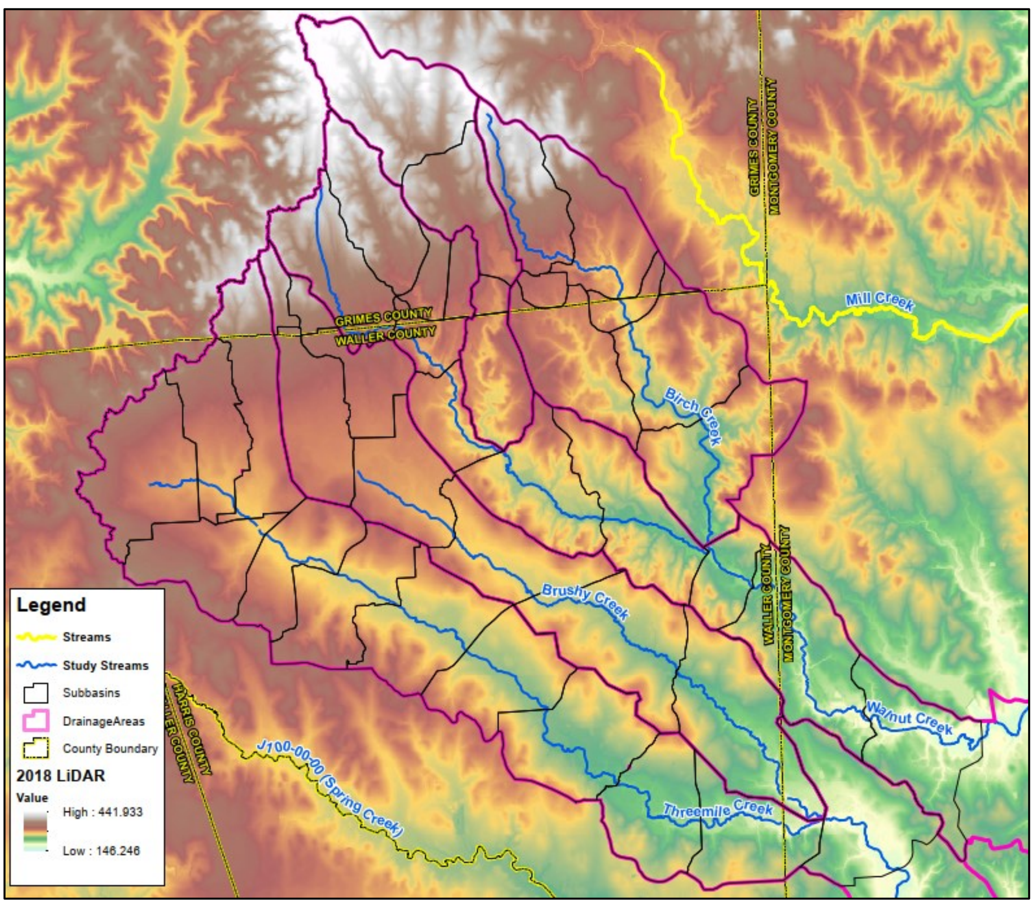

Figure 3-1. Existing Subbasins

3.2 Rainfall data

Rainfall data was obtained from HCFCD Rainfall Depths and Intensities white paper for Harris County Hydrologic Region No. 1, which encompasses the Spring Creek watershed. Table 3-1 below provides the Atlas 14 rainfall depth, duration, and frequency data used for the hydrologic analysis.

Table 3-1. Spring Creek Watershed Atlas 14 Rainfall Data.

Duration	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
5-min	0.57	0.70	0.81	0.96	1.07	1.19	1.49
15-min	1.14	1.40	1.62	1.91	2.13	2.36	2.95
60-min	2.16	2.66	3.07	3.64	4.06	4.51	5.87
2-hr	2.69	3.40	4.03	4.94	5.67	6.49	9.04
3-hr	3.01	3.86	4.66	5.85	6.84	7.99	11.50
6-hr	3.58	4.69	5.79	7.47	8.94	10.70	15.90
12-hr	4.18	5.56	6.95	9.13	11.10	13.40	20.10
24-hr	4.83	6.50	8.22	10.90	13.40	16.30	24.20

The following control specifications were used for the HEC-HMS model to simulate frequency events.

- Starting Date: 04 Jul 2020
- Starting Time: 00:00
- Ending Date: 07 Jul 2020
- Ending Time: 00:00
- Computation Interval: 15 min

3.3 Hydrologic losses

The Green & Ampt Method was utilized in this study to account for rainfall losses within the hydrologic model. The Green & Ampt methodology requires suction and hydraulic conductivity values, which are based on soil type. The Canopy Loss Method was used in conjunction with Green and Ampt to account for losses due to vegetation. The values used in the HEC-HMS model are based on the previous study modeling and presented below in Table 3-2.

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Table 3-2. Green Ampt Loss Parameters.

Soil Type	Sandy Loam
Hydrologic Soil Group	B
Initial Canopy Storage	0.0
Max Canopy Storage (in)	1.0
Initial Moisture Content	0.059
Saturated Content	0.46
Suction (in)	2.286
Conductivity (in/hr)	0.181

3.4 Hydrologic parameters

The Clark Unit Hydrograph transform method in HEC-HMS simulates the process of converting precipitation into a runoff hydrograph. The time of concentration (Tc) and storage coefficient (R) are the two required parameters for this method and are calculated using a combination of the basin development factor (BDF) and watershed parameters. The BDF is determined based on drainage system improvements within a watershed and is related to the overall efficiency of how runoff is collected and drained to a subbasin's outlet location.

The Tc and R parameters were used unmodified from the Spring Creek MAAPnext hydrology. For subbasins near the County boundary, the subbasin flow hydrograph was redistributed by applying a constant ratio multiplier based on area percentage from the revised subbasin delineation along the Grimes and Waller County boundary.

A detailed summary of subbasin hydrologic parameters is provided in Appendix B.

4 Existing hydraulics

Hydraulic modeling was performed using HEC-RAS (version 6.2.0). New hydraulic models were developed for Brushy Creek and Birch Creek using the 2018 terrain, land use, and survey data. The hydraulic models for Walnut Creek and Threemile Creek were developed using terrain, land use, and surveyed bridge/culvert data.

4.1 Terrain

The terrain data was 2018 lidar data produced by the HGAC on the North American Vertical Datum of 1988 (NAVD88), Geoid 12B. The terrain throughout the study area is shown in Figure 4-1.

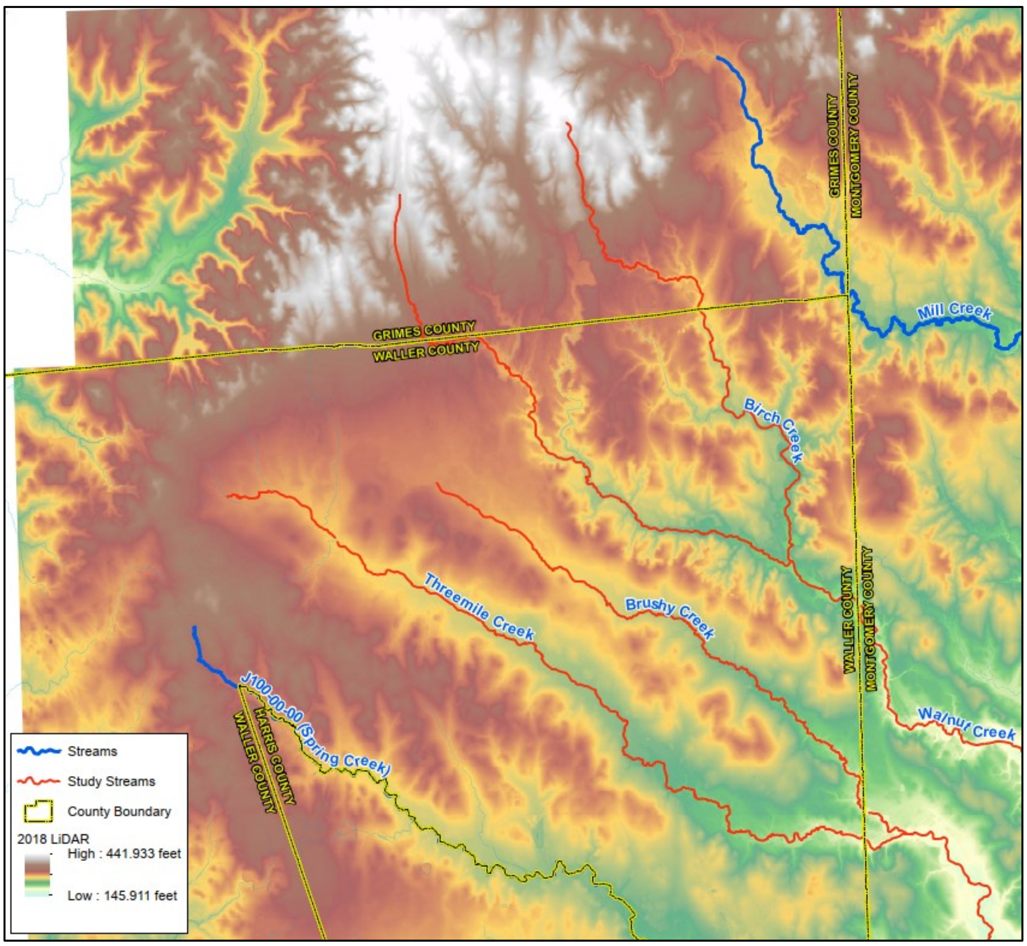

Figure 4-1. Study Area 2018 Lidar Terrain

4.2 Cross sections

New cross sections were delineated along Brushy Creek from the headwaters to the confluence with Threemile Creek. New cross sections were delineated along the upper portion of Walnut Creek from the Waller County boundary to the confluence of Birch Creek and Walnut Creek. Cross section station-elevation data was based on the 2018 terrain data to define the shape and dimensions of the channel and adjacent overbank areas. Cross sections were drawn in ArcGIS perpendicular to the stream centerline at 1,000 foot spacing.

Cross sections were located in accordance with standard HEC-RAS modeling guidance to accurately reflect flow through structures and at confluences. GeoRAS tools were used to process the cross sections, populate required attributes, and extract station-elevation data from the terrain. Figure 4-2 and Exhibit 5 shows the cross-section layout for the entire study area.

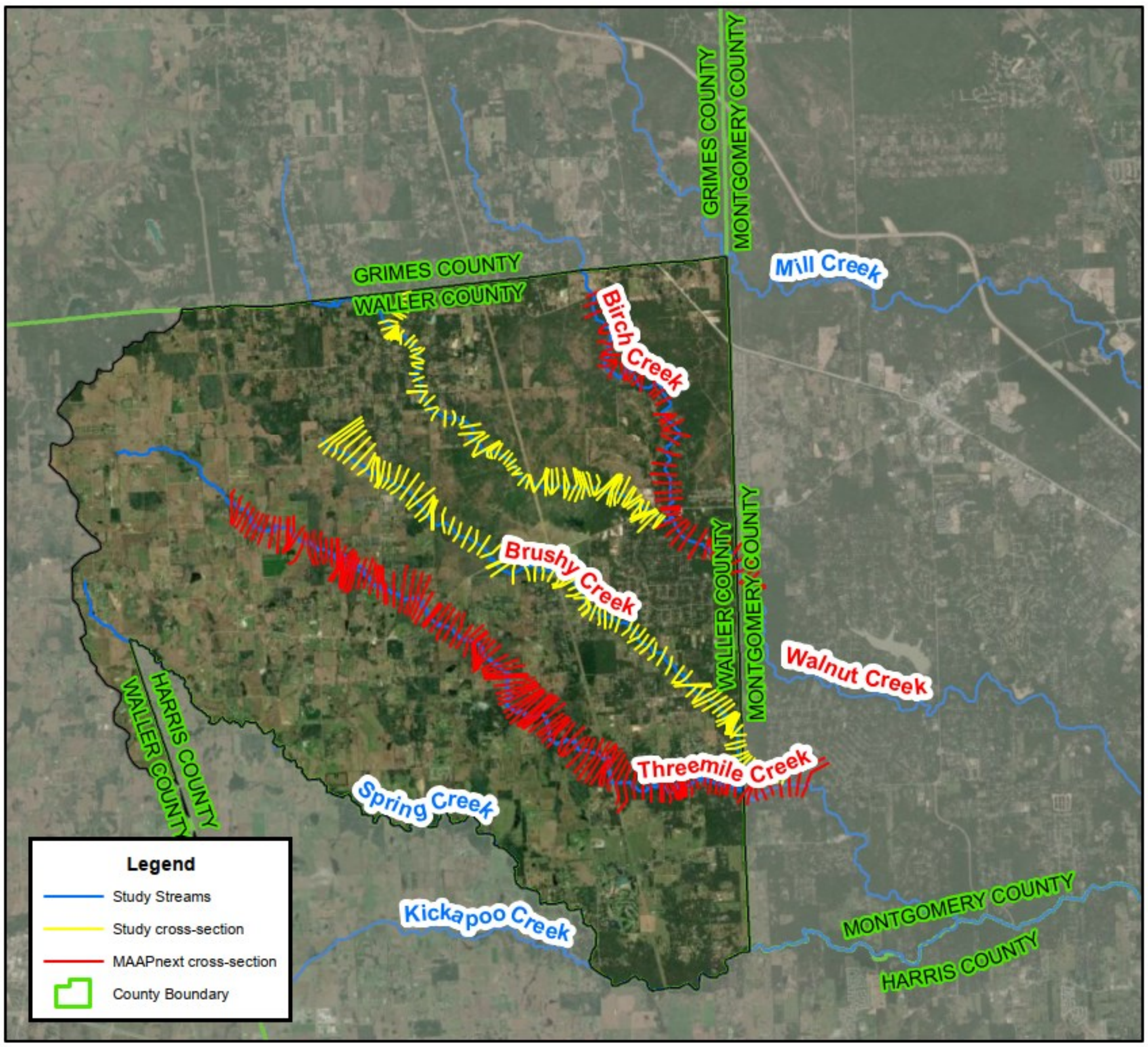

Figure 4-2. Study Area Hydraulic Model Cross Sections

4.3 Manning's n values

Manning's n roughness values are used to quantify resistance to overland flow in hydraulic modeling. Higher Manning's n values are representative of land uses such as a dense forest that provide greater resistance to flow, while lower Manning's n values represent land uses such as paved surfaces that allow water to freely flow across. Base Manning's n values for the 1D channel and 2D area model domains classified by land use type are provided in Table 4-1 and Table 4-2, respectively. The base 1D Manning's n values were then adjusted based on a review of aerial imagery and consistency with other watershed studies. The Manning's n values for the 2D areas are based on the guidance provided in the HEC-RAS 2D User's Manual. Manning's n values for the study area are illustrated in Figure 4-3.

Table 4-1. Manning's n-values for 1D Channel and Overbank.

Land Use Type	Value Used	Recommended Range
Pasture	0.08	0.06 - 0.08
Crops	0.08	0.08 - 0.1
Forested Shrubs	0.1	0.08 - 0.12
Dense Woods	0.15	0.12 - 0.18
Large Lot Development	0.11	0.1 - 0.12
Small Lot Development	0.15	0.1 - 0.15
Natural Channel	0.06	0.05 - 0.08
Concrete	0.02	0.01 - 0.03

Table 4-2. Manning's n-values for 2D.

Land Use Type	Value Used	Recommended Range
Open Water	0.02	0.01 – 0.03
Developed High Intensity	0.03	0.02 – 0.06
Developed Medium Intensity	0.18	0.06 – 0.2
Developed Low Intensity	0.16	0.06 – 0.2
Developed Open Space	0.06	0.04 – 0.1
Barren Lands	0.04	0.03 – 0.08
Forest/Shrubs	0.25	0.18 – 0.3
Pasture/Grasslands	0.22	0.15 – 0.3
Cultivated Crops	0.17	0.1 – 0.3
Wetlands	0.08	0.03 – 0.1
Building	10	10

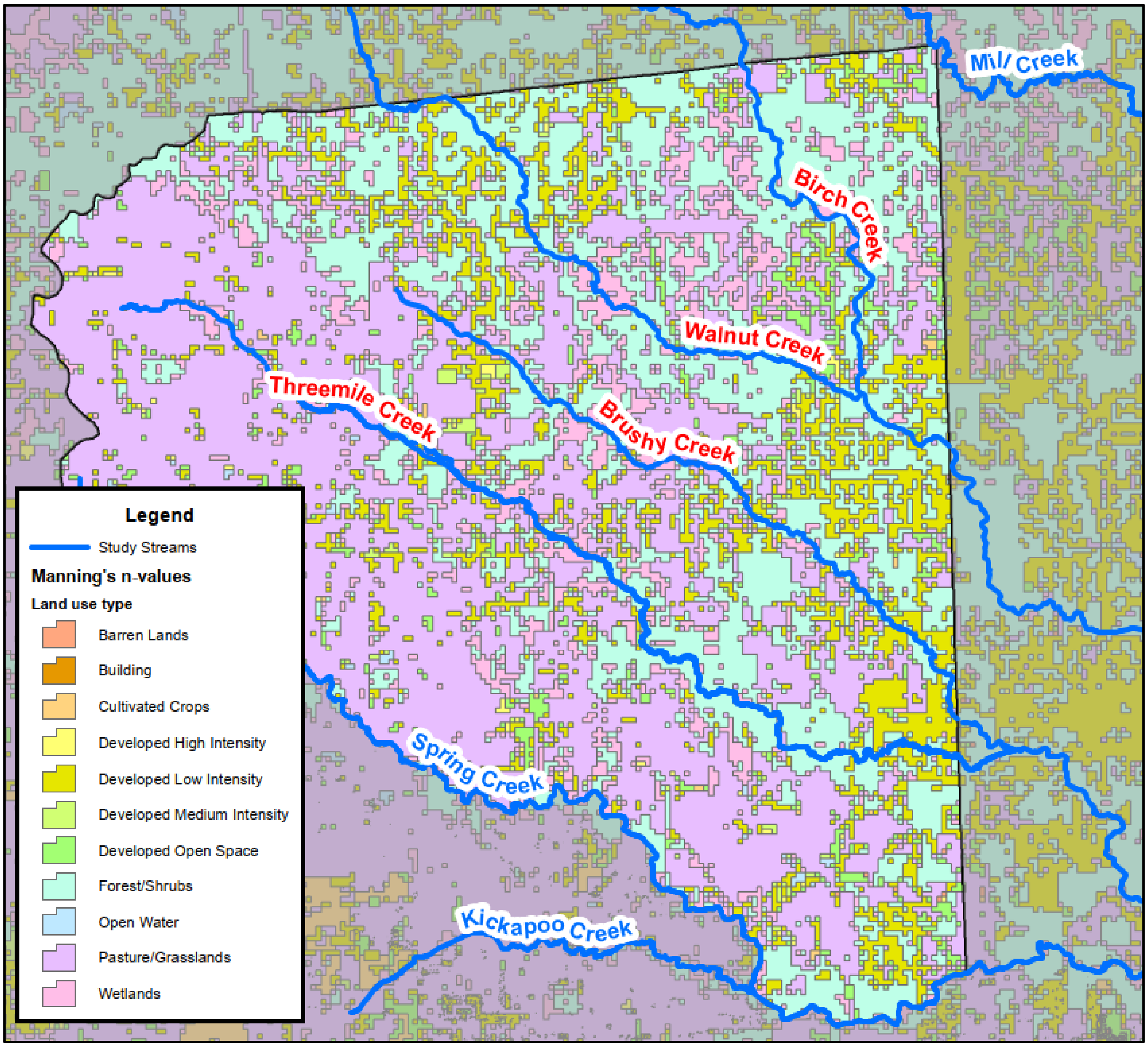

Figure 4-3. Study Area 2D Manning's n Values

4.4 Bridges and culverts

A total of 14 bridges and 5 culverts were modeled in HEC-RAS based on field survey. Structure hydraulic information, such as bridge or culvert dimensions and flowline elevations, was updated in the model and HTab parameters assigned. Ineffective flow areas for bridges and culverts were added according to standard HEC-RAS guidance to account for contractions and expansions at structures as well as sand pits located along the banks of several streams within the study area.

4.5 2D areas

Since the upper Spring Creek watershed consists of flat terrain, several areas were modeled using two-dimensional modeling rather than the traditional 1D cross sections to better represent overland flow patterns. Within the 2D area, the model determines flow exchange on a cell-by-cell basis based on differences in ground elevation (from terrain data) and roughness (from land use data).

4.5.1 *2D extents*

A 100 by 100-foot grid cell size was selected to accurately assess flow patterns while maintaining a manageable model run time. Several 2D areas were added either at the upstream portion of channels near the headwaters or adjacent the 1D cross section domains. Areas modeled in 2D are shown in Figure 4-4 and Exhibit 5. The 2D extents are connected to 1D model domains by lateral structures. Lateral structures are used to model the movement of flow from a river or main channel into adjacent areas, such as floodplains, wetlands, or side channels. These structures serve as pathways for water to move laterally, perpendicular to the main flow direction.

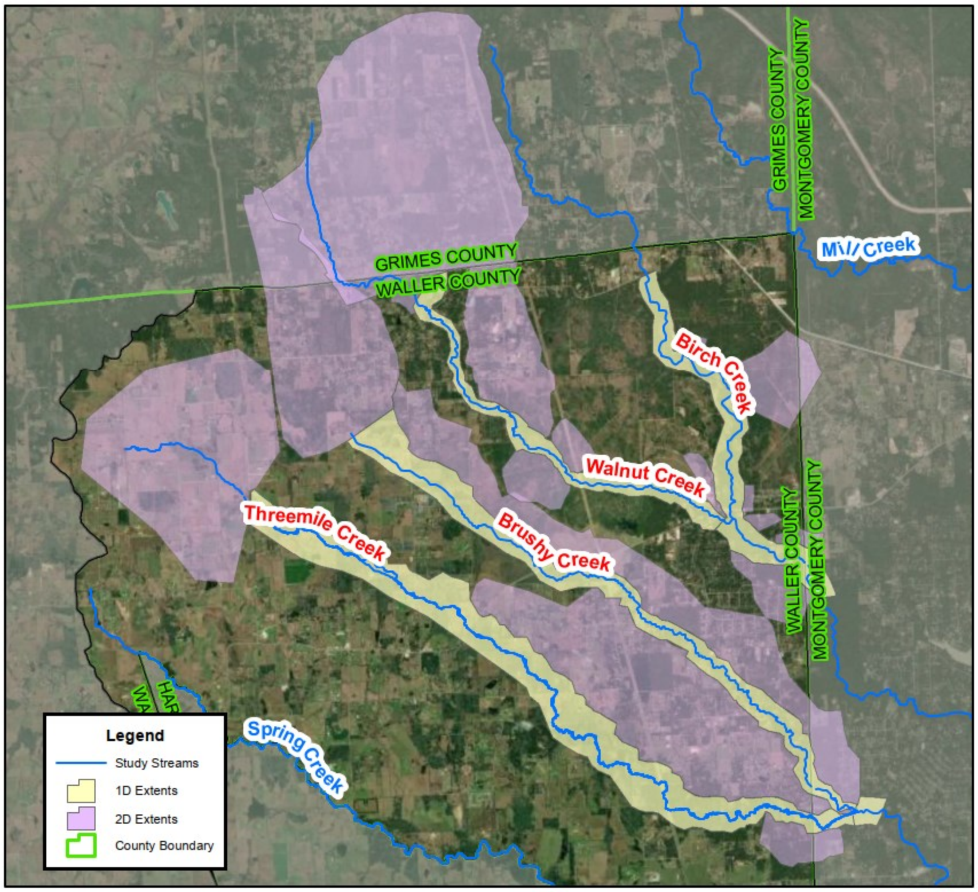

Figure 4-4. Hydraulic Model 1D and 2D Areas

4.5.2 *2D breaklines*

Cell alignment with high points, such as roads, and berms is important for the model to accurately convey flow. Breaklines were used to delineate these topographic features to force the cell mesh to follow high points. The 2D breaklines for a portion of the study areas are shown in Figure 4-5 and Exhibit 5.

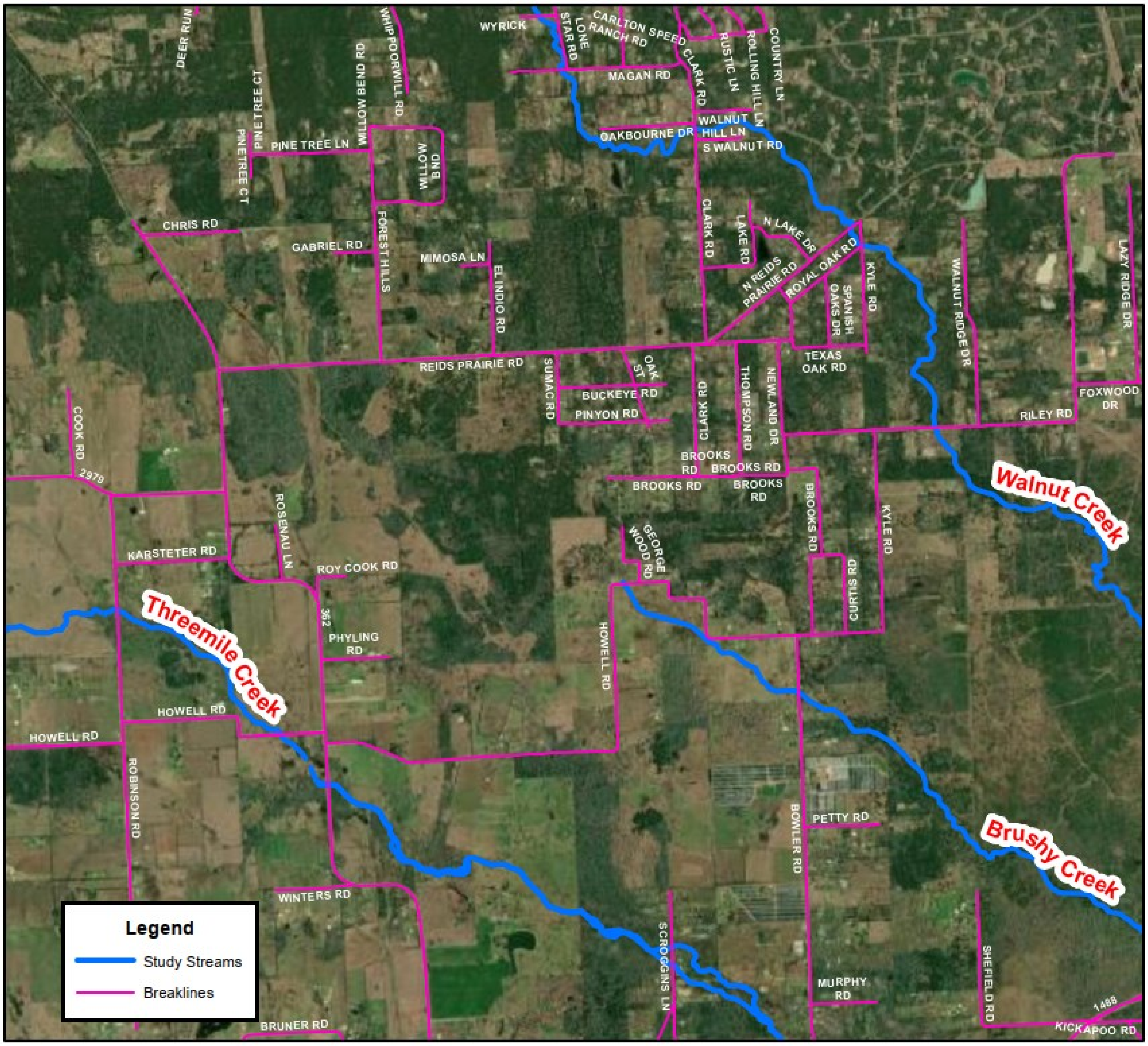

Figure 4-5. Hydraulic Model 2D Mesh Breaklines

4.6 Boundary conditions

Flow hydrographs from the existing hydrologic analysis were applied to the hydraulic model. For 1D channels, flow hydrographs were applied as lateral inflow hydrographs and uniform lateral inflows at the appropriate cross section to reflect where flow from the subbasins enter the channel. Within the 2D mesh, flows were applied along either the upstream boundary of the 2D mesh or along the stream centerline. The locations of flow applications are shown in Figure 4-6 and Figure 4-7.

The Spring Creek MAAPNext hydraulic model was used to develop a rating curve relating flow and water surface elevation for each of the streams within the study area. These rating curves were used as a tailwater boundary condition for the study streams near their confluence with Spring Creek.

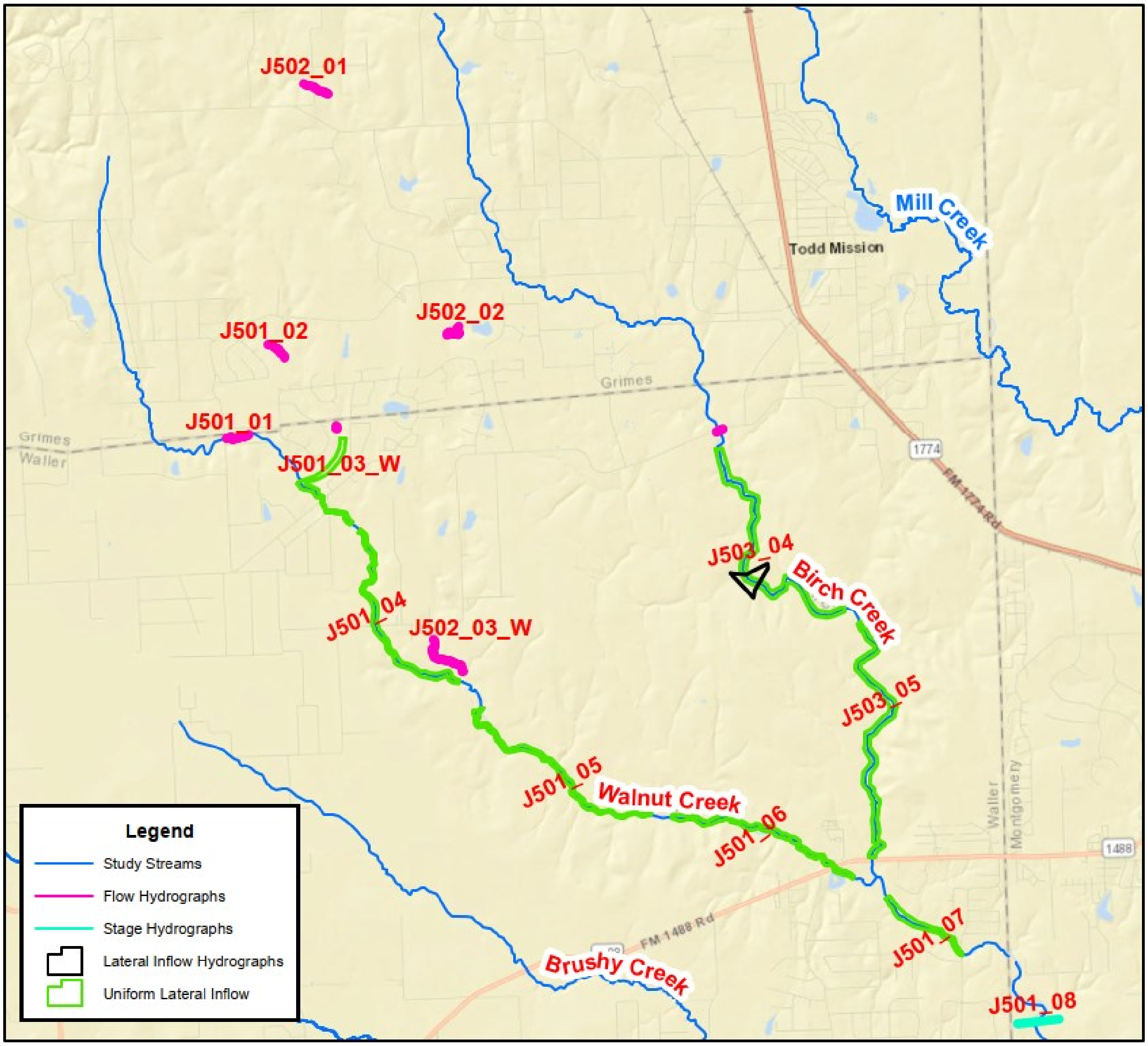

Figure 4-6. Walnut Creek and Birch Creek Boundary Conditions

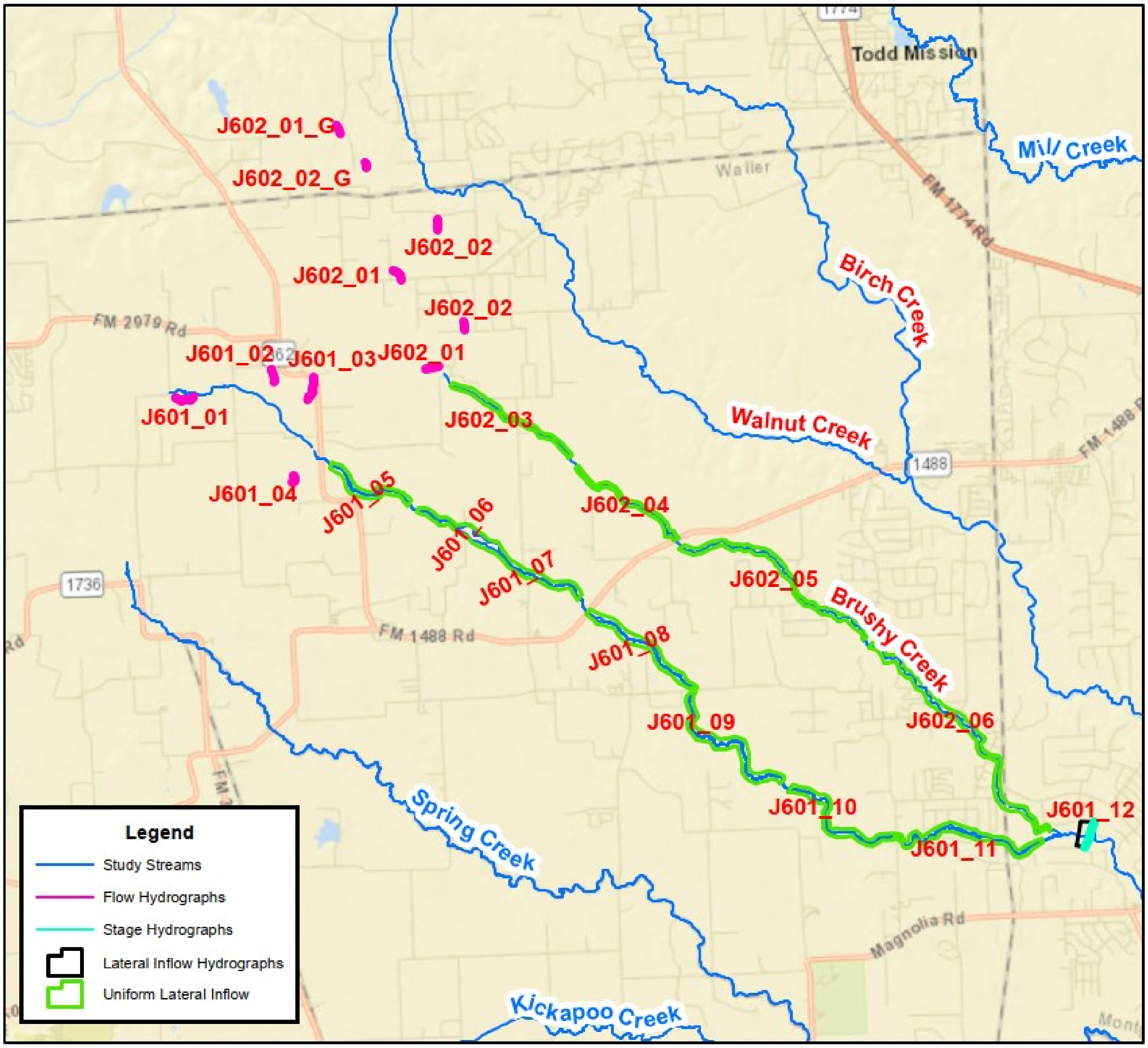

Figure 4-7. Threemile Creek and Brushy Creek Boundary Conditions

5 Existing conditions results

The hydrologic and hydraulic models were simulated for the seven different storm events to calculate discharges and elevations and prepare inundation mapping throughout the study area. This information was used to assess existing flood risk throughout Waller County and inform the development of flood mitigation project alternatives.

5.1 Frequency storm comparisons

Flood profiles were developed for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year frequency storm events to identify the existing conditions for the watershed. These profiles provide information on the potential extent of flooding in the area under different storm conditions. Comparisons to the FEMA FIS discharges and elevations were performed at several locations on each stream. At most locations, discharges and elevations were higher than the 2009 FIS due to the incorporation of Atlas 14 rainfall and updated hydrologic methods. Table 5-1 and Table 5-2 summarize the differences in the 10- and 100-year peak discharges and 100-year water surface elevation for each of the modeled tributaries.

Table 5-1. Existing Peak Discharge Comparison.

Stream	Location	10-Year Discharges (cfs)		100-Year Discharges (cfs)	
		2009 FIS	2023 Study	2009 FIS	2023 Study
Threemile Creek	Macedonia Road	4,935	3,216	10,195	12,209
	Kickapoo Road	4,265	3,233	8,715	9,487
	FM 1488	3,915	3,181	7,950	9260
	Bowler Road	3,680	3,340	7,440	8888
Brushy Creek	County Line	3,220	1,908	6,510	4,884
	Robin Hood Lane	3,100	1,833	6,240	4,780
	Joseph Road	2,940	1,734	5,900	4,643
	Rice Road	2,630	1,424	4,660	4,101
	FM 1488	1,920	1,273	3,720	3,597
Walnut Creek	FM1488	4,790	3,537	10,020	9,431
Birch Creek	FM1488	3,940	3,949	8,200	8,809
	0.47 Miles D/S of West Tributary	2,980	3,791	6,080	8,120

Table 5-2. Existing Water Surface Elevation Comparison.

Stream	Location	Elevation (ft)	
		2009 FIS	2023 Study
Threemile Creek	Macedonia Road	222.6	222.1
	Kickapoo Road	247.9	248.3
	FM 1488	253.7	253.3
	Bowler Road	259.1	258.2
Brushy Creek	County Line	211.0	211.5
	Robin Hood Lane	216.1	216.5
	Joseph Road	224.4	224.1
	Rice Road	244.4	244.5
	FM 1488	261.2	259.5
Walnut Creek	FM1488	233.2	234.4
Birch Creek	FM1488	232.5	234.6
	0.47 Miles D/S of West Tributary	254.8	252.5

5.2 Mapping comparisons

Existing inundation extents were mapped in RAS Mapper and are shown on Exhibit 6. In general, the 100-year and 500-year mapping extents were consistently larger than the current effective floodplains, updated terrain, rainfall, and land use data may have contributed to the differences. A high-level comparison of existing inundation with the effective floodplain extents is provided below:

- **Brushy Creek**: The 500-year study inundation extent for Brushy Creek is generally larger than the effective floodplain for the area north of Howell Road, by nearly 0.5 miles. This increases the number of parcels within the floodplain. Similar conditions can be seen at the FM 1488 and Brushy Creek crossing.
- **Threemile Creek**: The study inundation extents in both the 100-year and 500-year events are generally consistent with the effective floodplain. South of Macedonia Road, there is a significant distinction in the floodplain (around 0.15-mile increase in width) all the way down to the Waller County boundary.
- **Walnut Creek**: The study inundation extent upstream of Riley Road on Walnut Tributary #1 is larger than the effective floodplain during both 100-year and 500-year storm events, increasing its width by up to 0.1 mile during the 100-year storm event. For the 100-year event, the study inundation extents for the area near N Reids Prairie Road and Kyle Road, downstream of the confluence with Tributary #1 and at the confluence

with Birch Creek, were larger than the effective floodplain, resulting in an increase in the number of parcels within the floodplain.

- **Birch Creek**: The study inundation extents for Birch Creek upstream of its confluence with the West Tributary are larger than the effective floodplain, increasing in width by up to 0.25 mile during the 500-year storm event. This resulted in an increase in the number of parcels within the floodplain.

5.3 Roadway level of service

One of the main concerns within the County is mobility during storm events. Model results showed 15 of the 21 modeled roadways overtop during the 2-year storm event and 20 of the 21 roadways during the 100-year storm event. Flooding was observed along the overbanks at the crossing structures although the water surface elevation appeared to be lower than the low chord elevation. Table 5-3 shows the modeled water surface elevations, lowest bridge deck elevation, and the level of service (LOS) of the roadway.

Table 5-3. Summary of Roadway WSE and LOS.

Threemile Creek							
Road Name		**US High Chord**	**2-yr**	**10-yr**	**100-yr**	**LOS**	**LOS Approach Roadway**
Private Road	Bridge	265.0	264.2	264.9	266.5	10-yr	<2-yr
Scroggins Lane	Culvert	260.5	260.8	261.0	261.7	<2-yr	<2-yr
Bowler Road	Bridge	257.2	254.9	256.9	258.2	10-yr	5-yr
FM 1488	Bridge	251.7	249.4	249.7	253.3	10-yr	10-yr
Kickapoo Road	Bridge	245.3	244.5	245.7	248.3	5-yr	<2-yr
Joseph Road	Bridge	241.9	240.6	241.6	243.5	10-yr	2-yr
Macedonia Road	Bridge	221.6	215.6	218.4	222.1	50-yr	10-yr
Creek Bend Road	Bridge	214.0	211.4	213.9	217.5	10-yr	<2-yr
Clear Creek Road	Bridge	207.0	205.9	208.1	212.7	2-yr	<2-yr

Brushy Creek							
Road Name		**US High Chord**	**2-yr**	**10-yr**	**100-yr**	**LOS**	**LOS Approach Roadway**
Bowler Road	Culvert	276.0	276.7	277.0	278.1	<2-yr	<2-yr
FM 1488	Bridge	259.6	257.9	257.8	260.0	100-yr	100-yr
Rice Road	Bridge	242.3	240.5	241.8	244.5	10-yr	2-yr
Joseph Road	Bridge	223.6	220.0	221.2	224.1	50-yr	25-yr
Robinhood lane	Culvert	212.1	210.1	213.2	216.5	2-yr	2-yr

Walnut Creek							
Road Name		**US High Chord**	**2-yr**	**10-yr**	**100-yr**	**LOS**	**LOS Approach Roadway**
N Reids Prairie Road	Culvert	275.9	278.0	279.8	282.8	<2-yr	<2-yr
Kyle Dr	Culvert	276.5	277.5	279.2	282.3	<2-yr	<2-yr
Riley Road	Bridge	264.1	263.2	265.0	267.6	2-yr	<2-yr
Riley Road	Culvert	258.9	261.5	263.5	266.7	<2-yr	<2-yr
FM 1488	Bridge	229.4	227.3	230.4	234.4	5-yr	5-yr
Joseph Road	Bridge	221.4	221.8	223.5	227.7	<2-yr	<2-yr

Birch Creek							
Road Name		**US High Chord**	**2-yr**	**10-yr**	**100-yr**	**LOS**	**LOS Approach Roadway**
FM 1488 (Combined with Walnut Creek)	Bridge	229.6	227.2	230.1	234.6	5-yr	5-yr

5.4 Inundated structures

The TWDB provided building footprints for all structures within the watershed that were used to identify potentially inundated structures for the modeled storm events. These structures were first filtered to remove non-inhabitable structures such as sheds, barns, and garages commonly found in rural areas. Finished floor elevations (FFEs) were estimated to be six inches above the lidar elevation at the structure's centroid; the FFEs were compared to water surface elevations from the updated modeling to determine if structural flooding was expected to occur. Using the model results and the structural shapefile from the TWDB, the number of inundated structures was calculated for each storm event and is summarized in Table 5-4.

Table 5-4. Inundated Structure Count.

	Inundated Structures						
Stream Name	**2-year**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**	**500-year**
Threemile Creek	15	25	37	51	74	106	185
Brushy Creek	8	21	41	58	80	126	269
Walnut Creek	6	8	15	22	32	52	97
Birch Creek	0	0	0	0	0	0	2

Brushy Creek has the greatest number of inundated structures, with concentrations near Reids Prairie Road, Rice Road, and Joseph Road. Many of these neighborhoods were developed prior to detailed floodplain information being available and floodplain regulations being enacted; consequently, many of these structures are located in flood prone areas. Threemile Creek has concentrations of structural flooding near Scroggins Lane and Joseph Road. The Birch Creek drainage area is mostly undeveloped, which results in a relatively low numbers of inundated structures. Walnut Creek has inundated structures located mostly near the county line at Joseph Road.

5.5 Existing condition summary

A detailed analysis was performed to determine water surface elevations and flows along Birch Creek, Brushy Creek, Threemile Creek and Walnut Creek in Waller County. This analysis included updates to previously developed hydrology and the development of additional hydraulic modeling. After developing this information, the results were compared with available existing information to assess flood risk infrastructure in Waller County. The results of this analysis for the 100-year event can be seen in Table 5-5. Although the flood risk analysis was focused on this storm event, more frequent events are also shown to pose flood risk to infrastructure throughout Waller County.

Table 5-5. Infrastructure at 100-Year Flood Risk.

Infrastructure Type	Threemile Creek	Brushy Creek	Walnut Creek	Birch Creek
Structures	106	126	52	1
Residential Structures	66	98	32	1
Critical Facilities	0	0	0	0
Low Water Crossings	7	2	1	0
Length of Roads (mi)	6.52	5.64	3.72	0.18
Road Closures	23	32	22	1
Agricultural Areas (ac)	1150.27	590.84	122.57	13.69

5.6 Flood prone area identification

Flood prone areas were identified within the study area to reflect locations within the County that have the highest flood risk and greatest potential to benefit from flood mitigation projects. Initial flood prone areas were identified based primarily on existing modeling results. Additional information, such as flood claims and historical flooding observations from County representatives and residents, were used to validate and prioritize the flood prone areas. The four problem areas identified, shown in Figure 5-1 and Exhibit 7, are described below:

- **Problem Area No. 1 (PA1)**: This problem area is located along the lower portions of Brushy and Threemile Creek. The main cause of flooding for this area is dense vegetation along the top of the banks restricting flow and resulting in limited conveyance capacity.
- **Problem Area No. 2 (PA2)**: Located at the crossing of Walnut Creek with North Reids Prairie Road and Kyle Road, the main cause of flooding for this area is restriction caused by the undersized existing culverts at the roadway crossings.
- **Problem Area No. 3 (PA3)**: Located at the crossing of Walnut Creek with Riley Road and Kyle Road, the main cause of flooding for this area is restriction caused by the undersized existing culvert at the roadway crossings.
- **Problem Area No. 4 (PA4)**: This problem area, located between Reid's Prairie Road and Howell Road, is characterized by higher levels of existing development. The primary cause of flooding is the lack a defined channel upstream of Howell Road. The natural channel here, a portion of Brushy Creek, lacks sufficient depth and width to provide adequate conveyance capacity.

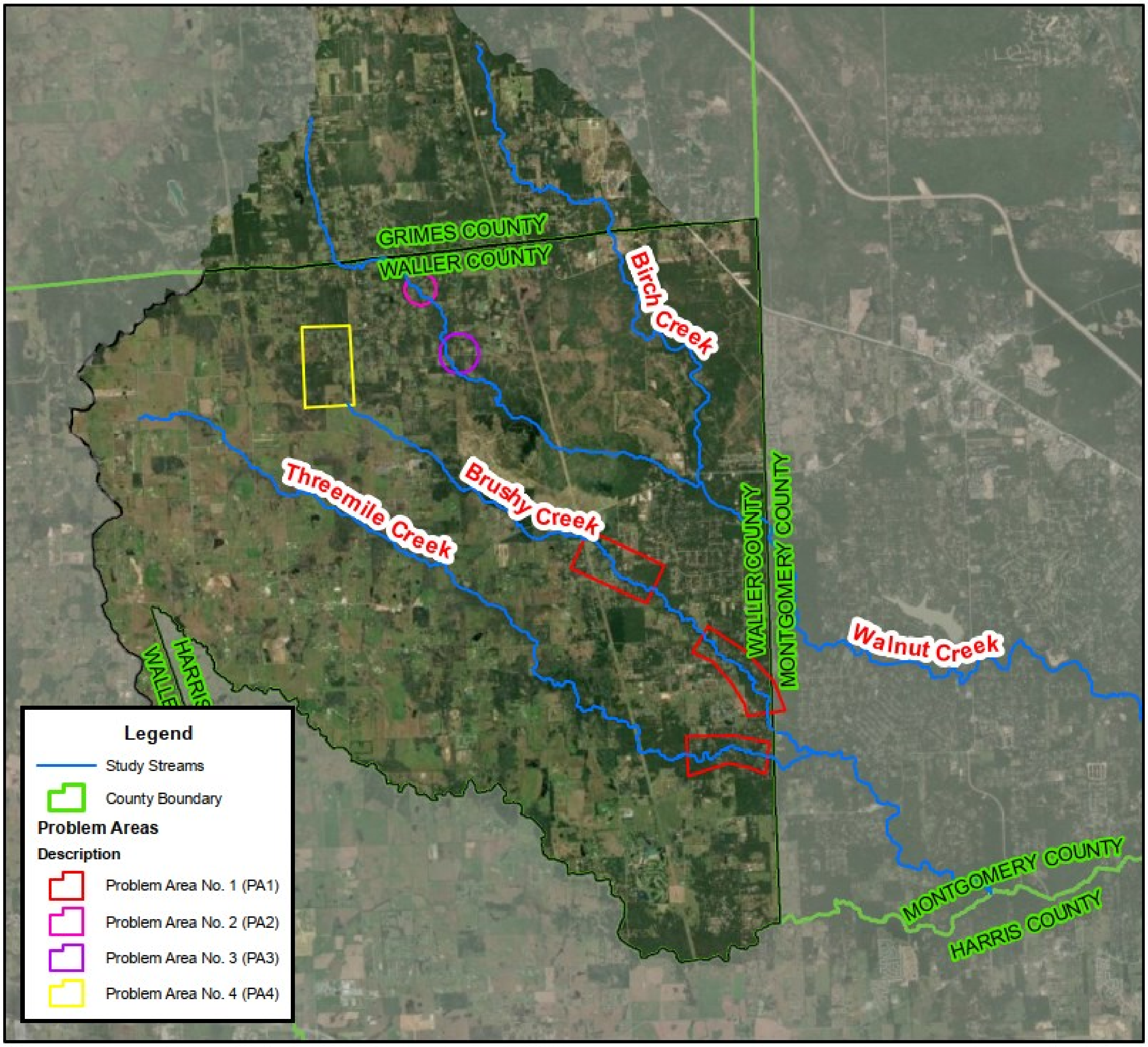

Figure 5-1. Flood Prone Area Identification

It is important to note that additional flood prone areas exist within the watershed. The areas listed above represent areas with the high risk to structures and roadways; however, additional flood prone areas within the County should be identified and studied further to develop flood mitigation solutions.

6 Alternative analysis

Potential structural and non-structural flood mitigation project alternatives were evaluated for locations with high flood risk in the Spring Creek watersheds within Waller County based on the results of the flood prone area identification effort.

6.1 Concept development

Conceptual alternatives were first assessed to determine the general feasibility of potential drainage improvement projects at each flood prone area location. Conceptual alternatives considered the following flood risk reduction solutions:

- Selective Clearing
- Channel Conveyance Improvements
- Culvert and/or Bridge Enhancements
- Detention
- Channel Diversions
- Non-structural solutions

Conceptual alternatives that showed potential for further consideration where identified, further developed, and then analyzed. Conceptual alternatives were evaluated based on the following criteria:

1. Potential to reduce the number of impacted structures
2. Potential to reduce roadway flooding and improve mobility
3. Potential to avoid adverse impacts
4. Potential project cost and relatively cost-effectiveness of providing project benefits
5. Potential implementation considerations (site constraints and construction challenges)

Four flood mitigation alternatives were evaluated as part of a detailed alternative analysis. These projects are summarized in Table 6-1 below:

Table 6-1. Summary of Evaluated Alternatives.

Alt ID	Channel	Description	Goal
PA1	Threemile Creek and Brushy Creek	Selective clearing along both sides of channel	Reduce water surface elevations along channel
PA2	Walnut Creek	Replacement of existing culvert structures with bridges and raising the roadway to convey	Reduce roadway flooding and improve mobility
PA3	Walnut Creek	Replacement of existing structures with bridges and raising the roadway to convey	Reduce roadway flooding and improve mobility
PA4	Threemile Creek and Brushy Creek	Channel extension and roadside ditch improvements along with a detention basin for mitigation	Reduce inundated area and reduce structural flooding

All alternatives were modeled for seven storm events: 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, 100-yr, and 500-yr. Alternative benefits presented in this report were calculated based on the FMP boundary. Modeling results for each evaluated alternative are discussed in the following sections.

6.2 Alternative PA1 - selective clearing on Threemile and Brushy Creek

The flood prone areas on Threemile Creek and Brushy Creek are generally attributed to limited channel conveyance capacity with both streams being characterized as natural channels with heavy vegetation along the channel banks. Conveyance improvements such as channel widening would involve extensive right of way acquisition and environmental permitting while requiring significant construction cost and maintenance. These hurdles would make the implementation of large channel improvements challenging for the County.

Instead, selective clearing was considered as a more cost-effective and easily implementable solution. Underbrush and small trees in the heavily vegetated overbank areas would be cleared to reduce the resistance to flow and increase the conveyance capacity during frequent storm events.

The limits of selective clearing extend outwards 50 feet from the top of the channel banks for approximately 9,500 feet along Threemile Creek and approximately 19,900 feet along Brushy Creek. The limits of selective clearing on Threemile Creek and Brushy Creek are shown in Figure 6-1.

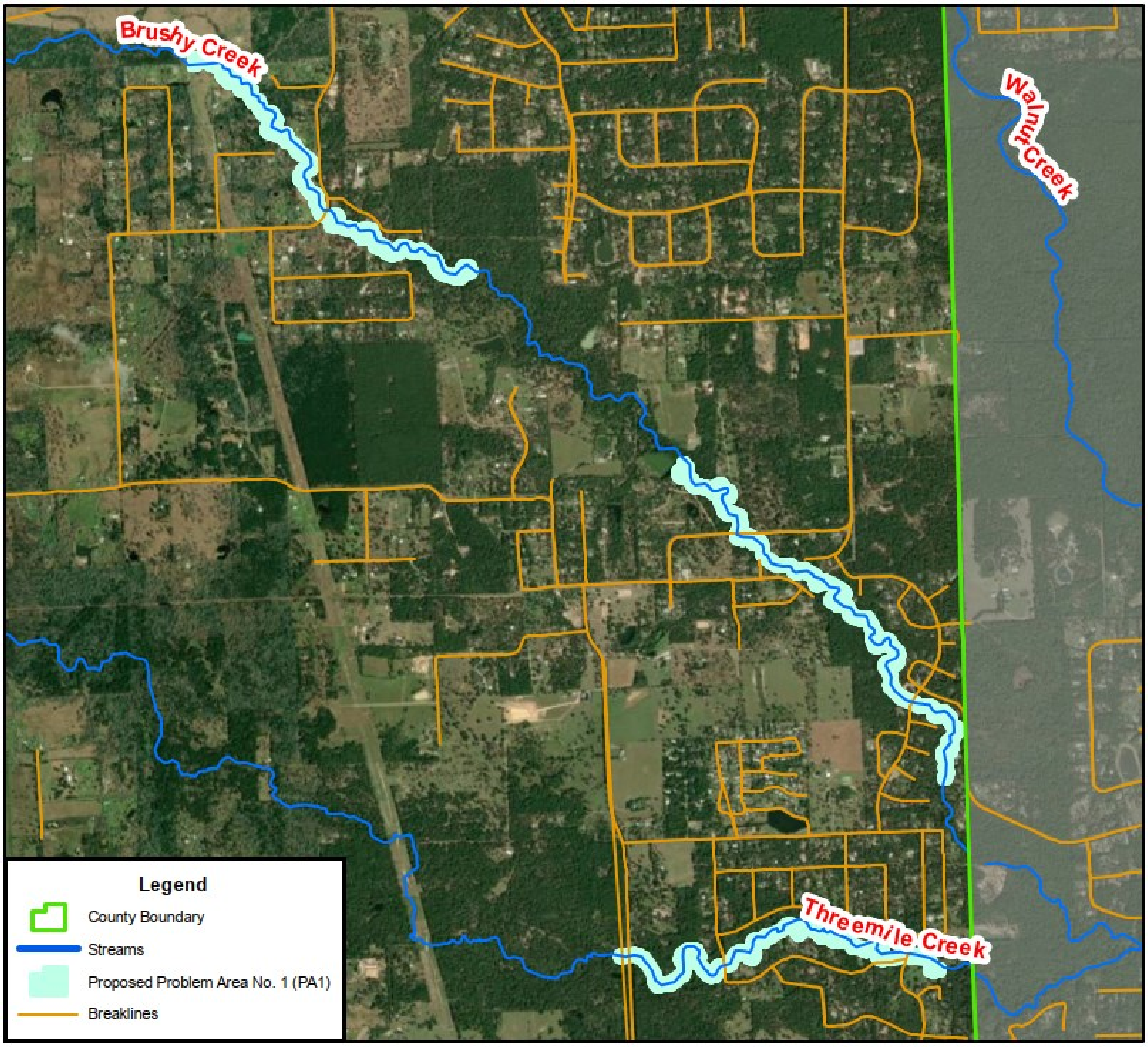

Figure 6-1. Alternative PA1 Selective Clearing (PA1) on Threemile Creek and Brushy Creek

6.2.1 *Model results*

Selective clearing (PA1) was conducted with the intention of altering the composition of vegetation within an area, transitioning it from a densely wooded areas characterized by higher Manning's n values, to one dominated by forest shrubs. This transformation would lower the flow resistance caused by dense vegetation. The hydraulic model was updated to reflect the change in the Manning n value in the selectively cleared area. The land use for the overbanks of Threemile and Brushy Creek was mostly dense wood which is characterized by a Manning's value ranging from 0.12 to 0.18, this was reduced to values ranging from 0.08 to 0.1 representing the cleared area. Table 6-2 shows water surface reductions and impacts in each storm event.

Table 6-2. Model Results for Alternative PA1.

Storm Event	Reach	Max WSE Reduction	Max WSE Increase
2-yr	Threemile Creek	0.10	0.03
	Brushy Creek	0.12	0.03
5-yr	Threemile Creek	0.18	0.02
	Brushy Creek	0.16	0.04
10-yr	Threemile Creek	0.00	0
	Brushy Creek	0.01	0
25-yr	Threemile Creek	0	0
	Brushy Creek	0.01	0
50-yr	Threemile Creek	0.03	0
	Brushy Creek	0.12	0.02
100-yr	Threemile Creek	0.03	0
	Brushy Creek	0.01	0
500-yr	Threemile Creek	0.03	0.01
	Brushy Creek	0.36	0

6.2.2 *Benefits*

Detailed benefits metrics were not calculated for Alternative PA1 as this alternative was screened out from further consideration based on the initial modeling results. Water surface elevation reductions were localized to the channel overbanks and therefore located in areas with low structure density. These results indicated that Alternative PA1 would not provide significant benefit to structures or roads, so it was not carried forward for detailed analysis.

6.2.3 *No negative impact analysis*

Water surface elevation increases ranging from 0.01 to 0.08 were seen in the various modeled storm event for Alternative PA1. These impacts could be mitigated through detention; however, the costs associated with the excavation and land acquisition needed for the construction of detention could be significant relative to the benefits provided by the project.

6.3 Alternative PA2 – N. Reids Prairie and Kyle Road improvements at Walnut Creek

The North Reids Prairie and Kyle Road crossings are located at Walnut Creek as shown in Figure 6-2. These crossings are prone to frequent inundation causing mobility constraints for the neighborhood located north of the roadways during storm events. Inundated roadways at this location could potentially strand residents and impede the passage of emergency vehicles attempting to access the neighborhood.

Field investigation showed the road elevation decreases significantly when approaching the stream bed. Raising the roadway through the floodplain and replacing the existing culvert structures with a bridge would reduce roadway flooding, increase the level of service, and improve mobility for both crossings.

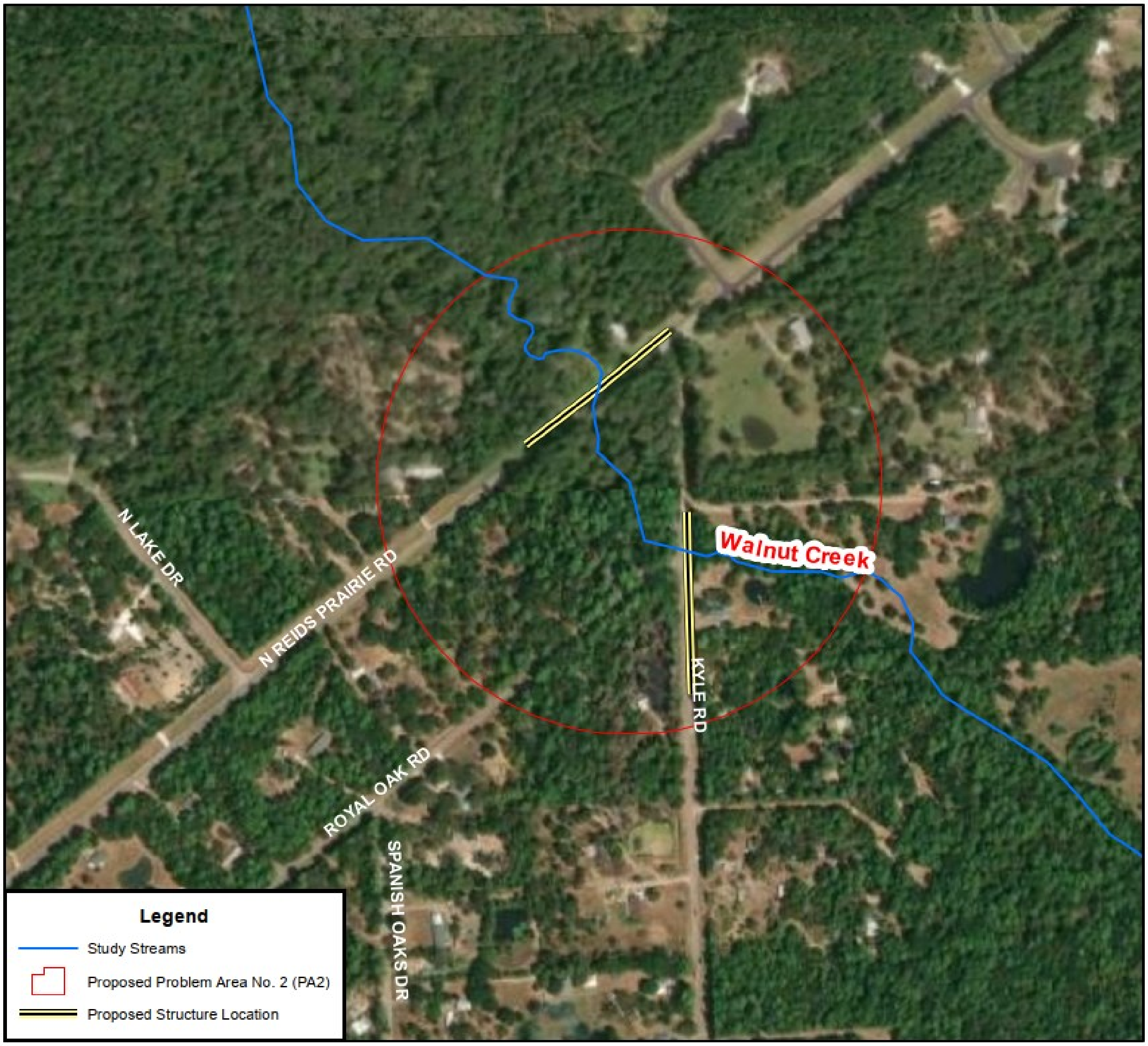

Figure 6-2. Alternative PA2 Walnut Creek Crossing Locations

At the North Reids Prairie crossing, the roadway is proposed to be raised by approximately 7.6 feet, accompanied by the replacement of the existing culvert (1 barrel) with the construction of a 550-foot-long bridge, with a deck elevation of 283.5 feet, to convey the flow underneath the road. The bridge design would consist of 10 piers (one every 50 feet) and a low chord elevation 3 feet below the deck elevation (see Figure 6-3). At the Kyle Road crossing, the roadway is proposed to be raised by approximately 7.0 feet, accompanied by the replacement of the existing culvert (2 barrel) with the construction of a 550-foot-long bridge, with a deck elevation of 283.5 feet, supported by 10 piers (see Figure 6-4). The proposed projects are shown on Exhibit 11.

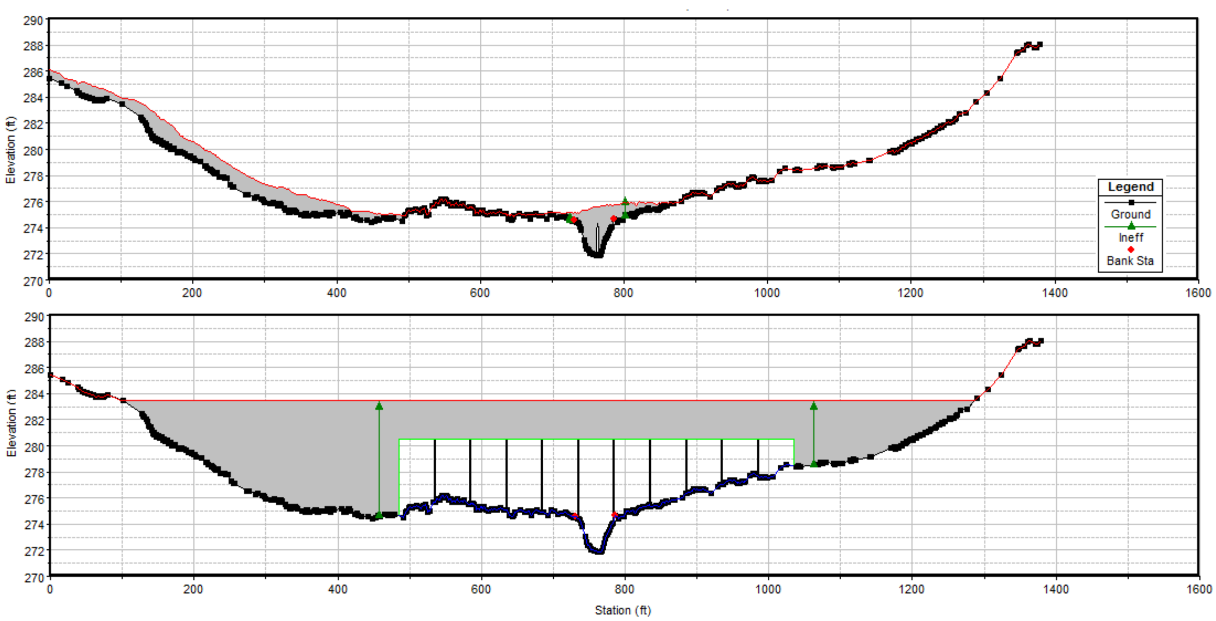

Figure 6-3. Alternative PA2 Existing and Proposed Structure Cross-Sections at North Reids Prairie Road

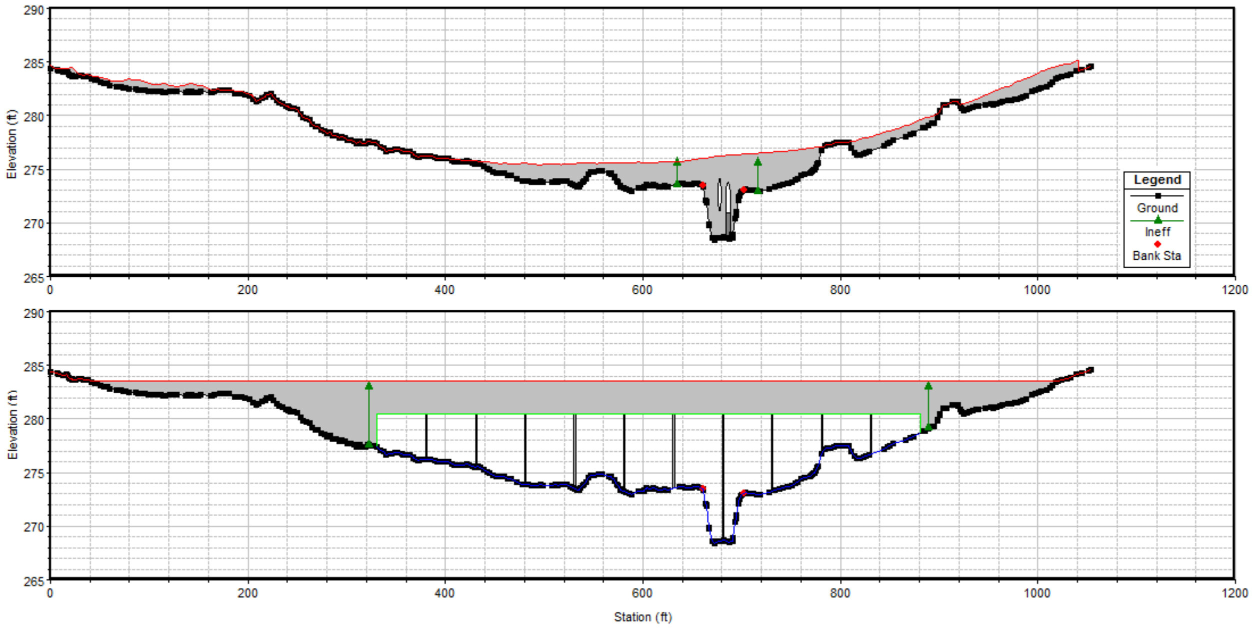

Figure 6-4. Alternative PA2 Existing and Proposed Structure Cross-Sections at Kyle Road

6.3.1 *Model Results*

The hydraulic model was updated to incorporate the structure improvements made to North Reids Prairie and Kyle Road crossings. Modeling indicated that with the improved structures, the level of service of the roadway is raised to a 100-year storm. This would mean that during rain events lower than 16-inches in a 24-hour period, the roadway would be passable. To provide a clearer understanding of conveyance improvements, Table 6-3 and

Table **6-4** summarize the quantity of flow passing through the structure and overtopping the road under both existing and proposed conditions during 2-year, 10-year and 100-year storm events.

Table 6-3. Alternative PA2 Discharge Comparison for N Reids Prairie Crossing.

	Discharge (cfs) 2-yr			Discharge (cfs) 10-yr			Discharge (cfs) 100-yr		
	Total	**Structure**	**Roadway**	**Total**	**Structure**	**Roadway**	**Total**	**Structure**	**Roadway**
Existing	1,246	6.1	1,240	2,437	6.1	2,431	4,957	7.2	4,950
Proposed	1,229	1,229	0	2,446	2,446	0	4,959	4,959	0

Table 6-4. Alternative PA2 Discharge Comparison for Kyle Rd Crossing.

	Discharge (cfs) 2-yr			Discharge (cfs) 10-yr			Discharge (cfs) 100-yr		
	Total	**Structure**	**Roadway**	**Total**	**Structure**	**Roadway**	**Total**	**Structure**	**Roadway**
Existing	1,273	48.2	1,225	2,490	41.2	2,449	5,079	45.2	5,034
Proposed	1,254	1,254	0	2,500	2,500	0	5,093	5,093	0

6.3.2 *Benefits*

The raising of the roadways provided limited water surface elevation benefits as shown in Table 6-5, primarily due to the absence of channel improvements or removal of a significant hydraulic restriction. However, the project enhances vehicle mobility on North Reids Prairie and Kyle Road during frequent storm events. This enhancement is particularly important for the residents of nearby subdivisions, ensuring their ability to navigate towards west-east roadways to access safer areas while also facilitating emergency vehicle access. For a more comprehensive understanding of the mobility improvement, the reduction in depth was analyzed, revealing a notable improvement, particularly at North Reids Prairie where the reduction ranges from 0.35 to 2.30 ft during 25-year to 100-year storm event, respectively. Table 6-6 summarizes the depth reduction at both crossings. Exhibit 8 shows the reductions in water surface elevations for alternative PA2.

Table 6-5. Alternative PA2 Benefits.

Frequency Storm	Structures Benefitted	Structures Removed	Crossing Benefitted
1% ACE	4	0	2
10% ACE	0	0	2
50% ACE	0	0	2

Table 6-6. Alternative PA2 Depth Reduction at North Reids Prairie and Kyle Road Crossings.

Frequency Storm	Depth Reduction at Crossing (ft)	
	N Reids Prairie	Kyle Road
1% ACE	2.30	1.76
2% ACE	1.31	0.76
4% ACE	0.35	0.08

6.3.3 *No negative impact analysis*

The proposed bridges were sized so as to not affect current water surface elevations and flows within Walnut Creek. The alternative P2 shows no negative impact in accordance with Texas Water Development Board criteria.

6.3.4 *Estimate of probable project cost*

The estimated project cost for the structure improvements on both North Reids Prairie and Kyle Road crossings (PA2) was determined to be $4,347,068.00 as shown in Appendix C. The opinion of probable costs was developed based on recent bid tabulations from TxDOT, Harris County, and previous projects. Costs include embankment, culvert removal and disposal, bridge construction, 15% engineering fee, and 30% contingency fee.

6.3.5 *Benefit cost analysis*

An analysis was performed to determine the benefit cost ratio for the for the roadway improvements using the BCR spreadsheet provided by the TWDB. Structural benefits were calculated using the structure size, structure type, and pre- and post-project conditions flooding depths. Benefits to mobility were also estimated using daily traffic and durations of flooding across effected roadways in pre- and post-project conditions. The BCR for Alternative PA2 is 0.1 (Appendix D).

6.4 Alternative PA3 – Riley Road improvements at Walnut Creek

Riley Road is a major east-west road for this portion of Waller County. However, it is overtopped by Walnut Creek and Walnut Creek Tributary #1 at two locations as shown in Figure 6-5. When these areas are overtopped during storm events, many residents are unable to access major thoroughfares at the east and west, causing mobility constraints for the residents. Similar to the previously mentioned alternative, in the absence of alternative routes, residents could potentially become stranded and emergency vehicles would have to cross flooded roadways to try to access the neighborhood.

The overtopping is mostly attributed to the low water crossings at Walnut Creek. Field investigation showed the road dips significantly when approaching the stream bed. Raising the roadway through the floodplain, replacing the existing bridge on Walnut Creek, and replacing the existing culvert structure with a bridge on Walnut Creek Tributary #1 would reduce roadway flooding, increase the level of service, and improve mobility on Riley Road.

Figure 6-5. Alternative PA4 Riley Road Crossings at Walnut Creek and Walnut Creek Tributary #1

At the Walnut Creek crossing, the roadway is proposed to be raised by approximately 8.2 feet, accompanied by the replacement of the existing bridge (57-foot-long) with the construction a 600-foot-long bridge with a deck elevation of 270.5 feet, to convey the flow underneath the road rather than over. The bridge design would involve incorporating 11 piers (one every 50 feet) and a low-chord elevation 3 feet below the deck elevation (Figure 6-6). At the Walnut Creek Tributary #1 crossing, the roadway is proposed to be raised by approximately 7.6 feet, accompanied by the replacement of the existing culvert (1 barrel) with the construction of a 142-foot-long bridge with a deck elevation of 266.5 feet, supported by 2 piers to also facilitate the flow underneath the road (Figure 6-7). The proposed projects are shown on Exhibit 12.

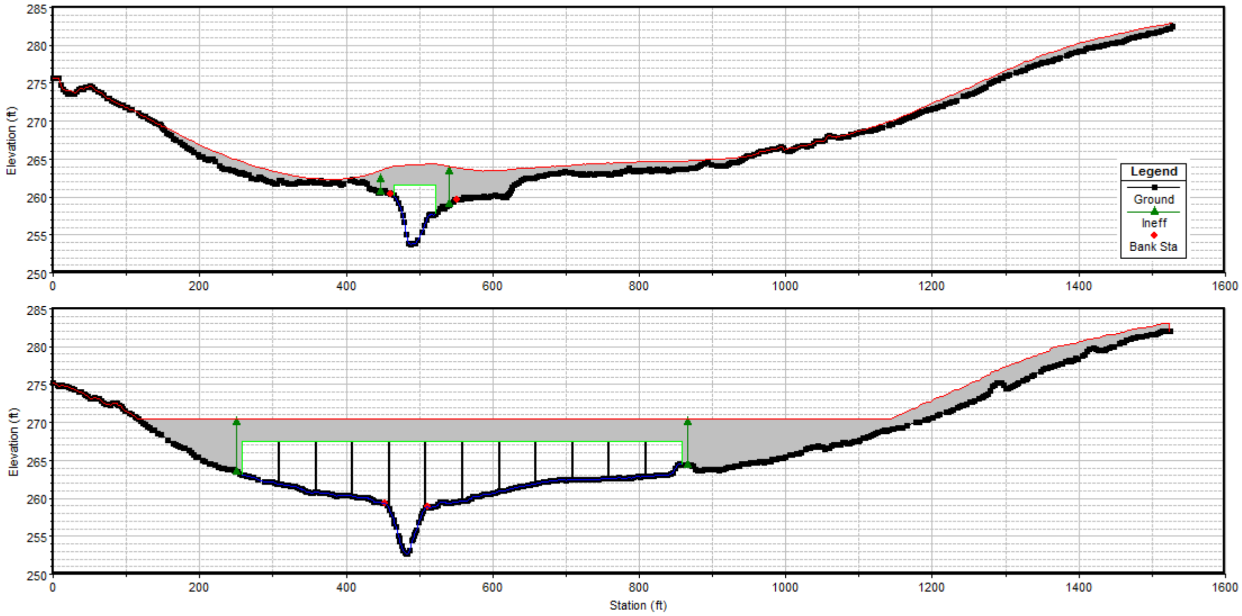

Figure 6-6. Alternative PA3 Existing and Proposed Cross-sections on Riley Road at Walnut Creek

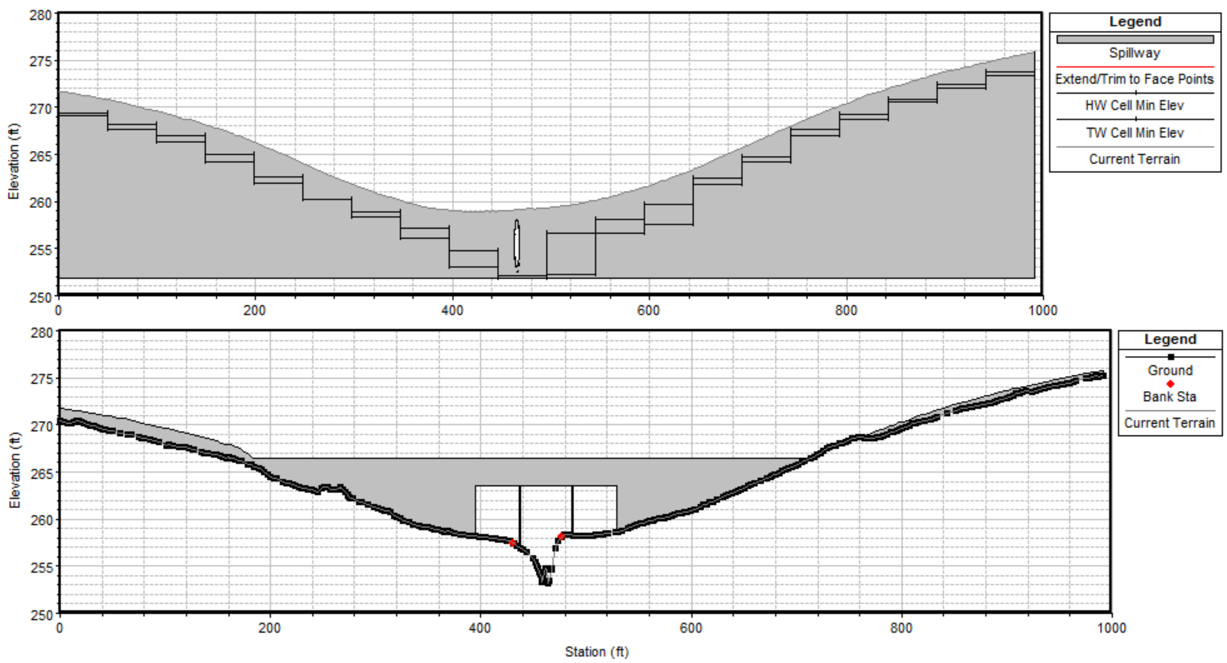

Figure 6-7. Alternative PA3 Existing and Proposed Cross-Sections on Riley Road at Walnut Creek Tributary #1

6.4.1 *Model results*

The hydraulic model was updated to incorporate the structure improvements made to Riley Road crossings. Modeling indicated that with the improved structures, the level of service of the roadway at Walnut Creek crossing is raised to a 500-year storm event. This would mean that during rain events lower than 24-inches in a 24-hour period, the roadway would be passable. Alternatively, the level of service of the roadway at Walnut Creek Tributary #1 crossing is raised to a 100-year storm. This would mean that during rain events lower than 16-inches in a 24-hour period, the roadway would be passable. To provide a clearer understanding of the mobility enhancements, Table 6-7 and Table 6-8 summarize the quantity of flow passing through the structure and overtopping the road under both existing and proposed conditions during 2-year, 10-year and 100-year storm events.

Table 6-7. Alternative PA3 Discharge Comparison on Riley Rd at Walnut Creek Crossing.

	Discharge (cfs) 2-yr			Discharge (cfs) 10-yr			Discharge (cfs) 100-yr		
	Total	**Structure**	**Roadway**	**Total**	**Structure**	**Roadway**	**Total**	**Structure**	**Roadway**
Existing	1,365	1,165	200	2,729	808	1,921	5,748	774	4,974
Proposed	1,363	1,363	0	2,728	2,728	0	5,749	5,749	0

Table 6-8. Alternative PA3 Discharge Comparison on Riley Rd at Walnut Creek Tributary #1 Crossing.

	Discharge (cfs) 2-yr			Discharge (cfs) 10-yr			Discharge (cfs) 100-yr		
	Total	**Structure**	**Roadway**	**Total**	**Structure**	**Roadway**	**Total**	**Structure**	**Roadway**
Existing	494	141	353	1,230	144	1,086	3,295	137	3,158
Proposed	498	498	0	1,239	1,239	0	3,306	3,306	0

6.4.2 *Benefits*

The raising of the roadways provided limited water surface elevation benefits within the watershed (Table 6-9), primarily due to the absence of channel improvements such as diversion channel, widening or deepening. However, the modeling showed reduced water surface elevation by up to 0.23ft upstream Riley Road.

Besides, it significantly enhanced the mobility of vehicles during frequent storm events. This enhancement is particularly important for the residents of Waller County, as its amplifiers their ability to navigate towards west-east roadways to access safer areas, while also facilitating emergency assistance. For a more comprehensive understanding of the mobility improvement, the reduction in depth was analyzed, revealing a notable improvement, particularly at the Walnut Creek Tributary #1 crossing where the reduction ranges from 0.8 to 1.3 ft during 25-year to 100-

year storm event, respectively.

Table **6-10** summarizes the depth reduction at both crossings. Exhibit 9 shows the reductions in water surface elevations for Alternative PA3.

Table 6-9. Alternative PA3 Benefits.

Frequency Storm	Structures Benefitted	Structures Removed	Crossing Benefitted
1% ACE	2	0	2
10% ACE	0	0	2
50% ACE	0	0	2

Table 6-10. Alternative PA3 Depth Reduction at Riley Road Crossings.

Frequency Storm	Depth Reduction at Crossing (ft)	
	Riley Road	Riley Road (Walnut Creek Tributary #1)
1% ACE	0.06	0.8
2% ACE	0.06	1.1
4% ACE	0.06	1.3

6.4.3 *No negative impact analysis*

The proposed bridges were sized so as to not affect current water surface elevations and flows within Walnut Creek. The Alternative P3 shows no negative impact in accordance with Texas Water Development Board criteria.

6.4.4 *Estimate of probable project cost*

The estimated project cost for the structure improvements on both Riley Road crossings (Alternative PA3) was determined to be $4,018,475.00 as shown in Appendix C. The opinion of probable costs was developed based on recent bid tabulations from TxDOT, Harris County, and previous projects. Costs include embankment, culvert removal and disposal, bridge construction, 15% engineering fee, and 30% contingency fee.

6.4.5 *Benefit cost analysis*

An analysis was performed to determine the benefit cost ratio for the for the roadway improvements using the BCR spreadsheet provided by the TWDB. Structural benefits were calculated using the structure size, structure type, and pre- and post-project conditions flooding depths. Benefits to mobility were also estimated using daily traffic and durations of flooding across effected roadways in pre- and post-project conditions. The BCR for Alternative PA3 is 0.1 (Appendix D).

6.5 Alternative PA4 – Brushy Creek Channel extension at N. Reids Prairie Road

One of the major flood prone areas is along Brushy Creek between N Reids Prairie Road and Bowler Road. The area is mostly drained by undersized roadside ditches through the neighborhood south of N Reids Prairie. As a result, significant portion of the flooding comes from overland flow north of N Reids Prairie Road. As runoff crosses the roadway, it is conveyed via sheet flow and roadside ditches to a residential area south of the road. Even during the 2-year storm event, structural flooding is noted along Buckeye Road and Pinyon Road. The inundation for 10-year storm event is shown in Figure 6-8.

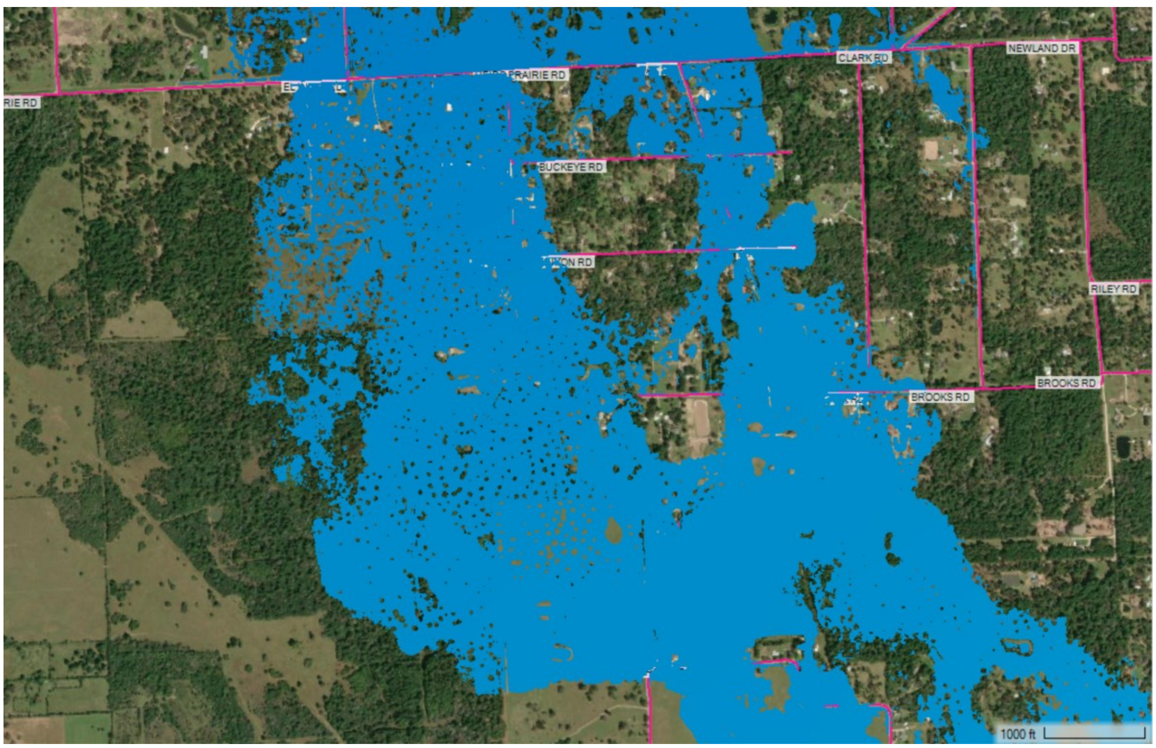

Figure 6-8. Alternative PA4 Existing 10-year Inundation Extents

Alternative PA4 includes construction of a channel that would convey the drainage from north of the subdivision to the beginning of Brushy Creek. This would convey flow around the subdivision, reducing the amount of sheet flow. Figure 6-9 and Exhibit 13 shows a schematic of the recommended project. The improvement includes the following major components:

- Re-grading of ditches on N. Reids Prairie to convey flow to the new drainage channel.
- Construction of a 10-foot deep, 150 feet wide bypass channel west of the neighborhood to convey flow around the neighborhood.
- Construction of a 250 acre-foot detention facility near the upper end of Brushy Creek to collect stormwater and mitigation discharges downstream. A pump station will also be required due to the limited topographic relief within the area.

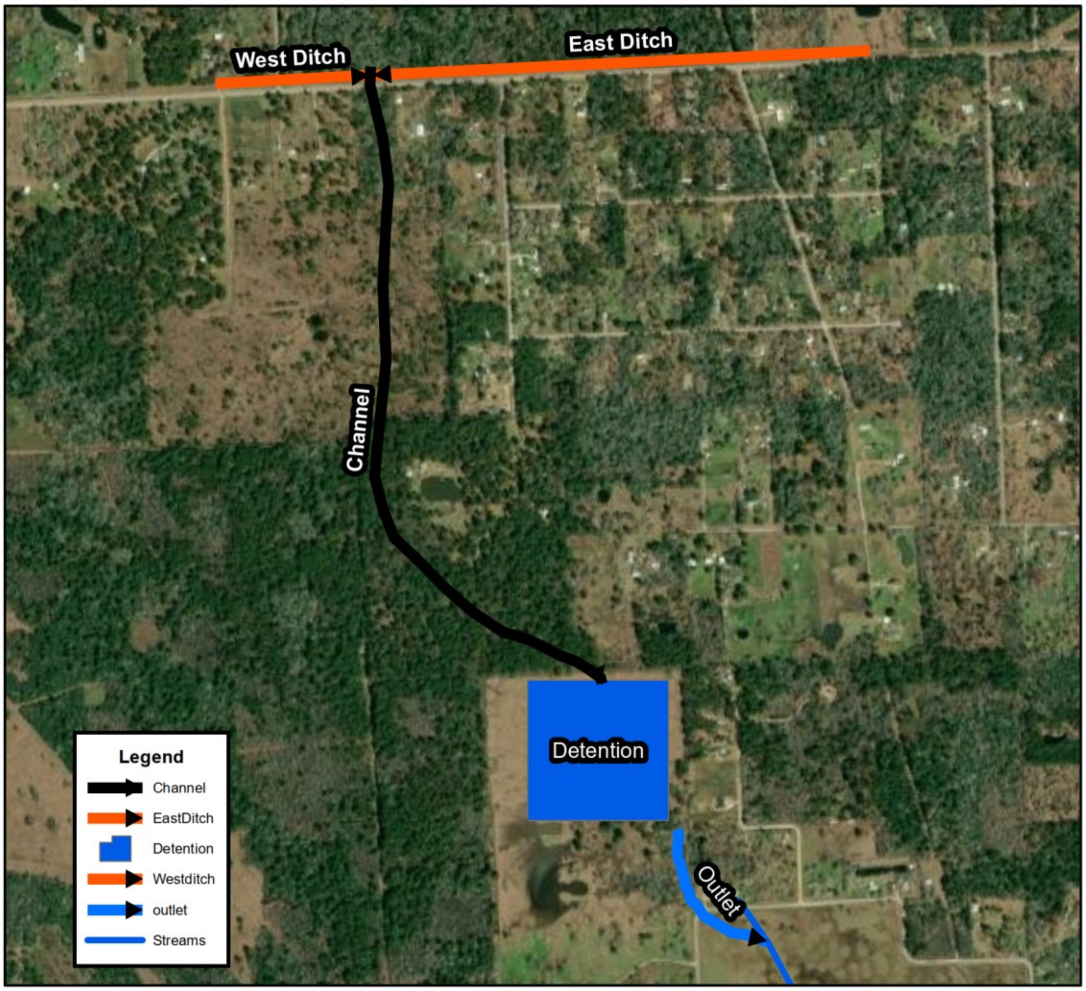

Figure 6-9. Alternative PA4 Proposed Improvements Layout

6.5.1 *Model results*

The recommended channel, side ditches and detention were modeled within the 2D mesh of the HEC-RAS model. The channel width was expanded to accommodate the 10-year storm event, which is approximately 469 cfs and removes 10-year inundation between N Reids Prairie and Bowler Road as shown in Figure 6-10.

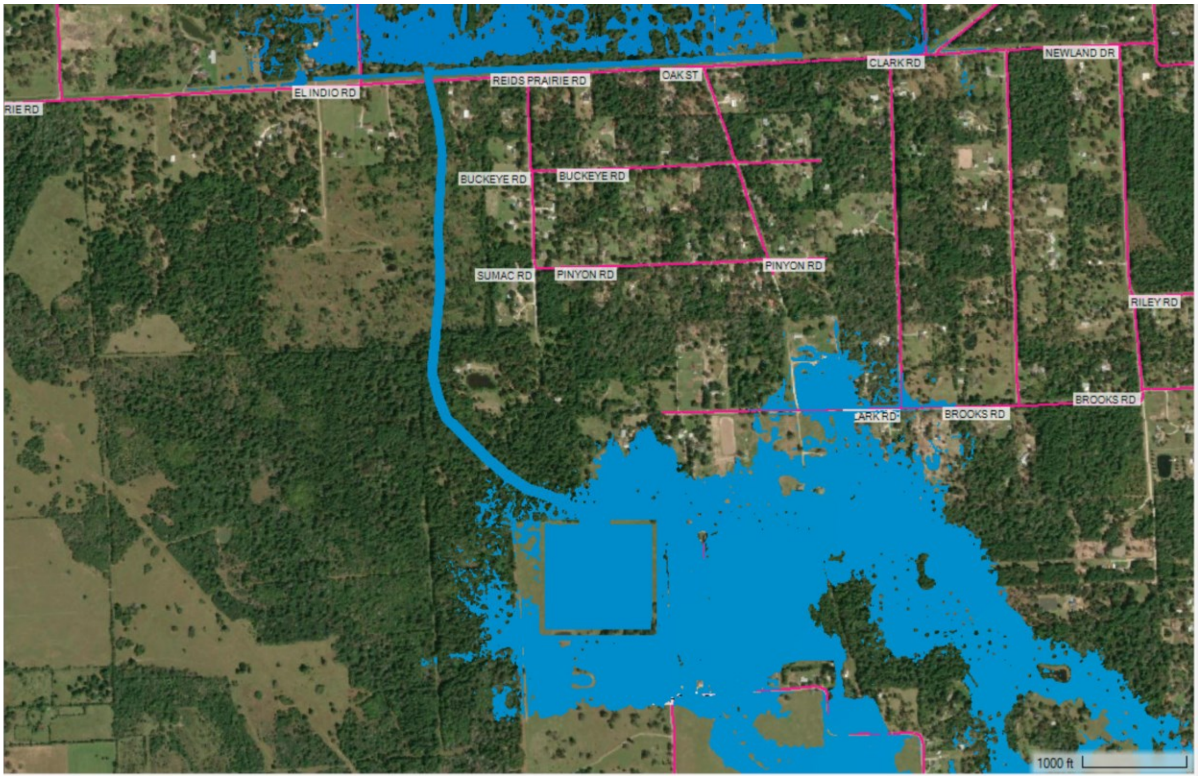

Figure 6-10. Alternative PA4 Proposed Inundation

6.5.2 *Benefits*

The concentration of flow within the channel removes some structures from flooding during frequent events and improves roadway level of service at N Reids Prairie Roads. Table 6-11 summarizes the benefits of the improvement for each modeled storm event. Exhibit 10 shows the reductions in water surface elevations for Alternative PA4.

Table 6-11. Alternative PA4 Benefits.

Frequency Storm	Structures Benefitted	Structures Removed	Roads Benefitted (miles)
1% ACE	16	47	1.17
10% ACE	23	16	0.89
50% ACE	4	4	0.52

6.5.3 *No negative impact analysis*

Using the unsteady HEC-RAS modeling, the channel improvements and detention do not result in adverse increases in neither flow, nor water surface elevation downstream of the alternative PA4t areas for the modeled storm events.

6.5.4 *Estimate of probable project cost*

The probable Alternative PA4 cost for the channel and detention is $34,920,281.00 as shown in Appendix C. Opinion of probable costs were developed based on recent channel and detention bid tabs from Harris County. Costs include culvert installation, roadside ditch and bypass channel construction, and detention excavation, right of way acquisition, engineering, and a 30% contingency.

6.5.5 *Benefit cost analysis*

An analysis for the benefit cost ratio for the channel project was conducted using the BCR spreadsheet provided by the TWDB. Structures were input based on the location, estimated finished floor elevation, and assigned a category via Waller County appraisal district information. The BCR for alternative PA4 is 0.17 (Appendix D).

6.6 Non-structural solutions

6.6.1 *Buyouts*

Although the recommended alternatives provide flood risk mitigation for structures within Spring Creek watershed for studied tributaries in Waller County, they do not mitigate all flooding. One of the most cost-effective approaches to mitigating flood risk for structures that experience frequent flood is property buyouts and land preservation. The 10-year inundation extents were used to identify structures and land that are prone to frequent flooding and therefore good options for property acquisition. The presumed cost of acquiring and removing a structure was assumed to be 2.5 times the property’s market value.

Table 6-12 below shows the estimated number of buyout properties as well as the estimated benefits and costs.

Table 6-12. Buyout Candidates for 10-year Storm Event.

	Number of Buyout Structures	Potential Buyout Cost
Walnut Creek	12	$ 13,701,400
Brushy Creek	39	$ 18,702,625
Threemile Creek	26	$ 28,548,025

6.6.2 *Criteria updates*

Drainage policy also has a significant impact on mitigating current flood damages and preventing future damages as Waller County continues to develop. Policy considerations for the County were not evaluated using detailed hydrologic and hydraulic modeling like the previous mitigation recommendations; instead, they are more general ideas based on team experience and historical trends indicating the importance of drainage criteria.

The Waller County Drainage Criteria Manual specifies guidance for developers and engineers including discharge rate calculation, minimum detention requirements, and open channel calculations. However, expanding the manual to include items below would provide a more comprehensive approach to minimizing the impacts of development. Updates should include:

- Requiring detention outflow calculations for the 2-year storm event. Many of the outfalls in the County are roadside ditches that have a 2-year capacity. Requiring the detention ponds to include a 2-year outfall would limit the outflows during this event and reduce the impacts on roadside ditches.
- Adopting site runoff curves for calculating discharge rates for areas 100 acres to 640 acres. The manual currently uses the rational method which can be inaccurate for these larger developments.
- Establishing a hydrologic methodology for areas greater than 640 acres. Many jurisdictions in the area have adopted the Basin Development Factor method which would be applicable for Waller County.
- Adopting criteria for pumped detention which occurs frequently due to the limited outfalls throughout the County.
- Adopting general computing software requirements to standardize approaches for channel and detention calculations.
- Including requirements for storm sewer design such as calculation requirements, manhole and inlet spacing, and maximum ponding elevations.
- Standardizing drainage report submittals by establishing a typical report outline.

6.7 Alternative analysis summary

The projects were developed in accordance with TWDB requirements to qualify them as Flood Mitigation Projects (FMPs) within the regional and state flood plans. Projects identified within this study were screened for feasibility using information available at the time of the study.

Alternative PA1 was considered but is not recommended due to limited water surface elevation reductions with a minimal impact to structural flooding. Furthermore, the presence of impacts would require mitigation that could add significantly to the project cost.

Alternative PA2 (N. Reids Prairie and Kyle Road Improvements at Walnut Creek) has significant benefit to mobility during storm events in particular to the Saddle Creek neighborhood. This enhancement not only may help residents in access safer areas during storm events but also ensures that emergency vehicles and services can access the neighborhood during these events.

Alternative project PA3 (Riley Road Improvements at Walnut Creek) has the capability to remove the risk of flooding for only one structure only during the 10-year event, but it significantly enhances mobility up to 100-year event on this major east-west roadway. This enhancement not only may help residents in access safer areas during storm events but also ensures that emergency vehicles and services can access the neighborhood during these events.

Alternative project PA4 (Proposed Channel and detention) provides significant flood risk reduction for structures near N. Reids Prairie Road but will have several challenges for implementation including land acquisition, construction of a large detention basin, and maintenance of a pump station. Waller County or another entity would need to establish a maintenance plan and budget for these facilities to maintain. However, this alternative is still recommended due to the benefit to the residents.

The recommended projects were all deemed to be permittable, constructable, and implementable. A summary of the recommended projects is provided in Table 6-13.

Table 6-13. Summary of Recommended Projects.

ID	Alternative Project	Brief Description	Summary of Benefits	Estimated Cost	BCR
PA2	N Reids Prairie and Kyle Road Improvements	Replacement of existing culverts with a bridge and raising the roadway.	LOS increased to 100-year and 4 structures benefitted in the 100-year event	$4,347,000	0.1
PA3	Riley Road Improvements	Replacement of existing structures with bridge and raising the roadway.	LOS increased to 100-year and 2 structures benefitted in the 100-year event	$4,018,500	0.1
PA4	Channel Extension at N Reids Prairie Road	Construction of a channel to convey overland flows upstream N Reids Prairie Road and Brushy Creek.	47 structures benefitted and 16 structures reduced in the 100-year event	$34,920,281	0.2

A summary of the flood risk benefits provided by the recommended alternatives is provided in Table 6-14. The projects were developed in accordance with TWDB requirements to qualify them as Flood Mitigation Projects (FMPs) within the regional and state flood plans.

Table 6-14. Recommended Project Flood Risk Benefits.

Mitigation Measurement	Alt PA2	Alt PA3	Alt PA4
Structures with reduced 1% ACE flood risk	4	2	16
Structure removed from 1% ACE flood risk	0	0	47
Structures removed from 0.2% ACE flood risk	0	0	53
Residential structures removed from 1% ACE	0	0	43
Population removed from 1% ACE flood risk	0	0	45
Critical facilities removed from 1% ACE flood risk	0	0	0
Low water crossings removed from 1% ACE	0	0	0
Reduction in road closure occurrences in 1% ACE	0	2	19
Length of road removed from 1% ACE (mi)	0	0.02	1.17
Farm & ranch land removed from 1% ACE	0.02	0.41	65.99
Estimated reduction in fatality	N/A	N/A	N/A
Estimated reduction in injury	N/A	N/A	N/A
Pre-Project Level of Service	< 50% ACE	< 50% ACE	< 50% ACE
Post-Project Level of Service	1% ACE	1% ACE	10% ACE
Cost/Structure Removed	0	0	$742,985
Percent Natured-Based Solution	0	0	0
Negative Impact?	N	N	N
Negative Impact Mitigation?	N/A	N/A	Any necessary mitigation included
Social Vulnerability Index	0.332	0.332	0.332
Water Supply Benefits?	N	N	N
Traffic Count for Low Water Crossing	0	0	0

6.8 Implementation and phasing

Once implemented, the projects and strategies identified in this study will reduce flood risk within the Spring Creek watershed. Implementation of structural projects, buyouts, and criteria updates will occur over time and include both short-term and long-term actions to complete.

In general, the project lifecycle follows the flow path shown in Figure 6-11. The Spring Creek Flood Update Study completed the planning portion of the project. Phase I includes short-term actions are those than can be implemented over the next few years and will be steppingstones to completing the larger projects. Phase II includes longer-term actions required to move a project through design and construction; these longer-term actions will likely take more than five years due to funding availability, construction time, and project constraints.

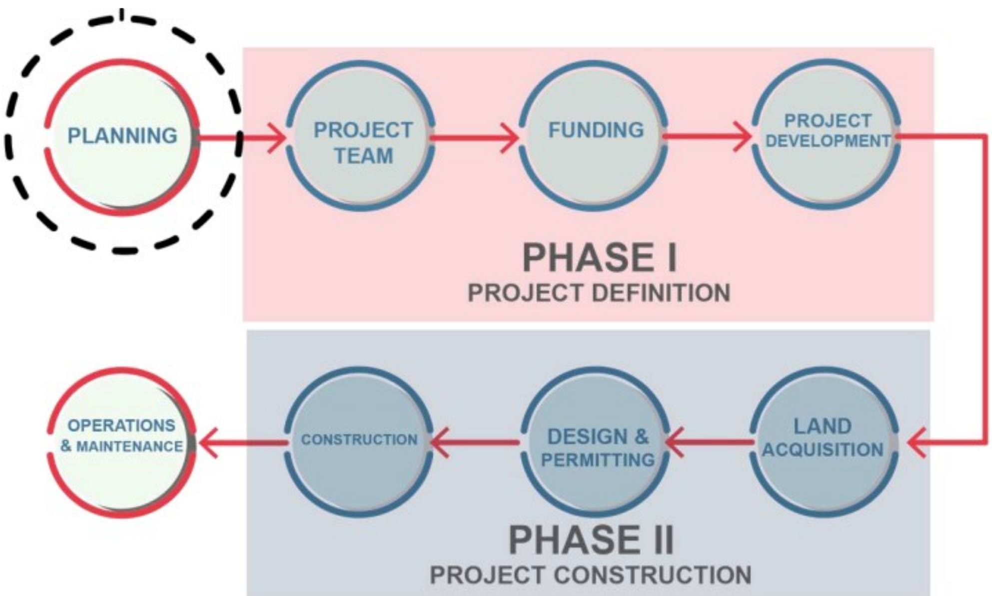

Figure 6-11. Drainage Project Lifecycle

6.8.1 *Short term actions*

Waller County has limited funding for drainage project implementation and therefore short-term actions are those that can be implemented with limited funding.

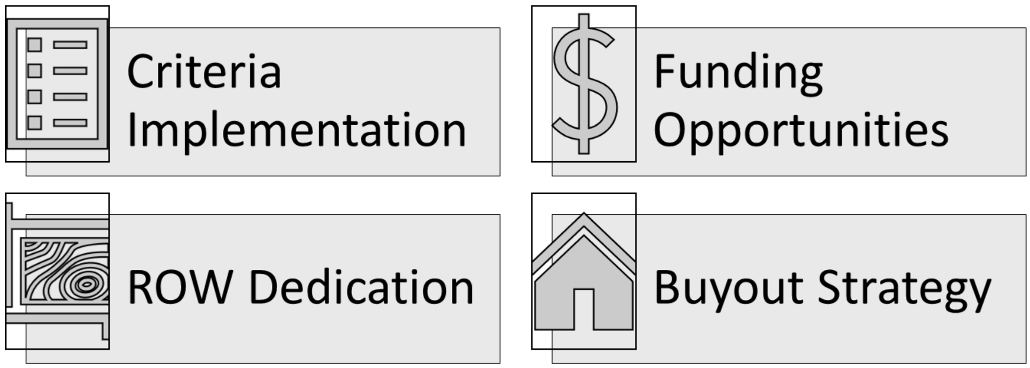

Figure 6-12. Short-term Implementation Actions

- **Criteria Implementation** – Updating drainage and development criteria is one of the most effective was to reduce flood risk within a growing County. An updated criteria would assist in reducing flood risk for future residents as well as mitigate the impacts of development on existing ones. Criteria could be implemented over a two-year budget cycle to reduce yearly costs. Brazoria, Fort Bend, Harris, and Montgomery Counties have recently developed and/or adopted criteria which could be used as a basis for Waller County. There are also multiple funding mechanisms to assist in criteria updates. The existing conditions flood risk results of this study can also be used to regulate future development.
- **Right of Way Dedication** – The bypass channel and detention pond proposed in Alternative 4 requires right of way for implementation. As tracts in these areas begin to develop, the County should require dedication of these areas to the County so that the right of way is available for future use. This could include dedication in fee to the County, dedicated to the public, or as a drainage easement. The County should work with developers and landowners as available.
- **Funding Opportunities** – With the limited available County budget, Waller should continue to investigate other funding strategies for implementation. The TWDB Flood Infrastructure Fund is a first choice due to the current project being FIF funded; however, other funding opportunities exist in both local, state, and federal sources. Some of these are included in Section 5.6.3. The proposed road bond may be a source of funding for the crossing improvements on N. Reids Prairie and Riley Roads.
- **Buyout Strategy** – Buyouts within the Spring Creek watershed for repetitive losses are effective at reducing structural flooding in rural areas. The County should work alongside FEMA to advocate for voluntary buyouts along the river for the repetitive and frequently flooded structures. The County should also investigate land acquisition in these areas to reduce future development within the floodplain.

6.8.2 *Long term actions*

As the short-term actions are completed, funding and other strategies will become available for the recommended projects. At this point, the long-term actions will commence.

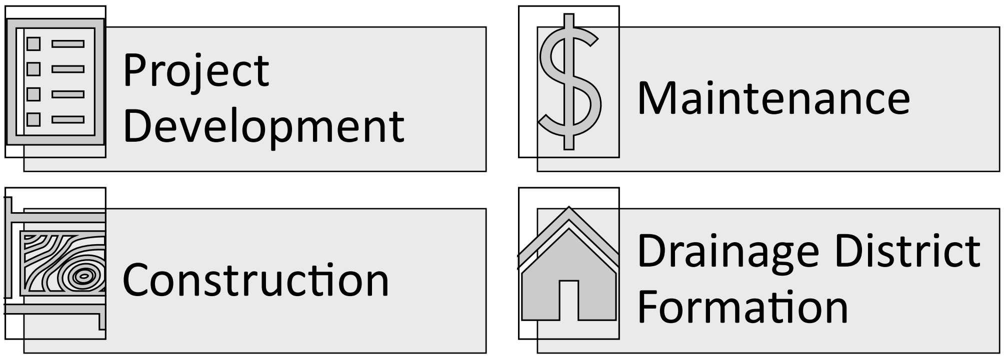

Figure 6-13. Long-term Implementation Actions

- **Project Development** – Further development and design of the project will be needed before construction. The development will include a preliminary engineering report which will include survey, geotechnical analysis, environmental study, utility coordination and land acquisition. The Design will include the development of engineering drawings and permitting needed to completely implement the project.
- **Construction** – Construction of the roadway and channel projects will likely take 12-18 months each. Construction will include mobilization of the project, acquisition of construction easements, and the excavation of the channel and detention facilities.
- **Maintenance** – Once constructed, the projects will require regular maintenance to remain functional for their life span. The channel projects will require regular mowing, regular inspections, and repair throughout the project life. The culvert and bridge improvements will require routine inspection to ensure the crossings are free from debris.
- **Drainage District Formation** – Identifying a local and consistent funding source would be beneficial to implementing the recommended projects, buyouts, and land purchase. The County should continue explore a drainage district which would provide both a revenue source for implementation of the projects as well as a dedicated entity for maintaining ditches and channels throughout the County.

6.8.3 *Funding sources*

The potential funding sources of the recommended projects and strategies will depend on the project type and readiness for construction. Funding sources are available from both local, state, and federal entities and each program identified may have differing procurement, administrative, and environmental requirements, impacting the cost and schedule of the projects. The funding sources below should be considered for the projects identified in the Spring Creek Watershed for the studied tributaries in Waller County.

Federal Funding Sources

- Community Development Block Grant Disaster Relief (CDBG-DR) - The CDBG-DR is based on response to Federally declared disaster and includes a variety of potential activities, including detention and conveyance improvements. The grant does have an LMI emphasis that may limit the applicability of this source in the watershed. The cost-share is typically 100% Federal to 0% Local. More information is at https://recovery.texas.gov/localgovernment/resources/overview/index.html.
- Community Development Block Grant Mitigation (CDBG-MIT) - The CDBG-MIT funds are also related to disaster declarations and are a little bit more flexible in that it has a lower threshold for the LMI component, which opens it to more of the watershed than the DR funding. Given the reduced requirement on LMI, the CDBG-MIT may be a viable funding source for several of the proposed flood mitigation projects in the watershed. As with the -DR funds, the cost-share is 100% Federal to 0% Local. Recommended future watershed protection studies could be partially funded through this grant program. For more information, visit https://recovery.texas.gov/action-plans/mitigation-funding/index.html.

State funding sources

- TWDB Development Fund (DFund) - The Dfund is a State of Texas loan program, that is relatively simple and has minimal red tape. Flood control projects are eligible; however, the fund is primarily loan based.
- TWDB Flood Infrastructure Fund (FIF) - The Flood Infrastructure Fund (FIF) is administered by the TWDB. The FIF allows for loans at or below market rates for a variety of actions, including flood planning, grant application, and engineering for structural and non-structural solutions. In addition, the FIF offers grants that can be used as the local entities matching funds for other federal funding programs. The state is currently allocating additional budget for the fund and will be accepting applications in 2024.

Local funding

- Bonds - Bond funding can be used for flood protection and management. Bonds typically provide project specific financing that requires proposed improvements to be ready for construction and meet the priorities set by the funder. Although repayment terms can offer low or no interest financing, these sources do require full repayment.
- Fees and Ad Valorem Taxes - A development impact mitigation fee is a tax that is imposed as a precondition for the privilege of developing land. Since the proposed projects address existing conditions are not meant for mitigating developing land, imposing a fee on new development to address pre-existing flooding conditions may be difficult to implement. Ad valorem taxes are based on the value of a transaction of a

property. Sales taxes or property taxes are ad valorem taxes that could be considered for funding the projects.

- Public Private Partnerships - While there is not an identified stream of funding available for private investment, it may be considered as an option if the opportunity is presented. The watershed includes several different industrial and commercial developments that were significantly damaged in recent flood events and whose owners may be looking for opportunities to reduce flood risk in the area.

6.8.4 *State Flood Planning*

The projects developed as part of this study have been developed in accordance with the requirements of the Regional and State Flood Planning process to ensure their eligibility for FIF funding. Requirements for inclusion in the State Flood Plan have been set forth by the TWDB, with additional requirements for inclusion in the Regional Flood Plan being set forth by the relevant Regional Flood Planning Group (RFPG). For the area being analyzed within this study, the San Jacinto RFPG (Region 6) was identified as the encompassing region.

The San Jacinto RFPG limited the collection of eligible flood mitigation projects (FMPs), flood management evaluation (FMEs) and flood mitigation strategies (FMSs) for inclusion within the first San Jacinto Regional Flood Plan to submittals received before March 2023. The projects developed as part of this study were not fully evaluated at this time, and therefore were not able to be brought forth for inclusion in the first cycle of Regional and State Flood Planning. As the second planning cycle initiates in 2024, it is expected that the San Jacinto RFPG will begin allowing for additional FMPs, FMEs and FMSs to be submitted for consideration. When this happens, the FMPs and all supporting data developed as part of this study will be provided to the RFPG for consideration.

7 Flood protection plan

The reduction of flood risk through structural and non-structural projects is a critical component to lessen the impacts of severe storm events and preserve the safety of life and property. However, the implementation of these projects can take years to complete, given the time needed to obtain funding, secure permits, and finish construction. By improving flood response through planning hazard mitigation actions, communities can lessen the impact of flooding and ensure the safety of residents is preserved.

The focus of this flood protection plan is to identify existing flood prone areas, roading crossings, and critical structures and recommend public safety features to warn residents and visitors of flood risk.

7.1 At-risk infrastructure mapping

Using the updated existing conditions modeling developed for Spring Creek tributaries through Waller County, at-risk infrastructure for different severities of rainfall was determined and mapped. These maps should be used by Waller County to locate potential overtopped roads and impacted structures for various rainfall scenarios. Exhibits 14 through 20 shows the identified at risk infrastructure for each simulated rainfall scenario.

7.1.1 *Critical facilities*

A database of critical facilities within the watershed was developed to identify if any of these structures may be at flood risk during the simulated conditions. Critical facilities are community assets that provide services vital to community survival such as medical centers or water supply. The following categories were included as critical infrastructure within the database:

- Hospitals
- Fire Stations
- Police Stations
- Government or cultural buildings storing critical records
- Energy-producing facilities
- Water and wastewater treatment plants

The dataset was primarily sourced from open-source GIS libraries associated with Homeland Infrastructure Foundation Level Data and the Texas Education Agency. This data was then supplemented with local knowledge provided by the study team, county staff, and the public. Once complete, the database identified 17 critical facilities within the Spring Creek watershed in Waller County.

The critical facilities dataset was intersected with the inundation bounds associated with the rainfall depths to identify potential at-risk structures. Although critical facilities are present within the study area, zero of these were identified to be at risk from riverine flooding caused by Spring Creek watershed during any of the simulated events.

7.1.2 *Road crossings*

A similar analysis was performed for roadway crossings in Spring Creek tributaries through Waller County. Roadway flooding poses many threats to a community. Roadways becoming impassible due to flooding can also restrict residents' access to emergency medical care during emergencies.

Seven of the major roadways within the Spring Creek Watershed of Waller County were analyzed to determine the level of service that could serve as local evacuation routes during storm events. Terrain data was used to identify road heights and determine what depths would overtop them, and by how much. After evaluation, it was revealed that among the seven selected roadways, three crossings experienced overtopping in less than 50% ACE events, two crossings overtop during 20% ACE events, overtops during 10% ACE events, and merely one overtops during 4% ACE. The level of service associated with the crossings is summarized in Table 7-1.

Table 7-1. Spring Creek Tributary Crossings Level of Service.

Stream	Crossing	LOS
Threemile Creek	Kickapoo Road	20% ACE
	Macedonia	2% ACE
Brushy Creek	Bowler Road	<50% ACE
	Joseph Road	4% ACE
Walnut Creek	N Reids Prairie Road	<50% ACE
	FM1488	20% ACE
Birch Creek	FM1488	20% ACE

7.1.3 *Structures*

The number of structures potentially at risk for inundation from the Spring Creek during different simulated events was analyzed next. To account for the difference between the terrain elevation, and the finished floor elevations of structures, a 6-inch adjustment was made to the depths at the structures. Some structures, especially mobile homes and stilted structures may have finished floor elevations even higher than 6-inches above the ground. However, the flooding depths may still inhibit residents' ability to leave during a flooding event or otherwise damage possessions adjacent to the structures, so the adjustment was applied uniformly.

The occurrence of 24.2 in rainfall depth during 24-hours will significantly impact a greater number of residential (442) and commercial structures (160), whereas a 4.8 in of rainfall depth during 24-hours, though affecting fewer structures (19 and 15 residential and commercial structures, respectively), will still have both economic and social implications for Waller County and its residents. The number and types of structures identified as prone to flooding during the different simulated events are summarized in Table 7-2.

Table 7-2. Structures At-Risk.

24-hour Rainfall Depth (in)	Residential Structures At-Risk	Commercial Structures At-Risk
4.8	19	15
6.5	43	24
8.2	67	37
10.9	106	54
13.4	146	73
16.3	242	93
24.2	442	160

7.2 Public safety features

Being able to notify the public of imminent flood risk is extremely important during storm events. By having infrastructure in place to help County officials to assess flood risk and communicate that to residents, the risk of loss of life due to the hazards associated with flooding can be decreased. Informational infrastructure such as gages and flood warning signs and systems can provide live flood data to County officials to assist them in making the best flood response decisions. Systems such as emergency notifications, sirens, and public facing websites with live flood risk information can ensure that County officials can inform residents of their flood response decisions in a timely manner.

7.2.1 *Flood warning*

The primary focus of flood warning infrastructure is to transmit live rainfall, lake, stream, or river data for use by public and government officials to make informed flood response decisions. The information collected by gages can also be used to develop post-flood reports and perform engineering analysis to determine the probability flooding events at gaged locations.

Flood warning infrastructure is primarily based on the information provided by gages. Gages can record and transmit river or stream water surface elevations, flows, and/or precipitation data. These gages can be linked together through a flood warning system to provide comprehensive coverage for an entity, or part of regional systems that provide coverage throughout the United States.

Gages

The Harris County Flood Warning System provides lake, riverine, and precipitation data coverage in the greater Houston area. Due to its easily accessible public interface, this system is often leveraged by entities for live flood risk information used to inform flood response actions. The addition of gages along creeks that cause significant flooding in the County could help provide more complete flood risk coverage in the event of severe weather. One potential gage location has been identified and is summarized in Table 7-3. Further analysis would be needed to evaluate the locations for constructability and maintenance access.

Table 7-3. Potential Gage Locations in Waller County.

Gage Location	Critical Features
Brushy Creek and FM 1488	Along FM 1488 evacuation route

The addition of these gages, or others throughout the County, could increase the available live flood-risk data County officials could leverage during storm events and could be incorporated within the HCFWS.

8 Conclusion

The Spring Creek Flood Update Study, sponsored by Waller County and funded through the TWDB's FIF program, focused on provide more accurate flood risk data and mapping for four tributaries of Spring Creek within Waller County and identifying high flood risk areas and recommending projects to mitigate this risk, including non-structural recommendations, such as voluntary buyout program.

Existing conditions data was leveraged by updating previous hydrologic and hydraulic modeling to reflect 2018 HGAC lidar, 2018 HGAC land use, and Atlas 14 rainfall data. The hydrologic analysis was conducted within HEC-HMS (version 4.3) to generate flow hydrographs for subbasins to be applied to the updated existing hydraulic model, and the hydraulic modeling was performed using HEC-RAS (version 6.2.0) to represent current drainage patterns and to develop updated inundation mapping and flood risk assessment for the study area.

Existing condition results were compared to FEMA Flood Insurance Study flows and water surface elevations where possible. The updated inundation mapping was used to evaluate flood risk from the four studied tributaries of Spring Creek within Waller County. At-risk structures, crossings, and critical facilities were identified for several flow conditions and were shown in Exhibits 14 through 20.

The updated modeling was used to identify flood prone areas. The study evaluated four alternatives as discussed in Sections 6.1 through 6.5 to reduce structural and roadway flooding in the flood prone areas. The four alternatives are summarized below:

- Alternative PA1 involved selective clearing as a cost-effective and easily implementable solution, but water surface elevation reductions and structural flooding benefits were minimal. In addition, there are impacts would need to be mitigated, which would increase the total implementation cost. The alternative was not recommended.
- Alternative PA2 and PA3 consisted of bridge improvements that improved mobility for the residents in the neighborhood although structural flooding reduction was minimal. Both alternatives were recommended.
- Alternative PA4 involved the construction of a bypass channel and detention basin that resulted in the greatest structural flooding reduction but also at the highest cost of all alternatives. The combined solution will require further refinement, specifically related to addressed phasing and implementation challenges due to site constraints. The alternative was recommended.

The recommended alternatives results were tabulated and compared for further consideration. In addition, the recommended alternatives were vetted for conformance to Technical Guidelines for Regional Flood Planning Exhibit C including ensuring no negative impact. The alternatives were developed to be feasible for both funding and construction; however, as the alternatives are progressed to design, construction and permitting needs and considerations will need to be revisited and addressed.

The results of this study, including the flood risk modeling and mapping, are available to Waller County to provide them with a database of current flood risk within their communities and provide context and guidance to inform decisions regarding the mitigation of flood risk.

Immediate actions can be taken to begin the process of implementing the recommendations outlined within this study. While searching for and applying to funding opportunities to support the implementation of the recommended flood risk mitigation projects, short-term actions such as the initiation of a voluntary buyout program and the development of criteria updates can help ensure flood risk does not increase in the future.