Texas Water Development Board

P.O. Box 13231, 1700 N. Congress Ave.
Austin, TX 78711-3231, www.twdb.texas.gov
Phone (512) 463-7847, Fax (512) 475-2053

June 12, 2015

The Honorable Judge Beckendorff
Waller County Judge
836 Austin Street, Suite 203
Hempstead, Texas 77445

RE: Flood Protection Planning Grant Contract between the Texas Water Development Board (TWDB) and Waller County (County); TWDB Contract No.1248321467, Draft Report Comments for Upper Barker Watershed Flood Protection Planning Study

Dear Judge Beckendorff:

Staff members of the TWDB have completed a review of the draft report prepared under the above-referenced contract and have no comments on the report. As stated in the TWDB contract, the County will include a copy of this letter in the Final Report.

The TWDB looks forward to receiving one (1) electronic copy of the entire Final Report in Portable Document Format (PDF) and six (6) bound double-sided copies. **Please further note, that in compliance with Texas Administrative Code Chapters 206 and 213 (related to Accessibility and Usability of State Web Sites), the digital copy of the final report must comply with the requirements and standards specified in statute. For more information, visit http://www.sos.state.tx.us/tac/index.shtml.** If you have any questions on accessibility, please contact David Carter with the Contract Administration Division at (512) 936-6079 or David.Carter@twdb.texas.gov

The County shall also submit one (1) electronic copy of any computer programs or models, and, if applicable, an operations manual developed under the terms of this Contract.

If you have any questions concerning the contract, please contact Ivan Ortiz, the TWDB's designated Contract Manager for this project at (512) 463-8184.

Sincerely,

Edna Jackson
Deputy Executive Administrator
Operations & Administration

c: Ortiz, TWDB

Upper Barker Watershed
Flood Protection Planning Study
Final Report

TWDB Contract No. 1248321467

Prepared for:
Texas Water Development Board

June 26, 2015

STATE OF TEXAS
SAMUEL A. HINOJOSA
103567
LICENSED
PROFESSIONAL ENGINEER
6/26/2015

Prepared By:
Halff Associates Inc.

2015 JUN 30 PM 1:44

For Waller County, Brookshire-Katy Drainage District
and the City of Katy

This document is for planning purposes only and is not intended for construction, bidding, or issuance of permits. It was prepared by or under the supervision of:

Samuel A. Hinojosa	103567	06/26/2015
Type or Print Name	PE#	Date

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EXECUTIVE SUMMARY

The Upper Barker Watershed, located in Waller County, Fort Bend County and Harris County has been the source of frequent flooding. As a result of the flooding, local officials applied for a Flood Protection Planning Grant to aid in the creation of new hydrologic and hydraulic modeling as well as flood damage reduction alternative analyses to aid in planning efforts.

Hydrologic and hydraulic modeling was performed on the Upper Barker Watershed in Waller County, Fort Bend County and Harris County. The creeks included in this study are Cane Island Branch, Snake Creek, and Willow Fork Buffalo Bayou. Detailed LiDAR elevation data as well as cross-section and bridge/culvert field surveys were used to enhance the accuracy of the models. The modeling resulted in updated and more accurate flows and water surface elevations for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year events. The resulting hydraulic data was then used to analyze various flood reduction alternatives for the City of Katy, Brookshire Katy Drainage District, and Waller County.

Several flood reduction alternatives were analyzed during the flood damage reduction analysis portion of the study. Alternatives were evaluated for each creek. A comprehensive alternative was also evaluated that combined the individual alternatives to help reduce detention and channel improvements needed. Each alternative was evaluated by cost and select alternatives were evaluated for producing a benefit-to-cost ratio greater than one. Alternatives were recommended for Waller County and the City of Katy for each watershed that consist of upstream detention along with culvert and channel improvements.

1.0 Introduction and Background

The Upper Barker Watershed, located in the southern portion of Waller County, western Harris County and northern part of Fort Bend County, has an area of 56 square miles. The study area limits and watershed is shown on **Figure 1**. The planning study watershed consists of the upper portion of the Barker Reservoir Watershed which has a drainage area of 129 square miles. The Upper Barker Watershed is split between Waller, Harris and Fort Bend Counties with most of the flow through the City of Katy originating in Waller County. The major creeks in this study are Cane Island Branch, Snake Creek, and Willow Fork Buffalo Bayou (Willow Fork).

The terrain through most of the study area is characterized by undulating plains with a timber belt of hardwoods along a majority of the channels. Because the majority of the terrain is characterized as being relatively flat, it is not conducive to effective drainage. The land use in Waller and Fort Bend County that falls within the Upper Barker Reservoir Watershed consists of pasture, agriculture, range, rural subdivisions, and woodland with more urban/residential land use to the east. The elevations vary from 120 feet above sea level (NAVD 88) at the crossing of Katy-Flewellen Road to about 190 feet above sea level in the North West area of this study. Annual rainfall in the watershed is on average 42 inches per year.

Significant floods have occurred in Waller County in 1929, 1935, 1960, 1966, 1979, 1981, 1983, 1984, 1994, and 1998. Most recently, the City of Waller experienced flooding from a rainfall event that occurred on July 2012. At the end of April 2009, a large storm event occurred over the Barker Watershed dropping 8 to 11 inches of rainfall and flooding over 20 homes. In October 1998, a large storm event occurred over the study area dropping 12 inches of rain overnight.[1] Photos of this storm event are shown in **Figure 2**. The flood hazard sources include local stream flooding due to inadequate stream capacity and restrictions in the channels including undersized crossings. Local officials in the study area recognize that the restrictions within the creek channels potentially cause backwater resulting in additional flooding. These flood waters, in-turn, pose a major risk to both life and property in the City of Katy and Waller County.

As a result of frequent flooding and the potential for increased development in the area, Waller County took a pro-active lead in applying for a Flood Protection Planning Grant from the Texas Water Development Board (TWDB), which was awarded in 2010. Waller County teamed with the Brookshire-Katy Drainage District (BKDD) and the City of Katy to assess the local drainage problems and to evaluate the overall flooding problems from a regional perspective. A sub-committee of representatives from Waller County, BKDD, City of Katy, Fort Bend County, and Harris County met throughout the study to discuss the approach, results, and public outreach. To facilitate regional input into the planning process, three public meetings were held within the Upper Barker watershed region. All three meetings were held at the Merrell Center on May 9, 2013, May 15, 2014, and February 26, 2015. A copy of the public notices can be seen in **Figure 3**. These public meetings served to inform the public about the planning study and to gather information that could be used to enhance and confirm the study results and conclusions. This study has resulted in new planning and regulatory information for use in floodplain management as well as flood reduction alternative analyses for the BKDD, City of Katy, and Waller County.

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[1] CNN.com. 1998. Rescue Workers Help Stranded Texas Flood Victims. [Online] Available at: http://www.cnn.com/US/9810/18/texas.storms.02/. [Accessed 13 February 15].

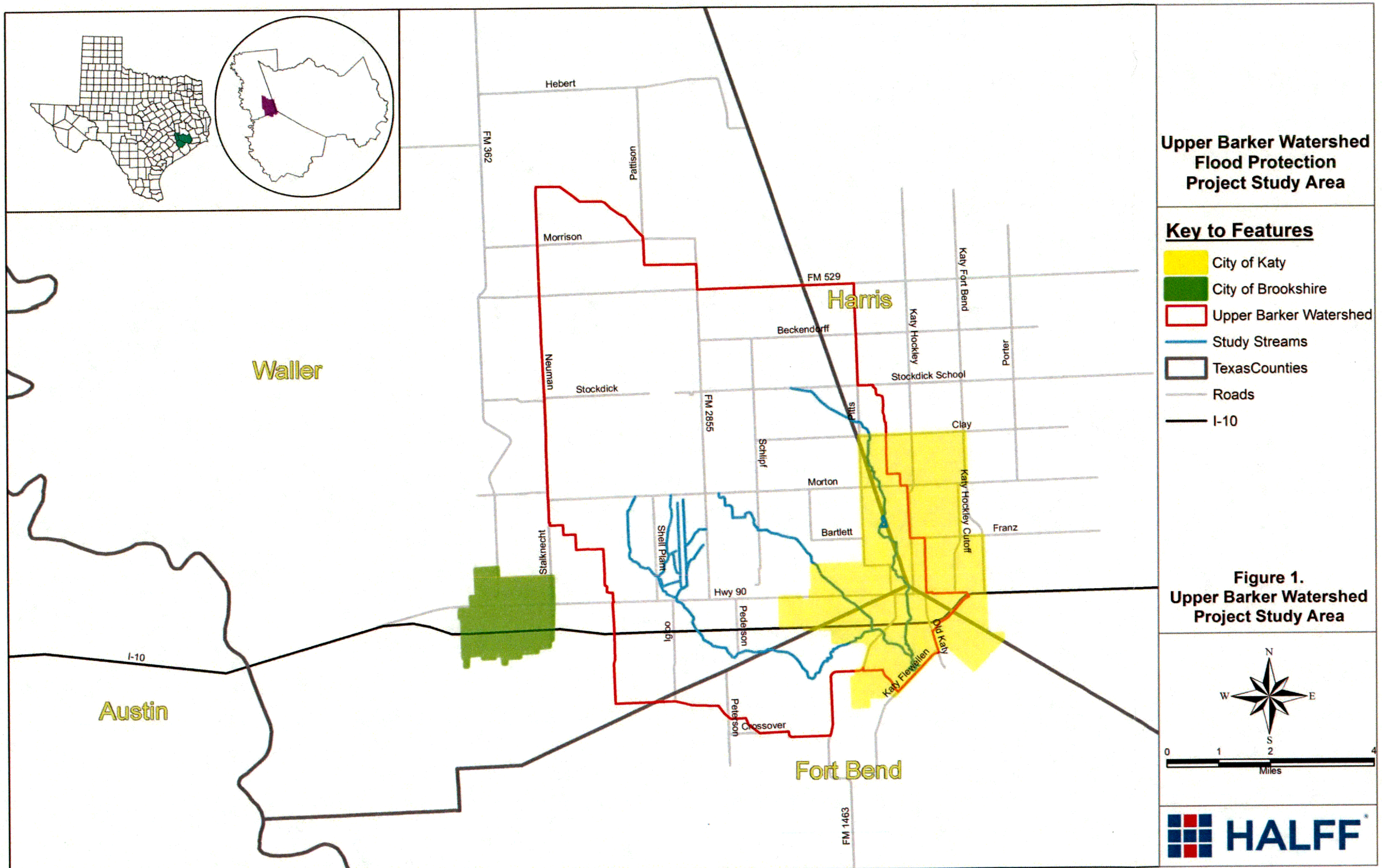

Figure 1.
Upper Barker Watershed
Project Study Area

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Figure 2 - Upper Barker Watershed Flooding Photos (October 1998 by BKDD)

This report presents the results of hydrologic, hydraulic, and alternative analyses of the Upper Barker Watershed. Halff Associates, Inc. (Halff) was responsible for existing conditions hydrologic and hydraulic models for Upper Barker in Waller County. Halff also performed the flood damage reduction alternative analysis for the watershed in Waller County. Items discussed in this report include:

- Hydrologic Analysis
- Hydraulic Analysis
- Existing Conditions Results
- Flood Damage Reduction Alternative Analysis
- Alternative Recommendation

NOTICE TO PUBLIC

The City of Katy, Brookshire-Katy Drainage District, and Waller County Announce a Public Meeting for the Upper Barker Watershed Flood Protection Planning Study

The Public Meeting will be held in the KISD Boardroom from 5:30 PM to 7:00 PM on Thursday, May 9, 2013, at the Merrell Center, 6301 South Stadium Lane, Katy, Texas. The purpose of this meeting will be to update the various communities on the overall status of this project including the purpose, geographic area, and schedule. The public is invited to attend and provide feedback needed to enhance the overall quality of this study. For more information, contact Orval Rhoads, PE (Waller County) at (979) 826-7670 or o.rhoads@wallercounty.us.

NOTICE TO PUBLIC

The City of Katy, Brookshire-Katy Drainage District, and Waller County Announce a Public Meeting for the Upper Barker Watershed Flood Protection Planning Study

The Public Meeting will be held in the KISD Boardroom from 5:30 PM to 7:00 PM on Thursday, May 15, 2014, at the Merrell Center, 6301 South Stadium Lane, Katy, Texas. The purpose of this meeting will be to update the various communities on the overall status of this project including the purpose, geographic area, and schedule. The public is invited to attend and provide feedback needed to enhance the overall quality of this study. For more information, contact Orval Rhoads, PE (Waller County) at (979) 826-7670 or o.rhoads@wallercounty.us.

NOTICE TO PUBLIC

The City of Katy, Brookshire-Katy Drainage District, and Waller County Announce a Public Meeting for the Upper Barker Watershed Flood Protection Planning Study

The Public Meeting will be held in the KISD Boardroom from 5:45 PM to 7:00 PM on Thursday, February 26, 2015, at the Merrell Center, 6301 South Stadium Lane, Katy, Texas. The purpose of this meeting will be to update the various communities on the overall status of this project including the purpose, geographic area, and schedule. The public is invited to attend and provide feedback needed to enhance the overall quality of this study. For more information, contact Orval Rhoads, PE (Waller County) at (979) 826-7670 or o.rhoads@wallercounty.us.

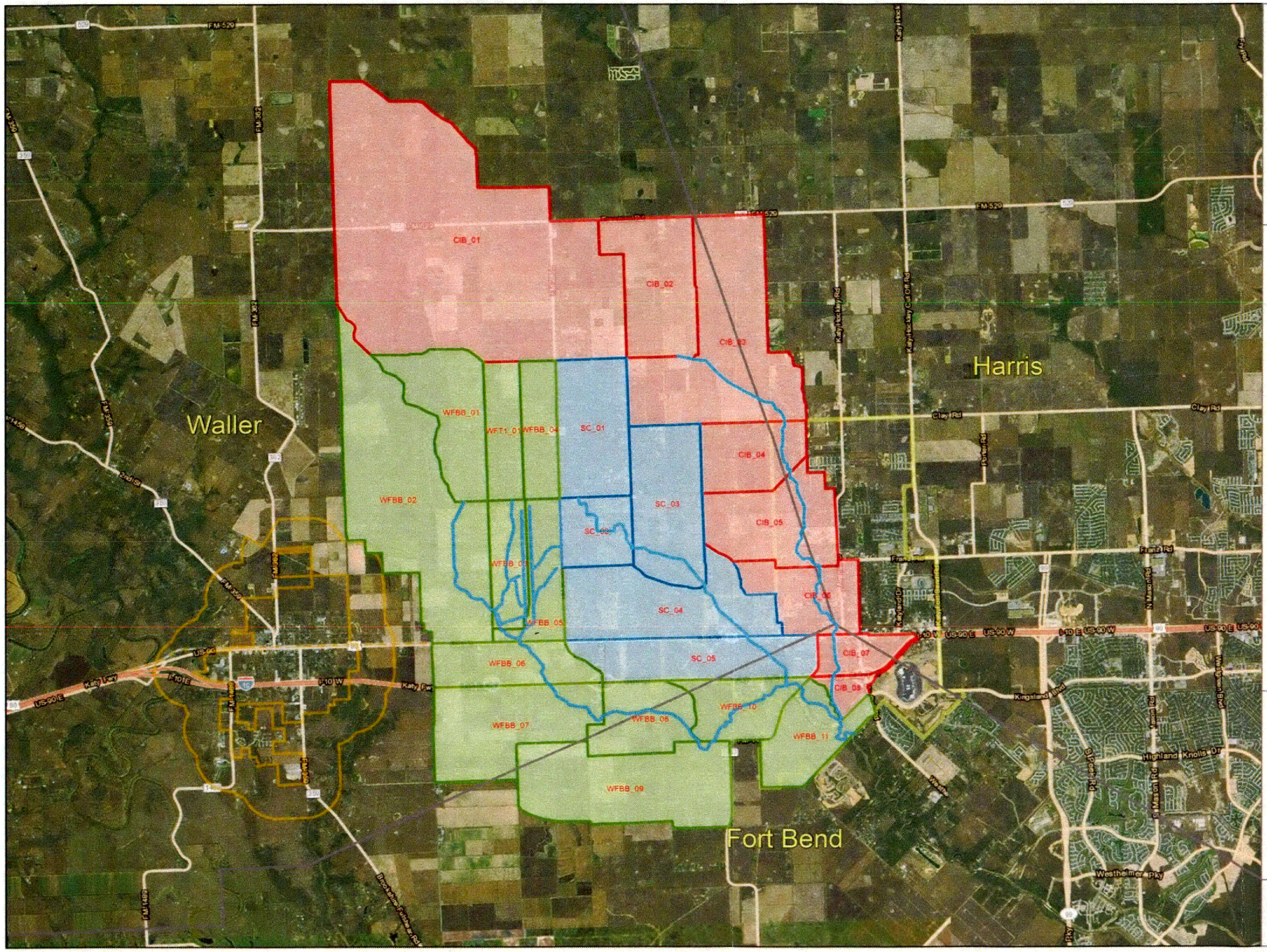
Figure 3: Copies of Notices Posted for the Public Meetings

2.0 Watersheds

The Upper Barker Reservoir Watershed was delineated as part of the Tropical Storm Allison Recovery Project (TSARP) by Harris County Flood Control District (HCFCD) using the best available LiDAR at that time. The TSARP delineation was then compared to the latest 2008 Houston Galveston Area Council (HGAC) LiDAR and adjusted to better match existing drainage networks. The study area was delineated from the downstream limits of study at Katy-Flewellen Road. Previous watershed delineations of the study area from BKDD and Fort Bend County were also considered. New HGAC 1 meter LiDAR data (2008) with a vertical Root Mean Squared Error (RMSE) of 0.22 feet was used. A total of 25 sub-basins were delineated from the headwaters upstream FM 529 to the limit of study. **Figure 4** illustrates the overall watershed delineation for the Upper Barker Watershed along with each sub-basin. **Table 1** is a summary of stream names and drainage areas for each sub-basin.

Table 1: Sub-basin Names and Areas

Sub-Basin	Stream Name	Drainage Area (Acres)	Drainage Area (Square Miles)
CIB_01	Cane Island	7354	11.49
CIB_02	Cane Island	1402	2.19
CIB_03	Cane Island	2829	4.42
CIB_04	Cane Island	877	1.37
CIB_05	Cane Island	1350	2.11
CIB_06	Cane Island	902	1.41
CIB_07	Cane Island	426	0.67
CIB_08	Cane Island	215	0.34
SC_01	Snake Creek	1274	1.99
SC_02	Snake Creek	640	1.00
SC_03	Snake Creek	1453	2.27
SC_04	Snake Creek	1774	2.77
SC_05	Snake Creek	1282	2.00
WFBB_01	Willow Fork	1202	1.88
WFBB_02	Willow Fork	3457	5.40
WFBB_03	Willow Fork	614	0.96
WFBB_04	Willow Fork	635	0.99
WFBB_05	Willow Fork	706	1.10
WFBB_06	Willow Fork	853	1.33
WFBB_07	Willow Fork	1630	2.55
WFBB_08	Willow Fork	864	1.35
WFBB_09	Willow Fork	2086	3.26
WFBB_10	Willow Fork	765	1.20
WFBB_11	Willow Fork	870	1.36
WFT_01	Willow Fork	651	1.02



Upper Barker Watershed Flood Protection Project Study Area

Key to Features

- Study Streams
- TexasCounties
- Cane Island
- Snake Creek
- Willow Fork
- Katy City Limits
- Brookshire City Limits

Figure 4. Upper Barker Watershed Sub-Basins

N W E S

0 0.5 1 2 3 Miles

HALFF

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3.0 Hydrologic Analysis

A detailed hydrologic analysis was performed on the Upper Barker watershed with the goal of providing a validated base conditions model for use in developing flood damage reduction alternatives, and helping to quantify the impacts of these alternatives to the surrounding area. The hydrologic analysis was conducted with the aid of the US Army Corps of Engineers HEC-HMS software, version 3.3, and was used to develop peak flows and flow hydrographs for existing land use conditions for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year events. Effective hydrologic models were obtained from HCFCD. Models were also obtained from Fort Bend County, BKDD, and Waller County and were then updated and enhanced with more detail to reflect existing conditions. Further details of the hydrologic analysis for the Upper Barker Watershed can be found in Appendix A. A large drainage area map is shown on **Figure D1** in Appendix D.

4.0 Hydraulic Analysis

Hydraulic analyses were performed for Upper Barker Watershed from the headwaters upstream of Morton Road to the limit of study at the Katy-Flewellen Road for a total length of approximately 19 river miles using HEC-RAS software, version 4.1. Model cross-section layouts were kept as close as possible to the effective sections where applicable and new cross sections were created where needed. Field surveys were collected at the bridge and culvert crossings and applied to the hydraulic models. Field survey locations are shown on **Figure D2** in Appendix D. The non-surveyed cross sections were updated to reflect the 2008 LiDAR. The hydraulic analysis was conducted to develop existing conditions peak stages for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year frequency events. Further details of the field survey and hydraulic analysis for the Upper Barker watershed can be found in Appendix A.

5.0 Results of Hydrologic and Hydraulic Analyses

The existing conditions hydrologic and hydraulic analyses resulted in validated flood hazard information that is useful for planning and regulatory purposes. Specifically, the analyses resulted in base flood elevations for the 2-, 5-, 10-, 25-, 50-, 100-, 250- and 500-year rainfall events and a floodplain for the 100-year event throughout the Upper Barker watershed within Waller, Fort Bend, and Harris Counties. The resulting 100-year floodplain delineation is shown on **Figure D3** included in Appendix D. The water surface elevation profiles for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year frequency events are provided in Appendix A.

Although this is new and, in some places, detailed information, there are sources of uncertainty in the hydrologic and hydraulic models that could affect the flows and stages calculated. One source of uncertainty is areas of shallow flooding and diversion of flows that appear to occur during higher flood events. It is apparent that these areas will provide significant storage and attenuation of flows during larger events, but it is often challenging to sufficiently incorporate these areas into a one dimensional model. An attempt was made to account for one such overflow that occurs to Cane Island Branch from the Addicks and Cypress watersheds. This overflow is represented in the hydrologic model for Upper Barker as a gage. There is also sub-basin interflow between Willow Fork Buffalo Bayou, Snake Creek, and Cane Island Branch. An attempt was made to account for the overflow between these basins by using diversions. The overflow diversions are further discussed in Appendix A.

Another source of uncertainty is the lack of a flow gauge with data to calibrate the models. While a full calibration was not possible, the models were compared to anecdotal flooding information provided by the County and BKDD. For example, flooding has occurred in large storm events at FM 2855 and US-90 (Willow Fork Creek), Schlipf Road (Snake Creek) and Morton Road and Pitts Road (Cane Island Branch). Photos of the October 1998 event are shown in **Figure 2**. The hydraulic analysis confirmed that these locations are subject to flooding even though they are in the upper portions of their respective basins.

6.0 Alternatives Analysis – Cane Island Branch Alternatives

Cane Island Branch has been a source of flooding inside the City of Katy. The City became a participant in the Upper Barker Creek Watershed Flood Protection Planning Study to determine alternatives to reduce potential flooding damages along the creek. A baseline alternative analysis was performed using hydraulic model results and impacts to existing structures. Details of the alternatives analyses are provided in Appendix B.

A total of four alternatives were evaluated for Cane Island Branch. These alternatives evaluated reducing the existing 100-year floodplain. The first two alternatives and the fourth do not increase the flows downstream nor result in adverse floodplain impacts. The third alternative results in a slight increase in downstream flow and water surface elevation. A non-structural flood damage reduction alternative considered was buying affected houses which are in the existing floodplain. The total value of the habitable structures is $37,980,000. However, it appears that the majority of the structures are generally above the base flood elevation as the flood depths in the overbanks are relatively shallow. No repetitive loss structures were located in the study area. Therefore, the focus of the alternatives was mainly on structural alternatives in this analysis.

The first alternative included placing detention upstream of Pitts Road in order to reduce the existing 100-year flows at Morton Road to that of a 25-year event. There are 99 habitable structures upstream of Morton Road subject to inundation since the floodplain is fairly at its widest in the City. The amount of detention required upstream of Pitts Road is approximately 2,800 ac-ft. This alternative potentially removes 147 habitable structures and 476 acres from the floodplain upstream and downstream of Morton Road. Though the amount of detention needed to reduce the flow to a 25-year storm was large, several sites upstream of Pitts Road may allow the detention to be distributed throughout the upper basin, i.e. upstream of Pitts Road. A 100-year floodplain comparison between the existing and improvement conditions with affected structures is shown in **Figure B1** in Appendix B.

The second alternative involved channelizing the existing stream from Schlipf Road to Franz Road while mitigating any increase in flows with 2,000 ac-ft of detention upstream of Pitts Road. The channel would be improved to carry a 50-year storm capacity. The amount of Right-of-Way required ranges from 150-ft to 240-ft to accommodate the improved channel. The Right-of-Way includes the proposed channel bottom width, side slopes of 3:1 and 30 feet for maintenance access on either side of the channel. The existing channel has a top width of approximately 100-

ft. The floodplain throughout the basin is reduced to be inside the improved channel to Franz Road. This alternative potentially removes 171 habitable structures and 1,177 acres from the floodplain. A 100-year floodplain comparison between the existing and improvement conditions with affected structures is shown in **Figure B3** in Appendix B.

The third alternative for Cane Island Branch involved clearing out the channel near the intersection with Morton Road, adding a weir at the upstream end of the detention facility upstream of Morton Road, and raising the downstream weir. This would lower the water surface elevations by approximately a half a foot upstream of Morton Road remove 43 habitable structures and 32 acres from the floodplain. However, due to hydrologic timing, an increase in flow of 1.6% (45 cfs) and water surface elevation of 0.12 feet would be expected at US-90. The downstream impact is minor and does not appear to place additional habitable structures in the floodplain. A 100-year floodplain comparison between the existing and improvement conditions with affected structures is shown in **Figure B5** in Appendix B.

The fourth alternative for Cane Island Branch involved improving road crossings in order to achieve a 100-year level of protection. Several of the current road crossings do not have a 100-year level of protection and are potentially overtopped by smaller and more frequent storm events. These roads include Stockdick Road, 1st Street, Franz Road, Morton Road, Clay Road, and Pitts Road. This alternative did not reduce flooding risk to the adjacent properties or habitable structures. The flood risk was reduced by elevating the road and placing culverts underneath to pass the overflow. The flow balance resulted in significant culvert needs to pass the 100-year storm event. A table of culvert needs and costs is shown in **Table B5**.

7.0 Alternatives Analysis – Snake Creek Alternatives

Snake Creek contributes to a wide floodplain along the center of the Upper Barker Watershed located in Waller County. Though the existing floodplain occurs in mostly undeveloped basins, this area has high potential for future development. Two alternatives were analyzed to determine the best alternative to reduce potential flooding hazards. Details of the alternatives analyses are provided in Appendix B.

The first alternative included a large detention pond located upstream of Schlipf Road. The purpose of the pond was to lower flows through the existing Snake Creek channel to a 25-year in order to reduce the floodplain. The amount of detention needed upstream of Schlipf Road is approximately 605 ac-ft. This alternative potentially removes 313 acres of developable property from the floodplain. Though the amount of detention needed to reduce the flow to a 25-year storm is large, potential contributions made by other entities, such as future developers, may assist in construction of the detention facility. A 100-year floodplain comparison between the existing and improvement conditions is shown in **Figure B7** in Appendix B.

The second alternative involved channelizing the existing stream from Schlipf Road to US-90 while mitigating any increase in flows with 356 ac-ft detention upstream of Schlipf Road. The channel would be improved to carry a 25-year storm capacity from Schlipf Road to the confluence with Willow Fork. The amount of Right-of-Way required ranges from 130-ft to 160-ft to accommodate the improved channel. The Right-of-Way includes the proposed channel bottom width, side slopes of 3:1 and 30 feet for maintenance access on either side of the channel.

The existing channel has an average top width of 50-ft. The floodplain throughout the basin is reduced to be inside the improved channel banks and potentially removes 684 acres of developable property from the floodplain. A 100-year floodplain comparison between the existing and improvement conditions is shown in **Figure B9** in Appendix B.

8.0 Alternatives Analysis – Willow Fork Alternatives

Willow Fork contributes to a wide floodplain in Waller County. Though the existing floodplain occurs in mostly undeveloped basins, this area has high potential for future development. Two alternatives were analyzed to determine the best alternative to reduce potential flooding hazards. Details of the alternatives analyses are provided in Appendix B.

The first alternative included a large detention facility located upstream of Morton Road. Waller County expressed a potential interest in making this site a regional detention pond as the City of Houston Airport System is the current owner of large parcels of land. The purpose of the detention facility was to lower flows through the existing Willow Fork channel to a 25-year storm event. The amount of detention required upstream of Morton Road is approximately 1,200 ac-ft. This alternative potentially removes 855 acres from the floodplain in Waller County and subsequently Fort Bend County. Though the amount of detention needed to reduce the flow to a 25-year storm was large, potential contributions made by other entities, such as Fort Bend County and future developers, may assist in construction of the detention facility. This alternative also consists of routing overflow from the Upper Cane Island basins down to the detention pond through a series of drainage ditches. A 100-year floodplain comparison between the existing and improvement conditions is shown in **Figure B11** in Appendix B.

The second alternative involved channelizing the existing stream from Morton Road to the Railroad Crossing upstream of Highway 90 while mitigating any increase in flows with 1,800 ac-ft of detention upstream of Morton Road. The channel would be improved to carry a 25-year storm capacity from Morton Road to the Railroad Crossing upstream of US-90. Approximately 220 feet of Right-of-Way would be required to accommodate the improved channel. The existing channel has an average top width of approximately 50-ft. The floodplain throughout the basin is reduced to be inside the improved channel banks and potentially removes 1526 acres of developable property from the floodplain. Though the amount of detention needed to reduce the flow to a 25-year storm was large, potential contributions made by other entities, such as Fort Bend County and future developers, may assist in construction of the detention facility. A 100-year floodplain comparison between the existing and improvement conditions is shown in **Figure B13** in Appendix B.

9.0 Alternatives Analysis – Comprehensive Alternative

The previous alternatives discussed in the sections above are independent. This alternative focused on a comprehensive solution to reduce the floodplain throughout the entire basin located in Waller County. Instead of allowing basin overflow, each basin was considered "isolated" and overflows removed. Also, this alternative assumed the upper basin of Cane Island Branch was transferred into the Willow Fork Watershed. This approach is in-line with the ongoing master drainage plan by the BKDD. The redirecting of the overflow from the upper basin of Cane

Island Branch to the Willow Fork potentially reduces the flows by 35% in Cane Island Branch at Pitts Road. As a result of the diversion, no other improvements are proposed in Cane Island Branch.

The Snake Creek Basin was also restricted from allowing overflow into Cane Island Branch. This involves channelizing the existing stream from Schlipf Road to US-90 while mitigating any increase in flows with 620 ac-ft of detention upstream of Schlipf Road as well as 130 ac-ft downstream. The channel would be improved to carry a 25-year storm capacity from Schlipf Road to the confluence with Willow Fork. Approximately 160 feet of Right-of-Way would be required to accommodate the improved channel and contain the floodplain within the banks. The existing channel has an average top width of 50-ft. The floodplain throughout the basin is reduced to be inside the improved channel banks.

In order to accommodate the redirected flow from the upper portion of Cane Island Branch, Willow Fork will need to be expanded from Morton Road to the Railroad Crossing upstream of US-90 while mitigating any increase in flows with 2,800 ac-ft of detention upstream of Morton Road. The channel would be improved to carry a 25-year storm capacity from Morton Road to the Railroad Crossing upstream of Highway 90. Approximately 220 feet of Right-of-Way would be required to accommodate the improved channel and contain the floodplain within the banks. The existing channel has an average top width of 50-ft. The floodplain is reduced to be inside the improved channel banks.

This comprehensive alternative for Cane Island Branch, Snake Creek, and Willow Fork potentially removes 141 habitable structures and 2,616 acres from the floodplain throughout the Upper Barker watershed. The isolation of the drainage basins and the prevention of overflow is in line with the ongoing master drainage plan by the BKDD. A 100-year floodplain comparison between the existing and improvement conditions for this comprehensive alternative is shown in **Figure B15** in Appendix B.

10.0 Alternatives Summary

Alternatives that reduce existing flood damages are summarized in **Table 2**. The summary includes cost estimates, number of structures removed from the 100-year floodplain and ratio of structure value to cost. Land that is removed from the floodplain is also included. Cost benefit ratios were not determined for Snake Creek and Willow Fork because these basins in Waller County are primarily industrial and do not contain habitable structures.

Only Alternative 3 for Cane Island Branch scored well with a benefit cost ratio over 1.0. However, this project results in slight increases in flow and water surface elevation downstream of the project area. While the increase is minimal, this project is not viable due to the slight increase. However, further study with a detailed unsteady hydraulic analysis could show that there are no downstream impacts.

Table 2: Alternative summary with benefit ratios

Basin	Project	Cost	Benefit Ratio*	Number of Homes Removed from Floodplain	Acres Removed from Floodplain
Cane Island Branch	Alternative 1	$72.8 M	0.01	147	476
Cane Island Branch	Alternative 2	$65.3 M	0.03	174	1,177
Cane Island Branch	Alternative 3	$148,000	3.60	43	32
Cane Island Branch	Alternative 4	$4.81 M	-	0	0
Snake Creek	Alternative 1	$13.7 M	-	-	313
Snake Creek	Alternative 2	$11.1 M	-	-	684
Willow Fork	Alternative 1	$28.9 M	-	-	855
Willow Fork	Alternative 2	$53.4 M	-	-	1,476
Upper Barker	Comprehensive Alternative	$108.3 M	0.00	141	2,616

11.0 Future Conditions

Future conditions in the Upper Barker Watershed were considered and evaluated as part of the Comprehensive Improvement Alternative discussed in Section 9. The land use in the Upper Barker Reservoir Watershed generally consists of pasture, agriculture, range, rural subdivisions, and woodland. Therefore, 80% of the basin in Waller County was considered to be developed to reflect future land use conditions in order to evaluate the hydrologic impact. In general, the flows increased in the watershed by 85% assuming no local site detention requirements. Regional detention options in lieu of site detention resulted in nearly doubling the size of the proposed detention alternatives which address existing conditions. Therefore, the proposed detention alternatives can be used to either reduce the existing conditions flood risk or to mitigate the future conditions development in lieu of site detention. If the proposed detention facilities are to be used to address both existing and future conditions, the proposed detention will need to be doubled.

12.0 Phasing and Recommendations

The Comprehensive Alternative described in Section 9 is recommended for consideration. The comprehensive solution provides significant benefit in reducing flood risk to the Upper Barker Watershed especially along Snake Creek and Willow Fork. Cane Island Branch will also see a reduction in the 100-year flood risk as a result of this alternative. The total cost of this alternative is $101.9 million and removes 141 homes from the floodplain as well as 2,616 acres of land. The Comprehensive Alternative provides benefit to Waller, Harris, and Fort Bend Counties. These counties could work together to develop a funding plan to implement this project. The amount of land that is removed from the floodplain from these projects could result in no floodplain mitigation requirements for development near the creeks.

Should the County pursue using the proposed detention in the Comprehensive Alternative to mitigate future conditions and reduce the detention requirements in the Snake Creek and Willow Fork Basins, the proposed detention would need to be doubled. It is recommended that the County and stakeholders consider using the proposed detention for existing conditions and continue to require site detention for future development.

The existing conditions floodplain mapping developed in the study should be considered for adoption by the County. This information can be used for future and current development in the Cane Island, Snake Creek, and Willow Fork basins. The County can use the results of this study to set Base Flood Elevations along Willow Fork Buffalo Bayou which is currently designated as a Zone A.

Finally, the County should consider establishing criteria to regulate discharges from agricultural areas that are to be developed. Rice fields that are surrounded by levees currently detain runoff during storm events. It is recommended that the detained runoff be considered versus the non-detained runoff. This approach may result in higher detention rates for these areas. However, it will likely mitigate any unforeseen downstream impacts that may result from releasing too much flow.

Appendix A

APPENDIX A: Hydrologic and Hydraulic Analysis of the Upper Barker Creek Watershed

A.1 Data Collection and Field Survey

Data was collected from the stakeholders to be used in the development of the hydrologic and hydraulic analysis. The data collected included construction drawings of the large ditch and roadways, site development plans and reports, flood photos, reports and models. Models obtained from Harris County, Fort Bend County, BKDD, and Waller County were then updated and enhanced with more detail to reflect existing conditions.

Topographic data was obtained from both TNRIS and HGAC. The TNRIS LiDAR data set was dated 2011 and the H-GAC LiDAR data set was dated 2008. The TNRIS data was used for watershed delineation and the H-GAC topographic data was used for hydraulics and riverine modeling. These data sets were merged to develop a comprehensive terrain across the study area. The LiDAR data (2008 HGAC 67 cm horizontal RMSE, 9.25 cm vertical RMSE) is based on the NAD 83 horizontal datum, and the NAVD 88 vertical datum. All mapping and hydraulic modeling in this study uses this datum.

Field survey was collected for all the bridges/culverts/crossings in the study area. Field surveys were also obtained of the spillways of five detention facilities in the study area. The survey is referenced to the Texas Coordinate System of 1983, South Central Zone. The elevations were referenced to Tropical Storm Allison Recovery Project Reference Mark (RM) Numbers 110230, 190050, 190105 and National Geodetic Survey (NGS) Benchmark Numbers AW0130, AW5500, and AW5501, North American Vertical Datum of 1988 (NAVD88) 2001 Adjustment and were determined as a result of an on-the-ground survey completed on January 29, 2013. The National Geodetic Survey (NGS) Benchmarks are published with NAVD88, 1991 Adjusted elevations as First Order, Class I. A constant value of 0.25 feet was subtracted from the published elevations to match the TSARP NAVD88, 2001 Adjustment. **Figure D2** in Appendix D shows the survey locations.

A.2 Hydrologic Analysis

A hydrologic analysis was performed in the Upper Barker Creek watershed utilizing the HEC-HMS software, version 3.3. The purpose of this hydrologic analysis was to develop peak discharges for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year frequency rainfall events. The hydrologic model required the selection of various parameters. These parameters are as follows:

1. Precipitation Parameters
2. Rainfall Runoff Loss Parameters
3. Unit Hydrograph Parameters
4. Flood Routing Parameters

Each of these sets of parameters is discussed in further detail below.

A.3 Precipitation

The Alternating Block method was used to develop frequency rainfall patterns for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year rainfall events. According to the HCFCD Hydrology and Hydraulics Guidance Manual, USGS rainfall depth-duration frequency relationships were determined for three hydrologic regions across Harris County. It was determined that the Upper Barker Creek watershed could use the same USGS rainfall totals as Hydrologic Region 1 in the Harris County map below (**Figure A1**). These rainfall totals used in the HMS model also matched the data used in the previous detailed study.

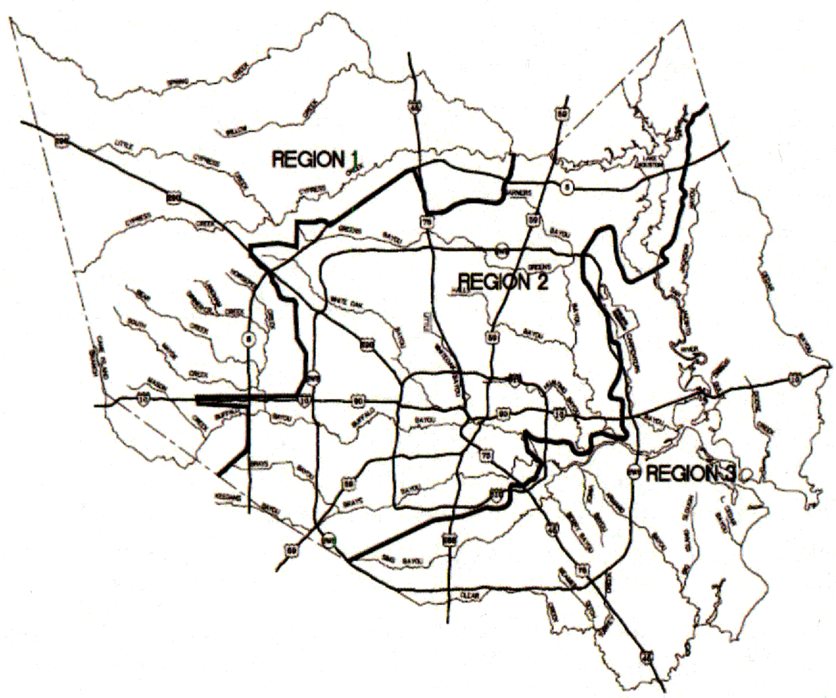

Figure A1: Harris County Hydrologic Region Map

Table A1 provides rainfall totals for various frequencies and durations for Hydrologic Region 1. All rainfall amounts have been rounded to the nearest 0.1 inch.

Table A1: Frequency Rainfall Depths for Hydrologic Region 1

Duration	Duration (hours)	Recurrence Interval (years)							
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
		Depth (inches)							
5 min	**0.08**	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.5
15 min	**0.25**	1.1	1.4	1.5	1.8	2.0	2.2	2.5	2.7
30 min	**0.50**	1.4	1.8	2.1	2.4	2.7	3.0	3.5	3.9
60 min	**1.00**	1.9	2.5	2.8	3.4	3.8	4.2	4.9	5.5
2 hr	**2.00**	2.2	3.0	3.5	4.2	4.9	5.5	6.6	7.5
3 hr	**3.00**	2.5	3.3	3.9	4.8	5.6	6.5	7.8	9.0
6 hr	**6.00**	2.9	4.0	4.9	6.1	7.2	8.5	10.4	12.2
12 hr	**12.00**	3.4	4.8	5.9	7.4	8.7	10.2	12.6	14.7
24 hr	**24.00**	4.1	5.8	7.1	9.0	10.6	12.4	15.2	17.7

A.4 Rainfall-Runoff Losses

All rainfall-runoff losses were computed using the Green and Ampt loss method according to the HCFCD Hydrology and Hydraulics Guidance Manual. According to the NRCS, the soils in the Upper Barker Watershed primarily consist of Katy fine sandy loam, 0 to 1 percent slopes. The following values for the Green and Ampt method taken from the effective hydrology model were used in the updated HEC-HMS model to provide a reasonable and adequate replacement for the previously used Exponential Loss function parameters.

Initial Loss =	0.262	inches
Volume Moisture Deficit =	0.731	
Wetting Front Suction =	6.182	inches
Hydraulic Conductivity =	0.062	in/hr

A.5 Unit Hydrograph Method

The Clark unit hydrograph method was used to develop the hydrographs and corresponding peak discharges for each sub-basin. The Clark Time of Concentration (Tc) and Storage Coefficient (R) for each sub-basin were calculated using formulas presented in the HCFCD *Hydrology & Hydraulics Guidance Manual.*[2] The methodology used by HCFCD was adopted for this study since the basin primarily drains into Harris County. This approach allows hydrologic consistency across the watershed. This unit hydrograph approach was also used in the Upper Cypress Study[3] for Upper Mound creek. The equations used are shown in **Table A2**. Ponded areas required for determining percent ponding were calculated by delineating rice fields and farm ponds from aerial photos. The percent urbanization parameter was estimated based on % impervious cover as described in the HCFCD manual. Other parameters used in this method such as percent channel improvement and percent channel conveyance were calculated using channel data but were not always necessary due to 85% of the Upper Barker sub-basins being rural in nature. Clark Unit Hydrograph parameters are shown in **Table A3**. A description of the parameters, as provided by the HCFCD, used to calculate Tc and R is as follows:

Drainage Area (A): the area within the watershed being analyzed, in square miles.

Watershed Length (L): the total length of the hydraulically longest watercourse in the watershed, from the outlet point to the upstream watershed boundary, in miles.

Length to Centroid (Lca): the distance along the longest watercourse from the outlet point to a point opposite the computed centroid of the drainage area, in miles.

Channel Slope (S): the weighted channel slope, measured along the longest watercourse and computed between station equal to 10 percent and 85 percent of L, in feet per mile.

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[2] Harris County Flood Control District, *Hydrology and Hydraulics Guidance Manual.* December 2009.
[3] Daniel Harris, PE, *Upper Cypress Creek Watershed Flood Protection Planning Study.* Prepared for Waller County, City of Prairie View, and City of Waller. November 16, 2012.

Watershed Slope (So): the watershed slope, measured along an average overland watercourse, from the bank of the main watercourse to the watershed divide, and computed between stations equal to 10 percent and 85 percent of the total overland watercourse length, in feet per mile.

Percent Land Urbanization (DLU): the portion of the drainage area developed for residential, industrial, commercial, or institutional use, measured from aerial photos, in percent of total drainage area.

Percent Channel Improvement (DCI): the portion of the longest watercourse with an improved channel, measured from aerial photos or construction drawings, expressed as a percentage of the total definable channel length.

Percent Channel Conveyance (DCC): the ratio of discharge carried in the channel to the total discharge, measured at several representative cross-sections along the main watercourse from the outlet to the upstream end of the main channel at the watershed boundary or the terminus of the channel, expressed in percent.

Percent Ponding (DPP): Portion(s) of a drainage area where runoff is retarded from reaching a watercourse because of physical obstructions (i.e. levees, ponds, rice fields, swamps, etc.), measured in percent of total drainage area.

The equations HCFCD developed for calculating Tc and R which were primarily utilized for this study are as follows.

Table A2: TC&R Calculation Procedure

$DLU - DET > DLU_{min}$	DLUdetention = DLU-DET $TC = D[1-(0.0062)(0.7\ DCI + 0.3\ DLUdetention)](Lca/\sqrt{S})^{1.06}$ $TC+R = 4295(DLUdetention)^{-0.678}\ (DCC)^{-.967}\ (L/\sqrt{S})^{0.706}$
$DLU > DLU_{min}$ and $DLU - DET < DLU_{min}$	DLUdetention = DLU-DET $TC = D[1-(0.0062)(0.7\ DCI + 0.3\ DLUmin)](Lca/\sqrt{S})^{1.06}$ $TC+R = 4295(DLUmin)^{-0.678}\ (DCC)^{-.967}\ (L/\sqrt{S})^{0.706}$
$DLU < DLU_{min}$	DLUdetention = DLU-DET $TC = D[1-(0.0062)(0.7\ DCI + 0.3\ DLU)](Lca/\sqrt{S})^{1.06}$ $TC+R = 7.25\ (L/\sqrt{S})^{0.706}$

Where: Tc = Time of Concentration
D = Watershed Slope Factor
DLU = % Land Urbanization
DET = On Site Detention
DCI = % Channel Improvement
Lca = Length to Centroid
S = Channel Slope
So = Watershed Slope

L = Watershed Length
DCC = % Channel Conveyance
R = Storage Coefficient

The R values were adjusted per section II.3.11 of the HCFCD Manual[4] with the Ponding Adjustment Factor that varied per storm event. This was used primarily to account for rice farming and small levees across the study area. The adjusted R-values are shown in **Table A4**. The land use and TCR Values are shown in **Figures A1 and A2**. The factors for intermediate storm events were interpolated.

[4] HCFCD, 2009.

Table A3: Clark Unit Hydrograph Parameters for Upper Barker Watershed Sub-Basins

SUB-BASIN	DRAINAGE AREA (mi^2)	WATERSHED LENGTH (mi)	LENGTH TO CENTROID (mi)	CHANNEL SLOPE (ft/mi)	OVERLAND SLOPE (ft/mi)	DEVELOPMENT %	CHANNEL IMPROVEMENT %	CONVEYANCE %	ON SITE DETENTION %	PONDING %	TC (HR)	TC+R	R (HR)
CIB_01	11.49	6.19	2.79	5.0	5.0	10.6	0	100	0.0	83	3.042	14.878	11.835
CIB_02	2.19	2.51	1.29	5.0	12.0	8.5	0	100	0.0	65.6	1.359	7.866	6.507
CIB_03	4.42	3.42	1.53	3.0	3.0	10.6	0	100	2.4	73.3	2.117	11.720	9.603
CIB_04	1.37	1.65	0.76	5.0	5.0	37.9	0	100	22.2	38.3	0.766	5.777	5.010
CIB_05	2.11	2.02	0.92	5.0	5.0	35.6	0	100	9.4	48.1	0.921	5.084	4.163
CIB_06	1.41	2.17	1.03	5.0	12.0	54.8	0	100	10.9	17.6	1.001	3.769	2.768
CIB_07	0.67	1.41	0.41	5.0	5.0	49.5	0	100	11.5	0	0.385	3.065	2.680
CIB_08	0.34	1.78	0.58	5.0	5.0	60.7	0	100	42.8	0	0.577	6.020	5.443
SC_01	1.99	2.24	1.24	2.8	5.9	24.7	0	100	0.0	58.9	1.706	6.948	5.242
SC_02	1.00	1.82	0.83	3.5	4.7	23.1	0	100	0.0	68	1.003	5.837	4.834
SC_03	2.27	2.96	1.84	5.1	4.7	18.3	0	100	0.0	55.1	1.909	8.427	6.518
SC_04	2.77	3.61	1.18	4.2	8.0	45.3	0	100	47.8	22.8	1.329	10.673	9.344
SC_05	2.00	3.60	1.24	8.0	6.4	38.3	0	100	20.4	0	0.999	8.366	7.367
WFBB_01	1.88	3.80	2.25	3.7	3.0	1.0	0	100	0.0	13.6	2.899	11.742	8.843
WFBB_02	5.40	6.42	2.64	3.9	6.5	11.5	0	100	1.5	53.1	3.274	16.722	13.447
WFBB_03	0.96	2.14	1.04	5.6	3.0	38.0	0	100	41.6	16.5	1.006	6.670	5.663
WFBB_04	0.99	2.47	1.48	4.5	5.2	1.9	0	100	0.0	0	1.674	8.062	6.388
WFBB_05	1.10	2.84	1.03	4.0	2.5	10.8	0	100	27.6	25.4	1.204	9.284	8.080
WFBB_06	1.33	2.00	0.94	7.4	9.1	35.4	0	100	19.4	23.4	0.776	5.754	4.978
WFBB_07	2.55	3.88	1.85	4.5	2.0	31.2	0	100	18.2	44.6	2.070	10.991	8.921
WFBB_08	1.35	1.88	1.02	5.9	9.9	6.1	0	100	6.1	43.9	0.977	6.055	5.078
WFBB_09	3.26	3.86	1.36	5.3	3.3	46.7	0	100	52.4	50	1.373	10.339	8.966
WFBB_10	1.20	1.98	0.99	9.4	15.5	32.7	0	100	13.5	0	0.727	4.950	4.223
WFBB_11	1.36	2.48	0.79	6.3	11.0	65.6	0	100	50.3	0	0.707	7.086	6.378
WFT_01	1.02	2.50	1.50	2.5	5.0	2.1	0	100	0.0	0	2.298	9.967	7.669

Table A4: R-Values Based on Ponding Adjustment Factor

SUB-BASIN	TC+R	R	Ponding Adjustment for R							
			50% (2-Yr)	20% (5-Yr)	10% (10-Yr)	4% (25-Yr)	2% (50-Yr)	1% (100-Yr)	0.4% (250-Yr)	0.2% (500-Yr)
CIB_01	14.878	11.835	46.483	39.915	36.499	31.496	28.622	25.662	22.498	20.249
CIB_02	7.866	6.507	24.155	20.869	19.151	16.635	15.181	13.678	12.066	10.911
CIB_03	11.720	9.603	36.608	31.537	28.892	25.018	22.787	20.483	18.016	16.256
CIB_04	5.777	5.010	16.345	14.320	13.248	11.682	10.765	9.809	8.775	8.021
CIB_05	5.084	4.163	14.343	12.492	11.517	10.091	9.261	8.399	7.469	6.796
CIB_06	3.769	2.768	7.491	6.697	6.268	5.649	5.279	4.890	4.463	4.144
CIB_07	3.065	2.680	2.680	2.680	2.680	2.680	2.680	2.680	2.680	2.680
CIB_08	6.020	5.443	5.443	5.443	5.443	5.443	5.443	5.443	5.443	5.443
SC_01	6.948	5.242	18.961	16.427	15.099	13.155	12.029	10.863	9.609	8.708
SC_02	5.837	4.834	18.098	15.621	14.327	12.432	11.339	10.208	8.996	8.129
SC_03	8.427	6.518	23.203	20.137	18.528	16.172	14.806	13.389	11.864	10.766
SC_04	10.673	9.344	26.913	23.900	22.283	19.936	18.544	17.083	15.489	14.305
SC_05	8.366	7.367	7.367	7.367	7.367	7.367	7.367	7.367	7.367	7.367
WFBB_01	11.742	8.843	22.500	20.250	19.027	17.272	16.215	15.101	13.877	12.950
WFBB_02	16.722	13.447	47.446	41.218	37.944	33.155	30.373	27.488	24.381	22.140
WFBB_03	6.670	5.663	15.094	13.517	12.664	11.433	10.697	9.921	9.071	8.433
WFBB_04	8.062	6.388	6.388	6.388	6.388	6.388	6.388	6.388	6.388	6.388
WFBB_05	9.284	8.080	23.886	21.152	19.688	17.562	16.304	14.985	13.549	12.486
WFBB_06	5.754	4.978	14.429	12.805	11.933	10.669	9.919	9.133	8.275	7.639
WFBB_07	10.991	8.921	30.185	26.341	24.313	21.348	19.618	17.820	15.878	14.469
WFBB_08	6.055	5.078	17.117	14.943	13.796	12.119	11.140	10.122	9.023	8.225
WFBB_09	10.339	8.966	31.182	27.131	24.999	21.880	20.066	18.183	16.153	14.686
WFBB_10	4.950	4.223	4.223	4.223	4.223	4.223	4.223	4.223	4.223	4.223
WFBB_11	7.086	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378
WFT_01	9.967	7.669	7.669	7.669	7.669	7.669	7.669	7.669	7.669	7.669

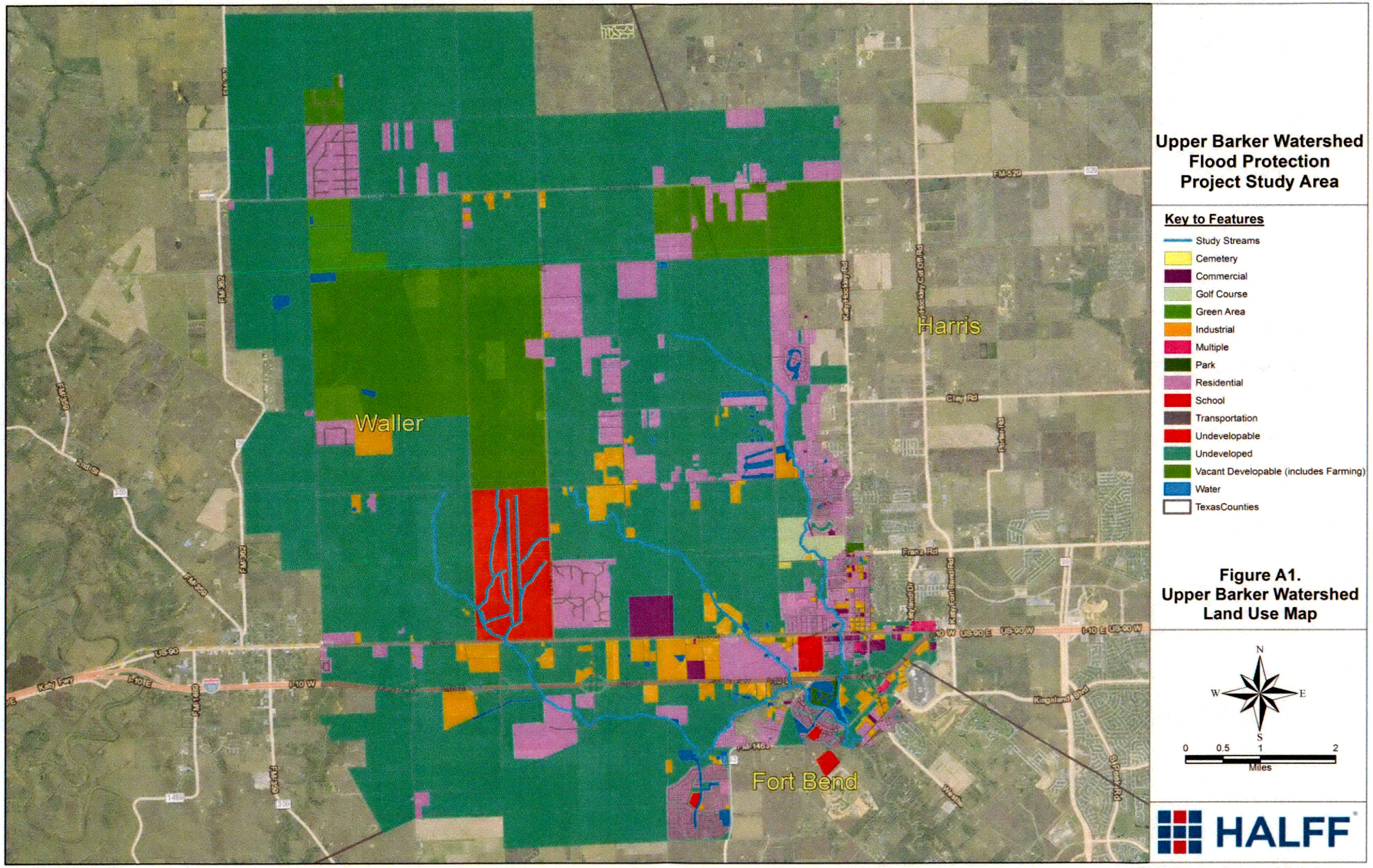
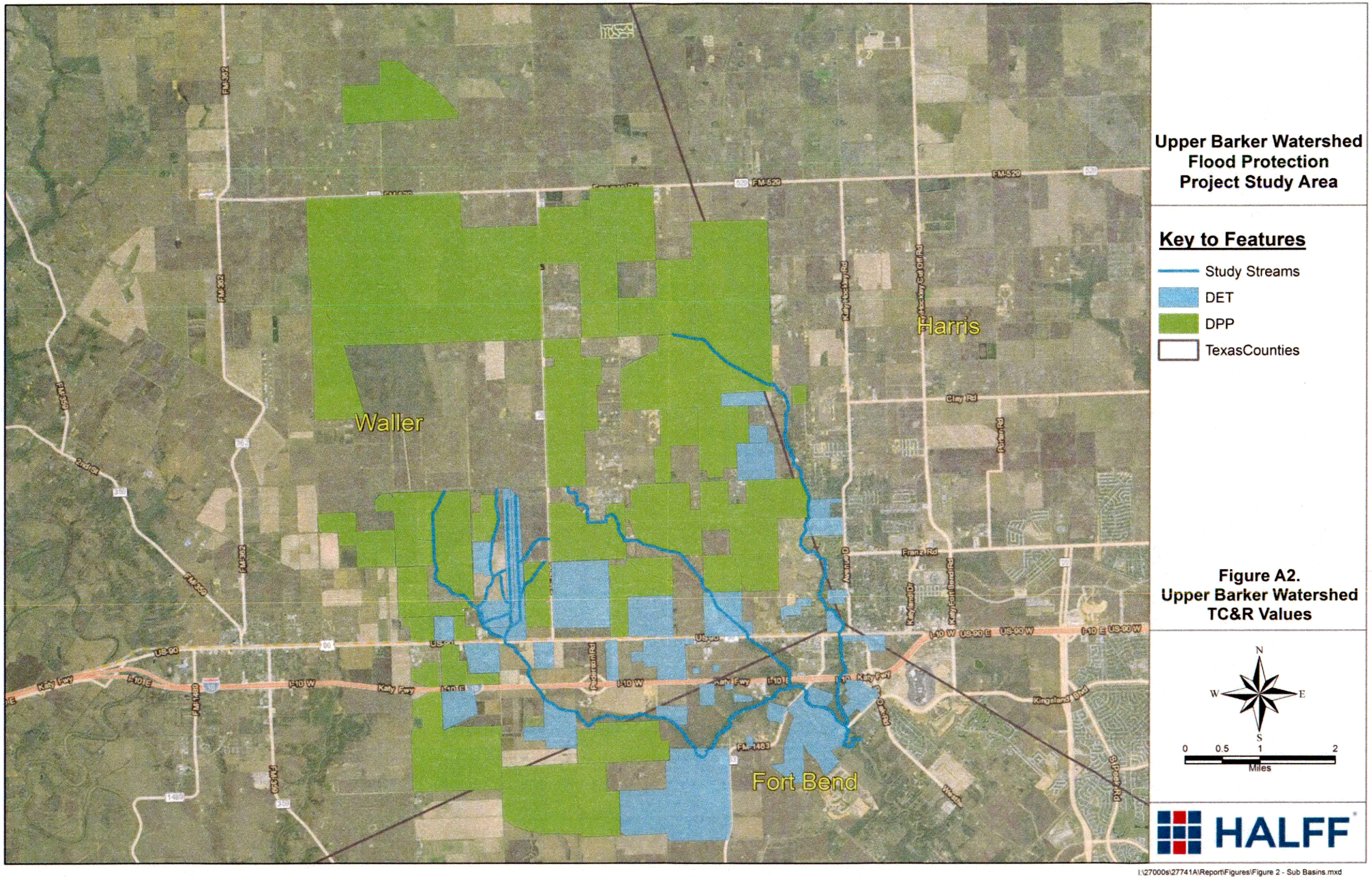


Figure A1.
Upper Barker Watershed
Land Use Map


Waller
Harris
Fort Bend
Upper Barker Watershed Flood Protection Project Study Area
Key to Features
Study Streams
DET
DPP
TexasCounties
Figure A2.
Upper Barker Watershed
TC&R Values
N
S
E
W
0 0.5 1 2
Miles
HALFF

A.6 Flood Routing

Flood routing through channel reaches in the hydraulic model was calculated using the Modified Puls routing method. This method was used because of its ability to account for the attenuation of the flood hydrograph associated with the effects of bridge/culvert backwater effects and overbank storage. Storage-outflow data for the Modified Puls routing method was extracted from the existing conditions hydraulic models for the Upper Barker Watershed.

A.7 Diversions and Inflows

The Upper Barker Watershed has a large drainage ditch network that extends across the study area. The larger ditches generally convey runoff from the upper portions of the watershed to the south during more frequent events. The ditches included in the hydrologic model are along Cardiff Road, FM 2855, Schlipf Road and Morton Road. During less frequent events such as the 10-year, the ditches generally overflow from the northwest to the southeast.

An attempt was made to account for the conveyance of the ditches during frequent events and the overtopping during less frequent events. In general, the ditches have capacity up to the 5-year storm event. Approximate ditch capacities were determined based using Manning's equation calculating the size of the ditch from 2008 terrain data. The diversions are shown on **Figure A3**.

Diversion D_CIB_01 represents the ditch upstream of Cardiff Road and Morton Road. This ditch conveys flow from the upper basin of Cane Island Branch down to Willow Fork during all storm events. The ditch capacity was calculated using Manning's equation, with the area attained from 2008 LiDAR data. Flows less than or equal to the ditch capacity were diverted from Cane Island Branch into Willow Fork Buffalo Bayou. To account for hydrologic timing, the diverted flow was routed to Willow Fork using the Muskingum-Cunge Routing Method in HEC-HMS. The length and slope were taken from GIS and terrain data. The shape of the cross section was assumed to be an eight-point section representing the drainage channel parallel to Cardiff Road.

Diversion D_FM2855 represents the roadside ditches along FM 2855. These ditches convey flow from the upper basin of Cane Island Branch upstream of FM 529 down to Willow Fork during storm events. The ditch capacity was calculated using Manning's equation, with the area attained from 2008 LiDAR data. Flows less than or equal to the ditch capacity were diverted from Cane Island Branch into Willow Fork Buffalo Bayou. To account for hydrologic timing, the diverted flow was routed to Willow Fork using the Muskingum-Cunge Routing Method in HEC-HMS. Approximately 1 square mile of the watershed drains to the ditch upstream of Morton Road. The length and slope of the ditch were taken from GIS and terrain data. The shape of the cross section in the HMS model was assumed to be an eight-point section representing the two ditches along either side of FM 2855.

Diversion J_CIB_01 represents the roadside ditches along Schlipf Road. This ditch conveys flow from the upper basin of Cane Island Branch down to the upper reach of Snake Creek during all storm events. The ditch capacity was calculated using Manning's equation, with the area attained from 2008 LiDAR data. Flows less than or equal to the ditch capacity were diverted from Cane Island Branch into Snake Creek.

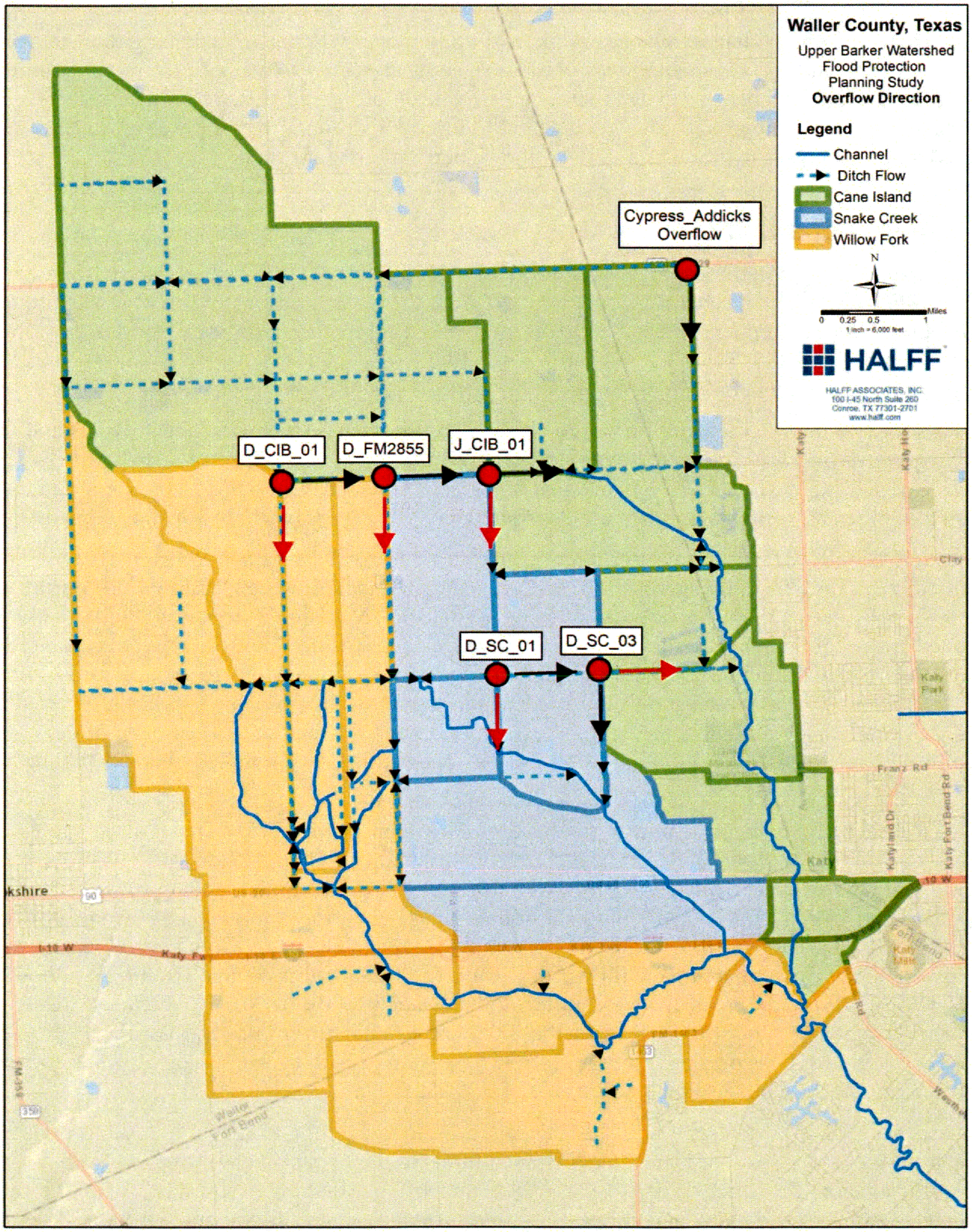


Figure A3: Flow Diversions to Represent Overflow

Diversion D_SC_01 represents the roadside ditches along Morton Road at Schlipf Road. The flow in the ditch down Schlipf Road is split between the ditch south of Morton Road and the ditch heading east along Morton Road. The ditch capacity was calculated using Manning's equation, with the area attained from 2008 LiDAR data. The flow was diverted to Diversion D_SC_03 at Bartlett Road and Morton Road.

Diversion D_SC_03 represents the roadside ditches along Bartlett Road at Morton Road. It was determined that any flow not contained by the roadside ditch along Bartlett Road would continue to sheet flow to the Cane Island Branch basins along Morton Road. The ditch capacity was calculated using Manning's equation, with the area attained from 2008 LiDAR data. Flows less than or equal to the ditch capacity were diverted from Snake Creek, into Cane Island Branch.

The effective model for Cane Island Branch included overflow from the Cypress Creek watershed. During less frequent events, Cypress Creek generally overflows across the upper portion of the Addicks watershed into Cane Island Branch. The peak discharge in the effective model during the 100-year event from Cypress Creek is 1,200 cfs. An ongoing study by HCFCD for the TWDB determined that the overflow from Cypress Creek is 360 cfs.[5] The HCFCD study engineer provided an overflow hydrograph that was used included in the HMS model.

The Upper Barker Watershed has several large detention facilities that account for development and mitigate runoff. Many of these facilities were accounted for in the Unit Hydrograph Method. However, five detention facilities were included in the hydrologic model as they capture overflow from their respective creeks. These facilities were modeled in HEC-HMS as diversions. Flow was diverted using the weir equations and the weir survey data input into the model. The detention pond storage capacity was also input to limit the maximum amount of flow diverted. The facilities are summarized in **Table A5**.

Table A5: Detention Facilities in Upper Barker

Location	HEC-HMS Node	Volume (ac-ft)
Willow Creek Farms Three Ponds	WCFDET	141.09
Cane Island Branch Pond – Morton Rd	DETCIB	286.8
Detention Facility at Willow Creek and Cane Island Confluence	WCRDET	269.25

[5] Burton Johnson, PE, *Draft Study Report: Cypress Creek Overflow Management Plan.* Prepared for Harris County Flood Control, Harris County, and TWDB. September 25, 2014.

A.8 Peak Discharges

Peak discharges were computed at the downstream end of each sub-basin. **Table A6** displays peak discharge results from the HEC-HMS model with Modified Puls routing.

Table A6: Computed Peak Discharge for Upper Barker Watershed

Stream	HEC-HMS Node	HEC-RAS X-Section	Q 2 (cfs)	Q 5 (cfs)	Q 10 (cfs)	Q 25 (cfs)	Q 50 (cfs)	Q 100 (cfs)	Q 250 (cfs)	Q 500 (cfs)
Cane Island Branch	J_CIB_01	40674.4	8.4	17.6	32.3	380.7	769.9	1,278	2,179	3,091
	J_CIB_02	35773.4	81.5	164.3	240.8	612.2	1,102	1,752	2,877	4,011
	J_CIB_03a	29056	172.5	354.8	532.7	927.3	1,512	2,320	3,722	5,122
	J_CIB_03b	27081	214.9	355.1	532.7	927.3	1,512	2,320	3,722	5,122
	J_CIB_04	22196	236.3	457.1	585.3	1,118	1,788	2,803	4,521	6,010
	J_CIB_05	13781	327.2	630.6	887	1,538	1,947	2,941	4,649	6,163
	J_CIB_06	7438	426.7	841.8	1,221	1,898	2,343	2,956	4,565	5,919
	J_CIB_07	4134	482.3	934	1,337	1,974	2,453	2,941	4,502	5,860
	J_CIB_08	449.4	523.9	996	1,425	2,054	2,548	3,022	4,507	5,868
Snake Creek	J_SC_02	16699	143	277	412	517	589.2	683	834	985
	J_SC_03	11437	217	400	584	652.	738.6	1,133	1,818	2,503
	J_SC_04	5197	304	569	813	971	1,184	1,665	2,445	3,189
	J_SC_05	133	455	796	1,088	1,390	1,730	2,291	3,216	4,056
Willow Fork Buffalo Bayou	J_WFBB_01	101562	247	506	682.2	874	1,040	1,237	1,549	1,851
	J_WFBB_02	91517	251	459	715.7	1018	1,345	1,772	2,424	2,942
	J_WFBB_03	90147	263	484	758.9	1099	1,463	1,890	2,685	3,282
	J_WFBB_04	88057	307	569	858.8	1,461	1,869	2,451	3,276	3,946
	J_WFBB_05	84016	324	592	899	1,481	1,881	2,469	3,328	4,105
	J_WFBB_06	78186	378	632	1,084	1,636	2,090	2,723	3,753	4,702
	J_WFBB_07	70426	421	717	1,169	1,695	2,160	2,794	3,859	4,866
	J_WFBB_08	67657	510	894	1,362	2,012	2,542	3,165	4,415	5,601
	J_WFBB_09a	61001	541	998	1386	2016	2571.7	3,212	4,425	5,632
	J_WFBB_09b	59361	962	1794	2383.5	322	4108.6	5,375	7,375	9,300
	J_WFBB_11	54417	1496	2679	3293.8	5290	6,740	8,447	11,475	14,110

A.9 Hydraulic Analysis

A hydraulic analysis was performed for the Upper Barker Watershed utilizing the HEC-RAS software, version 4.1. The purpose of this hydraulic analysis was to develop flood profiles for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year frequency rainfall events. Cane Island Branch, Snake Creek, and Willow Fork Buffalo Bayou currently have detailed Zone AE floodplains. The upper portion of Willow Fork Buffalo Bayou in Waller County is currently approximate Zone A floodplains on the current effective Flood Insurance Rate Maps (FIRM). The new hydraulic analyses conducted along Cane Island Branch, Snake Creek, and Willow Fork Buffalo Bayou to the limits of study are detailed hydraulic analyses totaling 19 stream miles. The new detailed study utilizes detailed channel and bridge survey data obtained by Halff. The locations of the detailed bridge surveys used in this study are listed in **Table A7** below. Non-surveyed cross-sections were cut from LiDAR elevation data. The river station is measured in feet from the outfall of the Upper Barker watershed study area.

Table A7. Structure Survey Locations

Stream	Road	Station
Cane Island Branch	I-10	3981
	Stock Dick Rd	4750
	US-90	7292
	RR Crossing	7401
	1st Street	7520
	10th Street	11542
	Franz Rd	13718
	Access Road	15091
	Access Road	16280
	Morton Rd	21080
	Clay Rd	27038
	Pitts Rd	28971
Snake Creek	I-10	747
	US-90	5039
	RR Crossing #1	5175
	RR Crossing #2	6484
	Factory Entrance	6567
	Schlipf Rd	16699
Willow Fork Buffalo Bayou	Katy Flewellen	51189
	Kingsland Blvd	54331
	FM 1463	58740
	Pederson Rd	78181
	I-10	84001
	US-90	87971
	RR Crossing	88051
	Cardiff Road	91681

The computed peak discharges from the hydrologic model were input into the hydraulic model to develop flood profiles for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year frequency events. All Manning's n-values were selected from a combination of aerial photos, site visits, and the table found in section 4.3.5 of the 2010 HCFCD *Policy, Criteria, and Procedure Manual.*[6] The downstream boundary condition for the Upper Barker watershed river models were set to normal depth. Water surface elevations for the various frequencies at the upstream end of the effective Willow Fork Buffalo Bayou model were entered as a known water surface downstream boundary condition in the new Willow Fork Buffalo Bayou hydraulic river model.

A.10 Flood Profiles

Flood profiles for existing conditions were computed along the study streams for the various frequency events previously mentioned. The results for each stream can be seen in **Figures A3 – A5**.

[6] Harris County Flood Control District, *Policy, Criteria & Procedure Manual.* October 2004, Adopted December 2010.

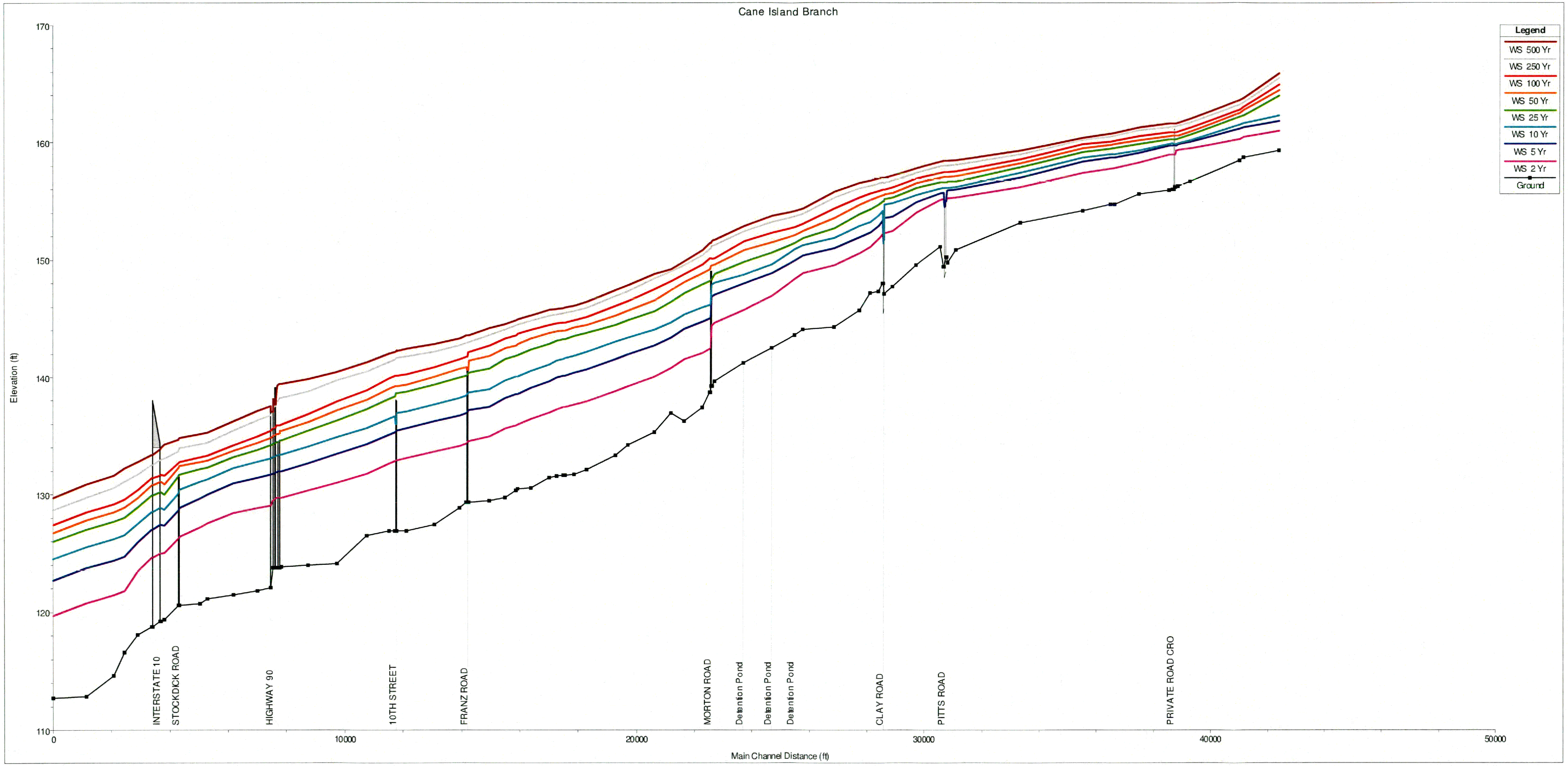


Figure A3: Cane Island Branch Frequency Profiles

Figure A3

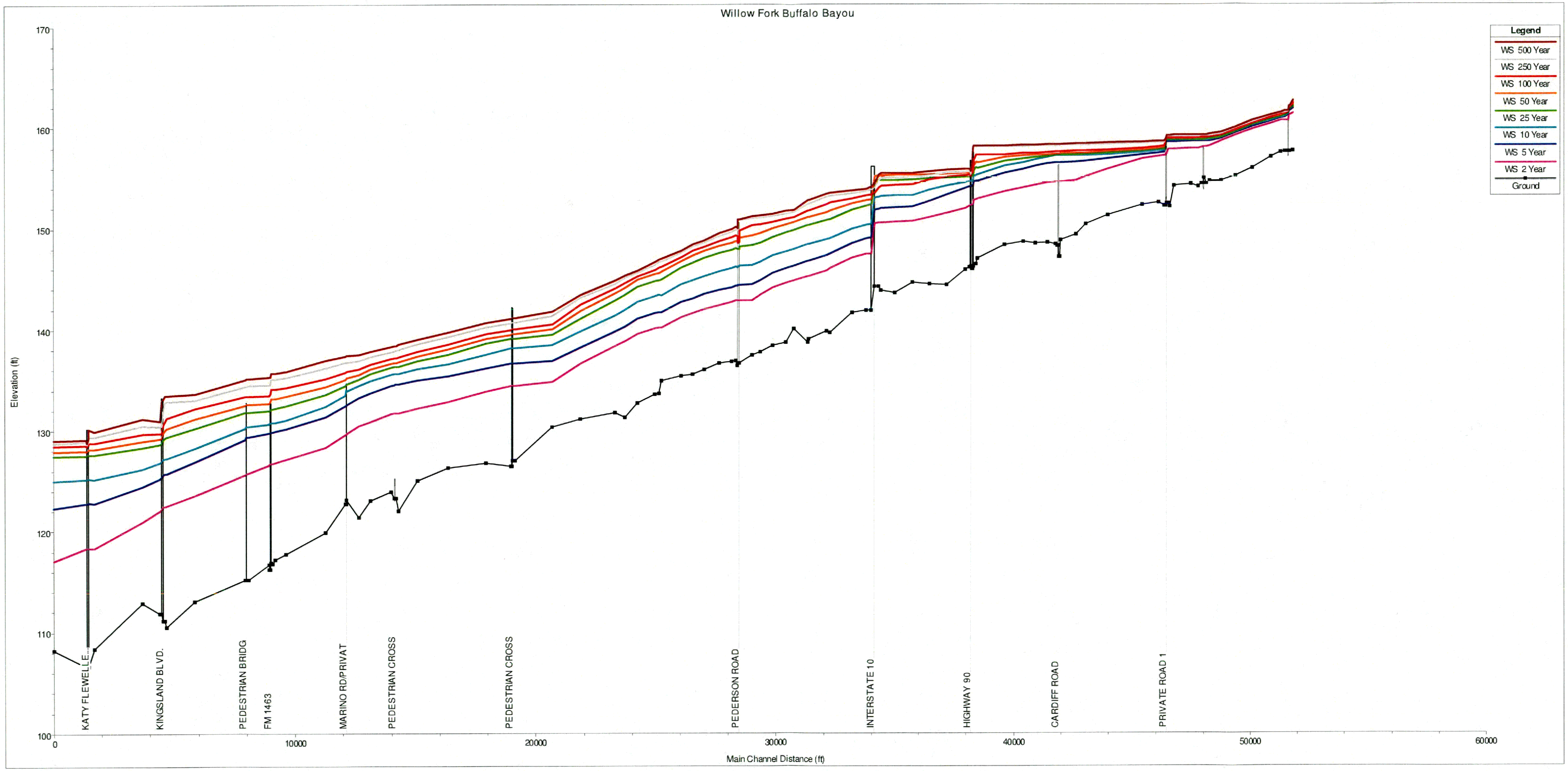


Figure A4: Willow Fork Buffalo Bayou Frequency Profile

Figure A4

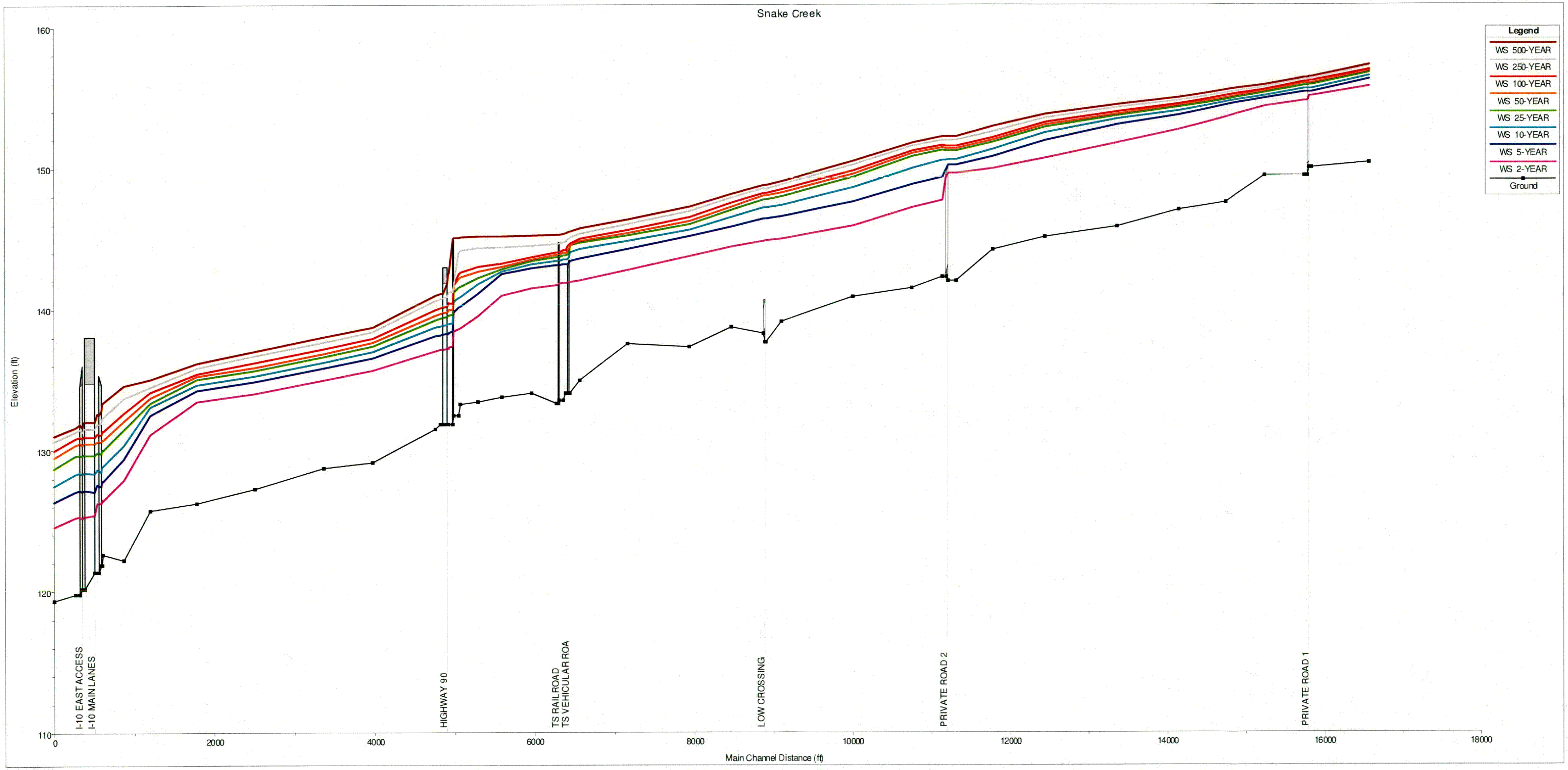


Figure A5: Snake Creek Frequency Profile

Figure A5

A comparison was made between the results from this study and the current effective base flood elevations and discharges listed in the Waller County current effective FEMA Flood Insurance Study. The 100-year flood elevation comparisons are shown in **Figure D3** in Appendix D and discharge comparisons are displayed in **Table A8**. **Figures D4 – D6** in Appendix D depict the cross section locations and water surface elevations for each creek.

Differences in the water surface profiles and discharges can be attributed to many factors. Following is a list of reasons the results could be different:

1. Spills and diversions were accounted for in the new model.
2. Hydrologic and Hydraulic parameters were calculated with different methodology.
3. Differences in the amount and accuracy of field survey available.
4. The use of detailed LiDAR topographic data.
5. Physical watershed changes may have occurred.

Table A8: Waller County Current Effective FIS Discharges vs. New Model Discharge

Study Stream	Location	10yr		100yr		500yr	
		FIS	New	FIS	New	FIS	New
Willow Fork	2.06 mi U/S FM 1463	1,492	1,169	2,213	2,794	2,717	4,866
	1 mi U/S FM 1463	2,121	1,362	3,326	3,165	4,168	5,601
	0.46 mi U/S FM 1463	2,319	1,386	3,654	3,212	4,587	5,632
	0.26 mi U/S FM 1463	3,648	2,409	5,654	5,399	7,056	9,126
	Approx 1mi D/S Crossover Rd	5,700	3,317	10,400	8,336	14,200	13,940
Snake Creek (LOMR)	Schlipf Rd	401	412	693	683	1,202	985
	US 90	989	825	1,795	1,665	3,653	3,189
	Conf with WF	1,132	1,088	2,148	2,291	4,178	4,056
Cane Island Branch	U/S Pitts	890	533	3034	2,322	5764	5,119
	U/S Morton Rd	947	587	3,154	2,665	6,017	5,932
	U/S Franz Rd	999	937	3,265	2808	6,250	6265
	U/S 10th St	1,015	905	3,285	2,825	6,279	6,117
	U/S US 90	1,088	1,225	3,380	2,831	6,414	5,860
	U/S Stockdick	1,115	1,340	3,381	2,871	6,415	5,803
	At Mouth	1,230	1,428	3,383	2,997	6,420	5,812

Appendix B

APPENDIX B: Flood Damage Reduction Alternative Analysis for the Upper Cypress Creek Watershed

B.1 Introduction

The alternative analysis for the Upper Barker Creek watershed included flood damage reduction alternatives for Cane Island Branch, Snake Creek and Willow Fork sub-basins. **Figures D7-D9** show the recommended alternatives for each entity is included in Appendix D. Most of the flood damages in the watershed are associated with the east side of Cane Island Branch located in the City of Katy. A benefit cost was conducted for select alternatives. Potential funding sources for the alternatives recommended below include disaster funding, storm water drainage fees and partnerships with new developments.

BCA 4.8 – Benefit Cost Analysis (BCA) Toolkit was used to calculate the Benefit Cost Ratio (BCR). BCA is a program by FEMA to determine the cost effectiveness of proposed mitigation projects for several FEMA mitigation grant programs. The factors required to determine the BCR included the structure appraised values, depth of inundation before and after mitigation, and project costs.

Detailed appraisal data including parcel information, structure type, location and appraised value was collected from the Harris County Appraisal District and the Waller County Appraisal District. The parcel information collected was for the properties currently within the limits of the 100-year floodplain.

The finished floor elevation for each structure was estimated from the ground surface developed from the 2008 surface LiDAR in the Flood Protection Planning Study. Several of the finished floor elevations were estimated to be up to 1 foot higher than the ground surface based on field observations. The elevations were compared to the pre- and post-mitigation water surface elevation profiles for the 10-, 50-, 100-, and 500-yr storm events. These comparisons were used in the BCA Toolkit to estimate the damages to structures as a result of flooding. The project costs were compared to the damages estimated from the damage curves in the BCA Toolkit. A 50-year project life was used for the analysis. The damage curves assigned cost of damages to a structure based on a comparison of the depth of flood inundation during pre- and post-mitigation conditions. For a project to be considered eligible for a grant application, the BCR must be greater than 1.0.

Only select alternatives on Cane Island Branch were evaluated for a BCA. A BCA was not conducted on Snake Creek and Willow Fork because the basins are primarily rural and have very few habitable structures with the improvement areas.

B.2 Cane Island Branch Alternatives

Cane Island Branch currently has 190 habitable structures in the delineated floodplain. A total of three structural flood damage reduction alternatives were considered for Cane Island Branch. These alternatives are described in **Table B1** below. Two alternatives require significant detention sites while the third uses the existing detention to mitigate flow. A fourth alternative considers roadway improvements with impacting the water surface elevations. A non-structural

flood damage reduction alternative for Cane Island Branch considered buying affected houses which are in the existing floodplain. The total value of the habitable structures is $37,980,000. However, it appears that the majority of the structures are generally above the base flood elevation as the flood depths in the overbanks are relatively shallow. No repetitive loss structures were located in the study area. Therefore, the focus of the alternatives was mainly on structural alternatives in the alternative analysis.
The alternatives analyzed are discussed below:

Table B1: Cane Island Branch Alternative Descriptions

Alternative Name	Description
Alternative 1	Large upstream detention – Approximately 2,800 acre-ft of detention needed to reduce flows downstream
Alternative 2	Detention along with channel improvements to reduce flow and floodplains downstream. Approximately 2,000 acre-ft of detention along with large channel improvements.
Alternative 3	Channel clearing upstream of Morton Road along with configuring the existing regional detention weir to account for increase in flow.
Alternative 4	Raising the existing roadways to have a level of protection of a 100-year storm event.

Alternative 1 – Detention Upstream of Pitts Road

Alternative 1 consisted of upstream detention that would reduce flows downstream of Clay Road. The large overflow coming from the upstream basin in Cane Island Branch results in flooding throughout downstream basins. There are 99 habitable structures upstream of Morton Road subject to inundation since the floodplain is fairly at its widest in the City. The amount of detention required upstream of Pitts Road is approximately 2,800 ac-ft. This alternative potentially removes a total of 147 habitable structures and 476 acres from the floodplain. Though the amount of detention needed to reduce the flow to a 25-year storm was large, several sites upstream of Pitts Road may allow the detention to be distributed throughout the upper basin, i.e. upstream of Pitts Road. By detaining the flow to a 25-year storm, the flooding area is significantly reduced in both Waller County and the City of Katy.

A comparison of existing and the alternative 100-year floodplains for Cane Island Branch can be seen in **Figure B1** and **Figure D7** in Appendix D. A profile comparison can be seen in **Figure B2**. A preliminary estimate of probable cost for the design and construction of the upstream pond is shown in **Table B2**.

Table B2: Preliminary probable cost estimate Cane Island Branch Alternative 1

Cane Island Branch				
Item	**Unit**	**Unit Price**	**Quantity**	**Cost**
Land Acquisition	AC	$ 20,000	560	$ 11,200,000
Detention	AC-FT	$ 16,000	2800	$ 44,800,000
			Total	$ 56,000,000
			Contingency (30%)	$ 16,800,000
			Grand Total	$ 72,800,000

The BCR for this alternative did not score well due to the shallow flooding in the overbanks and the resulting low damages. The benefits to this alternative were under $650,000 resulting in a BCR of 0.01.

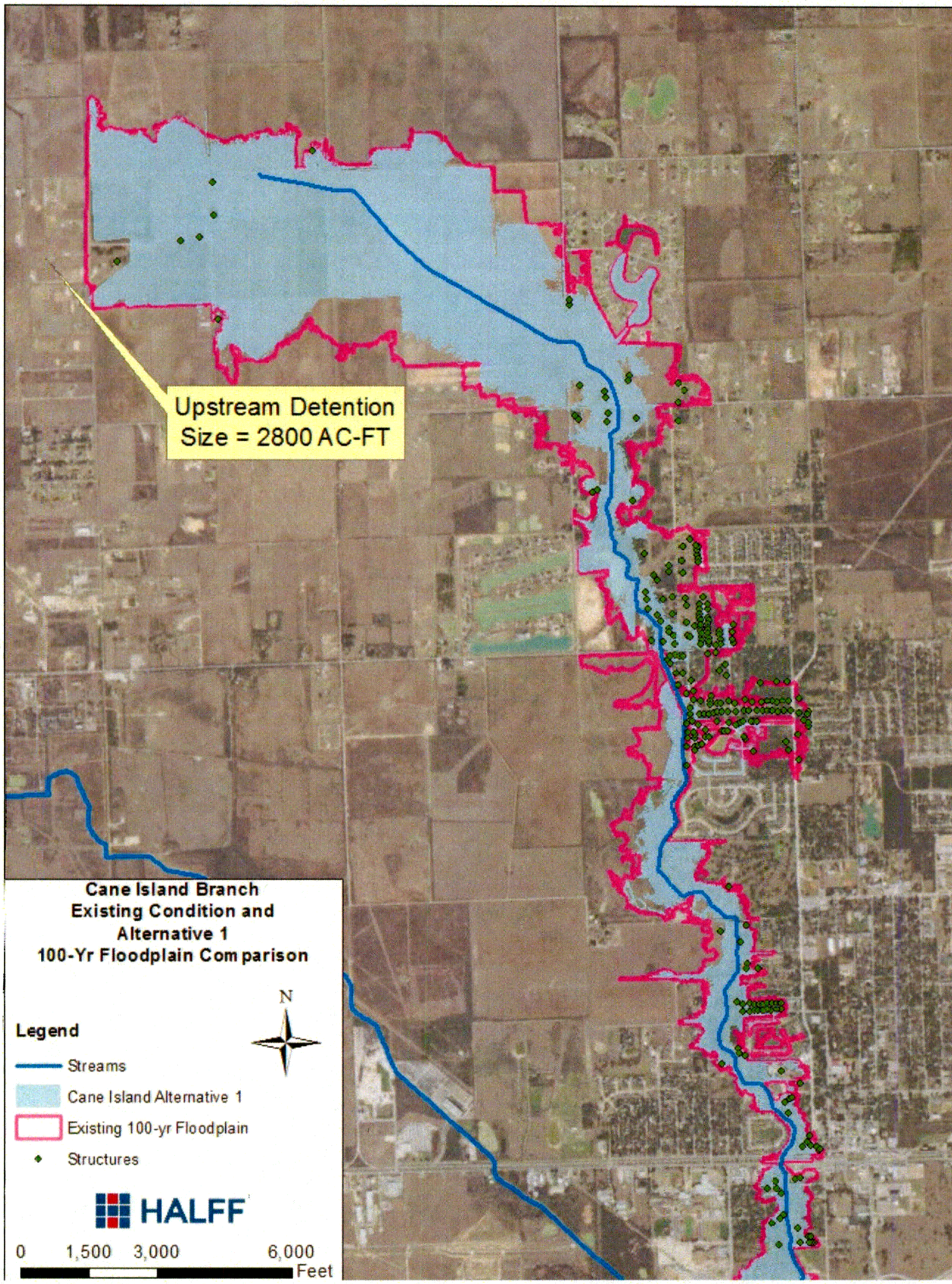


Figure B1: 100-yr Floodplain comparison between existing and Alternative 1 (Cane Island Branch)

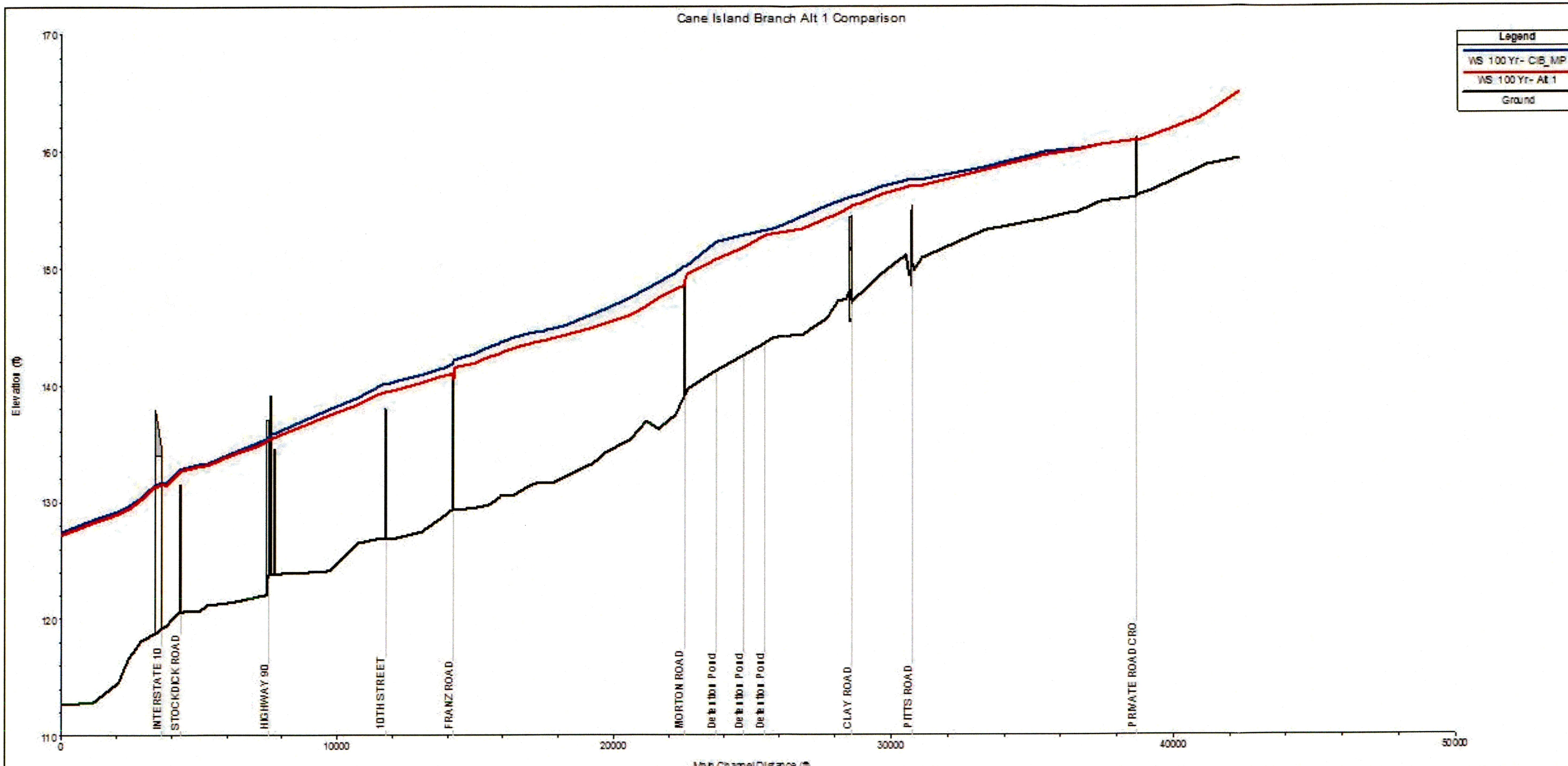


Figure B2. 100-yr profile comparison between existing and Alternative 1 (Cane Island Branch)

Figure B2

Alternative 2 – Upstream Detention with Downstream Channel Improvements

Alternative 2 consisted of upstream detention that would reduce flows downstream of Clay Road along with improvements to the existing channel and culvert crossings to further reduce the floodplain. The existing channel was widened to raise the capacity limit to a 50-year while the detention pond reduced flows for the 100-year storm downstream of Pitts to a 50-year storm. The existing channel has a top width of 100-feet. Approximately 150 feet to 240 feet of Right-of-Way would be required to accommodate the channel. The proposed channel includes 3:1 side slopes and 30 feet on either side for maintenance. The proposed channel alignment is shown on **Figure D8** in Appendix D. This alternative significantly reduced the floodplain from Clay Road to Franz Road, removing all structures in these locations from the floodplain.

A comparison of existing and the alternative 100-year floodplains for Cane Island Branch can be seen in **Figure B3** and a profile comparison can be seen in **Figure B4**. The detention pond requires a volume of 2,000 acre-ft. The channel from Schlipf Road to Franz Road was widened to increase the capacity from a 25-year storm to a 50-year storm. The increase in channel width will require additional Right-of-Way and additional culverts at the crossing of Pitts and Clay Roads. Alternative 2 removes 174 habitable structures and 1,177 acres from the 100-year floodplain. A preliminary estimate of probable cost for the design and construction of the upstream pond is shown in **Table B3**.

Table B3: Preliminary probable cost estimate Cane Island Branch Alternative 2

Cane Island Branch				
Item	**Unit**	**Unit Price**	**Quantity**	**Cost**
Land Acquisition	AC	$ 20,000	400	$ 8,000,000
Detention	AC-FT	$ 20,000	2000	$ 40,000,000
Channel Excavation	CY	$ 15	125000	$ 1,875,000
6'x6' Reinforced Concrete Box	LF	$ 500	760	$ 380,000
			Total	$ 50,255,000
			Contingency (30%)	$ 15,076,500
			Grand Total	$ 65,331,500

The BCR for this alternative did not score well due to the shallow flooding in the overbanks and the resulting low damages. The benefits to this alternative were under $2 million resulting in a BCR of 0.03.

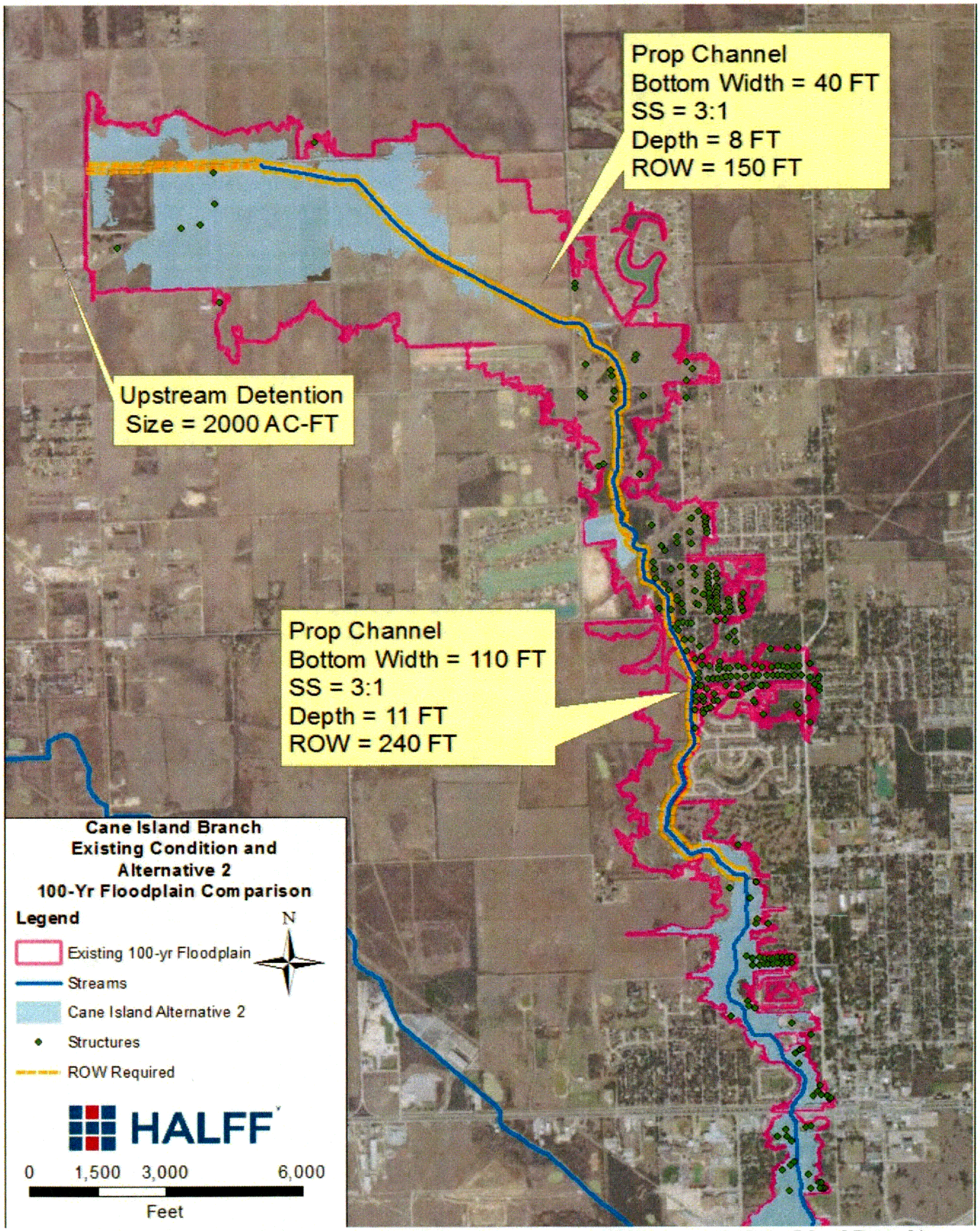


Figure B3: 100-yr Floodplain comparison between existing and Alternative 2 (Cane Island Branch)

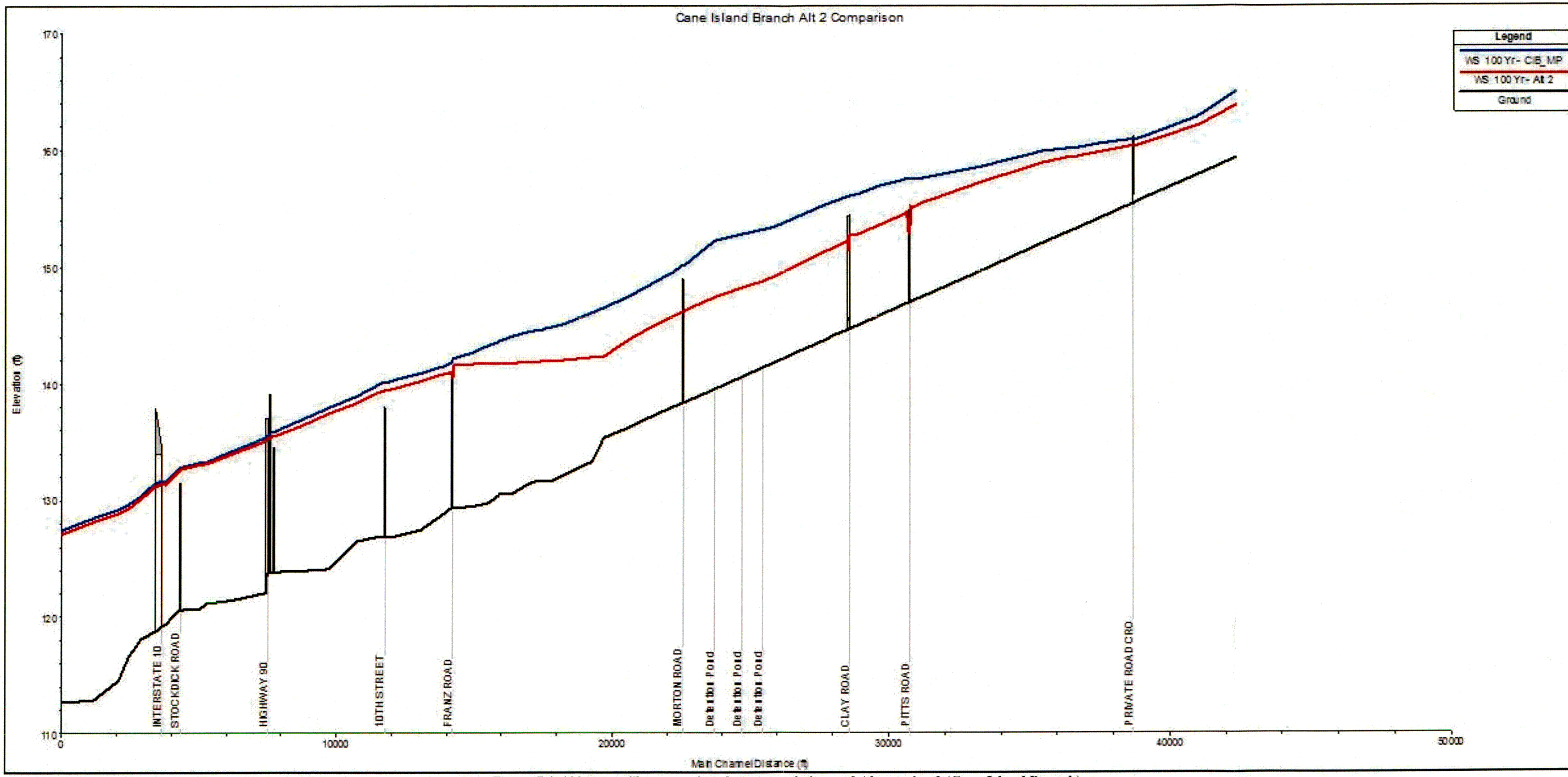


Figure B4. 100-yr profile comparison between existing and Alternative 2 (Cane Island Branch)

Figure B4

Alternative 3-Channel Clearing at Morton Road

Alternative 3 consisted of clearing the existing channel of excess vegetation and debris between Clay and Morton Road. In order to mitigate the rise in flow due to the reduced channel storage, the existing mitigation pond would need to be reconfigured. It was determined that by adding a weir 150 feet in length at an elevation of 150.1 feet along the north bank and increasing the elevation of the existing weir by 0.6 feet, would assist in mitigating any improvements to the channel. Upstream of Morton Road, the water surface elevation was reduced by 6 inches, resulting in 43 homes removed from the floodplain.

A comparison of existing and the alternative 100-year floodplains for Cane Island Branch can be seen in **Figure B5** and a profile comparison can be seen in **Figure B6**. However, due to hydrologic timing, an increase in flow of 1.6% (45 cfs) and water surface elevation of 0.12 feet would be expected at US-90. A preliminary estimate of probable cost for the design and construction of the upstream pond is shown in **Table B4**.

Table B4: Preliminary probable cost estimate Cane Island Branch Alternative 3

Cane Island Branch				
Item	**Unit**	**Unit Price**	**Quantity**	**Cost**
Tree/Brush Removal	AC	$ 5,000	3	$ 15,000
Weir	SY	$ 60	1400	$ 84,000
Excavation (Embankment)	CY	$ 15	1000	$ 15,000
			Total	$ 114,000
			Contingency (30%)	$ 34,200
			Grand Total	$ 148,200

The BCR for this alternative did not score well due to the shallow flooding in the overbanks and the resulting low damages. The benefits to this alternative were over $530,000 resulting in a BCR of 3.6. However, this project results is a slight increase in flow and water surface elevation downstream. It does not appear that any habitable structures would be significantly impacted by this project. Based in preliminary analysis, it is recommended that this alternative by analyzed with a more detailed and dynamic model to verify if there are impacts downstream. If there are none, this project may be eligible for grant funding.

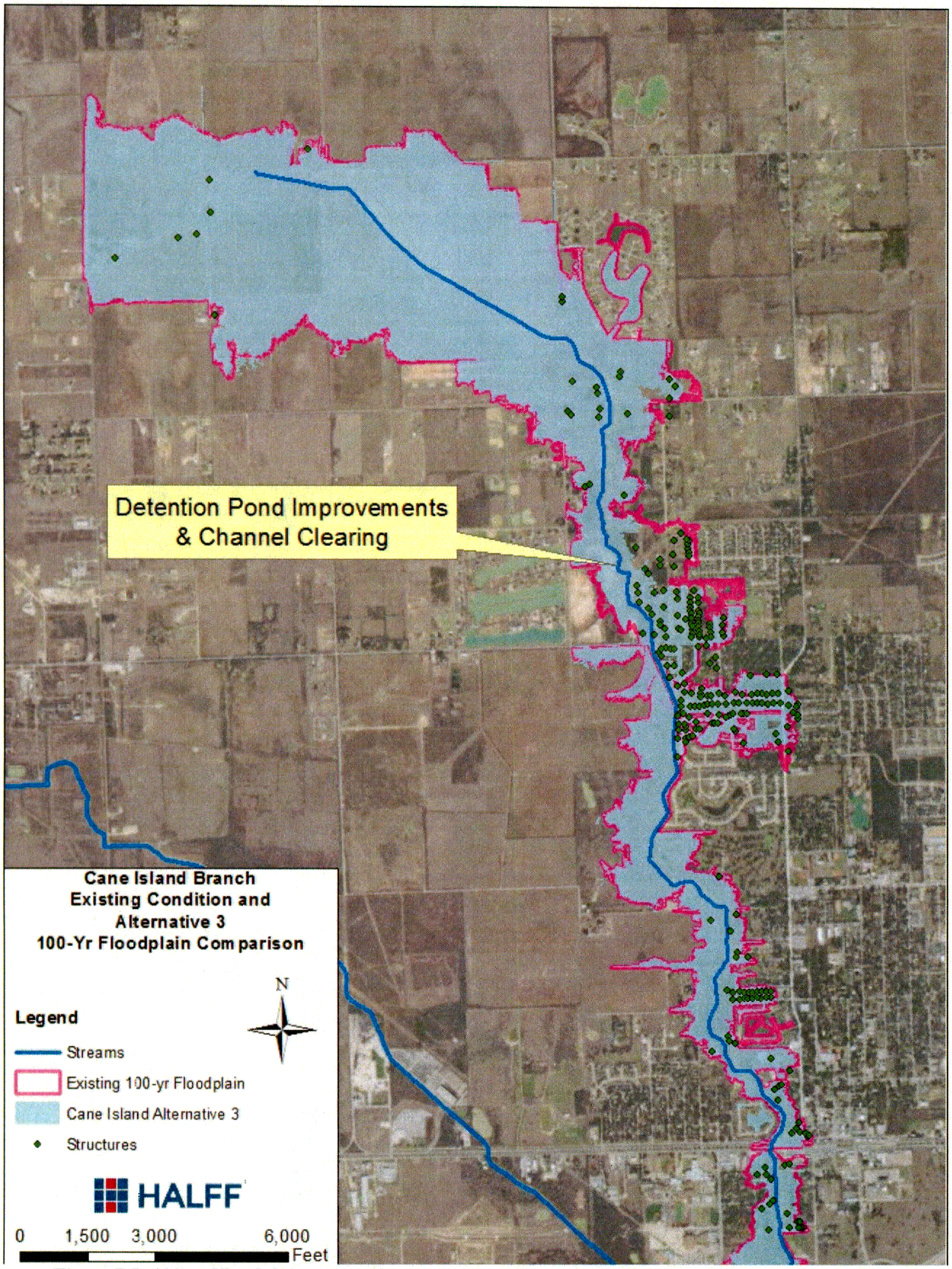


Figure B5: 100-yr Floodplain comparison between existing and Alternative 3 (Cane Island Branch)

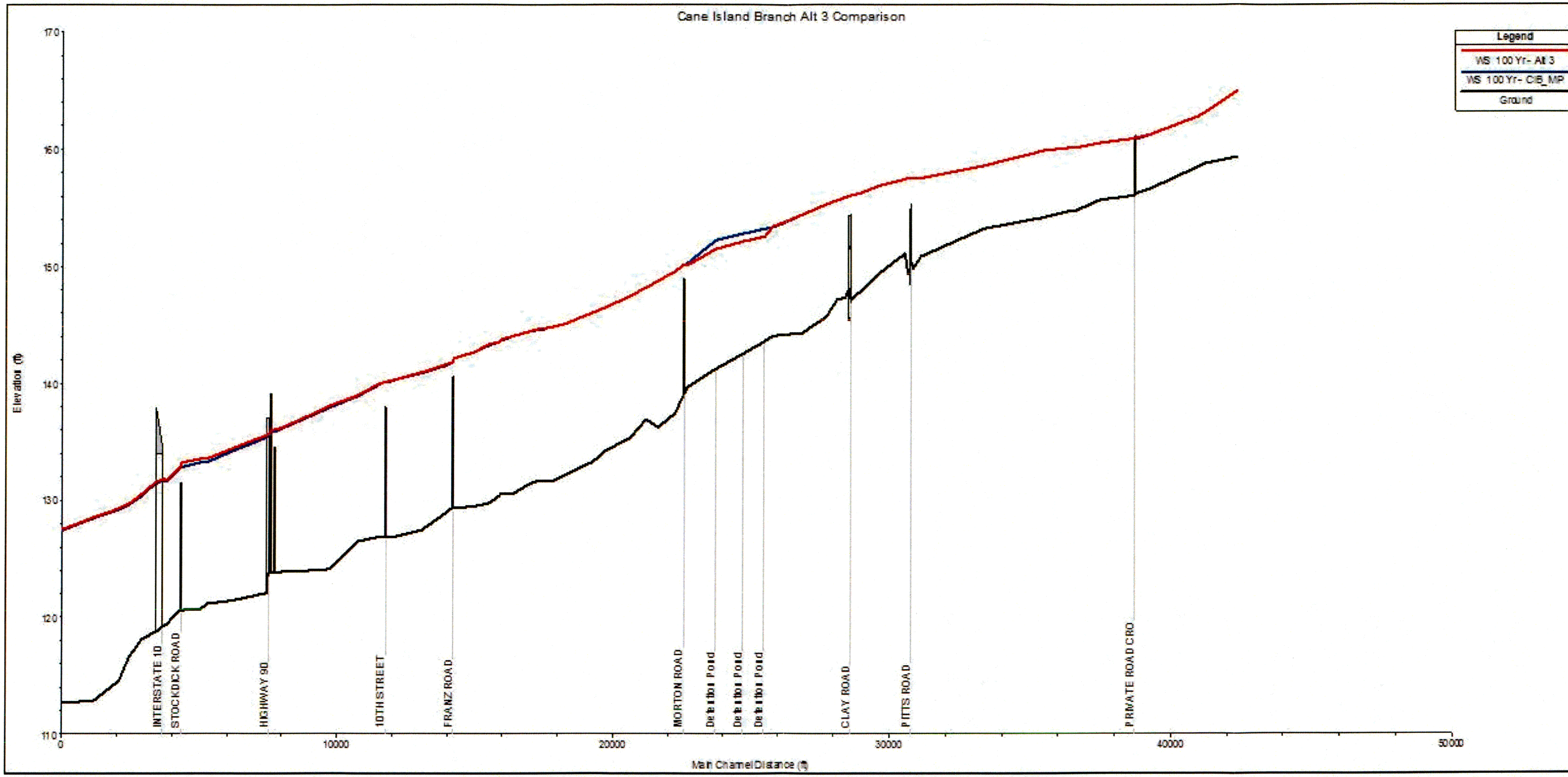


Figure B6. 100-yr profile comparison between existing and Alternative 3 (Cane Island Branch)

Figure B6

Alternative 4-Channel Clearing at Morton Road

The fourth alternative for Cane Island Branch involved improving road crossings in order to achieve a 100-year level of protection. Several of the current road crossings do not have a 100-year level of protection and are potentially overtopped by smaller and more frequent storm events. This alternative did not reduce flooding risk to the adjacent properties or habitable structures. The flood risk was reduced by elevating the road and placing culverts underneath to pass the overflow. The flow balance resulted in significant culvert needs to pass the 100-year storm event. More detailed analysis is needed to determine the hydraulic impacts of such improvements. For some of these crossings, a longer and elevated bridge may be an acceptable solution. A table of culvert needs and costs is shown in **Table B5**.

Table B5: Preliminary probable Cane Island Branch Alternative 4

Cane Island Branch				
Channel Crossing	**Current Level of Protection**	**Additional Culverts Needed**	**Additional Road Height**	**Cost for 100yr Protection**
Interstate 10	100-year	-	-	-
Stockdick Road	10-year	9-9'x6' RCB	1.75	$ 385,300
US 90	100-year	-	-	-
US-90 Railroad	100-year	-	-	-
1st Street	50-year	11-9'x6' RCB	0.65	$ 414,600
10th Street	10-year	12-9'x6' RCB	1.85	$ 494,200
Franz Road	50-year	10-9'x6' RCB	0.85	$ 421,100
Morton Road	25-year	22-9'x6' RCB	1.00	$ 965,700
Clay Road	10-year	22-9'x6' RCB	1.40	$ 1,005,500
Pitts Road	5-year	20-9'x6' RCB	2.20	$ 1,120,000

A BCR was not determined for this alternative since the existing floodplain was not modified.

B.3 Snake Creek Alternatives

Two structural flood damage reduction alternatives were considered for Snake Creek. These alternatives are described in **Table B6** below. Both alternatives require significant detention sites and Alternative 2 consists of channel improvements. Currently, there are no flooded habitable structures in the floodplain for Snake Creek in Waller County, but each alternative addresses reducing the floodplain to prepare for future development. The alternatives analyzed are discussed below:

Table B6: Snake Creek Alternative Descriptions

Alternative Name	Description
Alternative 1	Large upstream detention – Approximately 605 acre-ft of detention needed to reduce flows downstream to 25-year storm.
Alternative 2	Detention along with channel improvements to reduce flow and floodplains downstream. Approximately 356 acre-ft of detention along with large channel improvements.

Alternative 1 – Detention Upstream of Schlipf Road

Alternative 1 consisted of upstream detention that would reduce flows throughout Snake Creek. This alternative attempted to reduce the existing 100-year floodplain down to a 25-year floodplain by upstream detention. Waller County proposed a regional detention location west of Schlipf Road, just upstream of Snake Creek. This pond would detain flow from the upstream basin in Snake Creek, as well as any overflow from the adjoining watersheds. By detaining the flow to a 25-year storm, the flooding area is reduced in Waller County.

A comparison of existing and the alternative 100-year floodplains for Snake Creek can be seen in **Figure B7** and a profile comparison can be seen in **Figure B8**. Approximately 605 acre-ft of storage is required to detain the 100-year flow to a 25-year storm. The detention volume could be spread over several parcels of land in order to detain the required volume if needed. This alternative potentially removes 313 acres of developable property from the floodplain. Though the amount of detention needed to reduce the flow to a 25-year storm is large, potential contributions made by other entities, such as future developers, may assist in construction the detention facility. A preliminary estimate of probable cost for the design and construction of the upstream pond is shown in **Table B7**.

Table B7: Preliminary probable cost estimate Snake Creek Alternative 1

Snake Creek				
Item	**Unit**	**Unit Price**	**Quantity**	**Cost**
Land Acquisition	LS	$ 800,000	1	$ 800,000
Detention	AC-FT	$ 16,000	605	$ 9,680,000
			Total	$ 10,560,000
			Contingency (30%)	$ 3,168,000
			Grand Total	$ 13,728,000

A BCR was not determined for this alternative since there are no habitable structures in the floodplain.

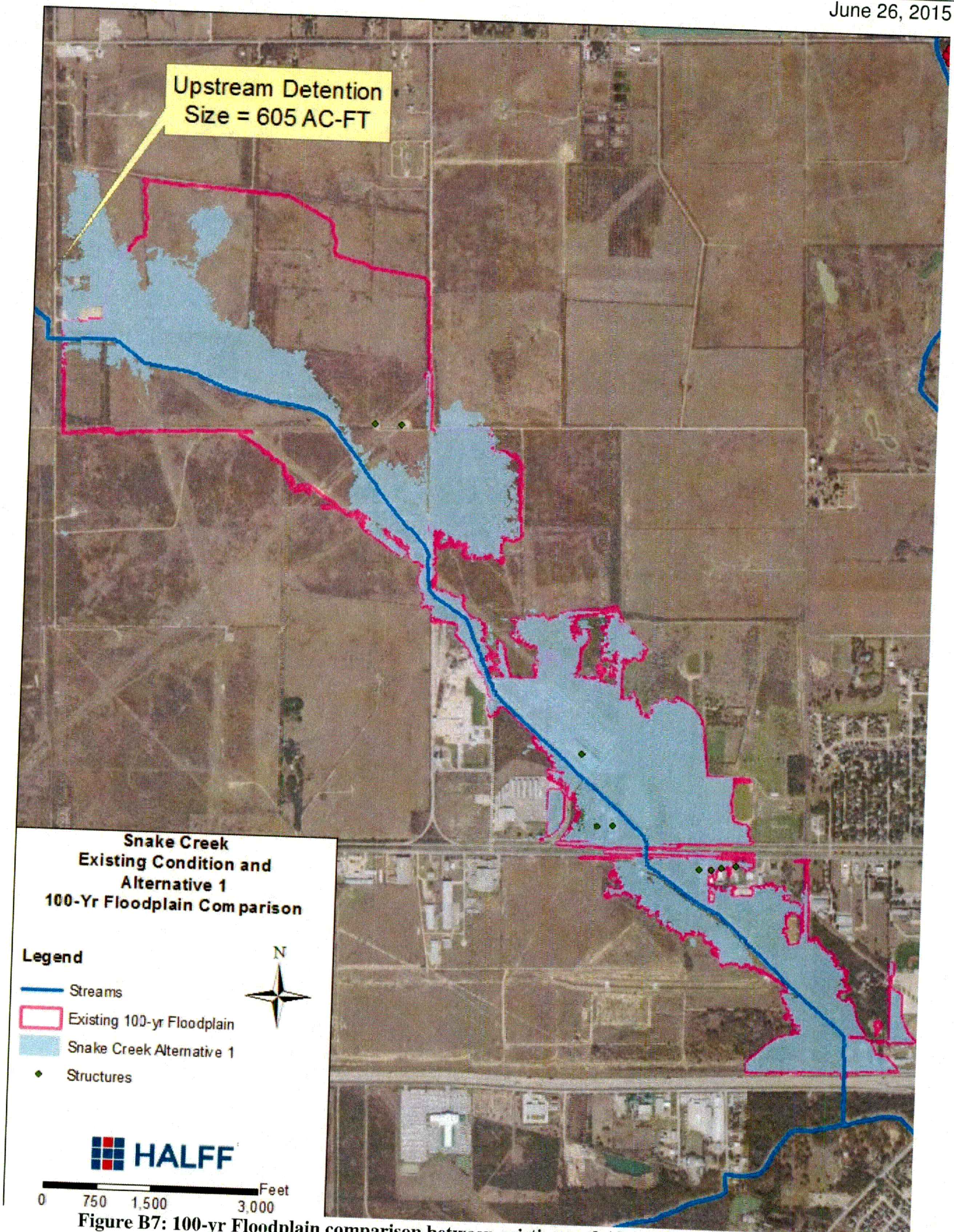


Figure B7: 100-yr Floodplain comparison between existing and Alternative 1 (Snake Creek)

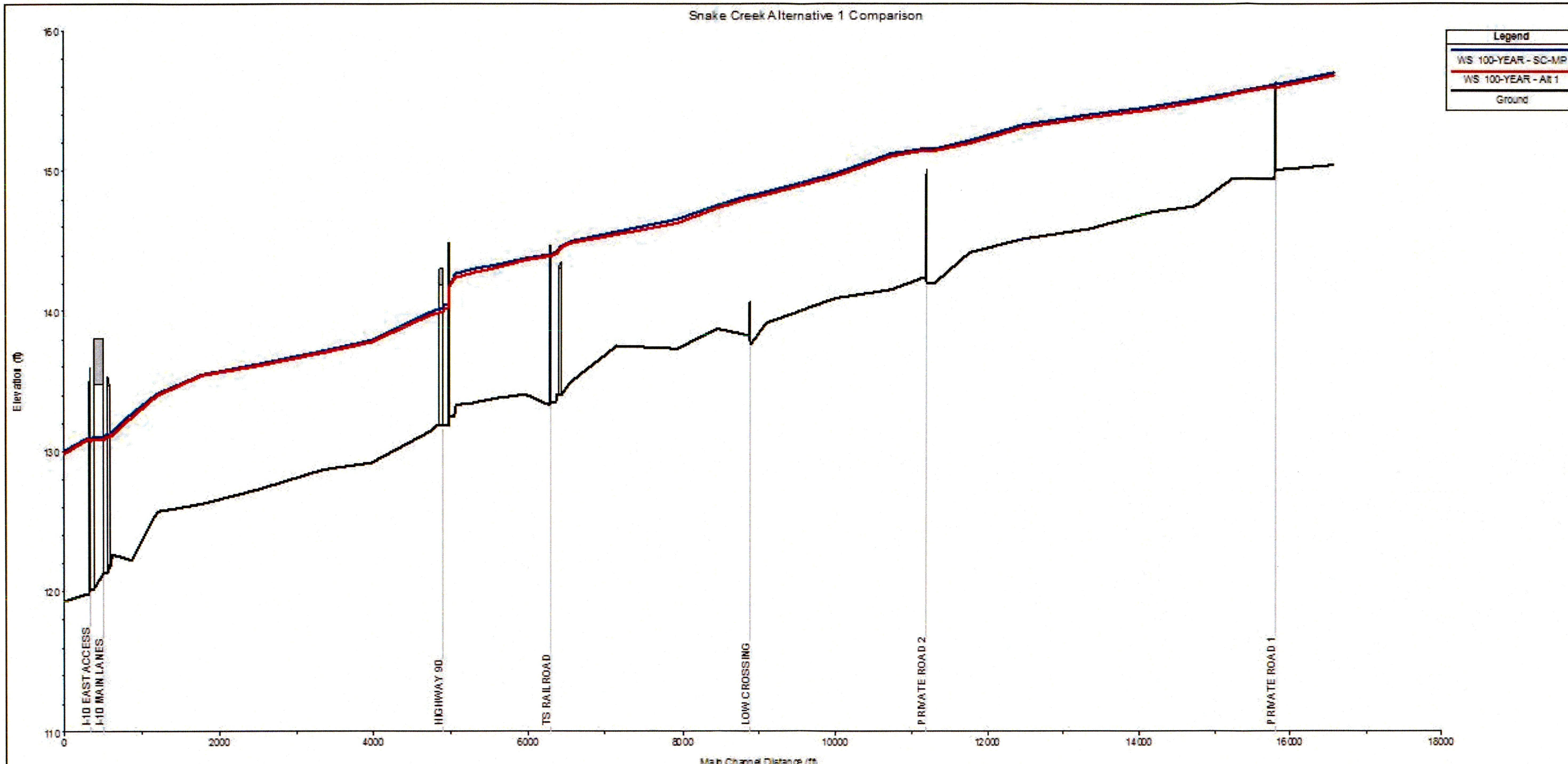


Figure B8. 100-yr profile comparison between existing and Alternative 1 (Snake Creek)

Figure B8

Alternative 2 – Detention and Channel Improvements

Alternative 2 consisted of upstream detention that would reduce flows through Snake Creek along with improvements to the existing channel and culvert crossings to further reduce the floodplain. The existing channel was widened reduce the 100-year floodplain to within the channel banks. The detention pond reduced the increased flows due to the larger channel down to existing conditions. Approximately 130-ft to 160-ft of Right-of-Way would be required to accommodate the improved channel. The Right-of-Way includes the proposed channel bottom width, side slopes of 3:1 and 30 feet for maintenance access on either side of the channel. The existing channel has an average top width of 50-ft. The floodplain throughout the basin is reduced to be inside the improved channel banks and potentially removes 684 acres of developable property from the floodplain. This alternative reduced the floodplain throughout the entire reach.

A comparison of existing and the alternative 100-year floodplains for Snake Creek can be seen in **Figure B9** and **Figure D8** in Appendix D. A profile comparison can be seen in **Figure B10**. The detention pond requires a volume of 356 acre-ft. A preliminary estimate of probable cost for the design and construction of the upstream pond is shown in **Table B8**.

Table B8: Preliminary probable cost estimate Snake Creek Alternative 2

Snake Creek				
Item	**Unit**	**Unit Price**	**Quantity**	**Cost**
Land Acquisition	LS	$ 800,000	1	$ 800,000
Detention	AC-ft	$ 20,000	356	$ 7,120,000
Channel Excavation	CY	$ 15	40000	$ 600,000
8'x6' Reinforced Concrete Box	LF	$ 600	50	$ 30,000
			Total	$ 8,550,000
			Contingency (30%)	$ 2,565,000
			Grand Total	$ 11,115,000

A BCR was not determined for this alternative since there are no habitable structures in the floodplain.

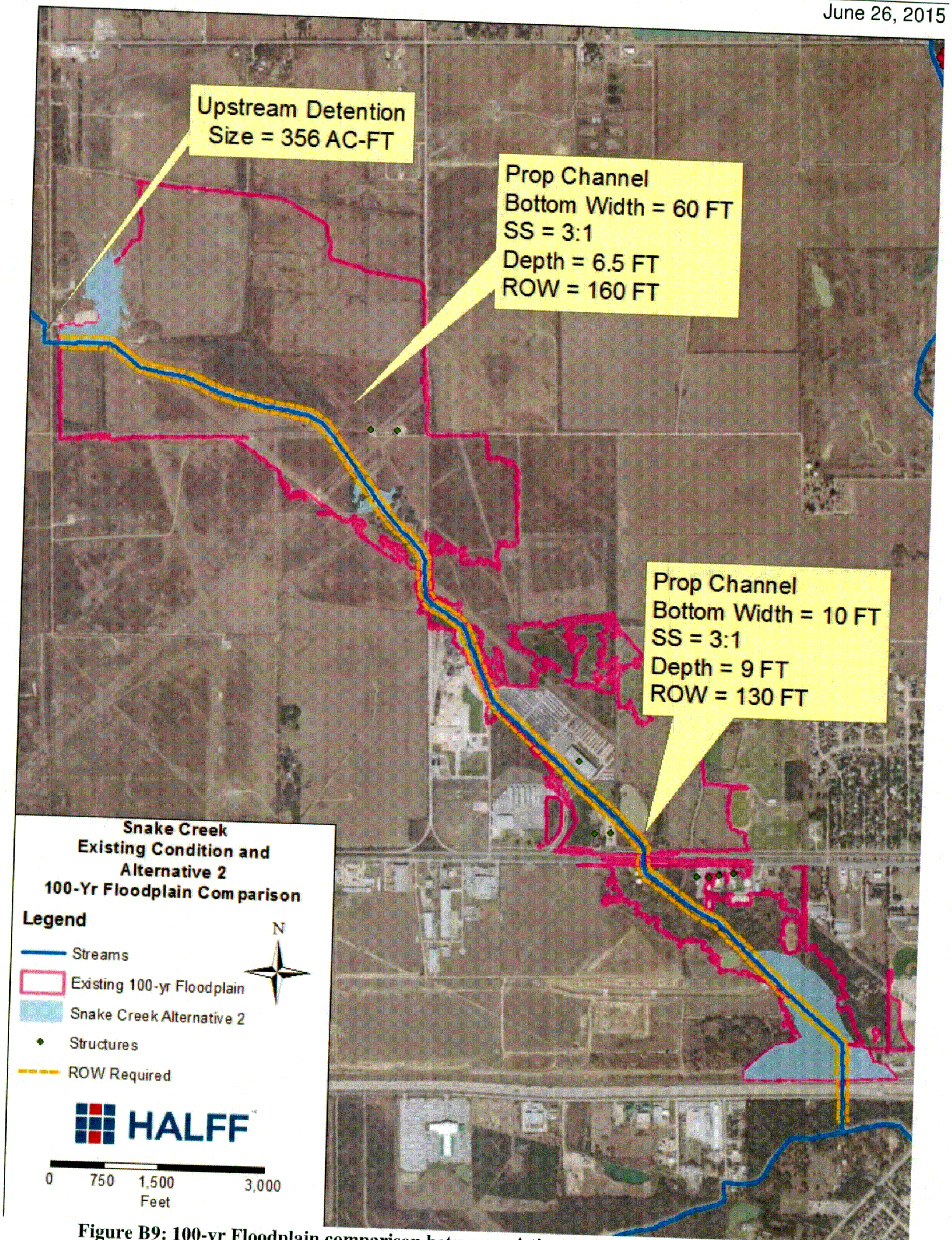


Figure B9: 100-yr Floodplain comparison between existing and Alternative 2 (Snake Creek)

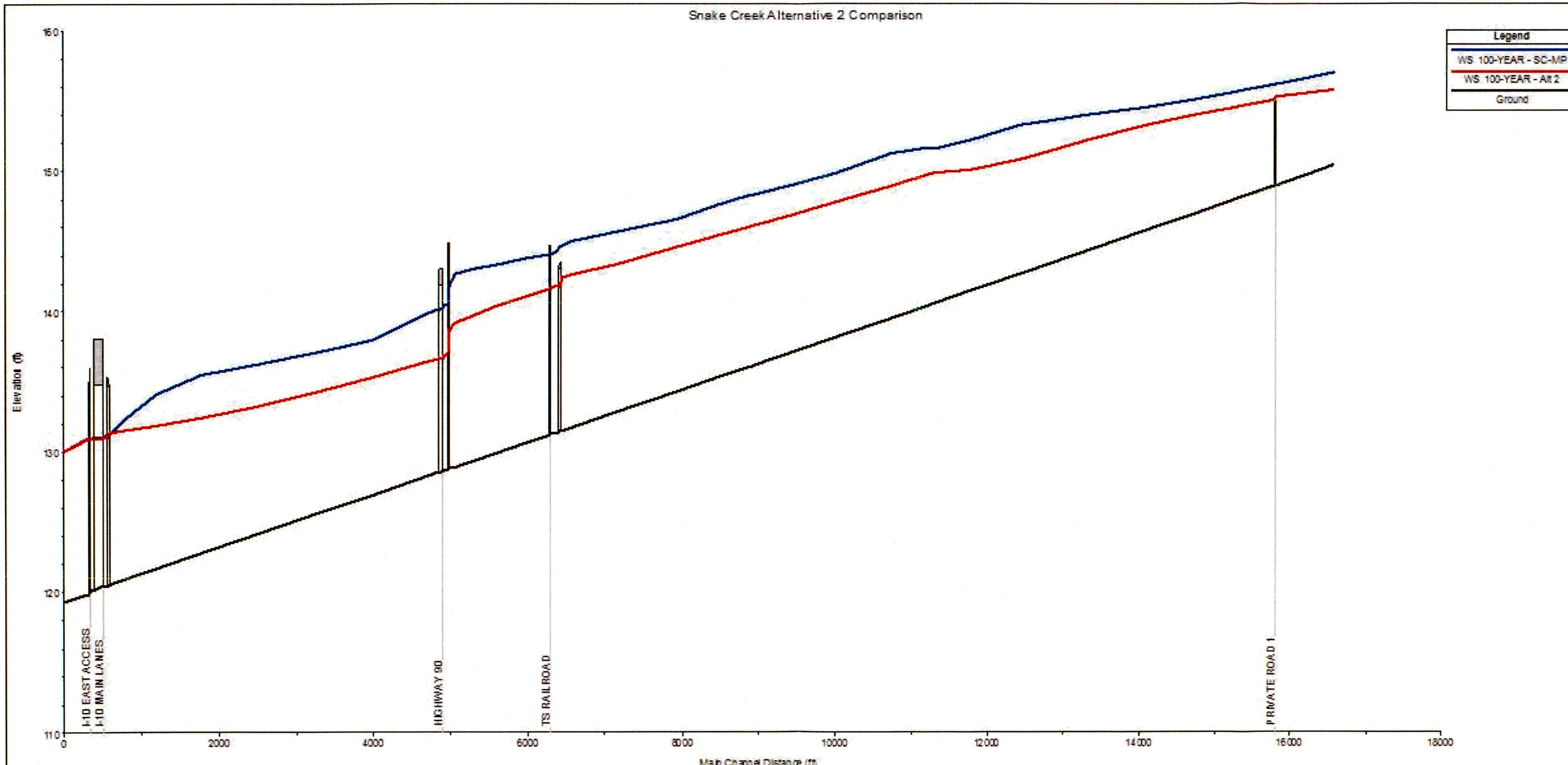


Figure B10. 100-yr profile comparison between existing and Alternative 2 (Snake Creek)

Figure B10

B.4 Willow Fork Alternatives

Two structural flood damage reduction alternatives were considered for Willow Fork. These alternatives are described in **Table B9** below. Both alternatives require significant detention sites and Alternative 2 consists of channel improvements. Currently, there are no flooded habitable structures in the floodplain for Willow Fork in Waller County, but each alternative addresses reducing the floodplain to prepare for future development. The alternatives analyzed are discussed below:

Table B9: Willow Fork Alternative Descriptions

Alternative Name	Description
Alternative 1	Large upstream detention – Approximately 1,200 acre-ft of detention needed to reduce flows downstream to 25-year storm.
Alternative 2	Detention along with channel improvements to reduce flow and floodplains downstream. Approximately 1,800 acre-ft of detention along with large channel improvements.

Alternative 1 – Upstream Detention at Morton Road

Alternative 1 consisted of upstream detention that would reduce flows through the upper reaches of Willow Fork. This alternative attempted to reduce the existing 100-year floodplain down to a 25-year floodplain by upstream detention. By detaining the flow to a 25-year storm, the flooding area is reduced in areas of Waller County. The amount of detention required upstream of Morton Road is approximately 1,200 ac-ft. This alternative potentially removes 855 acres from the floodplain in Waller County and subsequently Fort Bend County.

A comparison of existing and the alternative 100-year floodplains for Willow Fork can be seen in **Figure B11** and a profile comparison can be seen in **Figure B12**. Currently, the detention pond is proposed to be north of Morton Road in a tract of land owned by the City of Houston Airport System. Waller County expressed interest in making this area a regional detention pond. The detention volume could be spread over several parcels of land in order to detain the required volume if needed. Infrastructure along the existing roadside ditches along Morton Road would be required in order to route flow from the upper basins of Willow Fork into the proposed pond. A preliminary estimate of probable cost for the design and construction of the upstream pond is shown in **Table B10**.

Table B10: Preliminary probable cost estimate Willow Fork Alternative 1

Willow Fork				
Item	**Unit**	**Unit Price**	**Quantity**	**Cost**
Land Acquisition	AC	$ 10,000	300	$ 3,000,000
Detention	AC-FT	$ 16,000	1200	$ 19,200,000
			Total	$ 20,250,000
			Contingency (30%)	$ 6,660,000
			Grand Total	$ 28,860,000

A BCR was not determined for this alternative since there are no habitable structures in the floodplain.

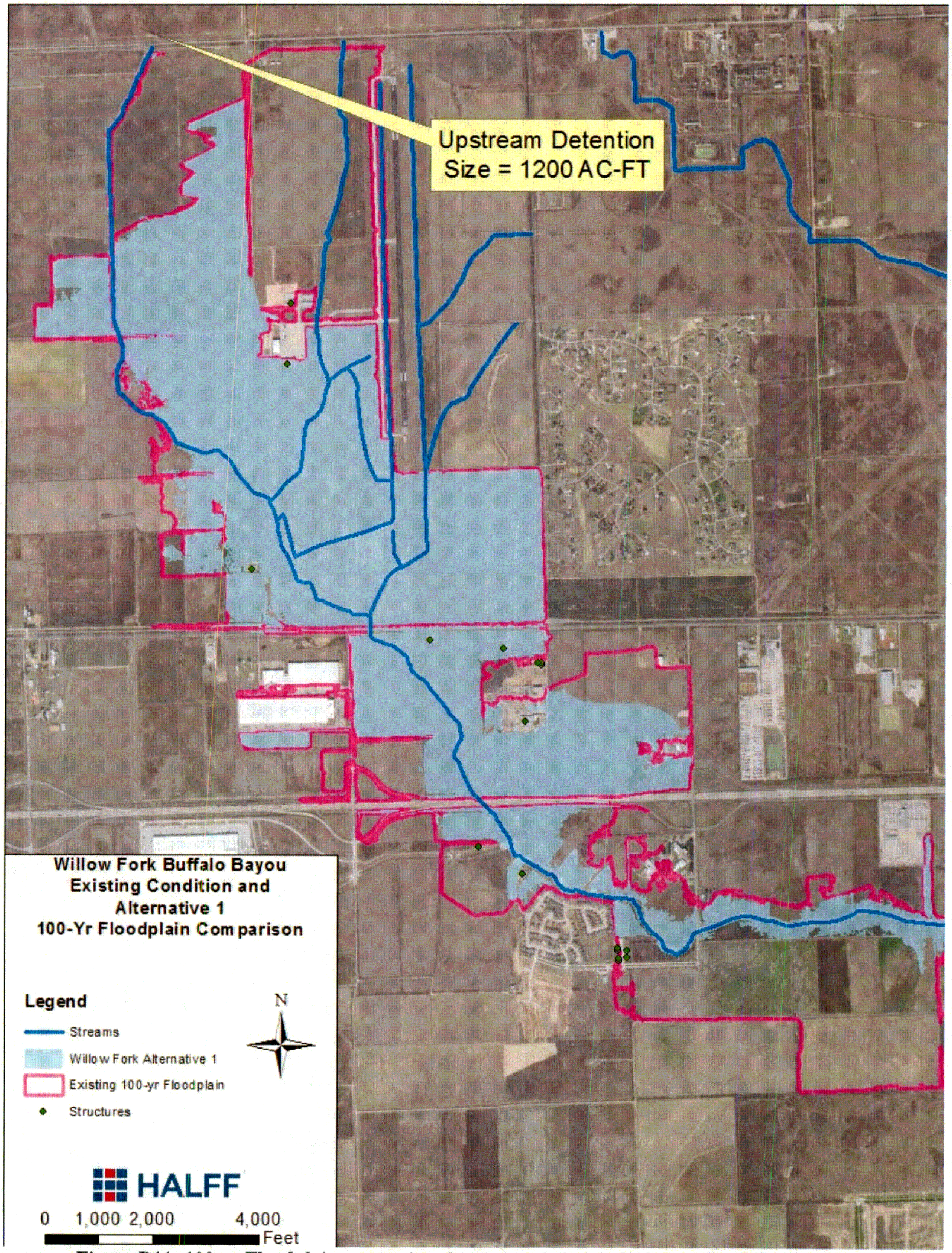


Figure B11: 100-yr Floodplain comparison between existing and Alternative 1 (Willow Fork)

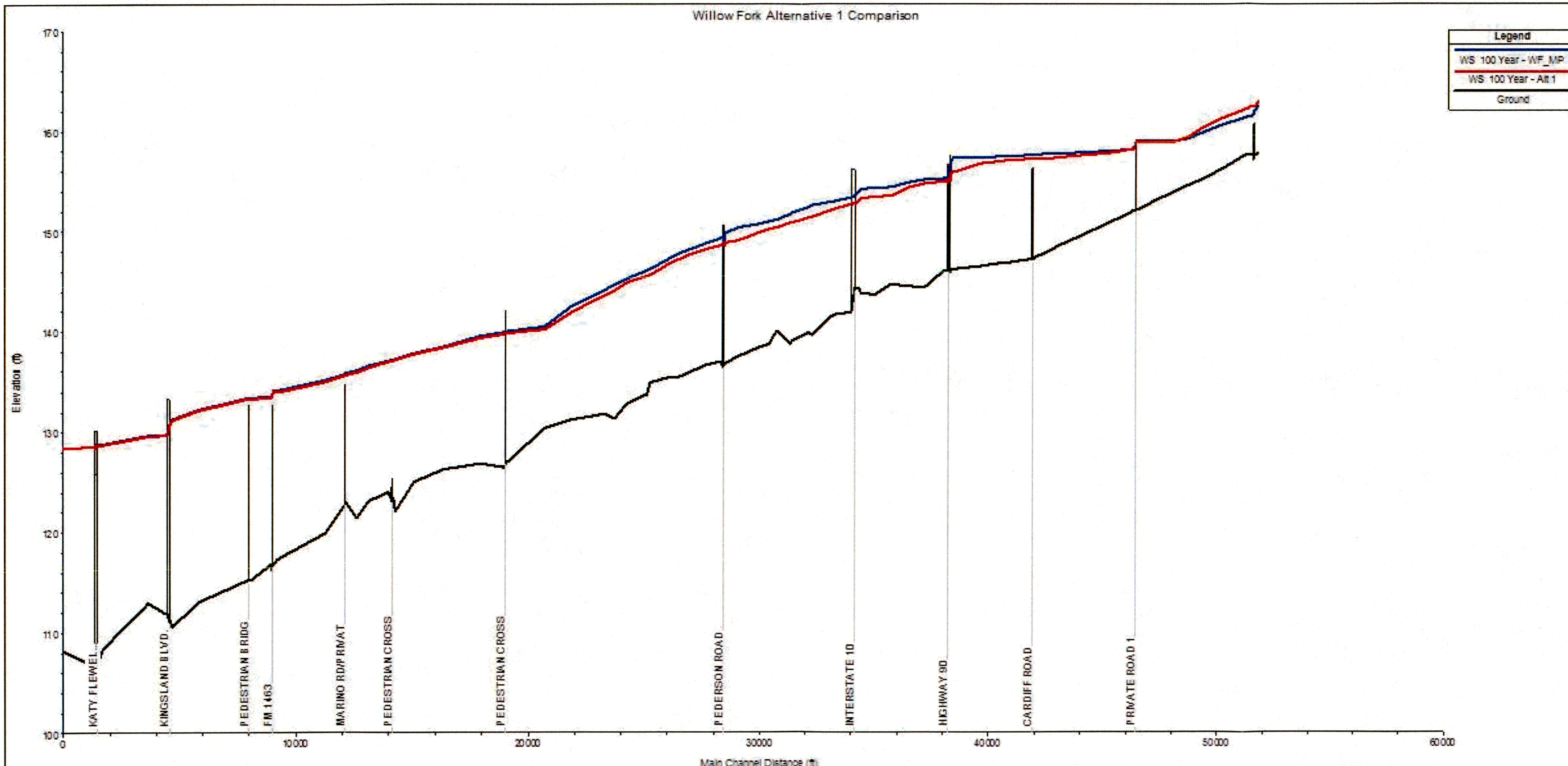


Figure B12. 100-yr profile comparison between existing and Alternative 1 (Willow Fork)

Figure B12

Alternative 2 – Upstream Detention and Channel Improvements

Alternative 2 consisted of upstream detention that would reduce flows through Willow Fork along with improvements to the existing channel and culvert crossings to further reduce the floodplain. The existing channel was widened to reduce the 100-year floodplain to within the channel banks upstream of US-90. The detention pond reduced the increased flows due to the larger channel down to existing conditions downstream of any channel improvements. Approximately15 0 to 220 feet of Right-of-Way would be required to accommodate the improved channel. The Right-of-Way includes the proposed channel bottom width, side slopes of 3:1 and 30 feet for maintenance access on either side of the channel. This alternative reduced the floodplain throughout the entire upper reach.

A comparison of existing and the alternative 100-year floodplains for Willow Fork can be seen in **Figure B13** and a profile comparison can be seen in **Figure B14**. The detention pond requires a volume of 1,800 acre-ft. The increase in channel width will require additional Right-of-Way and additional culverts at the private road crossing in the upstream section of Willow Fork. A preliminary estimate of probable cost for the design and construction of the upstream pond is shown in **Table B11**.

Table B11: Preliminary probable cost estimate Willow Fork Alternative 2

Willow Fork				
Item	**Unit**	**Unit Price**	**Quantity**	**Cost**
Land Acquisition	AC	$ 10,000	300	$ 3,000,000
Detention	AC-FT	$ 20,000	1800	$ 36,000,000
Channel Excavation	CY	$ 15	130000	$ 1,950,000
8'x6' Reinforced Concrete Box	LF	$ 600	165	$ 99,000
			Total	$ 41,049,000
			Contingency (30%)	$ 12,314,700
			Grand Total	$ 53,363,700

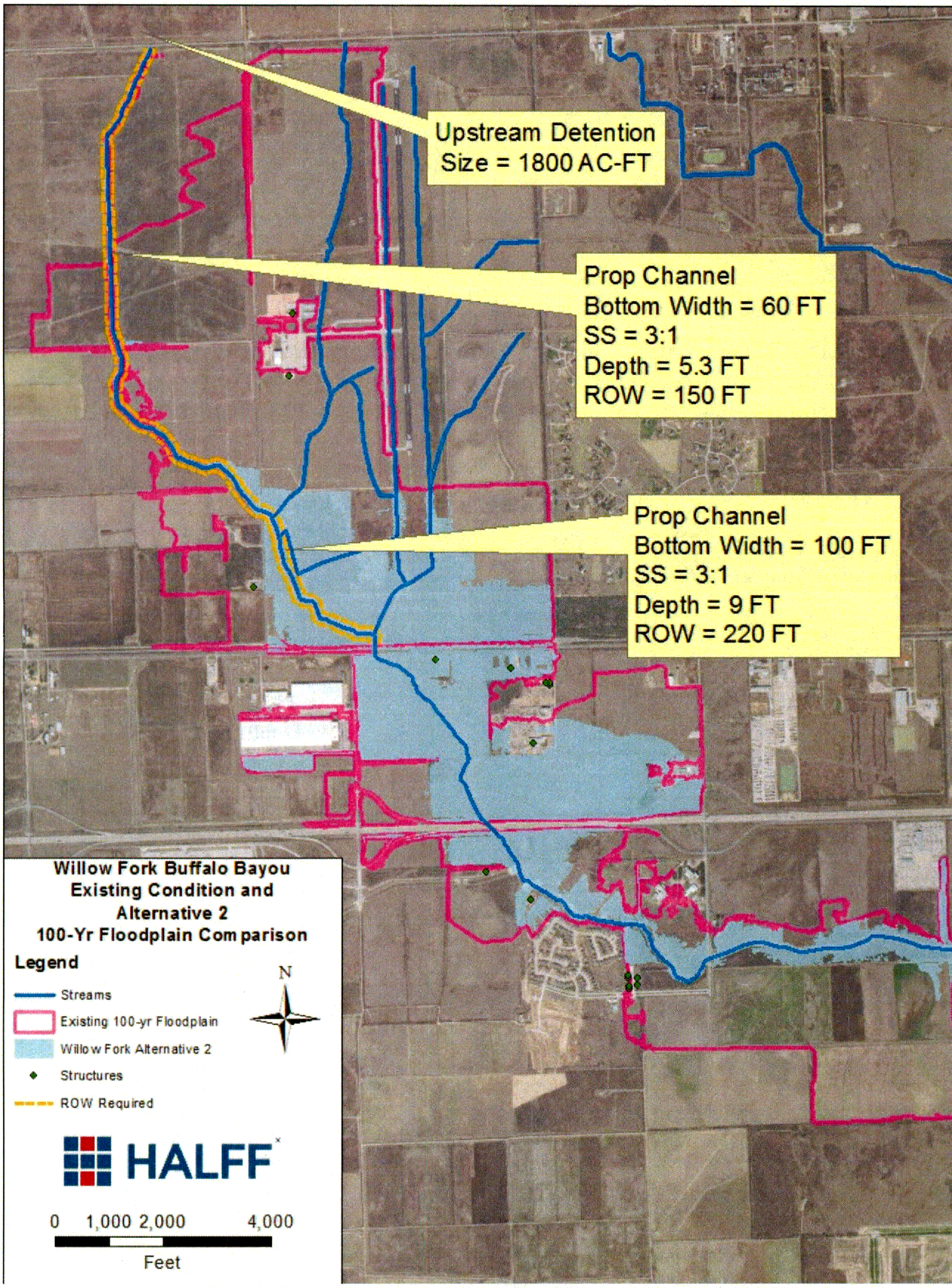


Figure B13: 100-yr Floodplain comparison between existing and Alternative 2 (Willow Fork)

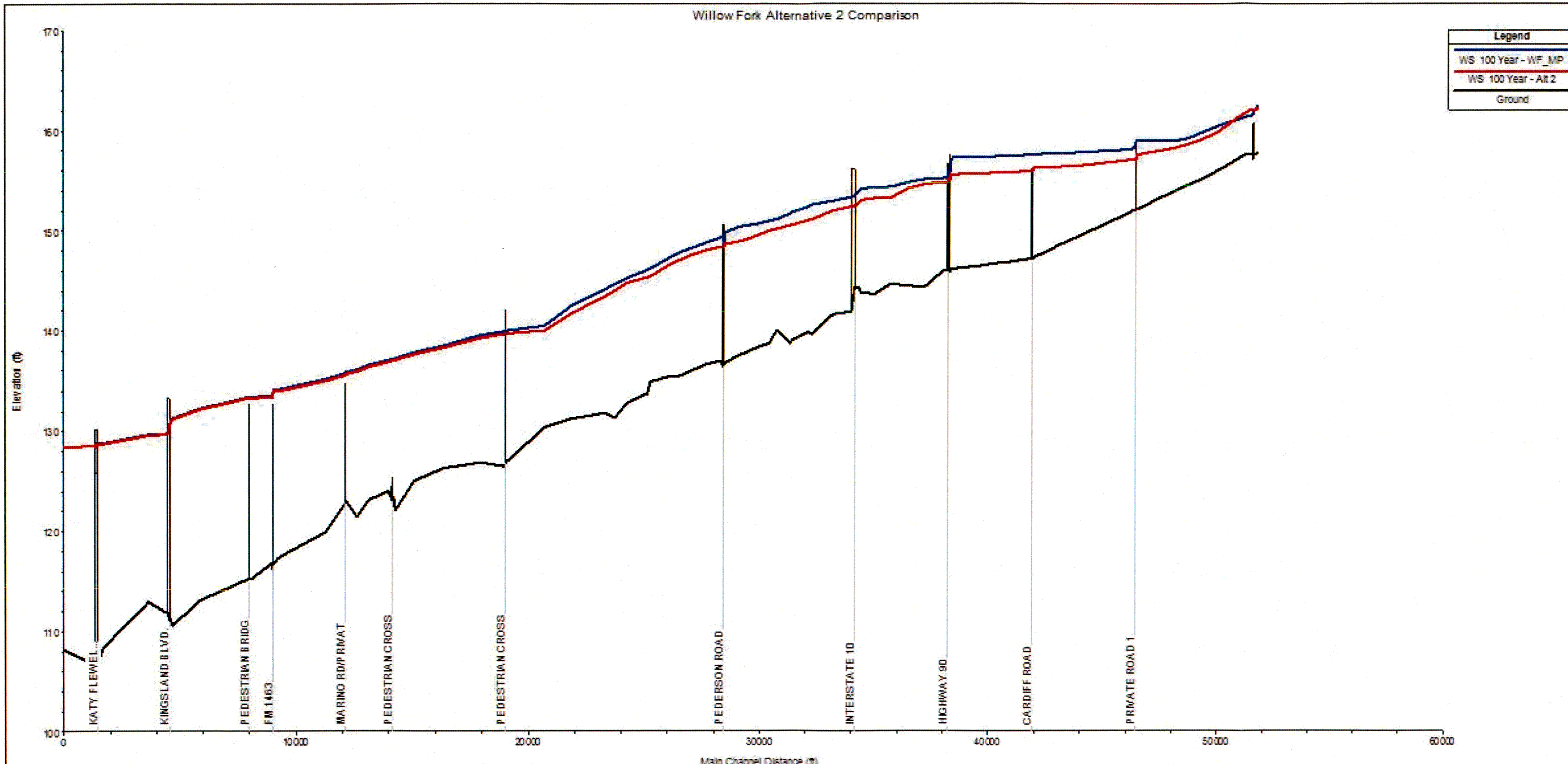


Figure B14. 100-yr profile comparison between existing and Alternative 2 (Willow Fork)

Figure B14

B.5 Combined Alternative

A final alternative was conducted to determine the required improvements for the entire Upper Barker Watershed. The combined alternative assumed that each sub-basin would be independent, eliminating any overflow occurring in the existing conditions analysis. This alternative incorporated the ongoing watershed master drainage plan proposed by the BKDD.

The Combined Alternative would eliminate any additional detention required in Cane Island Branch, placing all detention in the Snake Creek and Willow Fork basins. The redirecting of the overflow from the upper basin of Cane Island Branch to the Willow Fork potentially reduces the flows by 35% in Cane Island Branch at Pitts Road. As a result of the diversion, no other improvements are proposed in Cane Island Branch.

The Snake Creek Basin was also restricted from allowing overflow into Cane Island Branch. This involves channelizing the existing stream from Schlipf Road to US-90 while mitigating any increase in flows with 610 ac-ft detention upstream of Schlipf Road as well as 120 ac-ft downstream near Bartlett Road. The channel would be improved to carry a 25-year storm capacity from Schlipf Road to the confluence with Willow Fork. The amount of Right-of-Way required ranges from 130-ft to 150-ft to accommodate the improved channel. The Right-of-Way includes the proposed channel bottom width, side slopes of 3:1 and 30 feet for maintenance access on either side of the channel. The existing channel has an average top width of 50-ft. The floodplain throughout the basin is reduced to be inside the improved channel banks.

In order to accommodate the redirected flow from the upper portion of Cane Island Branch, Willow Fork will need to be expanded from Morton Road to the Railroad Crossing upstream of US-90 while mitigating any increase in flows with 2,800 ac-ft of detention upstream of Morton Road. The channel would be improved to carry a 25-year storm capacity from Morton Road to Railroad Crossing upstream of Highway 90. Approximately 210 feet of Right-of-Way would be required to accommodate the improved channel and contain the floodplain within the banks. The existing channel has an average top width of 50-ft. The floodplain is reduced to be inside the improved channel banks.

This comprehensive alternative for Cane Island Branch, Snake Creek, and Willow Fork potentially removes 141 habitable structures and 2,616 acres from the floodplain throughout the Upper Barker watershed.

A comparison of existing and the alternative 100-year floodplains for Willow Fork can be seen in **Figure B15** and a profile comparison can be seen in **Figure B16**. A large map is shown on **Figure D9** in Appendix D. A preliminary estimate of probable cost for the design and construction of the upstream pond is shown in **Table B12**.

Table B12: Preliminary probable cost estimate Combined Alternative

Combined Alternative				
Item	**Unit**	**Unit Price**	**Quantity**	**Cost**
		Snake Creek		
Land Acquisition	AC	$ 10,000	450	$ 4,500,000
Detention	AC-FT	$ 20,000	750	$ 15,700,000
Channel Excavation	CY	$ 15	40000	$ 600,000
8'x6' Reinforced Concrete Box	LF	$ 600	50	$ 30,000
		Willow Fork		
Land Acquisition	AC	$ 10,000	550	$ 5,500,000
Detention	AC-FT	$ 20,000	2800	$ 56,000,000
Channel Excavation	CY	$ 15	130000	$ 1,950,000
8'x6' Reinforced Concrete Box	LF	$ 600	165	$ 99,000
			Total	$ 83,279,000
			Contingency (30%)	$ 24,983,700
			Grand Total	$ 108,262,700

The BCR for this alternative did not score well due to the shallow flooding in the overbanks and the resulting low damages. The benefits to this alternative were under $480,000 resulting in a BCR of 0.00.

The Comprehensive Alternative provides benefit to Waller, Harris, and Fort Bend Counties. These counties could work together to develop a funding plan to implement this project. The amount of land that is removed from the floodplain from these projects could result in no floodplain mitigation requirements for development near the creeks.

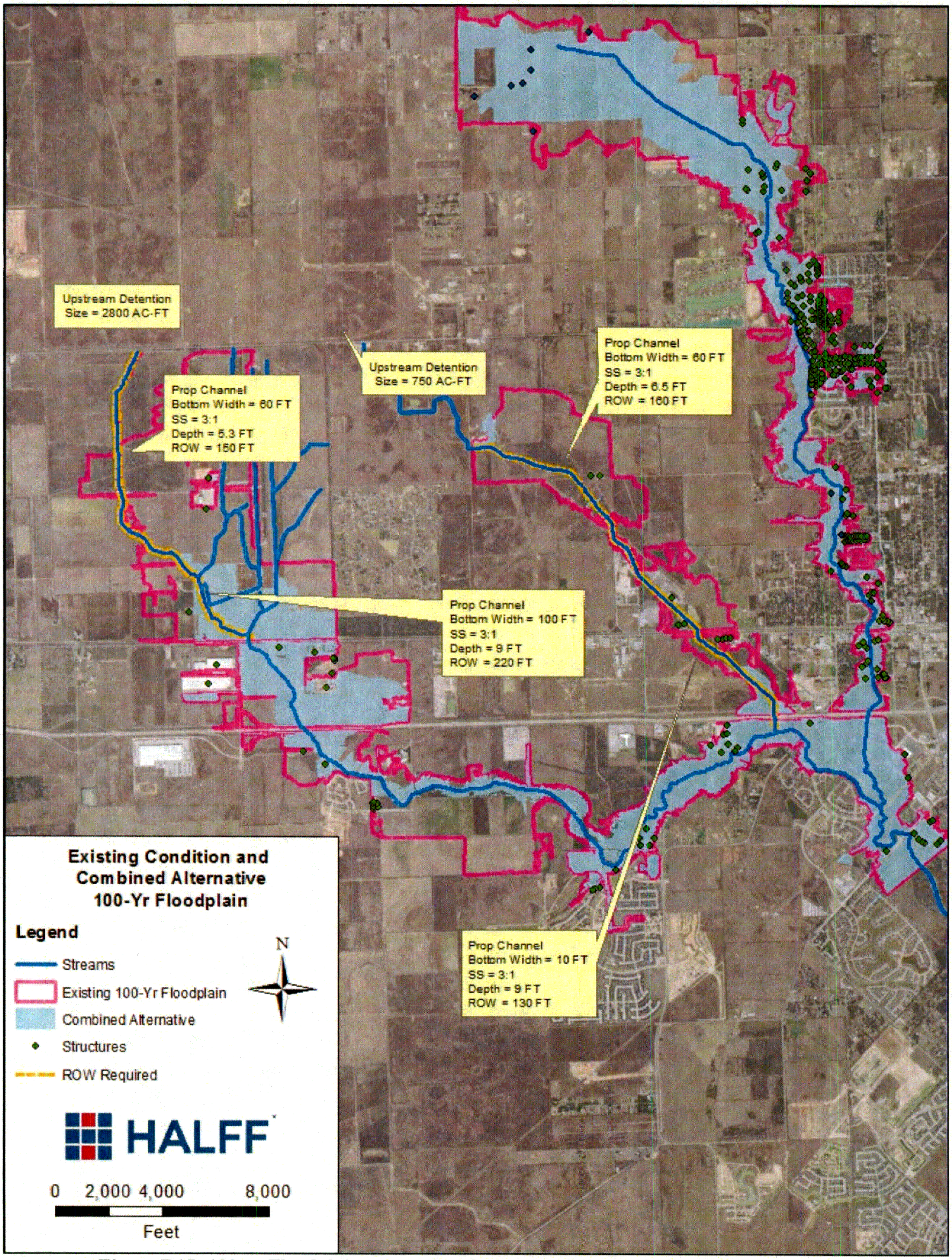


Figure B15: 100-yr Floodplain comparison between existing and Combined Alternative

B.6 Future Conditions

Future conditions in the Upper Barker Watershed were considered and evaluated as part of the Comprehensive Alternative. The land use in the Upper Barker Reservoir Watershed generally consists of pasture, agriculture, range, rural subdivisions, and woodland. Therefore, 80% of the basin in Waller County was considered to be developed to reflect future land use conditions in order to evaluate the hydrologic impact. Consideration was also given to the development of the current rice fields and assuming no on site detention. The adjustments were made by changing the DLU, DET, and DPP values in **Table A3** that were used in the hydrologic analysis. The DLU was set to 80% and the DET and DPP values were set to 0%. In general, the flows increased in the watershed by 85%. Regional detention options in lieu of site detention resulted in nearly doubling the size of the proposed detention alternatives which were sized to address existing conditions. Therefore, the proposed detention alternatives can be used to either reduce the existing conditions flood risk or to mitigate the future conditions development in lieu of site detention. If the proposed detention facilities are to be used to address both existing and future conditions, the proposed detention will need to be doubled.

Appendix C

APPENDIX C: Environmental Constraints Summary

For the purposes of the environmental constraints review, the planning study area includes the Upper Barker Watershed. The study area is within three counties: Waller, Fort Bend, and Harris between Katy and Brookshire, Texas. Numerous sources were reviewed to identify potential environmental constraints in the planning study area. Sources and data reviewed include the following: U.S Census Bureau community & socio-economic data, Texas Parks & Wildlife Department (TPWD) threatened and endangered species by county, United States Fish & Wildlife Service (USFWS) species by county, critical habitat, and national wetland inventory, Texas Commission of Environmental Quality (TCEQ) hazardous materials sites, cultural resources data from the Texas Historical Commission (THC), and other spatial information including roads, railroads, and waterwells. The occurrences of these constraints are displayed in **Figure C1**.

C.1 Socio-economics/Environmental Justice

Executive Order (EO) 12898 "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" requires each Federal agency to "make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies and activities on minority populations and low-income populations." Efforts will need to be made to engage minority and low-income persons through the project development process. Although minority and low-income persons are located within the project area, the proposed action is not expected to have adverse or disproportionate impacts on minority or low-income populations. The benefits of the flood control project are expected to equally benefit all residents. Public outreach planning for any future public involvement activities should take into consideration low-income and minority population.

C.2 Biological Resources

USFWS and TPWD county lists of Texas special species for Waller, Fort Bend, and Harris Counties were retrieved on November 4, 2014. Threatened or endangered species for each county is summarized below.

- **Waller County: USFWS lists one species as either threatened or endangered and TPWD lists 19 state threatened or endangered species.**
- **Harris County: USFWS lists 2 federal threatened or endangered species and TPWD lists 26 state threatened or endangered species.**
- **Fort Bend County: Two federal threatened or endangered species are listed by USFWS and TPWD lists 19 state threatened and endangered species.**

USFWS has delineated critical habitat for protected species and other protected areas. None of these areas were identified in the study area. A field visit by a qualified biologist is recommended prior to construction to determine the presence or absence of suitable habitat for these protected species.

C.3 Wetlands

Wetlands are identified as those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. A search of the USFWS national wetland inventory (NWI) database indicates that there are wetlands in the study area. **Figure C1** shows NWI locations within the Upper Barker watershed. These wetlands may be jurisdictional under Section 404 of the Clean Water Act and may require a permit prior to filling or dredging. It is recommended that a jurisdictional determination be performed in the field prior to construction in order to determine potential impacts to the waters of the United States.

C.4 Potential Hazardous Materials

The Texas Commission of Environmental Quality known hazardous materials database was reviewed for the study area. The data includes superfund sites, municipal solid waste sites, and permitted industrial hazardous waste sites. Four municipal solid waste sites were identified within the study area. There are no superfund or permitted industrial waste sites. Once the limits of the project are established during the design phase, a comprehensive database review and site visit are recommended to determine the level of assessment necessary. A Phase I Environmental Assessment may be needed prior to construction.

C.5 Physical Constraints

Physical constraints, such as railroads and roads, are depicted in **Figure C1** according to Texas Natural Resource Information Systems (TNRIS) data. Other constraints, such as water wells, are also shown. A field reconnaissance is recommended prior to construction to determine any conflicts with existing infrastructure.

C.6 Cultural Resources

Cultural resources are structures, buildings, archeological sites, districts (a collection of related structures, buildings, and/or archeological sites), cemeteries, and objects. Both federal and state laws require consideration of cultural resources during project planning. At the federal level, the National Environmental Policy Act and the National Historic Preservation Act of 1966, as amended, among others, apply to projects such as this one. In addition, state laws such as the Antiquities Code of Texas apply to these projects. Compliance with these laws often requires consultation with the THC/Texas State Historic Preservation Officer and/or federally-recognized tribes to determine the project's effects on cultural resources. Previously identified cultural resources in the study area such as cemeteries, national register properties, historical markers, and archeological surveys were reviewed from the THC data. There are two historical markers and one cemetery recorded in the study area. These are shown in **Figure C1**. To comply with federal and state laws regarding review and coordination, a site visit by an architectural historian and an archeologist to determine the likelihood of impacts on significant cultural resources would likely be required prior to construction. If any historical or archeological constituents are unexpectedly encountered in the study area during construction operations, appropriate measures should be taken with local, state, and federal officials.

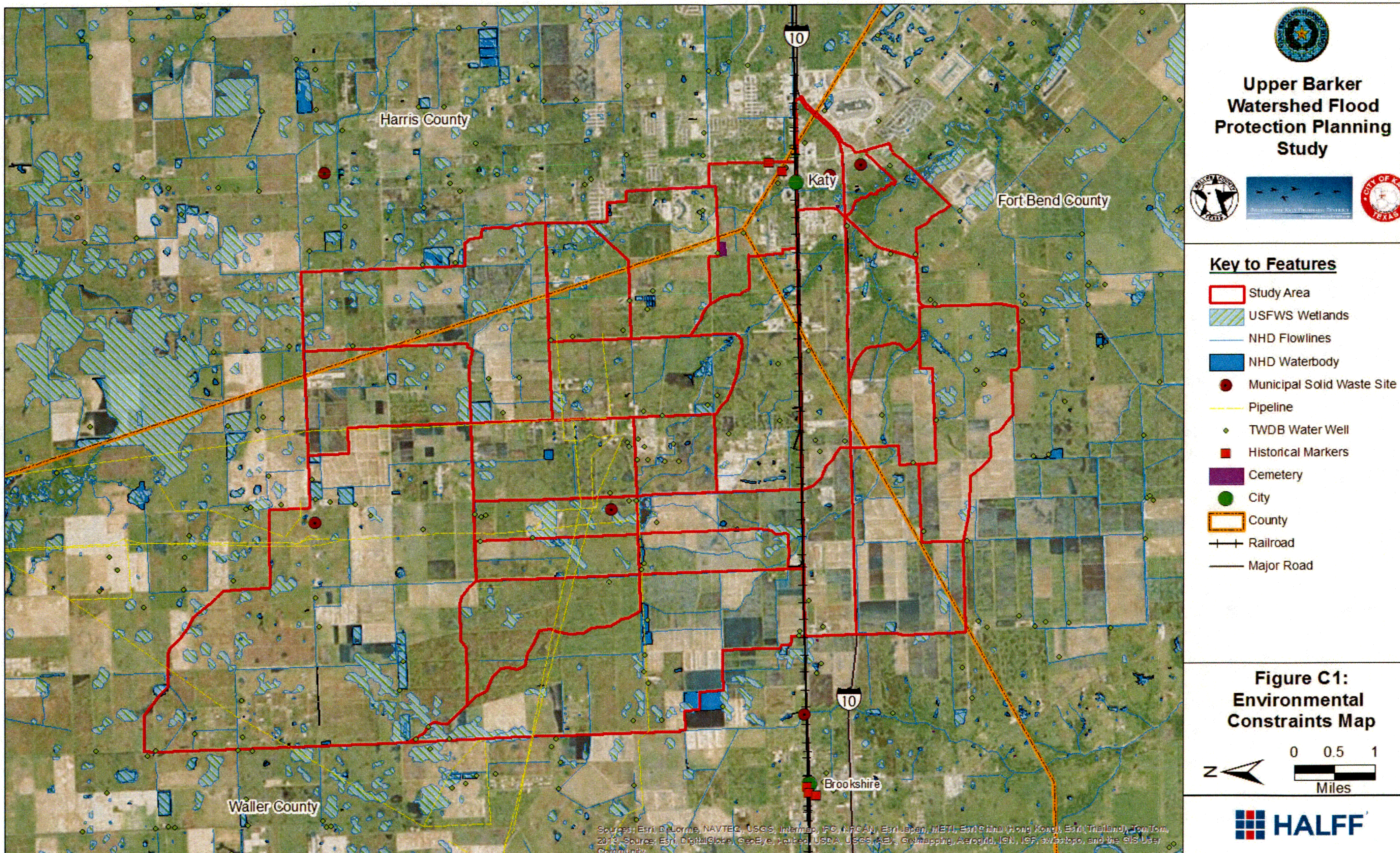


*Figure has been reduced to fit document and is not to scale.

List of References

CNN.com. 1998. Rescue Workers Help Stranded Texas Flood Victims. [Online] Available at: http://www.cnn.com/US/9810/18/texas.storms.02/. [Accessed 13 February 15].

Harris, Daniel PE, *Upper Cypress Creek Watershed Flood Protection Planning Study*. Prepared for Waller County, City of Prairie View, and City of Waller. November 16, 2012

Harris County Flood Control District, *Hydrology and Hydraulics Guidance Manual*. December 2009.

Harris County Flood Control District, *Policy, Criteria & Procedure Manual*. October 2004, Adopted December 2010.

Johnson, Burton, PE, *Draft Study Report: Cypress Creek Overflow Management Plan*. Prepared for Harris County Flood Control, Harris County, and TWDB. September 25, 2014.

Appendix D

APPENDIX D: Large Maps

Appendix E

APPENDIX E: Digital Data