Tres Palacios Watershed Flood Protection Planning Study Final Report

Prepared for:
Texas Water Development Board

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August 19, 2010

Prepared By:
Halff Associates Inc

STATE OF TEXAS
DANIEL LEE HARRIS
104646
LICENSED PROFESSIONAL ENGINEER

Daniel Lee Harris
8/19/2010
TBPE FIRM #312

For Wharton County, City of El Campo,
and Matagorda Drainage District #2

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EXECUTIVE SUMMARY

The Tres Palacios River, located in Wharton and Matagorda Counties has been the source of frequent flooding over the years and as recently as the Thanksgiving Day flood of 2004. 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 entire length of the Tres Palacios River from the headwaters in El Campo to its mouth at Tres Palacios Bay. Modeling was also completed for the El Campo Tributary to the Tres Palacios River in El Campo. Detailed LiDAR elevation data as well as cross-section and bridge/culvert 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-yr events. The resulting hydraulic data was then used to analyze various flood reduction alternatives for the City of El Campo, Wharton County and Matagorda County.

Eight El Campo flood reduction alternatives were analyzed during the flood damage reduction analysis. The damage reduction (benefits) provided by each alternative over the "without project" condition was compared to the respective costs with a benefit-to-cost (B/C) ratio. The recommended alternative, which had the highest B/C ratio, is the 25-yr earthen channel from Business 59 to CR 406. This alternative consists of channel widening with 4:1 side slopes and a 45 ft. bottom width and will allow the channel to contain up to the 25-yr flow.

In Matagorda County flood reduction options were analyzed for the residential communities along the Tres Palacios River. It was concluded from the analysis that detention options are extremely costly (greater than $60 million) and the benefits in flood damage reduction will most likely be much lower than the cost. Also, channel widening alternatives were analyzed with a similar result; the amount of flood reduction (less than 0.7 ft.) was small compared to the cost of channel widening. Although projects for flood reduction alone are not cost effective for Matagorda County, a viable alternative may be found when combined with other purposes such as water supply.

The hydraulic data was also used to examine the adequacy of bridges and culverts along the Tres Palacios River in both Wharton and Matagorda Counties for proper flow conveyance. A typical standard as taken from the TXDOT Hydraulic Design Manual is that county-maintained roads should pass at least the 5-yr flow and state-maintained roads should pass at least the 25-yr flow. Bridges and culverts that do not meet these standards should be considered for improvement.

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1.0 Introduction and Background

The Tres Palacios River watershed is located in the southern portion of Wharton County and the western Matagorda County (see Figure 1). The Tres Palacios watershed drains about 261.5 square miles and flows approximately 59.5 miles from its headwaters in El Campo, TX to Tres Palacios Bay. The terrain is generally characterized by level to undulating plains rising to the north with a timber belt of hardwoods along the river in most places. Along its length, the Tres Palacios River flows through many land use types. The river begins in the urban area of El Campo, flows through the agricultural areas of Wharton County and northern Matagorda County, and finally encounters four rural residential areas before entering Tres Palacios Bay. The topography varies from sea level at Tres Palacios Bay to about 100 feet above sea level (NGVD 88) in El Campo. Annual rainfall in the basin ranges from 40 to 47 inches per year.

Significant floods have occurred in Wharton and Matagorda Counties in 1913, 1922, 1926, 1935, 1938, 1957, 1985, 1991, 1998, 2001, and 2004. Most recently, the City of El Campo experienced extensive flood damages due to the Thanksgiving Day flood of 2004. Most parts of El Campo along the Tres Palacios were severely flooded as depicted in the photographs in Figure 2. Approximately five hundred homes in Wharton County were damaged during this flood. The 2004 flood also impacted residents of Matagorda County that live along the Tres Palacios River. The highest stage recorded at the Tres Palacios gage at FM 456 near Midfield, TX in Matagorda County, is 39.7 ft. in the November 2004 flood. Flood stage for this gage is 29 ft. The flood hazard sources include local stream flooding due to inadequate stream capacity, restrictions in the channels (including siltation), or tidal flooding. Local officials in the study area recognize that the blockages within the channel of the Tres Palacios River can back water up into the lesser tributaries resulting in additional flooding. These flood waters, in-turn, pose a major risk to both life and property in Wharton and Matagorda Counties.

As a result of frequent flooding and the potential for increased development in the area, Wharton 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 2008. Wharton County teamed with the City of El Campo and Matagorda Drainage District #2 to assess the local drainage problems, and to evaluate the overall flooding problems from a regional perspective. To facilitate regional input into the planning process, three public meetings were held within the Tres Palacios region. The first meeting was held in El Campo, TX on December 15, 2009, the second was held in Bay City, TX on March 23, 2010, and the final meeting was held in El Campo, TX on April 20, 2010. 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 City of El Campo, Wharton County, and Matagorda County.

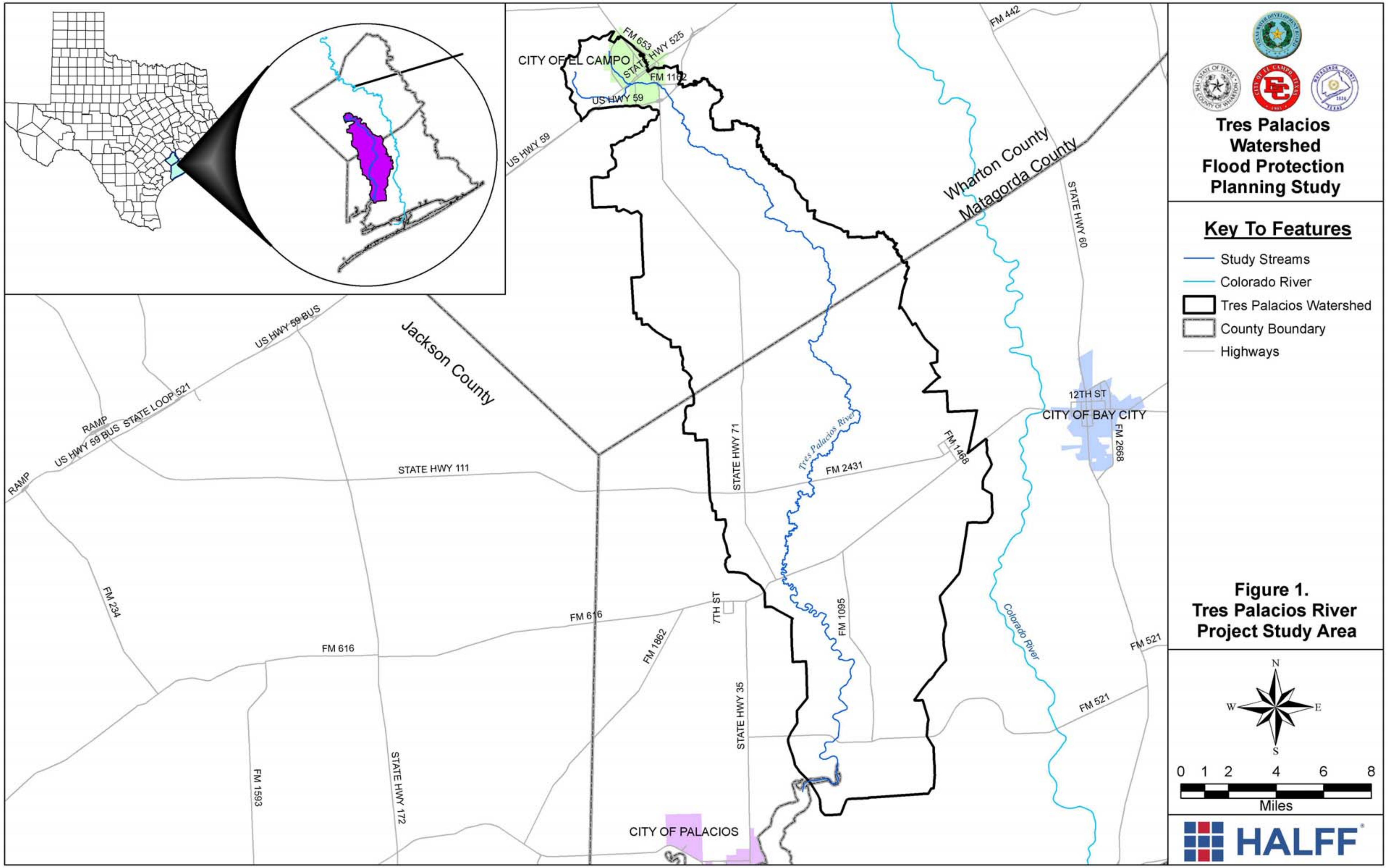


Figure 1.
Tres Palacios River
Project Study Area

Figure 1: Flooding from 2004 Event in El Campo, TX

This report presents the results of hydrologic, hydraulic, flood damage, and alternative analyses of the Tres Palacios Watershed. These analyses were completed in part through a teaming effort with the City of El Campo's consultant, HDR: Claunch and Miller (Figure 4). HDR: Claunch and Miller was responsible for creating existing conditions hydrologic and hydraulic models for the mainstem Tres Palacios River within the El Campo city limits as well as developing flood reduction alternatives for the City of El Campo (Appendix A). Halff Associates was responsible for existing conditions hydrologic and hydraulic models for the mainstem Tres Palacios River from the El Campo City limits to Tres Palacios Bay and the El Campo Trbutary. Halff Associates also performed the flood damage alternative analysis for the El Campo flood reduction alternatives created by HDR: Claunch and Miller as well as alternatives in Matagorda County. Items discussed in this report include:

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

NOTICE TO PUBLIC

The City of El Campo, Wharton County, and Matagorda County Drainage District #2 Announce a Public Meeting for the Tres Palacios Flood Protection Planning Project

The Public Meeting will commence from 3:00 PM to 5:00 PM on Tuesday, December 15, 2009, at the City of El Campo, City Council Chambers. The Council Chamber is located at 315 E. Jackson, El Campo, TX. 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 project. For more information, please contact Eric Scheibe, PE (Halff Associates, Inc.) at (512) 252-8184 or escheibe@halff.com.

NOTICE TO PUBLIC

The City of El Campo, Wharton County, and Matagorda County Drainage District #2 Announce a Public Meeting for the Tres Palacios Flood Protection Planning Project

The Public Meeting will commence from 5:00 PM to 7:00 PM on Tuesday, March 23, 2010, at the Bay City Service Center (North Club Room), located at 1912 Avenue I, Bay City, TX. The purpose of this meeting will be to update the various communities on the overall status of this project including the various flood reduction alternatives currently evaluated. The public is invited to attend and provide feedback needed to enhance the overall quality of this project. For more information, please contact Eric Scheibe, PE (Halff Associates, Inc.) at (512) 252-8184 or escheibe@halff.com.

NOTICE TO PUBLIC

The City of El Campo, Wharton County, and Matagorda County Drainage District #2 Announce a Public Meeting for the Tres Palacios Flood Protection Planning Project.

The Public Meeting will commence from 5:30 PM to 7:30 PM on Tuesday, April 20, 2010, at the City of El Campo, City Council Chambers. The Council Chamber is located at 315 E. Jackson, El Campo, TX. The purpose of this meeting will be to update the various communities on the final conclusions and recommendations of this project. The public is invited to attend and provide feedback. For more information, please contact Eric Scheibe, PE (Halff Associates, Inc.) at (512) 252-8184 or escheibe@halff.com.

Figure 2: Copies of Notices Posted for the Three Public Meetings

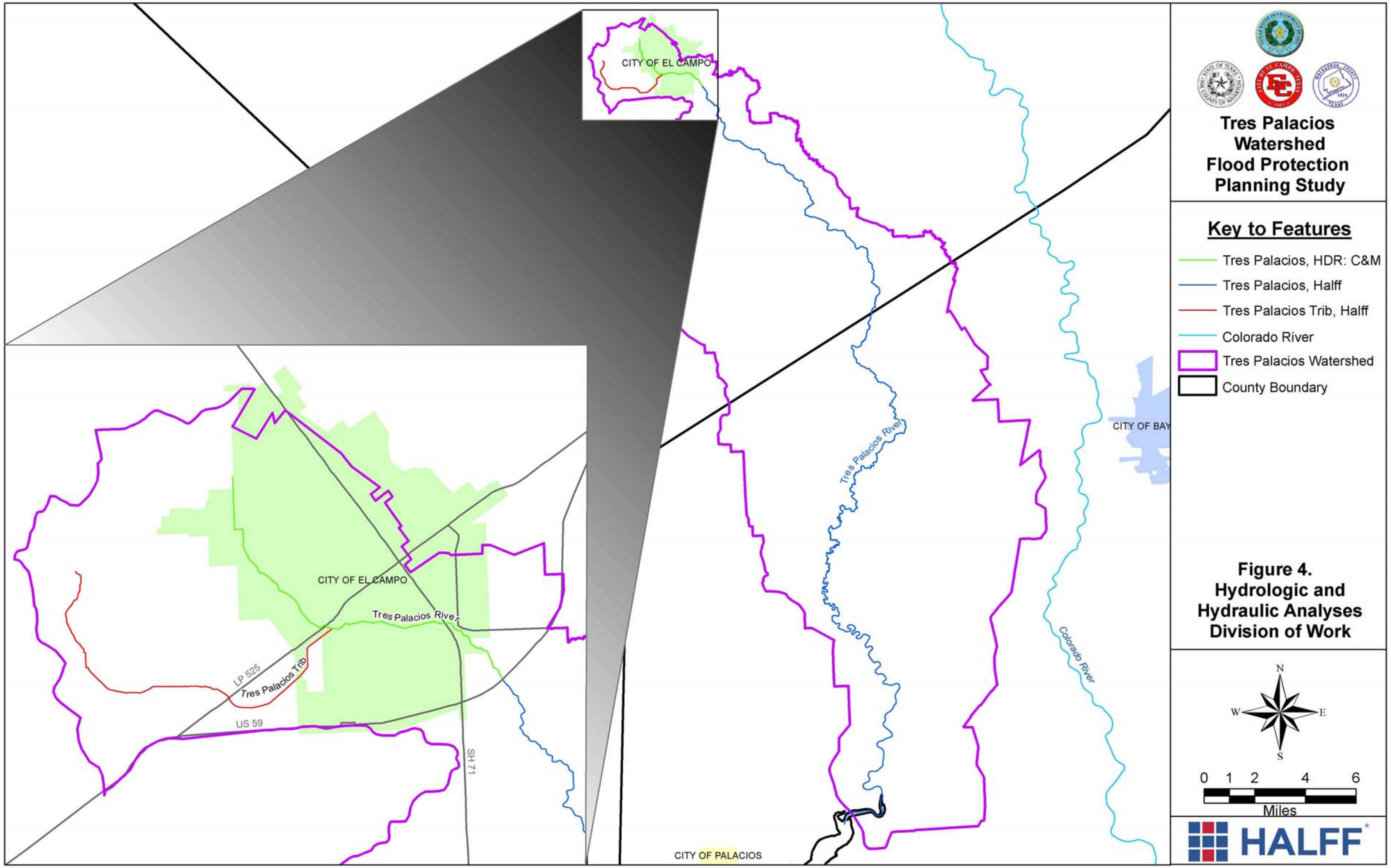


Figure 4. Hydrologic and Hydraulic Analyses Division of Work

2.0 Watersheds

The watershed for the Tres Palacios River was delineated utilizing HEC-GeoHMS and manually refined to better match existing drainage networks. Within Wharton County, new 1.4 m LiDAR data (September 2006) with a vertical Root Mean Squared Error (RMSE) of 18.5 cm was used. In El Campo, more detailed 0.7m LiDAR data with a vertical RMSE of 15 cm was used. For areas outside of Wharton County, a coastal LiDAR dataset with 37 cm RMSE was used. A total of 23 sub-basins were delineated from the Tres Palacios headwaters to Tres Palacios Bay in Matagorda County. Figure 5 illustrates the overall watershed delineation for the Tres Palacios River along with each sub-basin. Table 1 is a summary of stream names and drainage areas for each sub-basin. Sub-basin TP-01 was further subdivided for the studies along the mainstem within El Campo and the El Campo Tributary, and these sub-basins are provided in Appendices A and B, respectively.

Table 1: Sub-basin Names and Areas

SUB-BASIN	STREAM NAME	DRAINAGE AREA (acres)	DRAINAGE AREA (mi^2)
TP-01	Tres Palacios River	6803.7	10.63
TP-02	Tres Palacios River	4481.3	7.00
TP-03	Tres Palacios River	7126.5	11.14
TP-04	Tadpole Creek	6288.1	9.83
TP-05	Tres Palacios River	10574.3	16.52
TP-06	Tres Palacios River	9077.3	14.18
TP-07	Juanita Creek	11250.1	17.58
TP-08	Juanita Creek	7964.8	12.44
TP-09	Juanita Creek	6549.0	10.23
TP-10	Juanita Creek	4743.9	7.41
TP-11	Unnamed Tributary	6664.3	10.41
TP-12	Tres Palacios River	10657.4	16.65
TP-13	Tres Palacios River	5525.7	8.63
TP-14	Tres Palacios River	6237.9	9.75
TP-15	Tres Palacios River	5099.4	7.97
TP-16	Tres Palacios River	9095.0	14.21
TP-17	Tres Palacios River	7830.5	12.24
TP-18	Wilson Creek	6646.5	10.39
TP-19	Wilson Creek	8723.0	13.63
TP-20	Wilson Creek	5994.9	9.37
TP-21	Tres Palacios River	8002.7	12.50
TP-22	Tres Palacios River	7699.4	12.03
TP-23	Tres Palacios River	4303.7	6.72

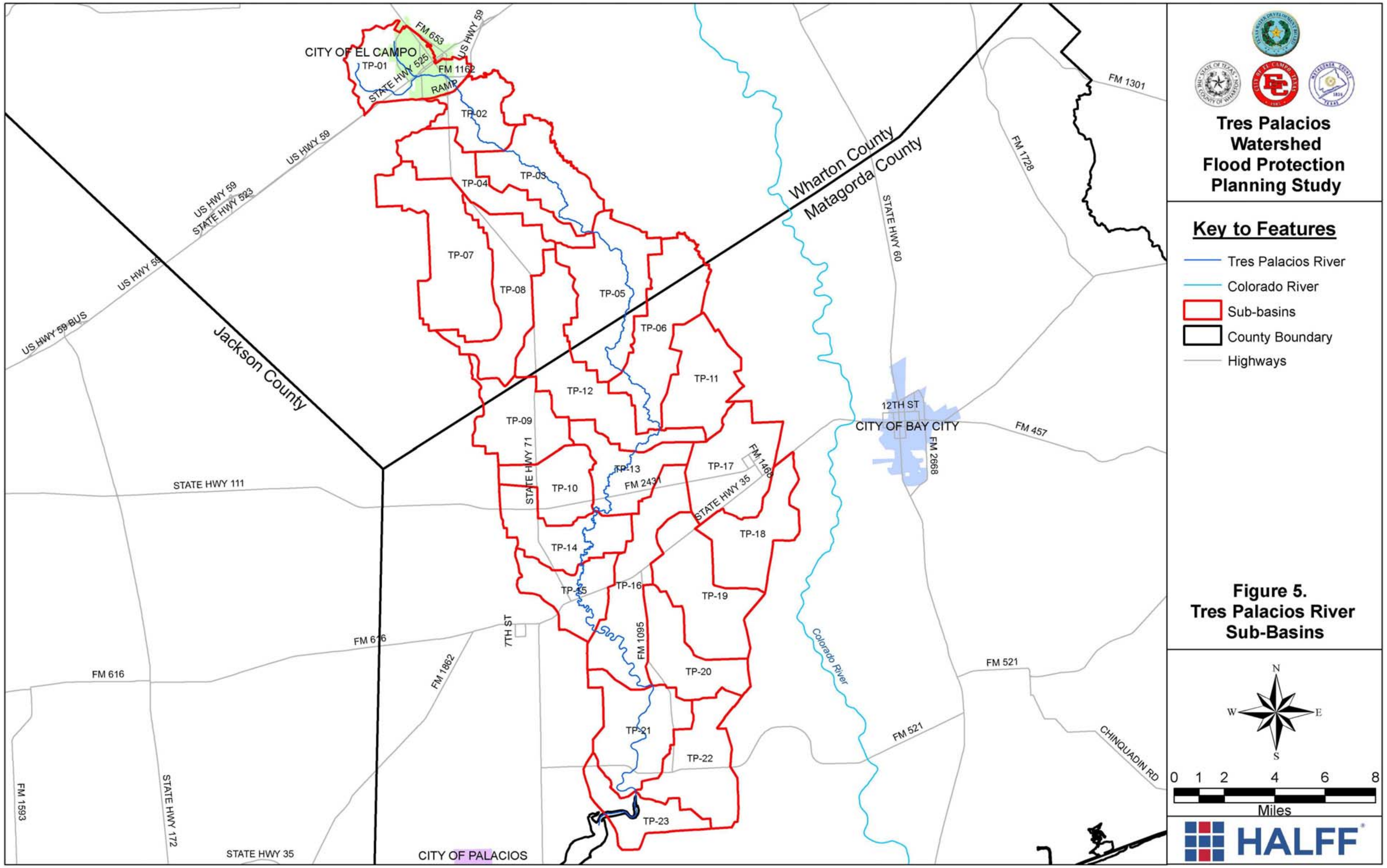


**Figure 5.
Tres Palacios River
Sub-Basins**

3.0 Hydrologic Analysis

A detailed hydrologic analysis was performed on the Tres Palacios watershed with the goal of providing a calibrated base conditions model for use in developing flood damage reduction alternatives, and helping to quantify the impacts of these alternatives to the surrounding area. Hydrologic Analyses for the mainstem in El Campo and the El Campo Tributary are summarized in Appendices A and B, respectively.

The hydrologic analysis downstream of El Campo was conducted with the aid of the US Army Corps of Engineers HEC-HMS software, version 3.3. The HEC-HMS software was used to develop peak flows and flow hydrographs for existing land use conditions 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year events. Peak flows were initially used in a steady-state hydraulic model downstream of El Campo, however, the results did not compare well with data from the USGS gage at FM 456. Ultimately, inflow hydrographs from the HEC-HMS model were used in an unsteady hydraulic model, which better accounted for overbank storage, routing, and timing downstream of El Campo. A detailed description of the hydrologic analysis downstream of El Campo with calibration procedures and results is provided in Appendix C.

4.0 Hydraulic Analysis

A hydraulic analysis was performed along the Tres Palacios River from the upstream limits in El Campo to Tres Palacios Bay in Matagorda County for a total length of about 59 river miles using HEC-RAS software, versions 3.1.3 (steady-state) and 4.0 (unsteady). The hydraulic analysis also included a tributary to the Tres Palacios River in El Campo totaling 3.8 stream miles. Hydraulic routing models were created for Tadpole Creek in Wharton County, and Juanita Creek, Wilson Creek, and one unnamed tributary in Matagorda County. 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. Initially, the mainstem hydraulic model downstream of El Campo was a steady-state model but was later converted to an unsteady model to better account for overbank storage and routing. Hydraulic analyses for the Tres Palacios River mainstem within El Campo and El Campo Tributary are summarized in Appendices A and B, respectively. A detailed description of the hydraulic analysis of the Tres Palacios mainstem downstream of El Campo is provided in Appendix C.

5.0 Results of Hydrologic and Hydraulic Analyses

The existing conditions hydrologic and hydraulic analyses resulted in calibrated flood hazard information that is very 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-yr event throughout the Tres Palacios watershed within Wharton County and Matagorda County. The resulting 100-yr floodplain delineation is illustrated in Figures 6 through 8. The water surface elevation profiles for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year frequency events are provided in Appendices A, B, and C.

Although this is new and, in some places, detailed information, there are several sources of uncertainty in the hydrologic and hydraulic models that could affect the flows and stages calculated. One source of uncertainty is the numerous areas of shallow flooding and diversion of

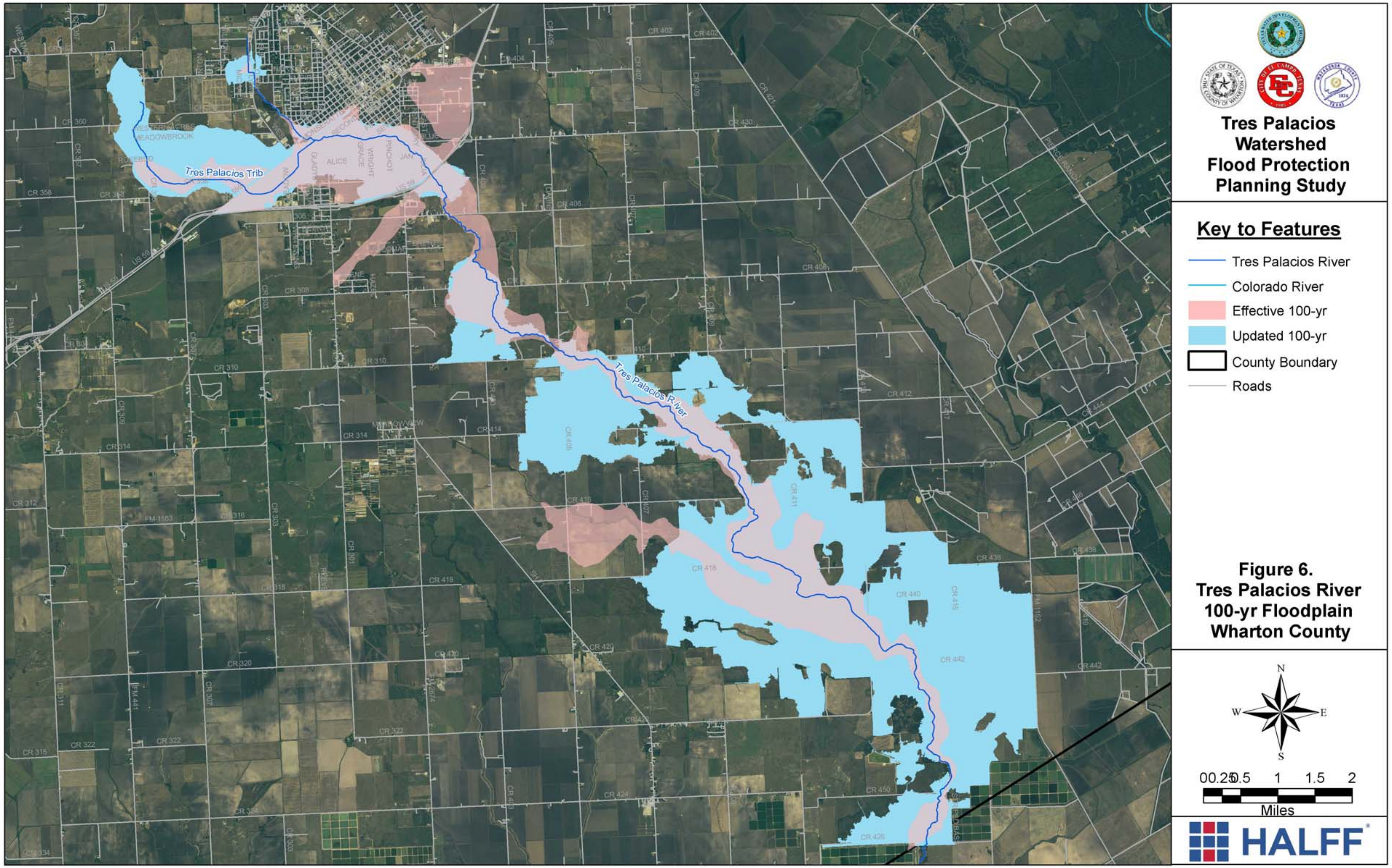


Figure 6.
Tres Palacios River
100-yr Floodplain
Wharton County

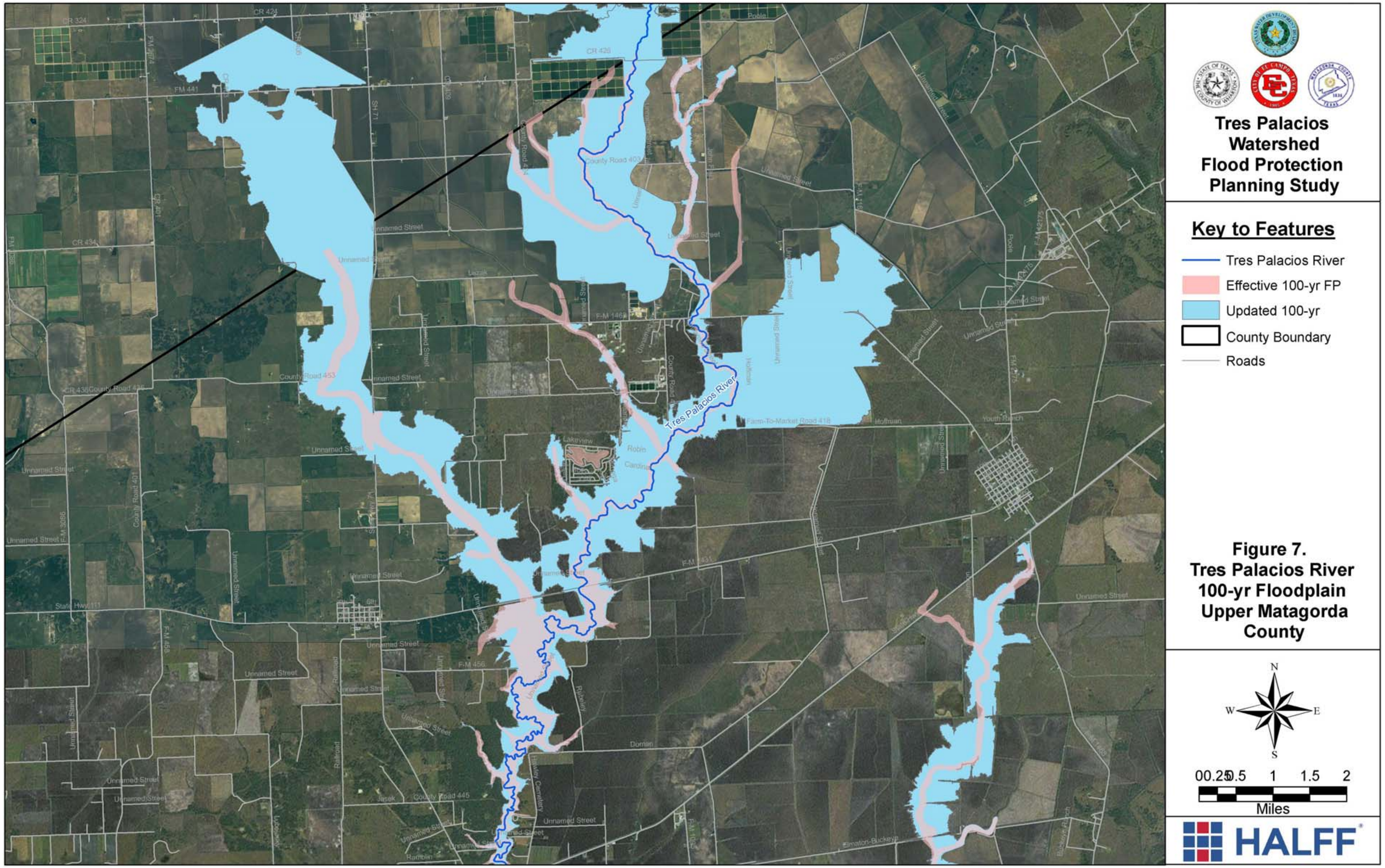


Figure 7.
Tres Palacios River
100-yr Floodplain
Upper Matagorda
County

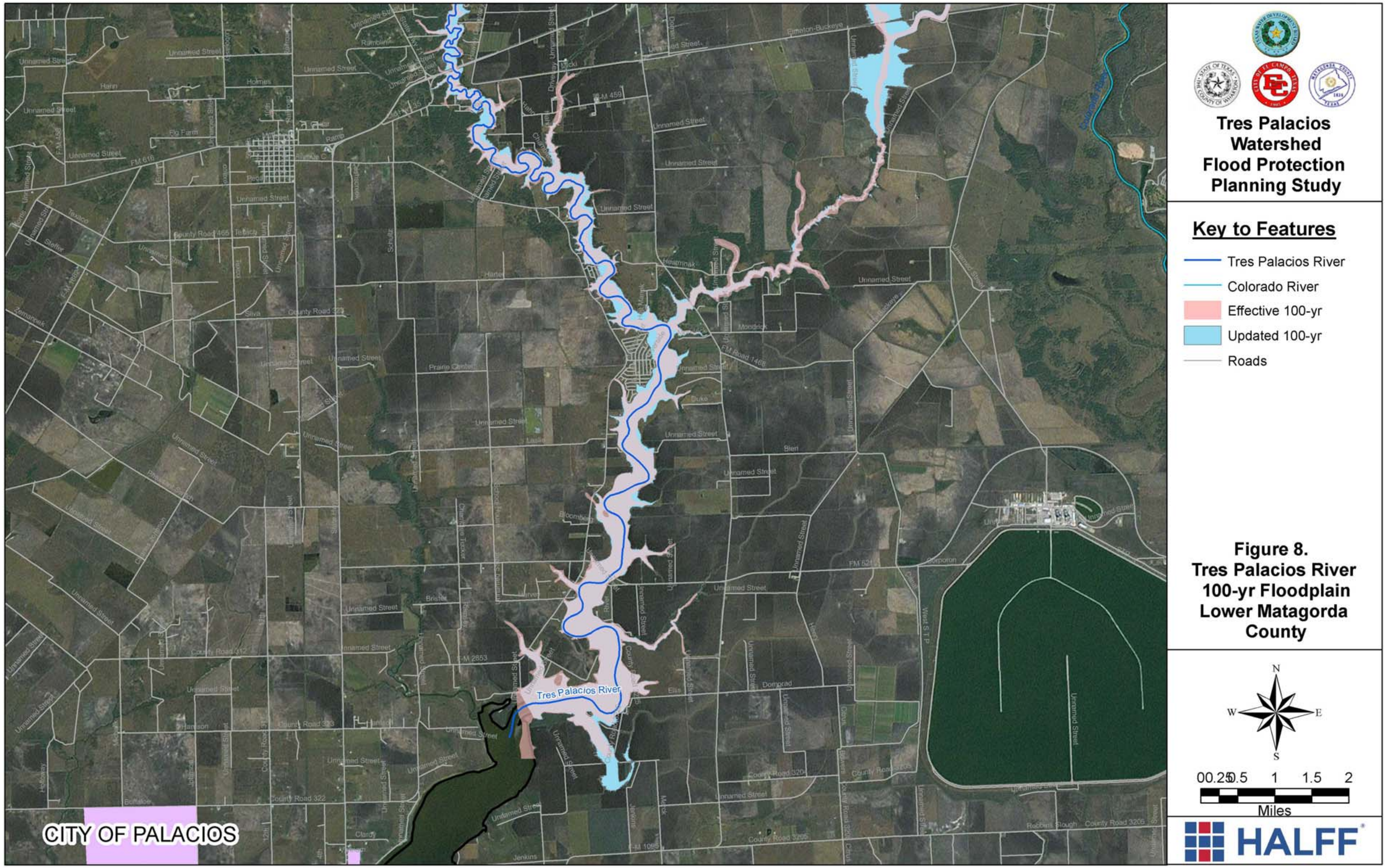


Figure 8. Tres Palacios River 100-yr Floodplain Lower Matagorda County

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 all major spills/overbank storage areas in the model. These areas are represented by four separate diversions in the unsteady RAS model downstream of El Campo in Wharton and Matagorda Counties. The diversions allow water to leave at the overflow points, be routed down adjacent tributaries and re-enter the main channel. Modeling overflows in this manner accounted for transient flood storage and resulted in an improvement in the calibration to gage data. Details of this process are discussed further in Appendix C.

Another source of uncertainty in the modeling process is associated with the calculation of the percent ponding parameter for the Clark Unit Hydrograph used in the HMS hydrologic model. Due to the extremely flat terrain, it is theorized that some percentage of runoff will never reach the main channel before the channel fills and overflows it banks. Again, this is a difficult scenario to simulate in HMS without a multi-dimensional overland flow simulation. For this analysis the percent ponding for each sub-basin was calculated by delineating rice fields and storage areas that could potentially pond storm runoff. Initial calibration results indicated that there was probably more "ponding" storage than was initially being accounted for. This was mainly based on comparing the results of sub-basin hydrographs to that of the main channel (post routing). With the original assumptions of percent ponding in place, the sub-basin hydrographs tended to have a much quicker time to peak than was reasonable for such flat terrain. Thus, percent ponding values were raised for all sub-basins in an attempt to better account for the extensive ponding/storage in the headwaters and sub-basins of the watershed. The adjustment of the percent ponding was only applied to the HMS model for the Tres Palacios downstram of El Campo. Percent ponding values in the El Campo HMS models were not adjusted and results were used as is. The result was a tighter calibration to both the May 2004 flood event and the frequency analysis of the gage at FM 456. More details of this issue are discussed in Appendix C.

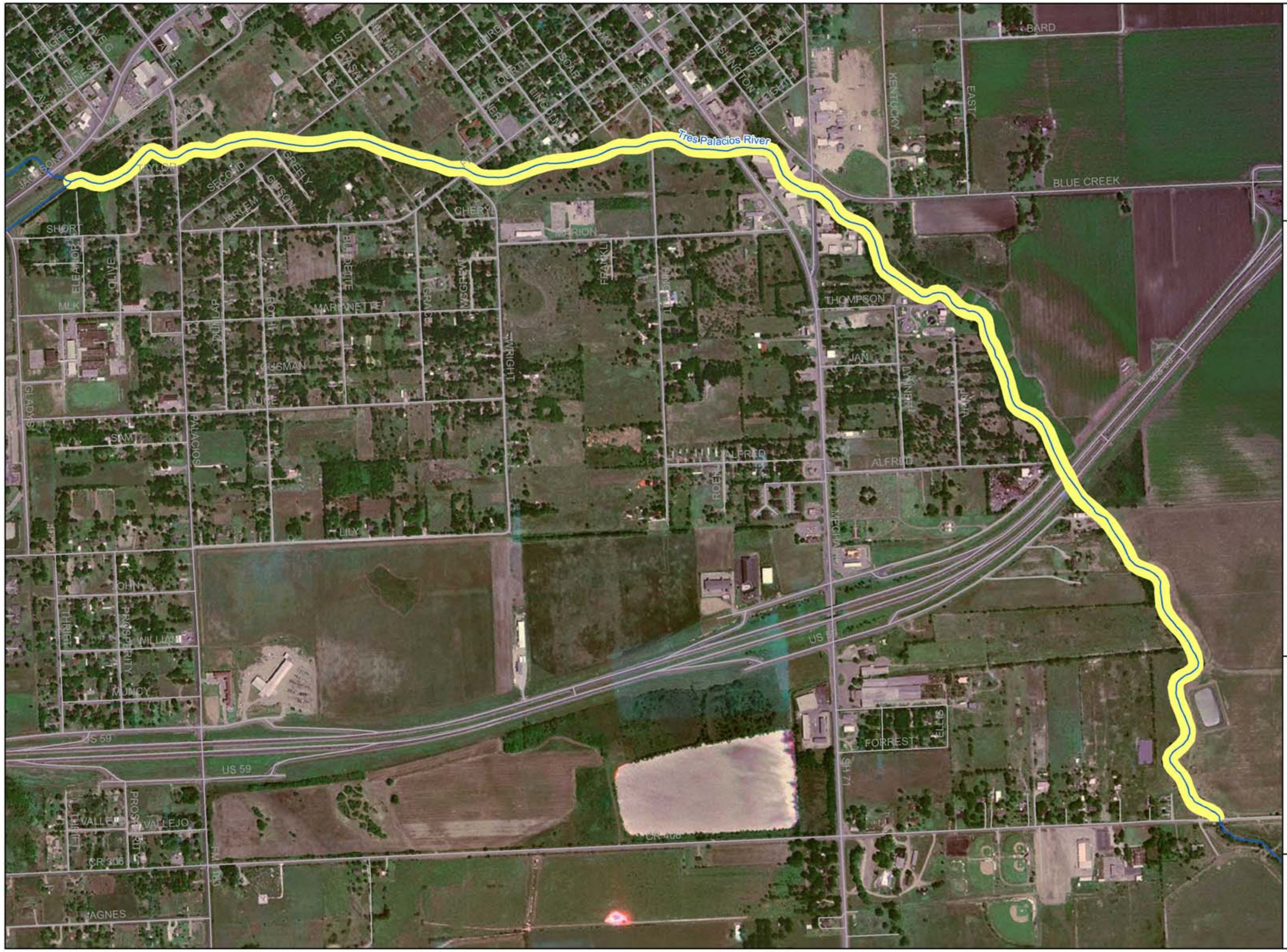
6.0 Flood Damage and Alternative Analysis – El Campo

The Tres Palacios River has been a source of frequent flooding for the citizens of the City of El Campo since the turn of the century, if not longer. Major floods have occurred in El Campo as recently as 1998 and 2004. The City of El Campo became a participant in the Tres Palacios Flood Protection Planning Study in large part to quantify flood damages in El Campo and determine the best (e.g. most cost effective) alternative to reduce potential damages. A flood damage and alternative analysis was performed using HEC-FDA version 1.2. Inputs to this program include hydraulic data from the existing condition and alternative hydraulic models for the El Campo mainstem and tributary, economic data including damage categories, depth-damage curves, and structure data. The output consists of the expected (average) annual damage associated with the existing or “without project” condition as well as reduction in damages supplied by each flood reduction alternative. Details of the inputs and analysis are provided in Appendices D and E.

Present value benefit-to-cost ratios were calculated for each potential flood reduction alternative. Benefits are equivalent to flood damage reduction over the “without project condition.” The most favorable results, with B/C ratios of 1.29 and 1.18 respectively, were for earthen channel widening to a 25-yr capacity (4:1 side slopes with a 45 ft. bottom width) and 50-yr capacity (4:1 side slopes with a 60 ft. bottom width). Both alternatives extend from Business 59 in El Campo to CR 406 in Wharton County (Figure 9). Between these two alternatives, the 25-yr earthen channel is slightly more cost effective and is therefore the recommended alternative. However, both the 25-yr and 50-yr earthen channel alternatives are economically viable. The reduction of the 100-yr floodplain resulting from these two channel widening alternatives can be seen in Figure 10. Figure 11 shows structures that are affected by the existing condition 100-yr floodplain. 135 of these structures will be removed from the 100-yr floodplain with the construction of the recommended 25-yr channel alternative which will reduce the 100-yr flood elevation by 1 ft. Of those 135 structures, 107 are classified as residential and 32 are non-residential. Wharton County and the City of El Campo will determine whether to move forward with the recommended 25-yr earthen channel or the 50-yr earthen channel and will seek funding through an HMGP grant from FEMA. If an HMGP grant cannot be obtained the project will be funded locally though municipal bonds or similar mechanism. Before the recommended project is built, environmental clearances and related permits will also need to be obtained. Appendix F contains a review of possible environmental constraints that will need to be thoroughly investigated prior to project construction.

Non-structural El Campo flood damage reduction alternatives considered include incorporation of data produced into the local floodplain ordinance, buyout of affected houses, and raising of affected houses. All information produced from this study will be submitted to FEMA via the LOMR process at the completion of the recommended channel widening project and will be available to the affected communities for regulation under their respective floodplain ordinances. Buyout of affected structures is not advisable because of the cost associated with purchasing hundreds (approx. 687) of affected structures and political issues associated with the area being predominantly lower income. Raising affected structures is inadvisable for similar reasons, especially the extremely high cost of raising hundreds of affected structures. Because of the issues associated with raising or buying out affected homes, the City of El Campo decided to focus mainly on structural alternatives in the alternatives analysis.

Drainage problems have also been reported by local officials along the El Campo tributary. A detailed site inspection of this tributary was performed on the week of March 8th resulting in the identification of numerous sedimentation issues. The soils along the El Campo tributary are predominately sands and silty sands. Several sedimentation "hot spots" were identified and recorded using GIS software. These "hot spots" are mostly due to poor or failing drop structures/inlet drains to the main channel and are provided in Appendix D. In addition, there were several locations where channel bank erosion was occurring due to runoff overtopping the lip of the bank and eroding the fine sediments on the existing side slopes. In order to resolve this issue, it is recommended that the County and City act jointly to re-channelize the main channel (by excavating roughly 8,600 cy of sediment), acquire easements (~100 ft wide), reconstruct the drop pipes/inlets (~ 26 total), and construct a backslope drainage system for both sides of the main channel to prevent future side slope scouring from occurring. A detailed B/C analysis was not performed for this particular issue as it is more of a maintenance problem and is not likely to receive outside funding to implement.



Tres Palacios Watershed Flood Protection Planning Study

Figure 9.
El Campo
Channel Widening
Alternative Extents

HALFF
HDR | CLAUNCH & MILLER
Engineering Consultants

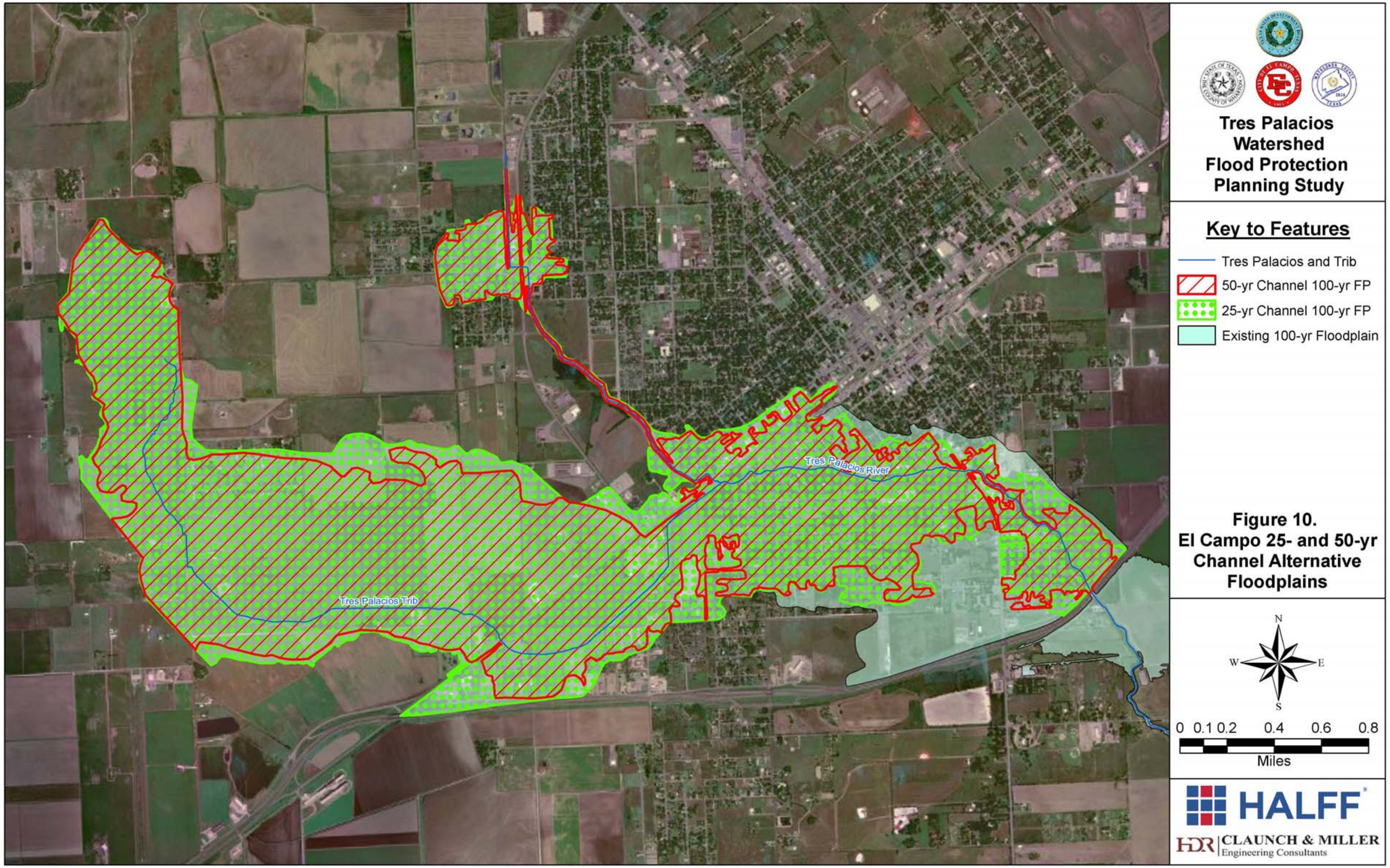


Figure 10. El Campo 25- and 50-yr Channel Alternative Floodplains

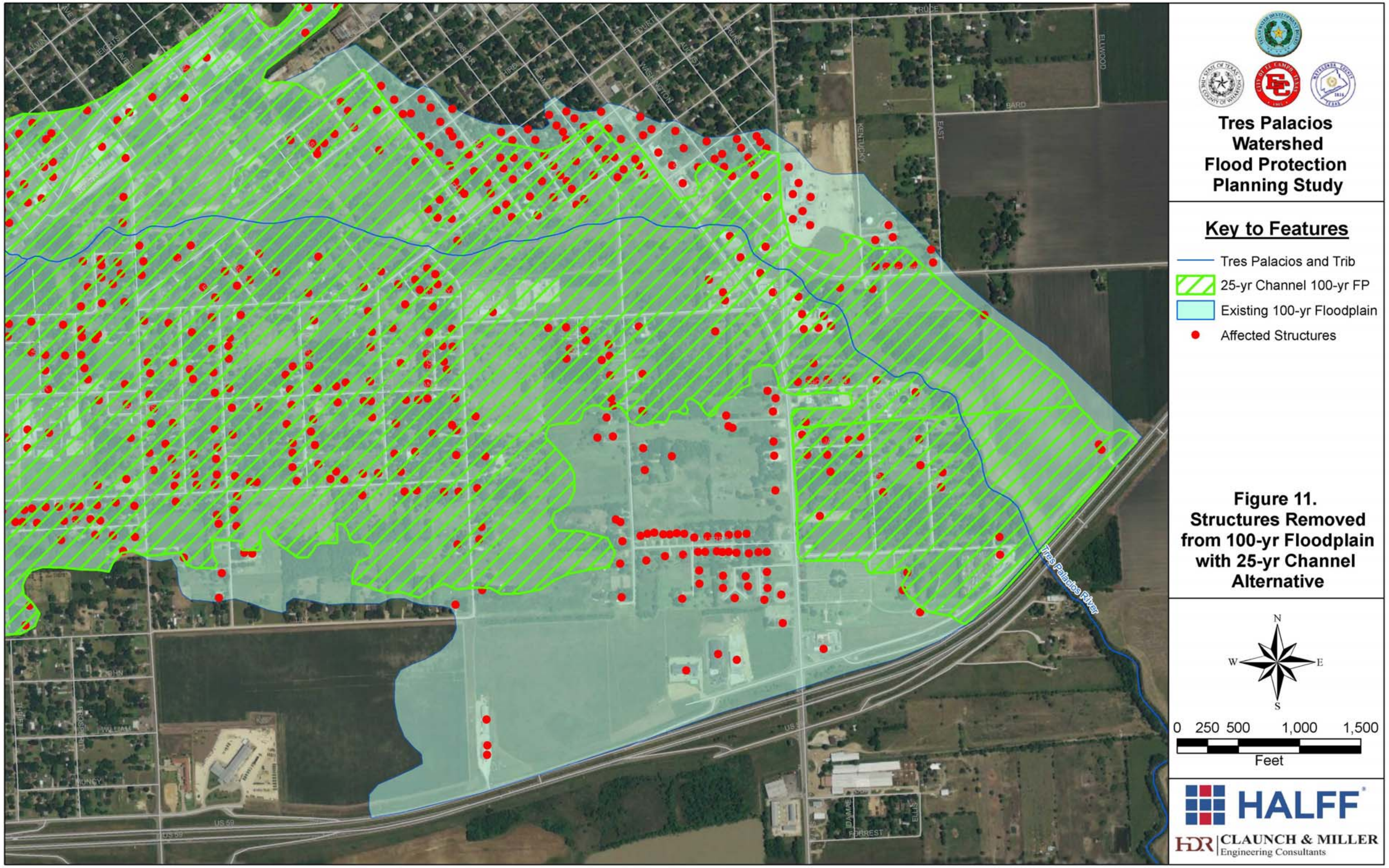


Figure 11. Structures Removed from 100-yr Floodplain with 25-yr Channel Alternative

7.0 Flood Damage and Alternative Analysis – Wharton County

In addition to the channel improvements recommended for El Campo, which extend into Wharton County as well, there are several bridge/culvert crossings in need of improvement that were identified in the hydraulic modeling effort. These crossings do not currently pass the 10-yr flood event and include CR 410, CR 422, and CR 442. It is recommended that County-maintained roads pass at least the 5-yr flow. While these three structures meet the 5-yr flow criterion, improvements including bridge widening, increased culvert sizes, and additional culvert barrels are still recommended to allow for the proper freeboard (approx. 2-ft). These improvements are mainly recommended for safety reasons during a flood event and should be addressed as soon as funds allow.

8.0 Flood Damage and Alternative Analysis – Matagorda County

Frequent flooding has also occurred along the Tres Palacios River in Matagorda County causing flood damages. These damages have been increased by establishment of residential communities along the river in Matagorda County. Existing residential sub-divisions in this area include El Dorado, Oak Hollow, Tidewater Oaks and Tres Palacios Oaks. In the last few years, several lots have been sold in two more recently platted sub-divisions between Oak Hollow and Tidewater Oaks; however, very few homes have yet to be built in the new neighborhoods. The locations of these residential communities are shown in Figure 12.

In the lower reaches of the Tres Palacios River, the channel is large and the flood volumes are high. Therefore, any structural alternative, such as channelization or storage, will be substantial in size and cost. Storage options were analyzed for different levels of flood reduction. The least expensive storage option was to reduce the 50-yr flow to the 25-yr flow, estimated at roughly 4,000 ac-ft of storage. The required storage volume and required area (based on 10 ft. depth) were calculated to determine excavation and land costs. The final cost for the 50-yr to 25-yr detention totaled approximately $46,240,000 including 15% mobilization and 20% contingency. This cost does not include cost of environmental work, engineering fees or cost of constructing the outflow structure, which could be substantial. With such high estimates for construction, no detailed B/C analysis was performed as the likelihood for a positive B/C ratio was very low. A channelization alternative was also tested to reduce flood elevations in the Tres Palacios Oaks sub-division. Even though the widening and excavation of the channel increased the flow area by at least 50% on average, the reduction in the 100-yr flood elevation was only 0.7 ft. or less. For more details on the structural alternative cost analysis see Appendix D.

Flood reduction benefits for structural alternatives are most likely much lower than costs judging from the number and value of homes in the affected neighborhoods. There is also some uncertainty in determining the impact of flooding on existing structures. Field reconnaissance revealed elevated homes in the Tidewater Oaks subdivision which would reduce the extent of flood damage to those structures. Tres Palacios Oaks is a gated community and it was not conclusively determined whether any homes there were elevated or not.

Due to the high volume of storage required to have any measurable impact to the existing residential communities along the lower reaches of the Tres Palacios, some effort was made to evaluate other possible options for storage that may also be utilized for other means. One such option was to consider the implementation of a reservoir that would provide both water supply and flood reduction benefits. Existing topographic relief in Matagorda County could provide for the construction of a large reservoir capable of storing more than 6,000 ac-ft of water (very preliminary numbers) if not more, where only 4,000 ac-ft would be needed for flood control. Before significant effort is exhausted on this strategy, additional information is needed related to existing water rights, downstream freshwater inflow requirements to the estuary, and the desire for water in the region. Continued coordination with Matagorda County, and Matagorda County Drainage District #2 is needed to better define the needs before this strategy can be fully evaluated.

In addition to the larger flooding problems identified in Matagorda County, there are several bridge/culvert crossings in need of improvement that were identified in the hydraulic modeling effort. These crossings do not currently pass the 5-yr flood event and include CR 426, CR 403, and FM 456. Recommended improvements include bridge widening, increased culvert sizes, and additional culvert barrels to pass at least the 5-yr flow for the county-maintained roads and the 25-yr flow for FM 456 without overtopping the roadways. These improvements are mainly recommended for safety reasons during a flood event and should be addressed as soon funds allow.

Along with the previously mentioned recommendations, the new floodplain and base flood elevation data produced in this study should be fully utilized to regulate development in the recently platted subdivisions and elsewhere (as needed) along the Tres Palacios River in Matagorda County. All detailed study information developed in Matagorda County will be incorporated into the current FEMA DFIRM mapping study for incorporation into the updated floodplain mapping effort for this county.

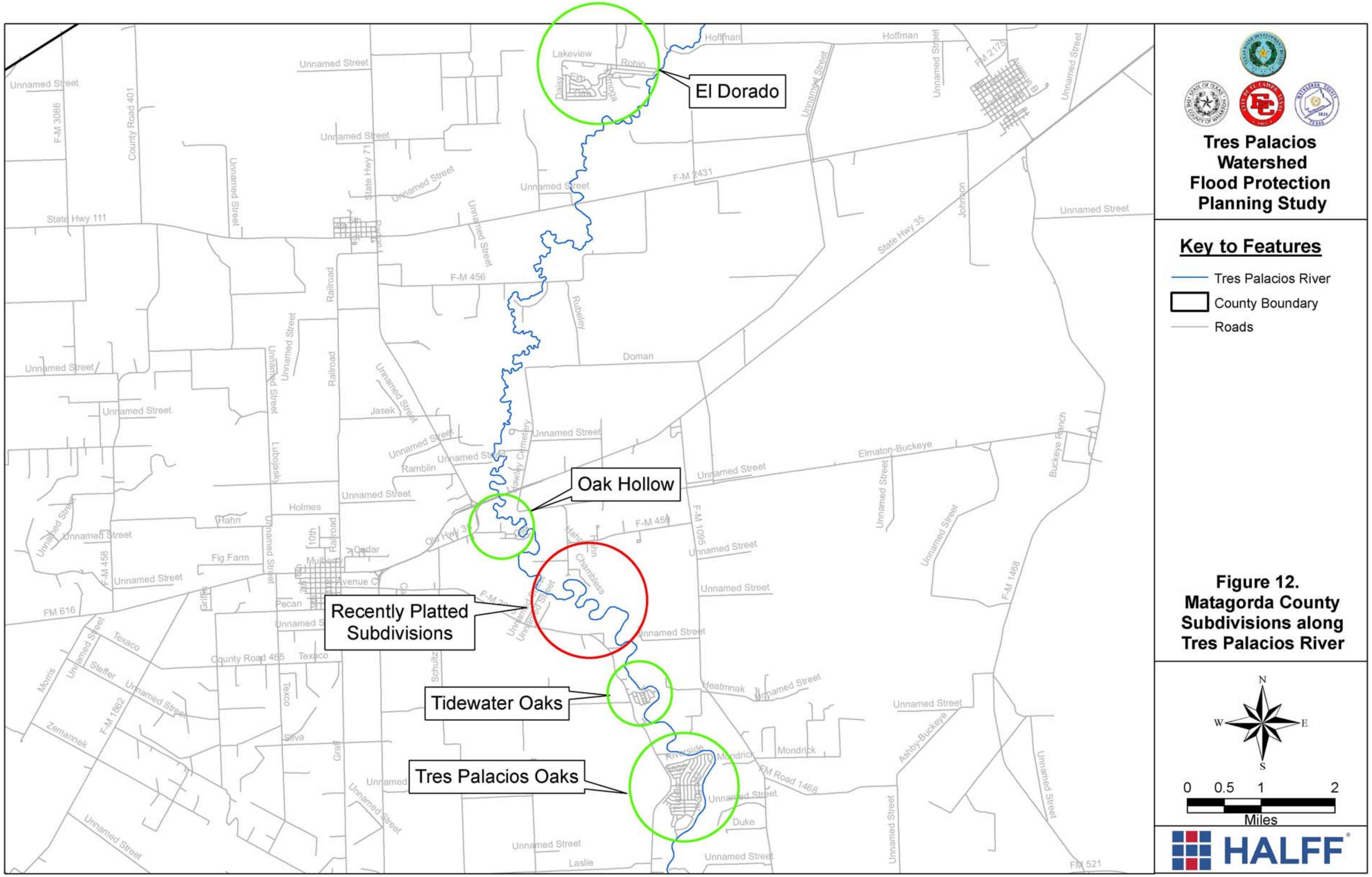


Figure 12. Matagorda County Subdivisions along Tres Palacios River

APPENDIX B: Hydrologic and Hydraulic Analysis of the El Campo Tributary to the Tres Palacios River

B.1 Hydrologic Analysis

A hydrologic analysis was performed the El Campo Tributary to the Tres Palacios River utilizing the HEC-HMS software, version 3.4. 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.

B.2 Precipitation

The Alternating Block method was used to develop frequency rainfall patterns for the 2-, 5-, 10-, 25-, 50-, and 100-year rainfall events. The statistical point rainfall data used for this analysis was obtained from the *Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas, USGS Scientific Investigation Report 2004-5041, Asquith 2004.* A central location in Wharton County (29°18’30.67” latitude and 96°06’13.72” longitude) was used with the aid of a computational procedure, developed by Asquith and based off the findings of this report, to determine the statistical point rainfall values used for this study. This was determined to be acceptable since El Campo, the main damage center in the Tres Palacios watershed, is located in central Wharton County. Asquith uses two different equations to determine rainfall depths for different durations, therefore the rainfall depths shown in Table B1 reflect an average of the two equations.

Table B1: Frequency Rainfall Depths

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**	0.80	1.00	1.10	1.20	1.30	1.50	1.80	2.20
15 min	**0.25**	0.96	1.07	1.13	1.26	1.39	1.59	1.93	2.28
30 min	**0.50**	1.45	1.80	2.04	2.41	2.74	3.13	3.77	4.35
60 min	**1.00**	1.94	2.53	2.95	3.56	4.08	4.68	5.60	6.43
2 hr	**2.00**	2.43	3.26	3.86	4.71	5.43	6.23	7.44	8.50
3 hr	**3.00**	2.71	3.69	4.39	5.38	6.21	7.14	8.52	9.71
6 hr	**6.00**	3.20	4.42	5.30	6.54	7.56	8.68	10.35	11.79
12 hr	**12.00**	3.69	5.16	6.21	7.69	8.90	10.23	12.19	13.86
24 hr	**24.00**	4.18	5.89	7.12	8.84	10.25	11.78	14.03	15.98

B.3 Rainfall-Runoff Losses

All rainfall-runoff losses were computed using the SCS Curve Number loss method. The composite curve numbers (CN's) selected for this analysis were based off the CN tables provided in the Natural Resources Conservation Service (NRCS) TR-55 Report. The hydrologic soil types in this study were obtained from the NRCS, Soil Survey Geographic database (SSURGO) for Wharton County, published in July 2006. The predominant soil types within the El Campo Tributary watershed are Hydrologic Soil types A and D. The existing 1990 digital land use map was obtained from U.S. Geological Survey (USGS) and was confirmed or edited in ArcGIS using the digital 2005 MrSID Ortho-photos for Wharton County. Percent impervious values were estimated based on ortho-photos. The percent impervious area was not included in the composite CN's. This was done to ease any future conditions modeling that might be performed. All initial abstractions were computed using the storage equation default formula within the SCS loss method procedure, which was automated within the HEC-HMS software. Table B2 shows the existing conditions hydrologic parameters for the El Campo Tributary sub-basins. Figure B1 displays the drainage basin delineation for the El Campo Tributary.

Table B2: Rainfall-Runoff Parameters for El Campo Tributary Sub-Basins

Sub-Basin	D.A. (Sq. Miles)	Initial Abstraction (in)	CN	% Imperv.
TPTrib6-1	0.756	0.439	82	5
TPTrib6-2	2.666	0.381	84	2
TPTrib6-3	1.015	0.597	77	15

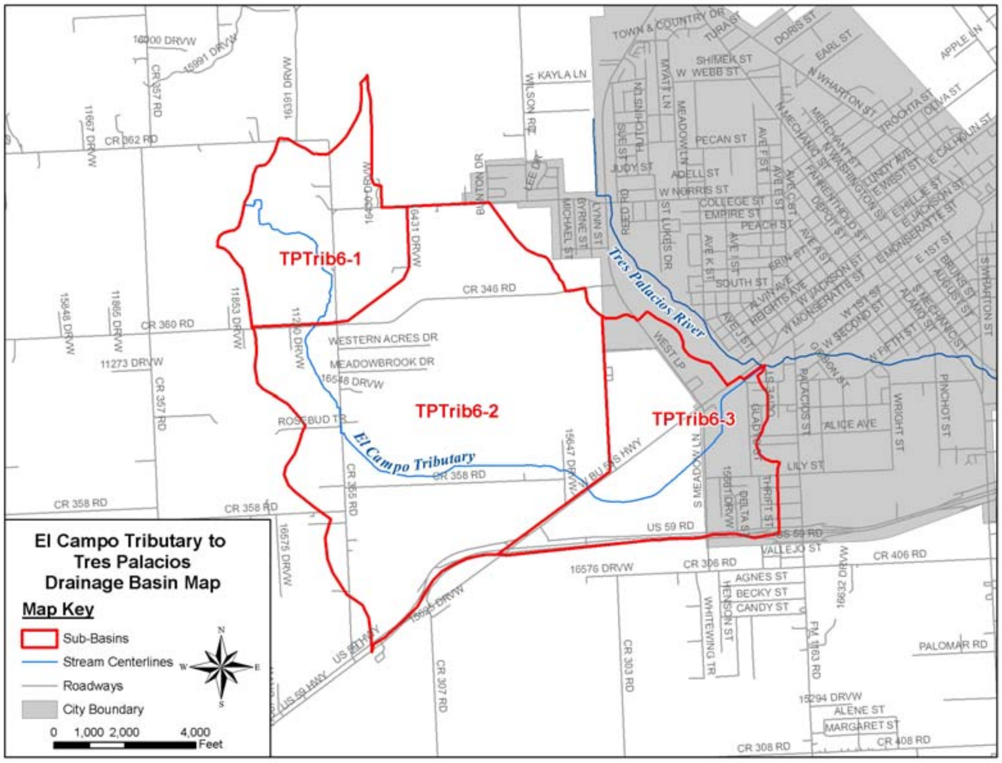


Figure B1: El Campo Tributary Sub-Basin Delineation

B.4 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 derived by the Harris County Flood Control District (HCFCD) in the early 1980s. Ponded areas required for determining percent ponding were calculated by delineating rice fields and farm ponds from ortho-photos. The percent urbanization parameter was estimated using ortho-photos. 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 El Campo Tributary sub-basins being rural nature. Clark Unit Hydrograph parameters are shown in Table B3. 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.

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 ortho-photos, in percent of total drainage area.

Percent Channel Improvement (DCI): the potion of the longest watercourse with an improved channel, measured from ortho-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 utilized for this project are as follows.

$Tc = D*[1-(0.0062*(0.30*(DLU)+0.70*(DCI)))]*(Lca/\sqrt{S})^{1.06}$

$D = 2.46$ if $So<=20$ ft./mi.

$D = 3.79$ if $So>20$ ft./mi/ but $So<40$ ft./mi.

$D = 5.12$ if $So>40$ ft./mi.

$Tc+R = 7.25*(L/\sqrt{S})^{0.706}$ (if $DLU <= 18\%$)

$Tc+R = (4295[DLU]^{-0.678}*[DCC]^{-0.967})*(L/\sqrt{S})^{0.706}$ (if $DLU > 18\%$)

Tc = Time of Concentration
DLU = % Land Urbanization
DCI = % Channel Improvement
Lca = Length to Centroid
S = Channel Slope
So = Watershed Slope
L = Watershed Length
DCC = % Channel Conveyance
R = Storage Coefficient

Table B3: Clark Unit Hydrograph Parameters for El Campo Tributary 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 %	PONDING %	TC (HR)	TC+R	R (HR)
TPTrib6-1	0.756	1.455	0.929	6.611	40.498	10	0	100	26.46	1.71	6.58	4.87
TPTrib6-2	2.666	2.293	1.150	5.314	12.878	8	0	100	26.26	1.16	10.56	9.40
TPTrib6-3	1.015	1.274	0.890	14.589	32.324	15	0	100	29.56	0.79	4.78	4.00

B.5 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. Modified Puls routing data was extracted from the existing conditions hydraulic model for the El Campo Tributary. The number of routing steps along the El Campo Tributary reaches was set equal to 1 to better replicate the impact of the low velocities and the flat terrain.

B.6 Sources and Diversions

Water spills from East Mustang Creek watershed at the upstream most section of the El Campo Tributary watershed. This additional flow to the El Campo Tributary watershed was accounted for using a source in the HEC-HMS file. Data for this source was determined using the East Mustang Creek hydrologic model prepared by Halff Associates as part of the 2008 Wharton County Drainage Master Plan.

There is one location along the El Campo Tributary where water spills outside the El Campo Tributary watershed boundary. This spilling was accounted for using a diversion in the HEC-HMS model. This diversion occurs between the hydraulic cross-sections 14422 and 15001 near CR 355. The diversion was computed using a lateral weir approach. The standard weir equation, $Q=CLH^{1.5}$, was then used to develop a curve relating water surface elevation at the weir to the flow (Q) leaving the channel. The length (L) of this diversion was measured to be approximately 1120 feet. The height of water for various flows in the channel was determined at each cross-section in the spill location. These water surface heights were then averaged to determine the height of water at the weir (H).

The appropriate weir coefficient (C) was computed using the Manning's equation, $Q=(1.49/n)\cdot A\cdot(A/P)^{2/3}\cdot S^{1/2}$. The Manning's n-value (n) was assumed to be 0.15, the area (A) and wetted perimeter (P) were computed based on a rectangular channel with a length of 1120 feet and a height of 0.64 feet, and the slope was computed to be 0.001 ft/ft. These assumptions resulted in a flow rate equal to 167 cfs. The weir equation was then used to determine the weir coefficient that would result in 167 cfs when using a height of 0.64 feet. The weir coefficient (C) selected for this diversion was calculated to be 0.3. Table B4 displays the resulting inflow – diversion curve that was used in the hydrologic model.

Table B4: Inflow-Diversion Curve for El Campo Tributary flow diversion

Inflow (cfs)	Diversion (cfs)
0	0
400	0
500	22
900	268
1200	407
1300	475
2200	1213
2800	1731
3400	2251

B.7 Peak Discharges

Peak discharges were computed at the downstream end of each sub-basin. Table B5 displays peak discharge results from the HMS model with Modified Puls routing.

Table B5: Computed Peak Discharges along El Campo Tributary

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)
East Mustang Spill	24198	1	1	1	20	190	490	2050	2910
Junction-0	20526	110	200	270	360	440	700	2320	3270
Diversion-1	15001	80	140	190	280	380	530	950	1110
Junction-1	10600	250	480	650	890	1090	1340	1740	2120
Outlet	3261	250	430	570	780	970	1200	1510	1870

B.8 Hydraulic Analysis

A hydraulic analysis was performed the El Campo Tributary to the Tres Palacios River utilizing the HEC-RAS software, version 3.1.3. 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. A portion of the El Campo Tributary from Business Highway 59 to the confluence of Tres Palacios is currently an detailed Zone AE floodplain and a portion between Rosebud Trail and Business Highway 59 is currently an approximate Zone A floodplain on the current effective Wharton County Flood Insurance Rate Maps (FIRM). The hydraulic analysis conducted along the El Campo Tributary is a detailed hydraulic analysis from the El Campo Tributary confluence with the Tres Palacios River for approximately 1.6 miles and an approximate hydraulic analysis for the next 3.0 miles upstream. The new detailed study utilizes detailed channel and bridge survey data. The locations of the detailed bridge surveys used in this study are listed below. The river station is measured in feet from the confluence with the Tres Palacios River.

1. Gladys Street (River Station 691)
2. Abandoned Roadway just upstream of Gladys Street (River Station 1,583)
3. Meadow Lane (River Station 3,199)
4. Railroad Bridge just downstream of Business Highway 59 (River Station 6970)
5. Business Highway 59 (River Station 7,071)
6. Private Low Water Crossing upstream of Business Highway 59 (River Station 7,455)
7. Private Dirt Roadway Crossing upstream of Business Highway 59 (River Station 8,023)

Eight additional channel surveys were completed in 2009 and were incorporated into the hydraulic model. Non-surveyed cross-sections were cut from LiDAR elevation data. All detailed survey (2009) and LiDAR data (2005 Wharton County 18.5 cm vertical RMSE and 2006 Coastal 37.0 cm vertical RMSE) were collected using the NAD 83 horizontal datum, and the NAVD 88 vertical datum. Structures located upstream of the surveyed structures were estimated using LiDAR elevation data and ortho-photos.

The computed peak discharges 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 ortho-photos and site visits, and based upon tables found in *Open Channel Hydraulics, Chow, 1959*. The downstream boundary condition for the El Campo Tributary model was set to the water surface elevations of the Tres Palacios River at the confluence. This procedure was used to eliminate discrepancy between the two water surface elevations in the downstream portion of the hydraulic model.

B.9 Flood Profiles

Flood profiles for existing conditions were computed along Tres Palacios River for the various frequency events previously mentioned. The results can be seen in Figure B2. The sharp dips in the profile represent locations where the channel bottom was surveyed. Other locations represent LiDAR topographic data which cannot penetrate below the water surface.

A comparison was made between this study and the current effective base flood elevations and discharges listed in the Wharton County current effective Flood Insurance Studies. The 100-yr flood elevation comparisons are shown in Figure B3 and discharge comparisons are displayed in Table B6.

Differences in the water surface elevations (WSEL) 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 B 6: Wharton County Current Effective FIS Discharges vs. New Model Discharge

Station	FIS 10-yr	New Model 10-yr	FIS 50-yr	New Model 50-yr	FIS 100-yr	New Model 100-yr	FIS 500-yr	New Model 500-yr
3261	1510	570	1850	970	2080	1200	2350	1870

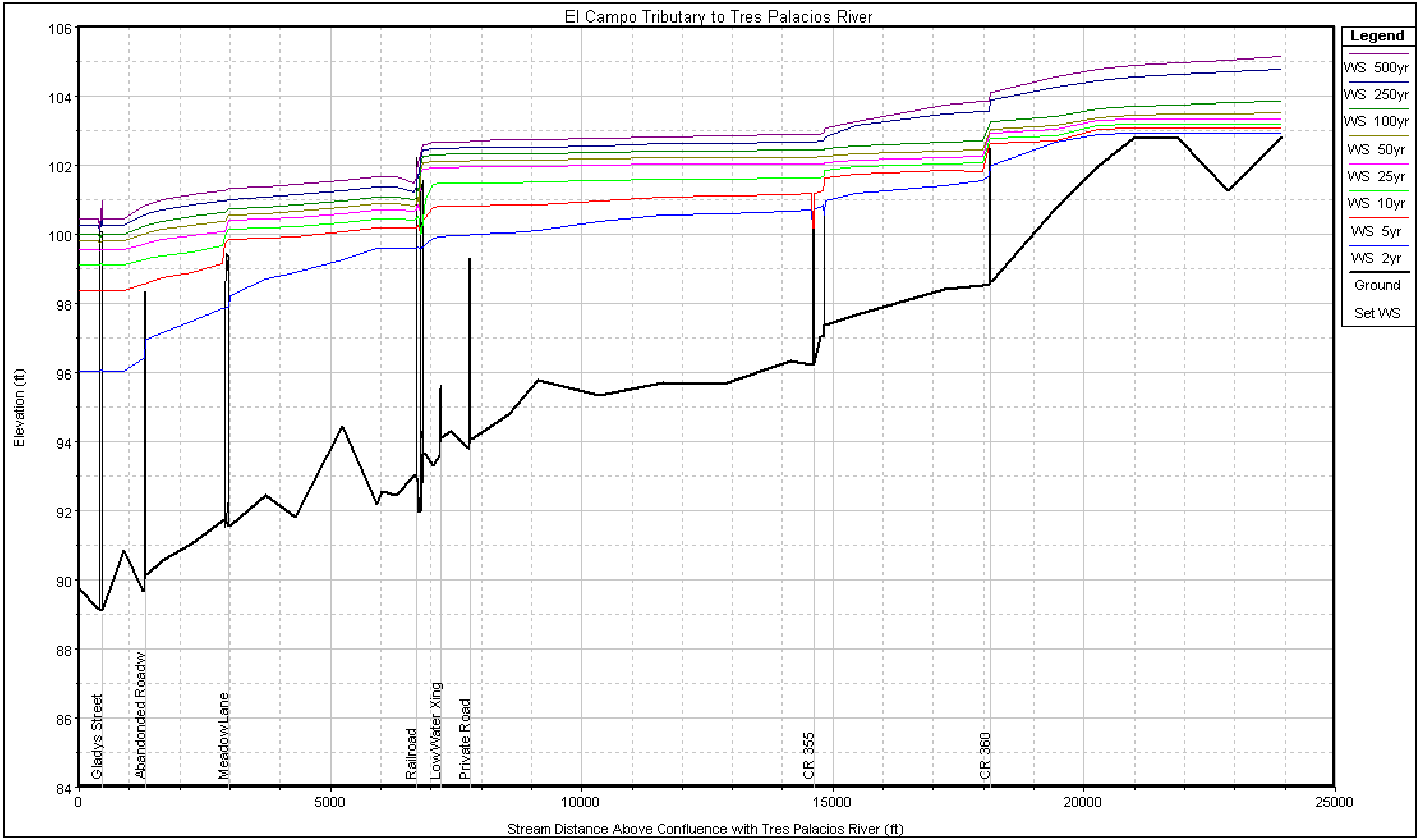


Figure B2: El Campo Tributary Water Surface Profiles

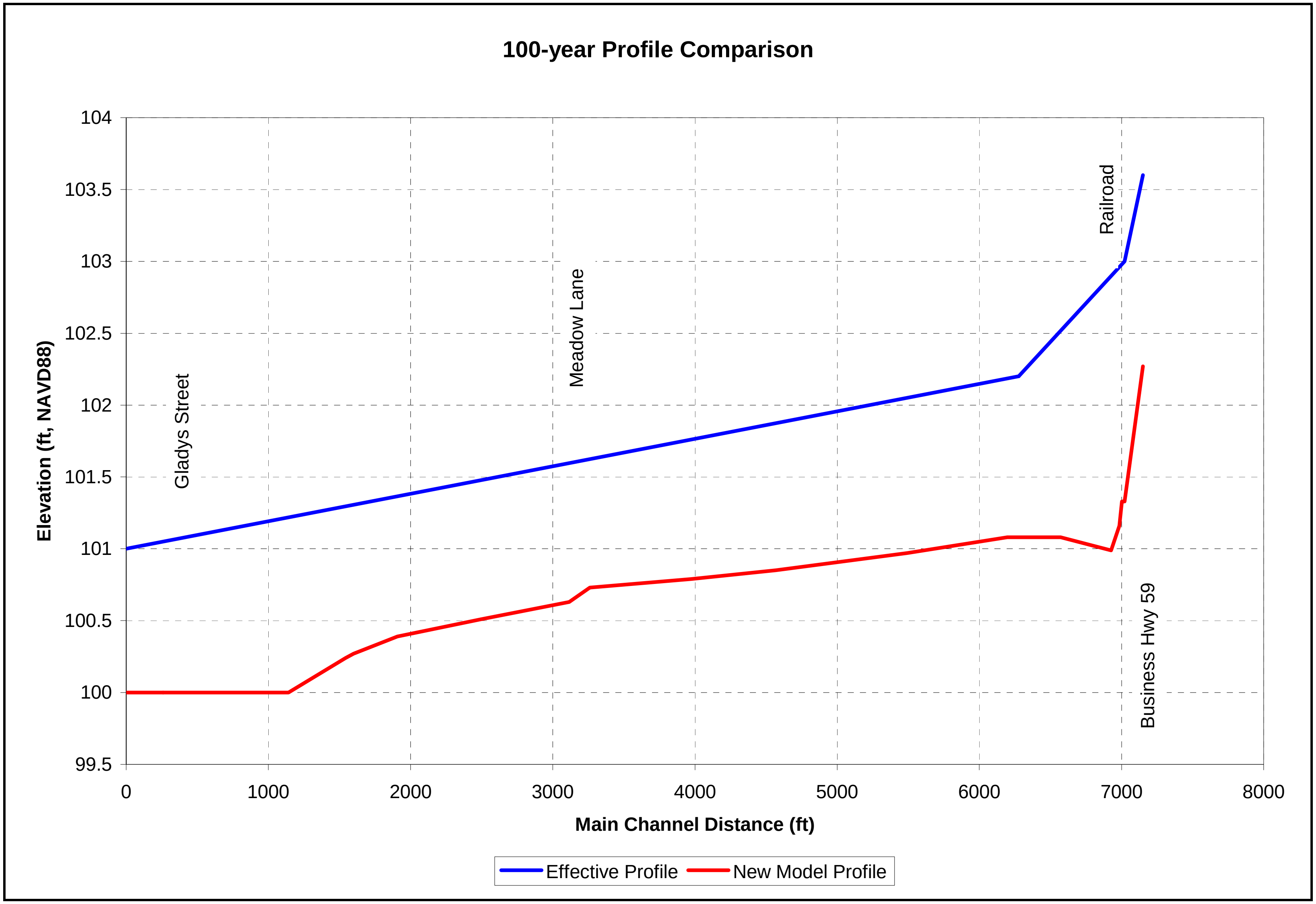


Figure B3: El Campo Tributary 100-yr Profile Comparison to FEMA Current Effective

APPENDIX C: Hydrologic and Hydraulic Analysis of the Tres Palacios River from El Campo to Tres Palacios Bay

C.1 Hydrologic Analysis

A hydrologic analysis was performed on the Tres Palacios River downstream of El Campo 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.

C.2 Precipitation

The Alternating Block method was used to develop frequency rainfall patterns for the 2-, 5-, 10-, 25-, 50-, and 100-year rainfall events. The statistical point rainfall data used for this analysis was obtained from the *Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas, USGS Scientific Investigation Report 2004-5041, Asquith 2004*. A central location in Wharton County (29°18'30.67" latitude and 96°06'13.72" longitude) was used with the aid of a computational procedure, developed by Asquith and based off the findings of this report, to determine the statistical point rainfall values used for this study. This was determined to be acceptable since El Campo, the main damage center in the Tres Palacios watershed, is located in central Wharton County. The storm duration for this analysis was selected to be a 48-hour event. Since the storm duration for any hydrologic analysis should be at least longer than the time of concentration of the watershed, it was concluded that the 48-hour duration would be sufficient for this study. Asquith uses two different equations to determine rainfall depths for different durations, therefore the rainfall depths shown in Table C1 reflect an average of the two equations.

Table C1: Frequency Rainfall Depths

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**	0.80	1.00	1.10	1.20	1.30	1.50	1.80	2.20
15 min	**0.25**	0.96	1.07	1.13	1.26	1.39	1.59	1.93	2.28
30 min	**0.50**	1.45	1.80	2.04	2.41	2.74	3.13	3.77	4.35
60 min	**1.00**	1.94	2.53	2.95	3.56	4.08	4.68	5.60	6.43
2 hr	**2.00**	2.43	3.26	3.86	4.71	5.43	6.23	7.44	8.50
3 hr	**3.00**	2.71	3.69	4.39	5.38	6.21	7.14	8.52	9.71
6 hr	**6.00**	3.20	4.42	5.30	6.54	7.56	8.68	10.35	11.79
12 hr	**12.00**	3.69	5.16	6.21	7.69	8.90	10.23	12.19	13.86

Duration	Duration (hours)	Recurrence Interval (years)							
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	250-yr	500-yr
		Depth (inches)							
24 hr	**24.00**	4.18	5.89	7.12	8.84	10.25	11.78	14.03	15.98
48-hr	**48.00**	4.67	6.62	8.03	9.99	11.59	13.33	15.87	18.01

C.3 Rainfall-Runoff Losses

All rainfall-runoff losses were computed using the SCS Curve Number loss method. The composite curve numbers (CN's) selected for this analysis were based off the CN tables provided in the Natural Resources Conservation Service (NRCS) TR-55 Report. The hydrologic soil types in this study were obtained from the NRCS, Soil Survey Geographic database (SSURGO) for Wharton County, published in July 2006. The predominant soil types within the Tres Palacios Creek watershed are Hydrologic Soil types B and D. The existing 1990 digital land use map was obtained from U.S. Geological Survey (USGS) and was confirmed or edited in ArcGIS using the digital 2005 MrSID Ortho-photos for Wharton County and 2004 NAIP imagery for Matagorda County. Percent impervious values were obtained from tables within the NRCS TR-55 report and were not included in the composite CN's for the more urbanized areas. This was done to ease any future conditions modeling that might be performed. All initial abstractions were computed using the storage equation default formula within the SCS loss method procedure, which was automated within the HEC-HMS software. Table C2 shows the existing conditions hydrologic parameters for the Tres Palacios River sub-basins. Sub-basin TP-01, which includes the City of El Campo, was replaced by a source containing hydrographs from the El Campo mainstem hydrologic model produced by HDR: Claunch and Miller. Further details of the El Campo mainstem hydrology can be seen in Appendix A.

Table C2: Rainfall-Runoff Parameters for Tres Palacios River Sub-Basins

Sub-Basin	D.A. (Sq. Miles)	Initial Abstraction (in)	CN	% Imperv.
TP-01	10.63	0.451	82	24.0
TP-02	7.00	0.451	82	7.4
TP-03	11.14	0.458	81	0.8
TP-04	9.83	0.468	81	1.3
TP-05	16.52	0.449	82	6.7
TP-06	14.18	0.452	82	6.4
TP-07	17.58	0.469	81	3.5
TP-08	12.44	0.467	81	0.4
TP-09	10.23	0.452	82	4.8
TP-10	7.41	0.433	82	1.3
TP-11	10.41	0.464	81	1.7
TP-12	16.65	0.460	81	2.5
TP-13	8.63	0.447	82	2.6
TP-14	9.75	0.404	83	4.1
TP-15	7.97	0.394	84	4.0
TP-16	14.21	0.438	82	2.7
TP-17	12.24	0.461	81	6.6

Sub-Basin	D.A. (Sq. Miles)	Initial Abstraction (in)	CN	% Imperv.
TP-18	10.39	0.454	81	2.5
TP-19	13.63	0.435	82	1.7
TP-20	9.37	0.436	82	1.3
TP-21	12.50	0.400	83	5.3
TP-22	12.03	0.418	83	2.8
TP-23	6.72	0.386	84	6.2

C.4 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 derived by the Harris County Flood Control District (HCFCD) in the early 1980s. Ponded areas required for determining percent ponding were calculated by delineating rice fields and farm ponds from aerial photos. The percent urbanization parameter was determined by using existing land use to locate areas of urbanization. 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 the rural nature of the Tres Palacios watershed. Clark Unit Hydrograph parameters are shown in Table C3. 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.

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 photographs, in percent of total drainage area.

Percent Channel Improvement (DCI): the potion of the longest watercourse with an improved channel, measured from aerial photographs 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, rice fields, swamps, etc.), measured in percent of total drainage area.
The equations HCFCD developed for calculating Tc and R which were utilized for this project are as follows.

$$Tc = D*[1-(0.0062*(0.30*(DLU)+0.70*(DCI)))]*(Lca/\surd S)^{1.06}$$

D = 2.46 if So<=20 ft./mi.

D = 3.79 if So>20 ft./mi/ but So<40 ft./mi.

D = 5.12 if So>40 ft./mi.

$$Tc+R = 7.25*(L/\surd S)^{0.706} \qquad \text{(if DLU <= 18\%)}$$

$$Tc+R = (4295[DLU]^{-0.678}*[DCC]^{-0.967})*(L/\surd S)^{0.706} \text{ (if DLU > 18\%)}$$

Tc = Time of Concentration
DLU = % Land Urbanization
DCI = % Channel Improvement
Lca = Length to Centroid
S = Channel Slope
So = Watershed Slope
L = Watershed Length
DCC = % Channel Conveyance
R = Storage Coefficient

Ponding in the form of rice farming and natural storage areas can have a significant impact on the attenuation of peak flows. TR-55 published by the NRCS developed a relationship between peak attenuation and percent ponding. The HCFCD developed a parallel relationship which equates percent of ponding to an increase in the Clarks storage coefficient (R). This increase is applied using the ponding adjustment factor shown below. The adjustment factor can have a significant impact so it was initially only applied when percent ponding was greater than 20%. This was consistent with the procedure recommended by the HCFCD. The adjustment factor in the HCFCD method varied for each frequency storm being considered. For this project, the 500-year adjustment factor was used for all storm events to limit the repetitive models that would be needed to vary this factor for eight different frequency events. Increases in percent ponding and subsequent storage coefficient adjustments are discussed with the calibration efforts in Section C.8.

$R_{event} = RM*R$

The adjustment factor, RM is computed from the percent ponding, DPP as follows:

$RM=1.17*DPP^{0.086}$

Table C3: Clark Unit Hydrograph Parameters for Tres Palacios River 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 %	PONDING %	TC (HR)	TC+R	R (HR)
TP-01	10.63	6.75	2.85	3.50	51.04	49	0	100	6.6	7.28	8.87	1.59
TP-02	7.00	3.77	2.20	4.33	12.23	10	0		7.0	2.56	11.04	8.47
TP-03	11.14	7.89	4.21	3.68	22.79	0	0		12.5	8.73	19.67	10.94
TP-04	9.83	10.26	6.24	4.08	45.00	2	0		6.8	16.85	22.82	5.97
TP-05	16.52	7.96	4.79	4.52	45.67	1	0		19.5	12.09	18.41	6.32
TP-06	14.18	11.90	6.13	3.08	17.51	2	0		14.3	9.22	27.99	18.76
TP-07	17.58	10.82	4.63	3.80	16.23	4	0		12.1	6.11	24.32	18.21
TP-08	12.44	8.15	3.75	5.09	65.67	1	0		3.0	8.76	17.96	9.20
TP-09	10.23	7.32	2.65	5.70	42.36	1	0		3.7	5.71	15.99	10.27
TP-10	7.41	5.55	2.55	10.25	28.85	1	0		0.4	2.97	10.69	7.72
TP-11	10.41	6.15	3.16	5.56	0.23	1	0		10.9	3.35	14.26	10.91
TP-12	16.65	10.54	4.54	4.79	14.91	3	0		1.6	5.30	21.99	16.69
TP-13	8.63	6.47	3.89	6.99	50.51	1	0		1.5	7.71	13.64	5.93
TP-14	9.75	6.26	2.11	8.45	1.69	5	0		0.1	1.73	12.46	10.73
TP-15	7.97	7.94	4.08	5.66	3.87	3	0		0.4	4.33	16.97	12.63
TP-16	14.21	13.65	7.75	3.67	54.65	2	0		6.8	22.42	29.00	6.58
TP-17	12.24	6.37	3.89	4.36	42.54	7	0		26.1	9.76	15.92	9.54
TP-18	10.39	7.17	3.27	3.54	98.45	1	0		14.9	9.18	18.63	9.45
TP-19	13.63	6.73	3.32	6.39	114.49	1	0		9.2	6.83	14.48	7.64
TP-20	9.37	6.29	2.64	5.92	26.44	1	0		16.2	4.13	14.16	10.04
TP-21	12.50	8.45	4.53	3.67	66.84	4	0		14.2	12.64	20.67	8.04
TP-22	12.03	7.00	3.62	4.92	18.99	2	0		14.2	4.12	16.32	12.20
TP-23	6.72	7.37	4.52	3.04	74.80	1	0		8.1	14.03	20.05	6.03

C.5 Flood Routing

Flood routing through channel reaches in the hydraulic model were initially calculated using the Modified-Puls routing method. This method was used because of its ability to adequately account for the attenuation of the flood hydrograph associated with the effects of bridge/culvert backwater effects and overbank storage. Modified Puls routing data for the mainstem was extracted from the existing conditions hydraulic model for the Tres Palacios mainstem downstream of El Campo. Simplified hydraulic models for the tributary reaches were created to extract the remaining Modified Puls routing data. These models do not contain detailed bridge/culvert data with many crossings being modeled by a series of three cross-sections (upstream, top-of-road, downstream).

The results of the hydrologic model with Modified Puls routing did not calibrate well with existing gage flows. Therefore, routing for all reaches was accomplished within the hydraulic model using the HEC-RAS unsteady flow feature. Unsteady HEC-RAS models provide more accurate attenuation of flow hydrographs for streams with very flat channel slopes and significant overbank storage. Both are characteristic of the Tres Palacios River watershed.

C.6 Peak Discharges

Peak discharges were computed at the downstream end of each sub-basin, as well as at key locations along the main channels of the Tres Palacios Creek watershed. Tables C4 and C5 show the peak discharge results from the initial HMS model with Modified Puls routing and the final fully calibrated unsteady HEC-RAS model, respectively. Notice the significant reduction in flow that results from to the routing in the unsteady hydraulic model. Comparison of final flows to gage analysis results can be seen in the model calibration section.

Table C4: Computed Peak Discharges along Tres Palacios River (Initial HMS Model)

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)
J_TP-001	292901	1050	1670	2200	2850	3320	3920	4810	5580
J_TP-002	281567	1100	2090	2720	3520	4150	4870	6230	7720
J_TP-003	245076	1270	2020	2980	4150	4980	6400	8320	10130
J_TP-004	238606	1900	3220	4180	5440	6440	8460	11660	14460
J_TP-005	209960	2230	3660	4630	6520	7940	9450	13030	16470
J_TP-006	190547	2750	4580	5940	7740	9350	11210	15040	18840
J_TP-007	175835	3190	5420	7100	9350	11100	12970	16160	20270
J_TP-008	167931	3640	6580	8680	11680	13860	16280	19860	23060
J_TP-009	152273	3720	6980	9240	12520	14950	17430	21360	24920
J_TP-010	138066	5310	11430	14990	19920	23720	27630	33880	39830
J_TP-011	115376	5550	11800	15560	20580	23930	28170	34630	40570
J_TP-012	96235	5830	12110	16000	21070	23900	28630	34730	40440
J_TP-013	63988	6600	12880	17070	22440	25620	29900	36250	42110
J_TP-014	48255	8330	15620	20950	27610	32020	36360	44980	50830
J_TP-015	29673	8570	15870	21460	28280	32930	36490	46040	51640
J_TP-016	13793	8860	16210	22000	28990	33890	37420	47170	52670
OUTLET_TP	5384	8890	16270	22170	29200	34180	37840	47340	53120

Table C5: Computed Peak Discharges along Tres Palacios River (Unsteady RAS Model)

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)
292901	1060	1730	2140	2750	3240	3920	4820	5600
281567	1220	1850	2040	2330	2570	2880	3320	3680
245076	1230	2610	3680	4830	5520	6190	7390	8410
238606	1260	2590	3700	4850	5630	6420	7720	8870
209960	1360	2670	3780	5070	5980	7050	8660	10090
190547	1510	2790	3840	5260	6210	7480	9370	11000
175835	1980	3380	4410	5810	6960	8640	11020	12910
167931	2320	3870	5080	6740	8100	9560	12150	14320
152273	2520	4110	5400	7160	8580	10190	12580	14830
138066	3880	6850	8810	11540	8580	16270	20310	23760
115376	4040	7200	9280	12090	13840	16930	20920	24180
96235	4120	7360	9520	12390	14770	17280	21200	24590
63988	4360	7880	10230	13310	15770	18350	22340	25780
48255	5940	10950	14290	18710	22530	26190	32080	36530
29673	6030	11190	14660	19220	23160	26980	33050	37720
13793	6270	11760	15520	20390	24570	28720	35210	40350
5384	6350	11970	15810	20790	25040	29320	35960	41290

C.7 Hydraulic Analysis

The hydraulic analysis conducted along the Tres Palacios River main channel downstream of El Campo was a combination of detailed and limited detail studies. The detailed analysis sections were from US 59 to CR 408 in Wharton County and FM 2431 to Tres Palacios Bay in Matagorda County. These detailed reaches match the Zone AE portion on the effective Flood Insurance Rate Maps (FIRM) in Wharton and Matagorda Counties. This portion of the analysis utilized detailed channel and bridge survey data. The locations of the detailed bridge surveys used in this study are listed below. The river station is measured in feet from Tres Palacios Bay in Matagorda County. The railroad downstream of State Highway 35 was not surveyed due to denied access, but was incorporated into the model using the bridge information provided in the FEMA current effective HEC-2 detailed study model.

1. Abandon Bridge downstream of FM 521 (River Station 25,417)
2. Bridge at FM 521 (River Station 26,116)
3. Bridge at State Highway 35 Eastbound (River Station 98,670)
4. Bridge at State Highway 35 Westbound (River Station 98,735)
5. Bridge at FM 2431 (River Station 149,007)
7. Bridge at CR 408 (River Station 281,474)
8. Bridge at CR 406 (River Station 289,516)

Nine additional channel surveys, approximately one per mile, were completed in 2009 and were incorporated into the hydraulic model. Non-surveyed cross-sections were cut from LiDAR elevation data. All detailed survey (2009) and LiDAR data (2006 1.4 m Wharton County 18.5 cm vertical RMSE, 2006 0.7 m El Campo 15 cm RMSE, and 2006 Coastal 37.0 cm vertical RMSE) were collected using the NAD 83 horizontal datum, and the NAVD 88 vertical datum.

The limited detail study reach is from CR 408 in Wharton County to FM 2431 in Matagorda County. The limited detail analysis did not incorporate detailed channel and bridge survey data but only used LiDAR elevation data for channel cross-sections. The limited detail bridge data was obtained from site visits, as-built drawings, and/or TXDOT BRINSAP reports. Floodplains from a limited detail study area are considered by FEMA to be Zone A floodplains.

The computed hydrographs from the hydrologic model were input into the hydraulic model to develop peak stages for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year frequency events. The hydraulic analysis was conducted with HEC-RAS software, version 4.0, utilizing the unsteady flow method. To model lateral spills and overbank storage more accurately, lateral weirs connected to tributary reaches were added to the unsteady hydraulic model at the three locations shown in Figure C1. All lateral weir coefficients were lowered to 1.6 to compensate for the overland roughness and distance of the spill. All Manning's n-values were selected from a combination of aerial photos and site visits, and based upon tables found in *Open Channel Hydraulics, Chow, 1959*. Calibration is discussed in more detail in Appendix C.8.

C.8 Model Calibration

Model calibration was performed using a historical flood event that occurred in May 2004 as well as a frequency analysis of gage peak flows. Gage data was taken from the USGS gage near Midfield, TX (No. 08162600). The May 2004 flood event was chosen because it was easily discernable in the Tres Palacios gage record and had corresponding rainfall data readily available. Rainfall data was obtained from OneRain Inc. in the form of hyetographs which were used as input for each sub-basin in the hydrologic model. Figure C2 shows a map of gridded rainfall depth in the project area for the May 2004 rainfall event.

When compared to the 2004 storm event gage hydrograph, it was determined that the original HEC-HMS output with Modified Puls routing was underestimating channel storage. A better calibration was accomplished by using an unsteady flow hydraulic model to route the flows through the stream reaches. The resulting model hydrographs for the two storm events compared more favorably after unsteady modeling.

The calibration was improved again after making adjustments to the Clark Unit Hydrograph storage coefficient (R-value) parameter. According to the HCFCD method for calculating Clark parameters discussed in Section A.4, if percent ponding is greater than 20%, an adjustment factor used to increase the R-value to compensate for the increased storage related to the ponding. Since there is some uncertainty involved in determining the exact amount of ponding in each sub-basin, it was assumed that percent ponding and therefore the R-value could be adjusted to increase storage and improve the calibration. The R-value was adjusted by assuming all sub-basins had at least 21% ponding thus invoking the R-value adjustment factor (RM). The R-values for the Tres Palacios sub-basins were compared before and after adjustment to the sub-basin R-values calculated for the recent hydrologic and hydraulic study of the San Bernard River. The comparison can be seen in Figures C3 and C4 which show the San Bernard R-values vs. sub-basin area as well as the Tres Palacios R-values with and without adjustment. When the Tres Palacios R-values are adjusted they match the San Bernard R-value vs. sub-basin area trend much more closely.

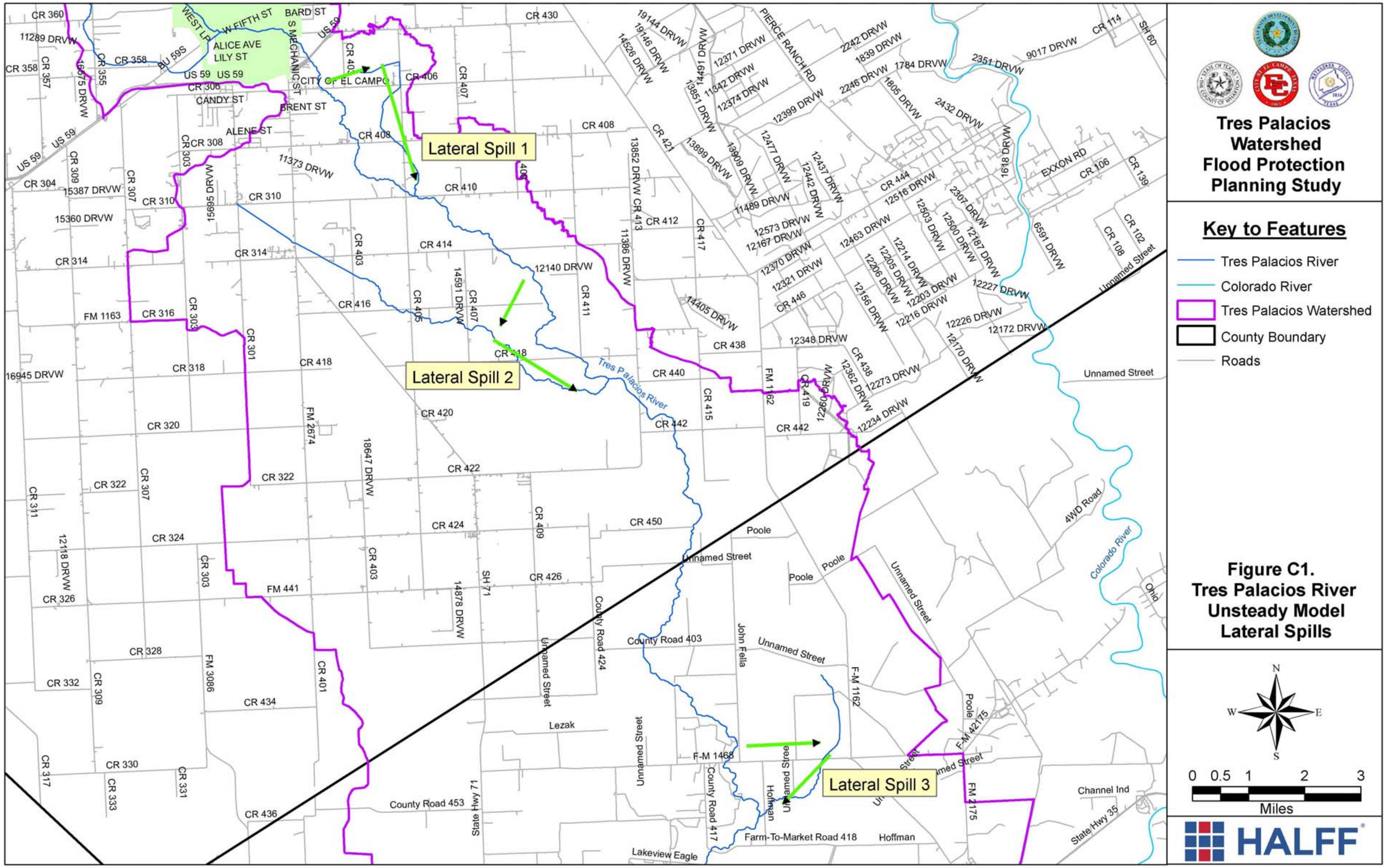


Figure C1. Tres Palacios River Unsteady Model Lateral Spills

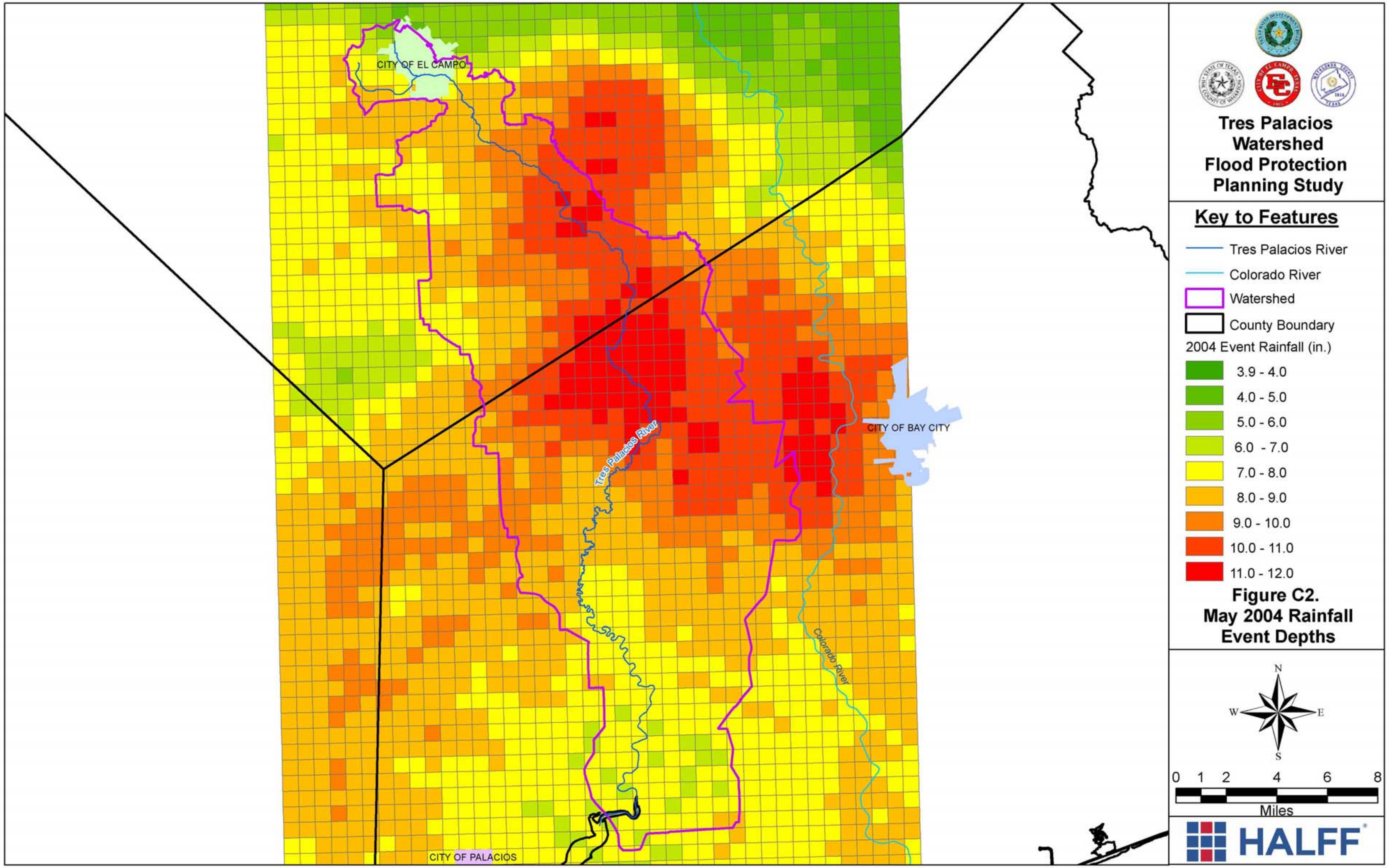


**Figure C2.
May 2004 Rainfall
Event Depths**

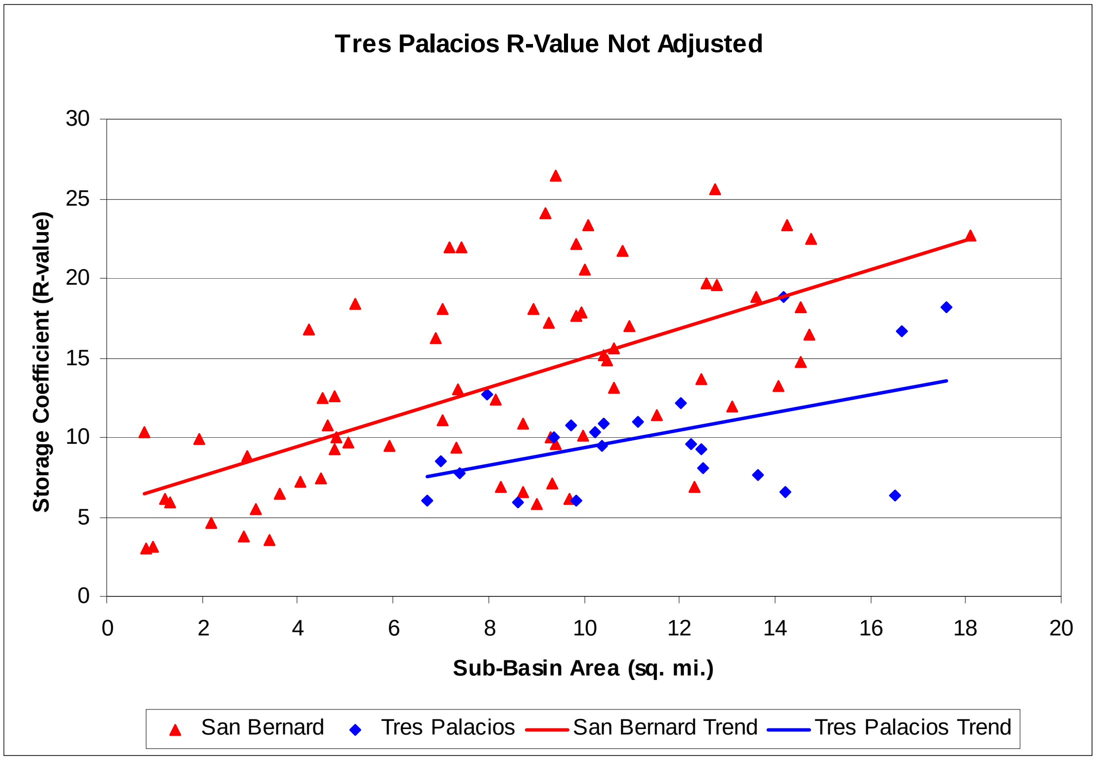


Figure C1: R-value vs. Sub-Basin Area: San Bernard vs. Unadjusted Tres Palacios

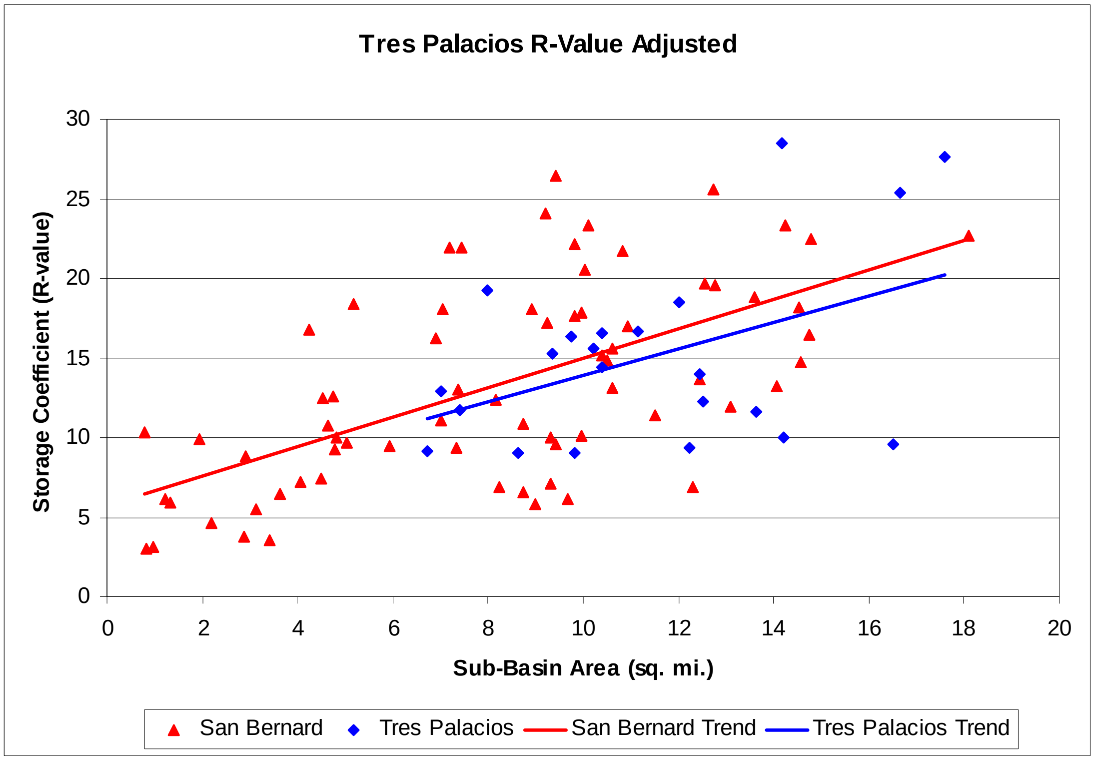


Figure C2: R-value vs. Sub-Basin Area: San Bernard vs. Adjusted Tres Palacios

Once all calibration adjustments were complete, the resulting model hydrographs were compared to the May 2004 event hydrograph. Figure C5 shows a comparison of the original un-calibrated HMS hydrograph, the final calibrated hydrograph and the actual gage hydrograph for the May 2004 event. Calibrated model results for the 2004 event show a peak flow with less than a 30% difference and a volume with less than a 20% difference when compared to the gage hydrograph. These results are detailed in Table C6 along with results from the original un-calibrated HMS model.

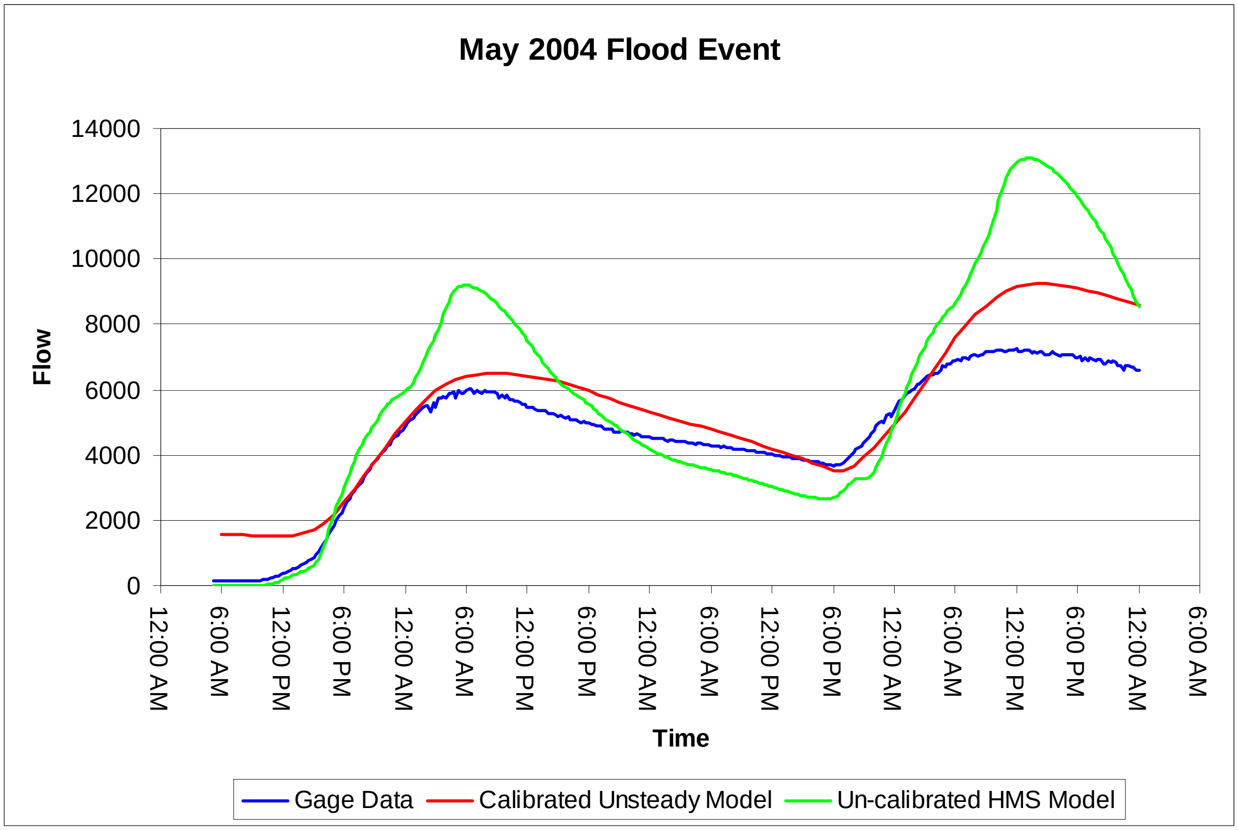


Figure C3: May 2004 Event Hydrograph Comparison

Table C6: May 2004 Event Peak Flow and Volume Comparison to Gage Data

2004 Flood Event Comparison				
Source	Volume (ac-ft)	Volume % Diff	Peak Flow (cfs)	Peak Flow % Diff
Gage	34962	0	7240	0
Calibrated Unsteady Model	41151	17.7	9250	27.8
Un-calibrated HMS Model	43494	24.4	13085	80.7

A flood frequency analysis was conducted on the USGS gage using HEC-SSP software. This software uses the maximum peak discharge for each year that the gage was in operation to develop a frequency-discharge relationship. The statistical analysis used in the program follows the procedures documented in the *US Department of Interior, Geological Survey, Bulletin 17B,* *"Guidelines for Determining Flood Flow Frequency", 1982*. This statistical analysis resulted in peak discharges for the 2-, 5-, 10-, 25-, 50-, 100-yr, 250-yr, and 500-yr events as shown in Table C7 and Figure C6. The frequency flows from the calibrated model calibrated well with the gage analysis. Therefore, it was assumed that areal reduction of rainfall inputs was not required. The comparison of calibrated frequency flows to the gage analysis frequency flows can be seen in Figure C7.

Table C7: Gage Frequency Analysis vs. Calibrated Model Flows

Recurrence Interval (years)	Gage Analysis Flow (cfs)	Model Flow (cfs)
2	5130	4975
5	7800	7790
10	9690	9110
25	12210	12490
50	14170	14820
100	16195	17750
250	18990	22180
500	21200	25730

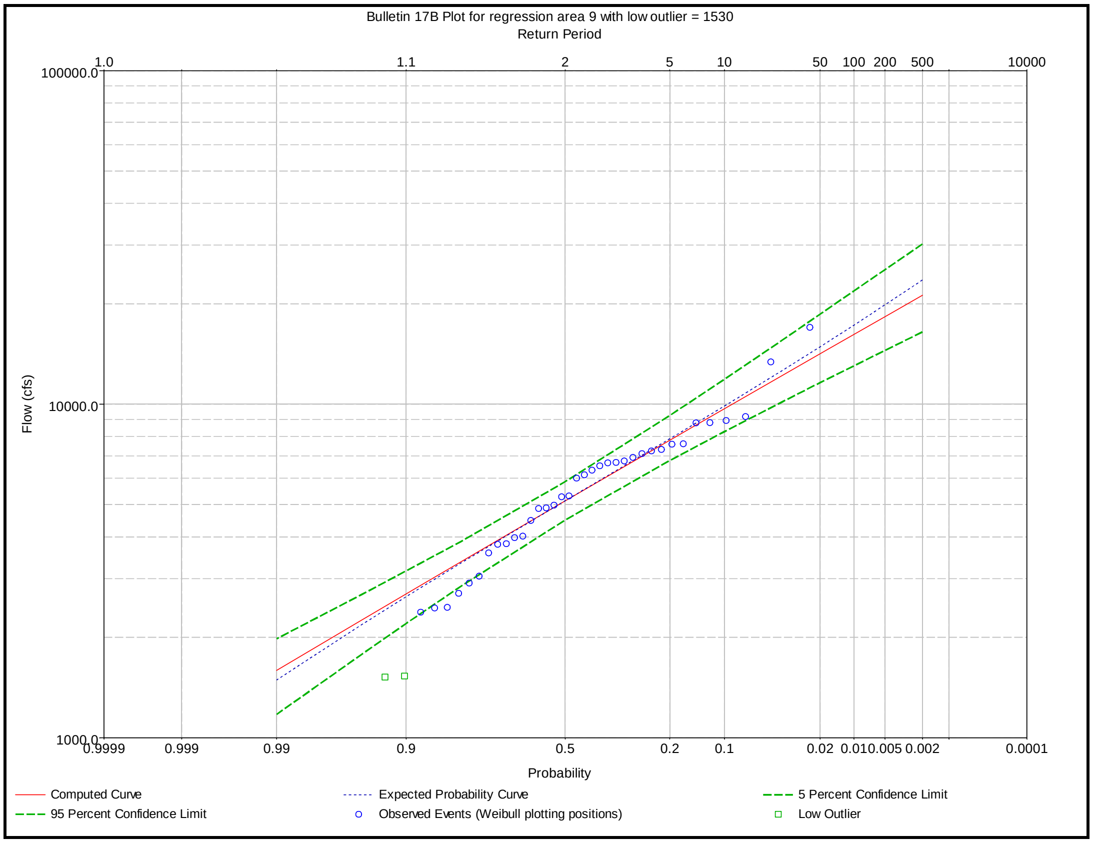


Figure C4: Gage Analysis Results for USGS Gage near Midfield, TX

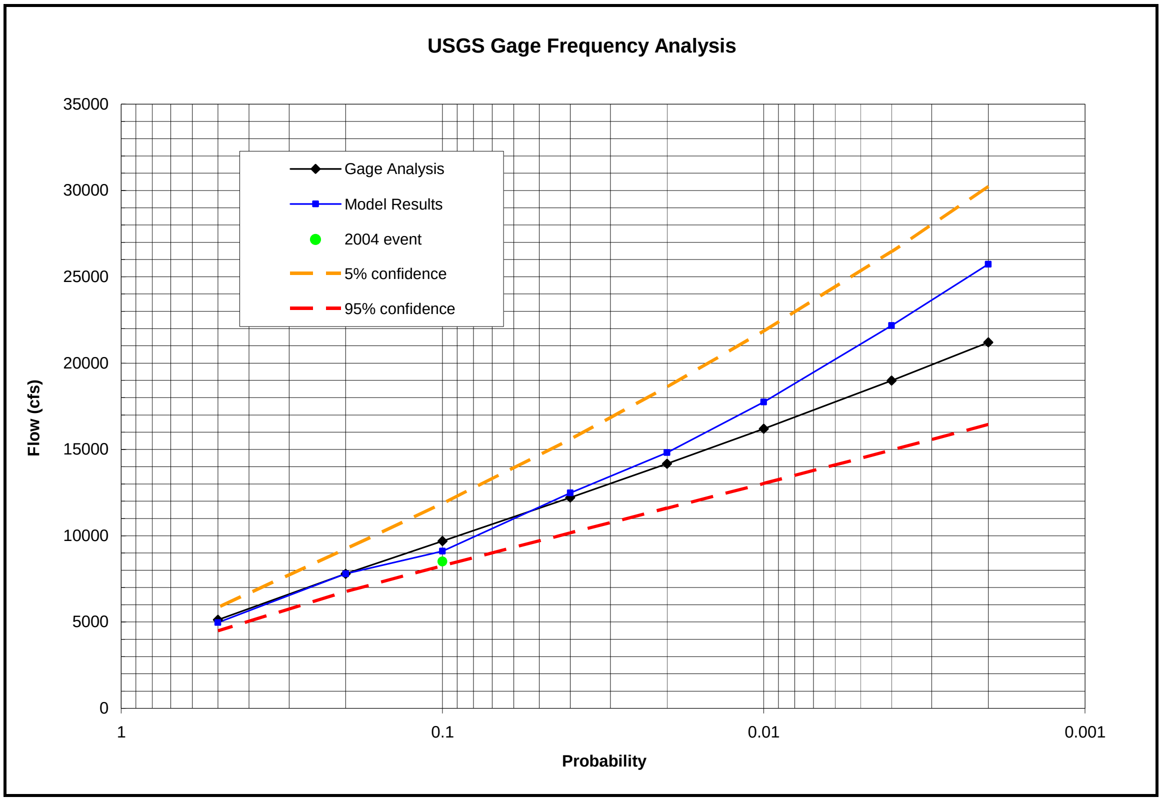


Figure C5: Comparison of USGS Gage Analysis to Calibrated Model Results

C.9 Flood Profiles

Flood profiles for existing conditions were computed along Tres Palacios River for the various frequency events previously mentioned. The results can be seen in Figures C8 and C9. The sharp dips in the lower part of the Matagorda profile represent locations where the channel bottom was surveyed. Other locations represent LiDAR topographic data which cannot penetrate below the tidal induced water surface. Normal water surface elevations in the lower portion are affected by Tres Palacios Bay and are therefore at or very near mean sea level resulting in a LiDAR channel invert hovering around 0 ft. The affects of mean sea level on the LiDAR channel invert extend to just upstream of SH 35.

A comparison was made between this study and the current effective base flood elevations and discharges listed in the Wharton and Matagorda County current effective Flood Insurance Studies. The 100-yr flood elevation comparisons are shown in Figures C10 and C11 and discharge comparisons are shown in Table C8.

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

6. The FIS is based on a HEC-2 model from the 1970s.
7. Hydrologic and Hydraulic parameters were calculated with different methodology.
8. Differences in the amount and accuracy of field survey available.
9. The use of detailed LiDAR topographic data.
10. Physical watershed changes may have occurred.

Table C8: Current Effective FIS Discharges vs. New Model Discharges

Station	FIS 10-yr	New Model 10-yr	FIS 50-yr	New Model 50-yr	FIS 100-yr	New Model 100-yr	FIS 500-yr	New Model 500-yr
Matagorda County								
0	7900	17650	13400	27900	15700	32700	20800	45750
19257	7800	16500	13100	26000	15400	30500	20400	42800
48778	6600	11800	11100	18200	13400	21100	17300	29000
63660	6700	10900	11400	16900	13100	19600	17700	27700
76370	6500	10100	10900	15900	12900	18600	17000	26900
113637	6100	9600	10400	15300	12200	18250	16100	26300
141959	4600	6200	7500	9700	8800	11450	11700	16200
Wharton County								
292901	2250	2200	3100	3300	3600	3900	4600	5600

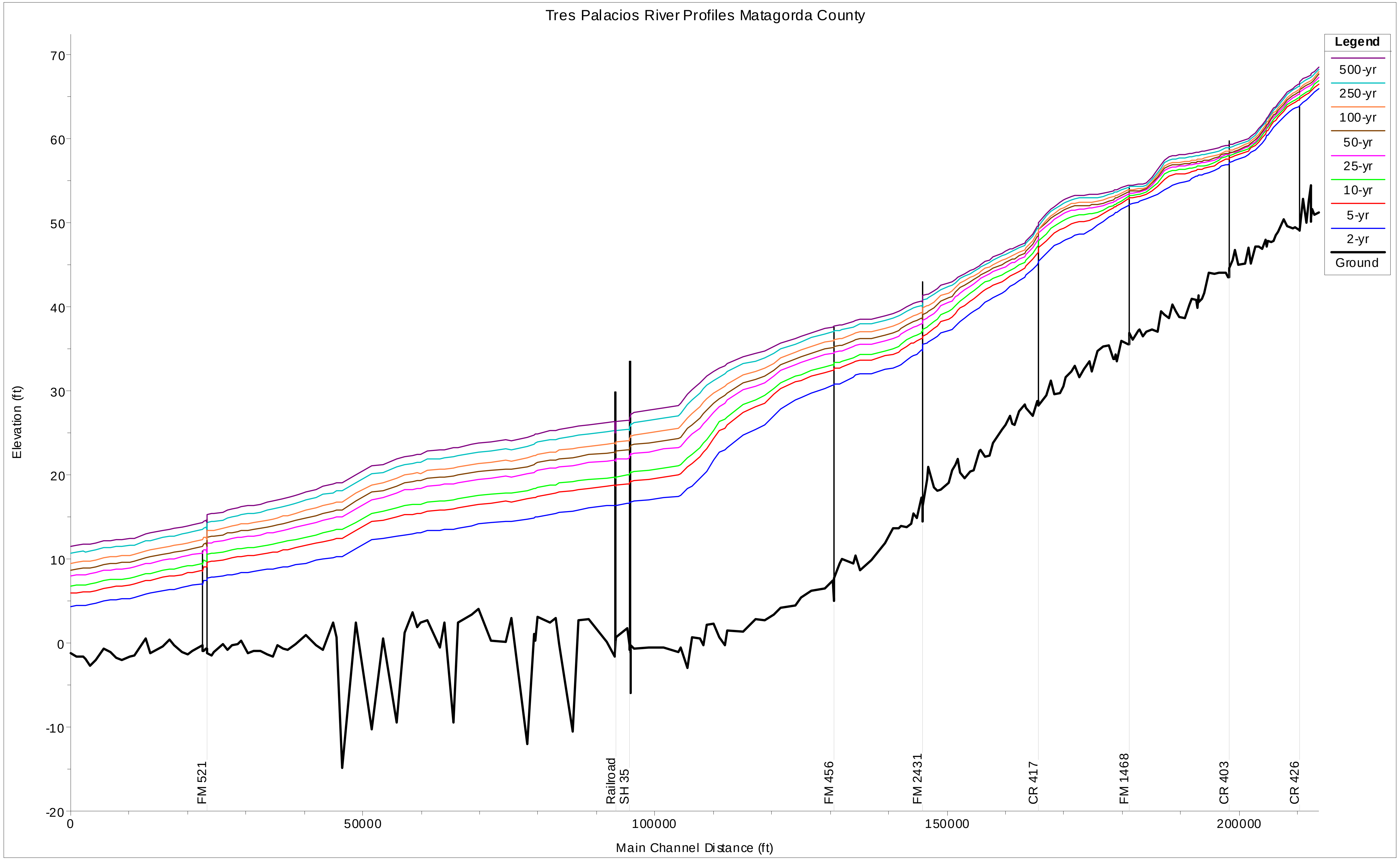


Figure C6: Tres Palacios River Matagorda County Water Surface Profiles

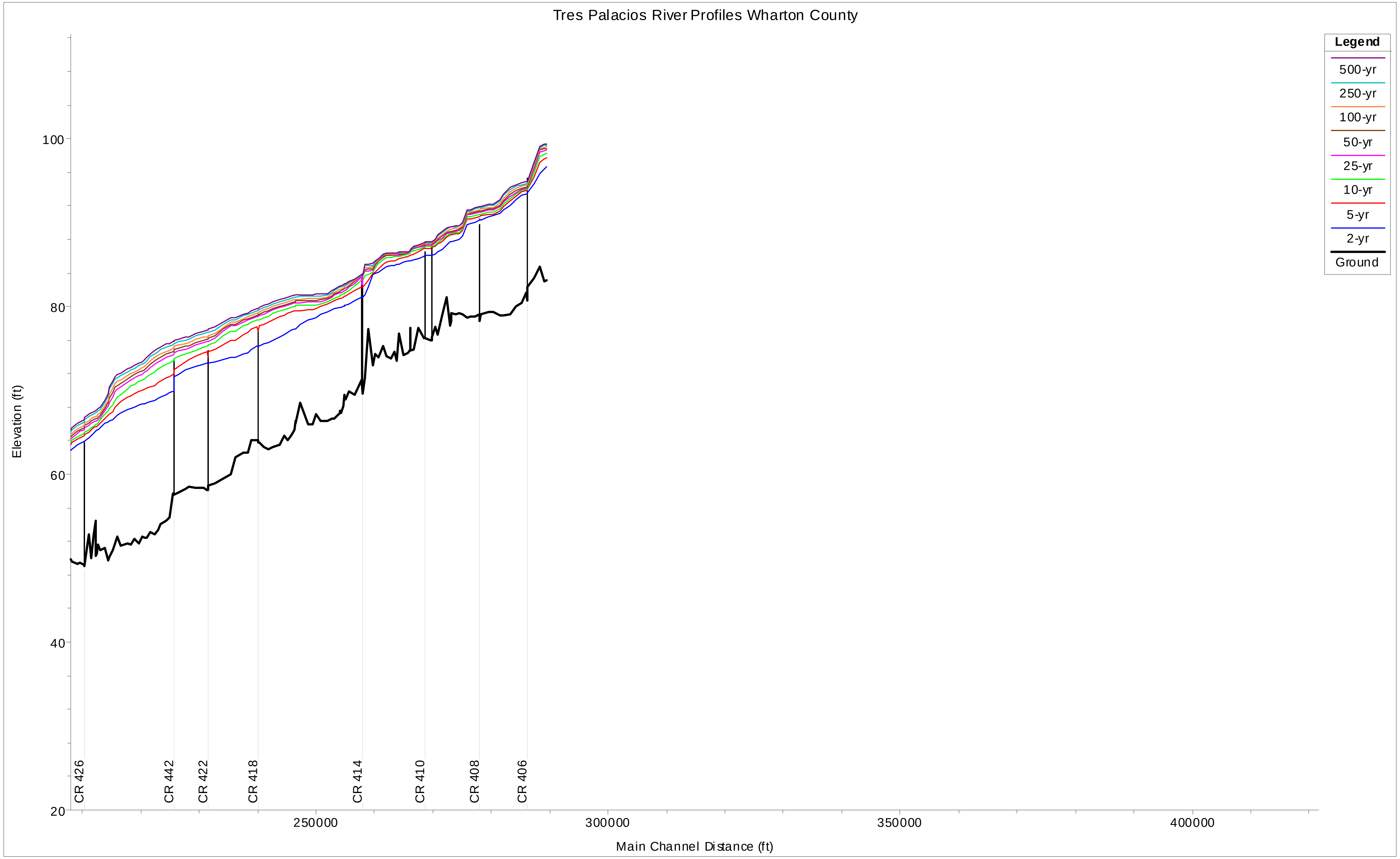


Figure C7: Tres Palacios River Wharton County Water Surface Profiles

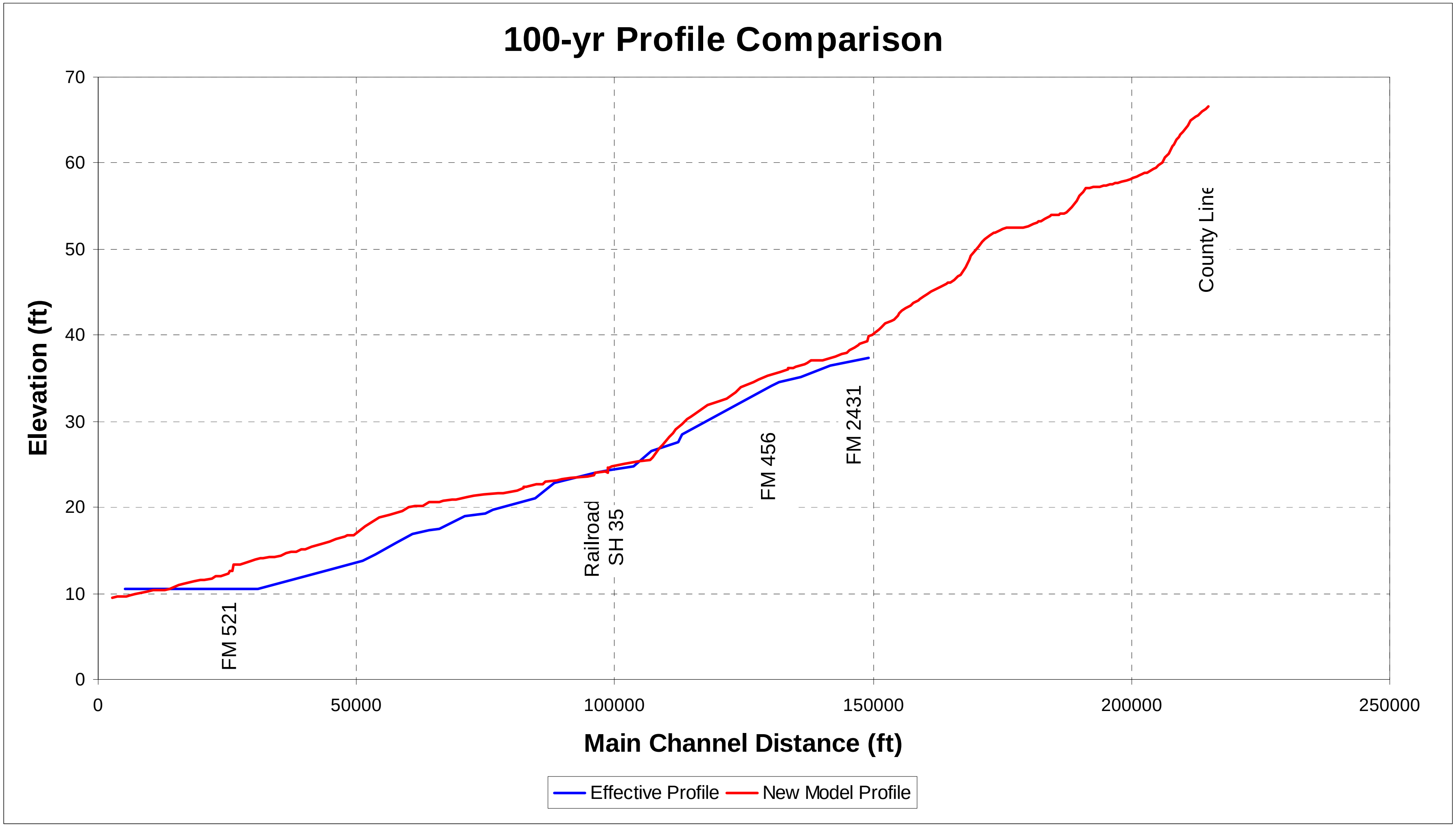


Figure C 8: Matagorda County 100-yr Profile Comparison to FEMA Effective

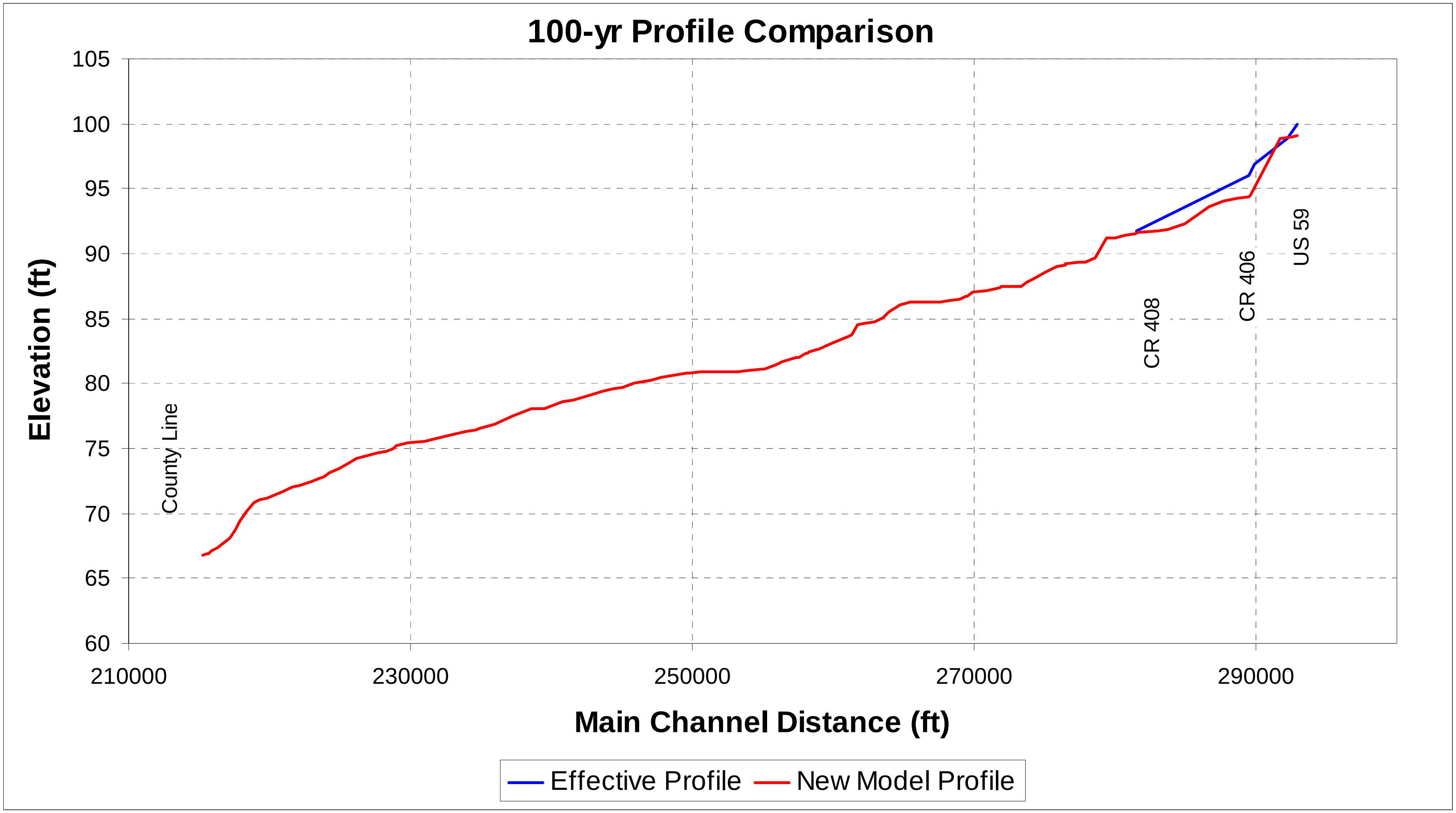


Figure C9: Wharton County 100-yr Profile Comparison to FEMA Effective

APPENDIX D: Flood Damage and Alternative Analysis of the Tres Palacios River

D.1 Introduction

The flood damage and alternative analysis for the Tres Palacios River was completed in two parts. The first part focused on The City of El Campo and the second focused on residential communities along the river in Matagorda County. Halff Associates teamed with HDR: Claunch and Miller to perform the flood damage and alternative analysis for the City of El Campo. Halff Associates also examined possible flood reduction measures for the Matagorda County communities. A description and results of the El Campo analysis will be given first (sections D.2 to D.7) followed by a discussion and results for the Matagorda County analysis (section D.8).

D.2 Hydraulic Engineering Data

The first inputs required by the HEC-FDA program are resulting water surface profiles for existing or "without project" conditions and for each flood reduction alternative. This water surface profile information was derived from hydraulic models representing existing conditions and each alternative. Hydraulic models for mainstem existing conditions and flood reduction alternatives in El Campo were developed by HDR: Claunch and Miller, and details of these models can be seen in their sealed report in Appendix A. Details for the existing conditions hydraulic model for the El Campo Tributary, developed by Halff Associates, can be seen in Appendix B. Adjustments to downstream boundary conditions to the El Campo Tributary model were made to reflect the mainstem water surface elevations for existing condtions and each alternative. From the imported hydraulic data, HEC-FDA was used to calculate exceedance probability vs. discharge and stage vs. discharge curves and their associated statistical uncertainties.

a. Water Surface Profiles

The water surface profile results of each hydraulic model were exported to a text file that was then imported into HEC-FDA. HEC-FDA requires that the results from the hydraulic model contain water surface elevations or stages for the 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, 100-yr, 250-yr and 500-yr events. Examples of these water surface profiles can be seen in Figures D1 through D3, which show the first six water surface profiles imported from the mainstem hydraulic model for the "without project" condition, 25-yr earthen channel, and 50-yr earthen channel alternatives respectively. Note the improvements in the alternative water surface elevations downstream of Jackson St. when compared to the existing condition water surface elevations.

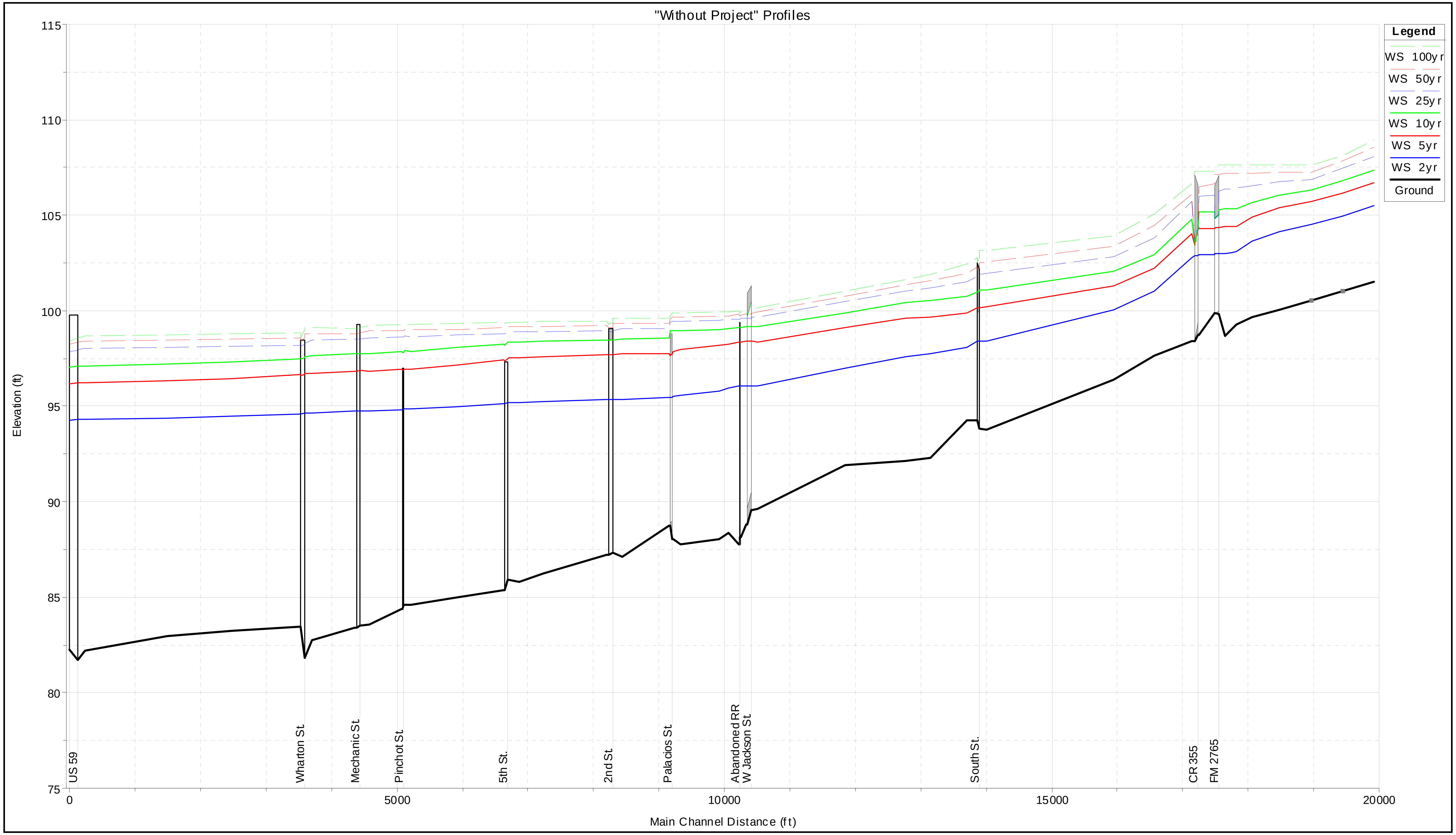


Figure D1: Tres Palacios Mainstem "Without Project" Condition Water Surface Profiles

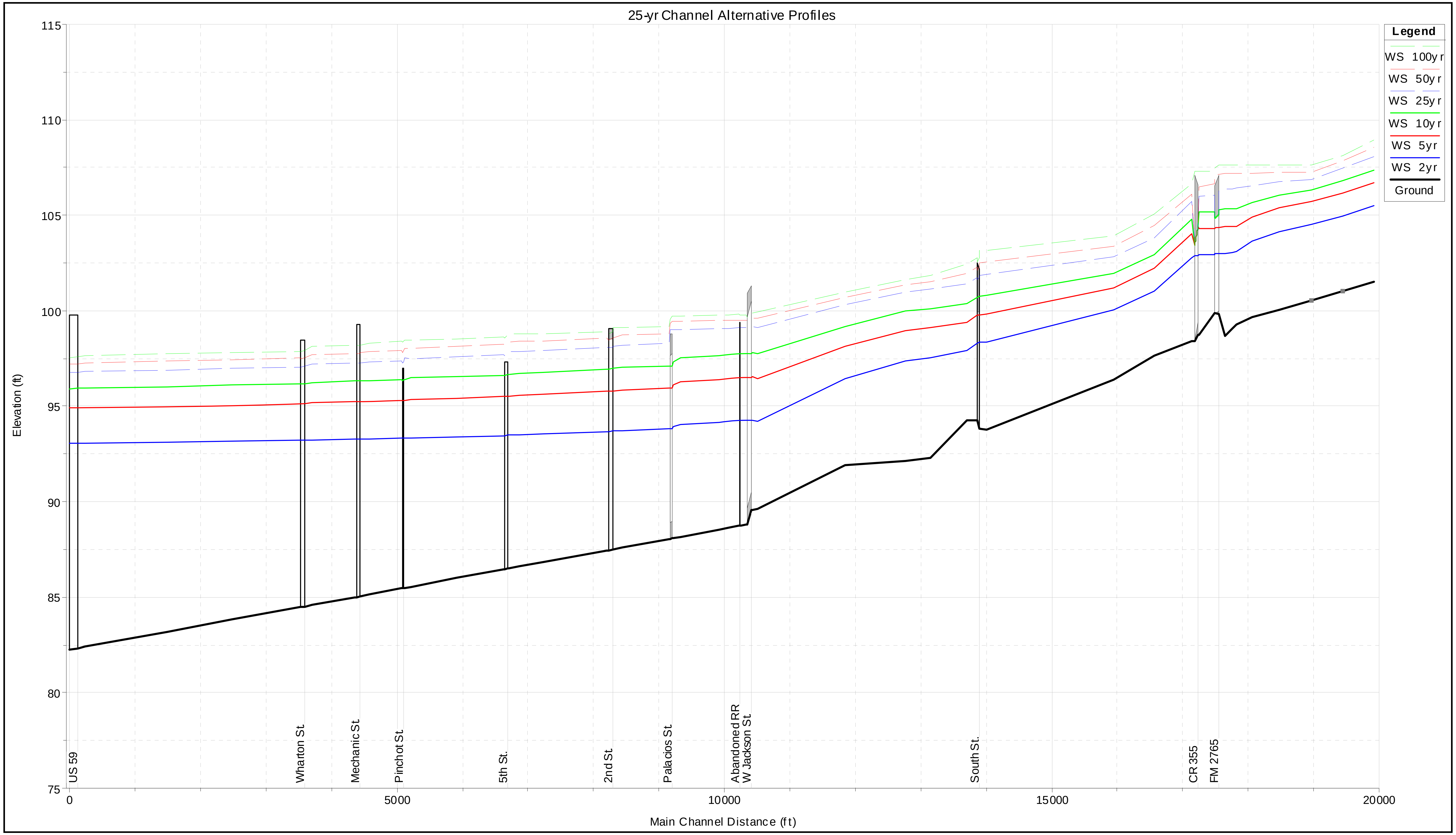


Figure D2: Tres Palacios Mainstem 25-yr Channel Alternative Water Surface Profiles

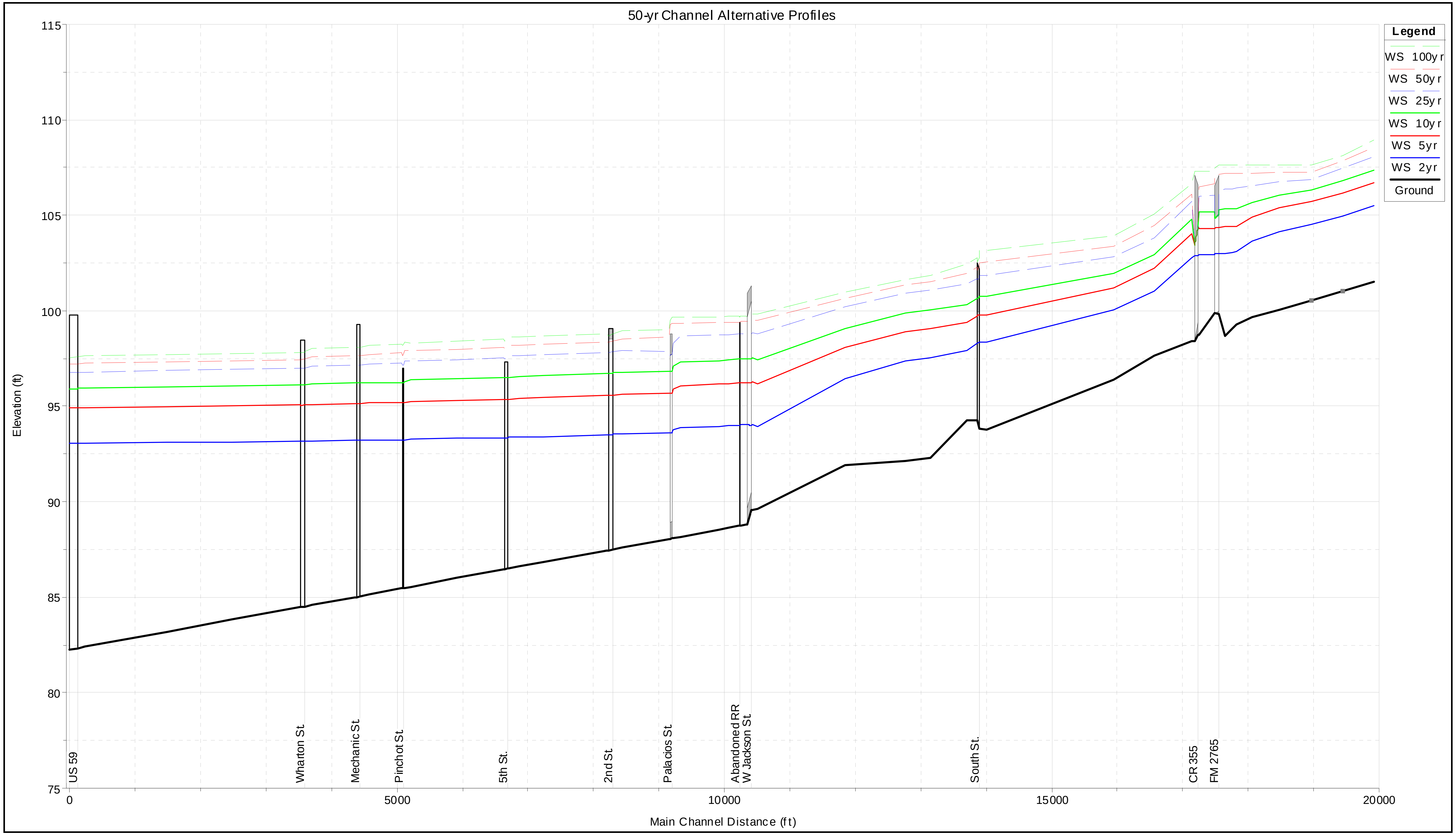


Figure D3: Tres Palacios Mainstem 50-yr Channel Alternative Water Surface Profiles

b. Exceedance Probability Functions

The exceedance probability function is calculated by HEC-FDA from the water surface profile data and consists of a series of exceedance probabilities and their associated discharges. To represent the uncertainty associated with the hydraulic model, confidence limits were calculated by HEC-FDA based on statistics derived from the USGS discharge gage at FM 456 near Midfield, TX on the Tres Palacios River. An exceedance probability function plot for the "without project" condition can be seen in Figure D4.

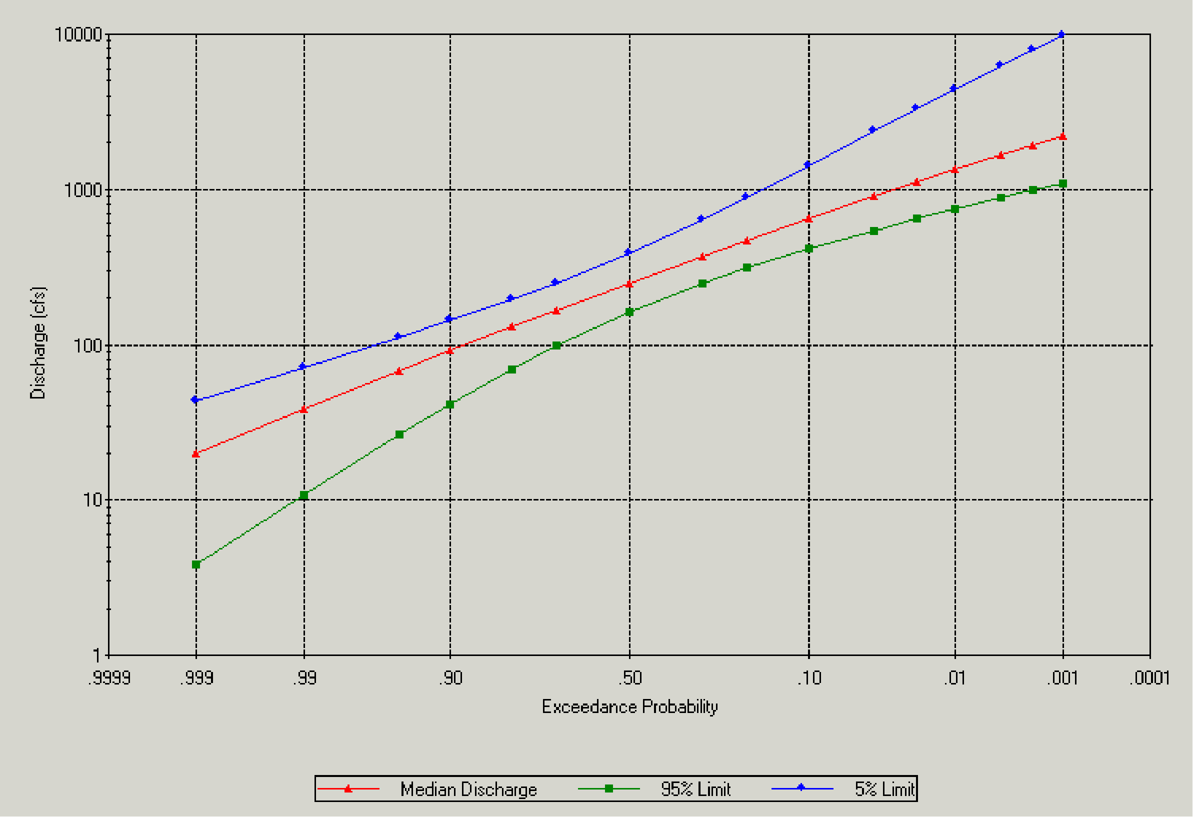


Figure D4: Existing Condition Exceedance Probability Curve

c. Stage-Discharge Function

The stage-discharge function and its associated uncertainty are the final hydraulic engineering calculations performed by HEC-FDA. For each alternative, as well as the "without project" condition, HEC-FDA calculates an average stage discharge function over the damage reach. This function is analogous to a rating curve associated with a stream gage. The uncertainty of the stage-discharge relationship is based on a normal distribution and is associated with a standard deviation of errors derived from the gage data for Tres Palacios River. The stage-discharge data from the USGS gage at FM 456 near Midfield, TX on the Tres Palacios River was analyzed to determine the standard deviation of errors. The standard deviation of errors was calculated using equation 5-3 from the U.S. Army Corps of Engineers Engineering Manual (USACE EM 110-2-1619). The resulting standard deviation of errors was 1.18 ft and was used by HEC-FDA to calculate a set of curves representing up to two standard deviations from the original stage-discharge curve. The stage-discharge curve with two standard deviations for the "without project" condition can be seen in Figure D5.

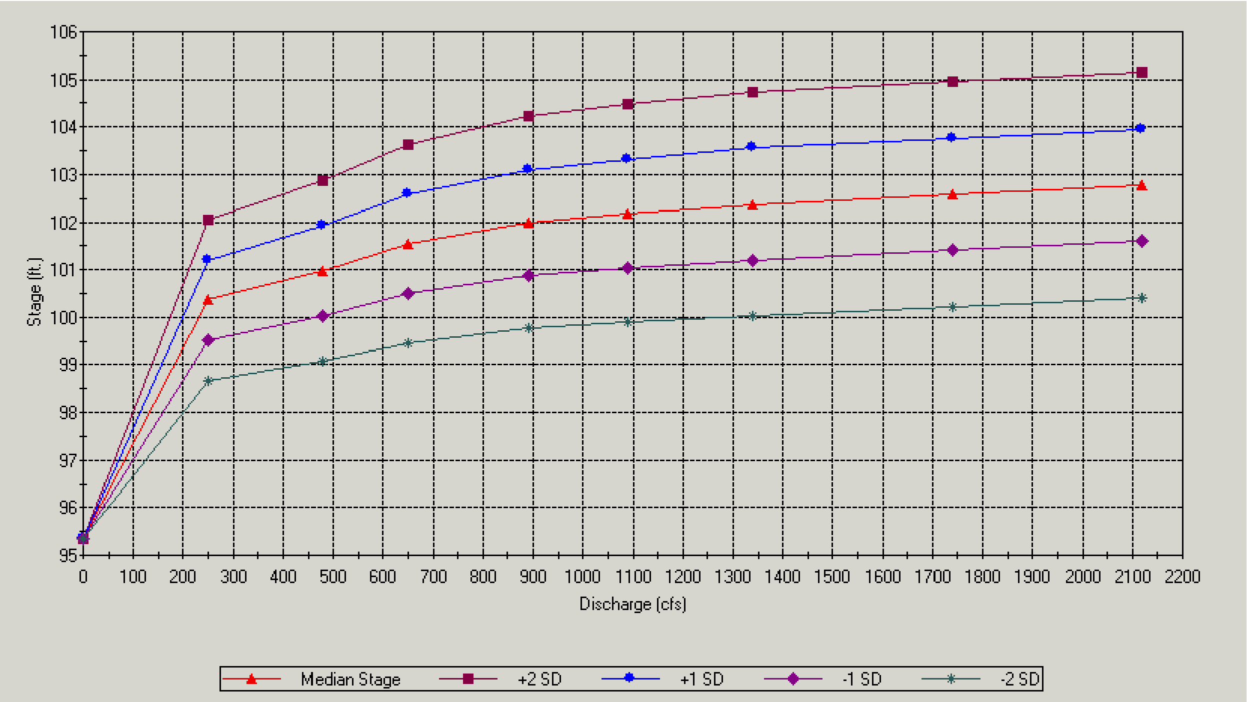


Figure D5: Existing Condition Stage-Discharge Curve

D.3 Economic Data

After the hydraulic data is entered, it must be associated with structure value data and the depths at which damage to those structures occurs. To do this, the structure database needs to be organized into damage categories and occupancy types with associated depth-damage curves. Finally, values and first floor elevations for each structure must be entered into the database.

a. Damage Categories

Damage categories are used to broadly classify the different structure types in the analysis. Five damage categories were used in the HEC-FDA analysis and are listed along with descriptions in Table D1.

Table D1: Damage Categories

Damage Category	Description
Public	Schools, Churches, Municipal Structures
Residential	Houses, Mobile Homes
Commercial	Stores, Businesses, etc.
Industrial	Processing and Manufacturing Facilities
Agricultural	Barns, Equipment Storage Facilities

b. Occupancy Types

Occupancy types are further structure classifications within the damage categories. A stage-damage function, relating water depth to typical amount of damage incurred, is associated with each occupancy type. The stage-damage curves that were used in this analysis were derived from functions supplied by USACE.

Occupancy types for the El Campo FDA study and their associated stage-damage functions imported into HEC-FDA are shown in Appendix E. Stage-damage data is given in 5 or 6 lines depending on the occupancy type and consists of stage data (STAGE), percent of damage to structure based on stage (S), standard deviation of errors associated with structure value for triangular or normal distributions (STU, STL, and SN), and percent of damage to contents based on stage (C). The last line (STRUCT) is used to define uncertainties for structure value, first floor elevation, content value and "other value" if desired. In this analysis, uncertainties were on the STRUCT line of the occupancy type input file.

c. Structure Inventory

The structure inventory consists of a structure value, content value, first floor elevation and cross-section associated with each structure. Dollar value for each structure comes from tax appraisal district property values and does not include the value of the land. The content value is approximated as 50% of the structure value for each structure as was done by the Corps in the City of Wharton FDA study. Each first floor elevation was determined by adding an assumed elevation adjustment to the 2006 LIDAR elevation at the structure location. This adjustment was assumed to be 3 feet for mobile homes, while all other structures were treated as having slab on grade with corresponding slab elevation adjustments of 0.5 feet. A field reconnaissance was done to make sure our first floor elevation adjustments were typical. Some adjustments were made following the reconnaissance to better represent first floor elevations. Each structure was also associated with a cross-section from the hydraulic models. The cross-section assignment is the link between the hydraulic and economic data required to calculate the resulting damages. Vehicle damage was included in the analysis by assigning typical vehicles to residential structures. The following formulas were used to calculate vehicle value based on residential structure value:

$V = (0.15*S) + 1000$ for houses

$V = (0.2*S) + 1000$ for mobile homes

Where V is vehicle value and S is the value of the residential structure. These formulas for determining vehicle values were used by the USACE in the City of Wharton FDA study and are considered applicable to this study. The complete structure inventory can be seen in Appendix E.

d. Reach Stage-Damage Function Uncertainty

Sources of uncertainty in the economic data that affect the stage-damage function include structure valuation, content valuation, vehicle valuation, and slab depth. Uncertainty in structure value was included in the occupancy type input file in the form of a percent standard deviation of structure value error. The percent standard deviation of structure value errors approximated for this study was 20%. In other words, a structure value of $60,000 will have a normally distributed error of plus or minus $12,000. The content and vehicle valuations are based off of the structure valuations and therefore have the same uncertainty as its corresponding structure valuation. The first floor elevation uncertainty is associated with the error inherent in its source data, which is the 2007 LIDAR elevation data. The root-mean squared error in the LIDAR data and therefore the first floor elevations is 18.5 cm, which is roughly plus or minus 0.6 ft.

HEC-FDA used these quantifications of uncertainty with the depth-damage curves for each occupancy type to determine an aggregate stage-damage curve for each damage reach. The aggregate stage-damage curves summarize the damage associated with all structures in a damage category within a damage reach. For this analysis, each individual cross-section was considered to be a damage reach allowing for a more accurate accounting of damages. The existing conditions aggregate stage-damage curve with two standard deviations for the residential damage category and the damage reach at cross-section 296768 is shown in Figure D6. Aggregate stage-damage curves were also developed for each alternative.

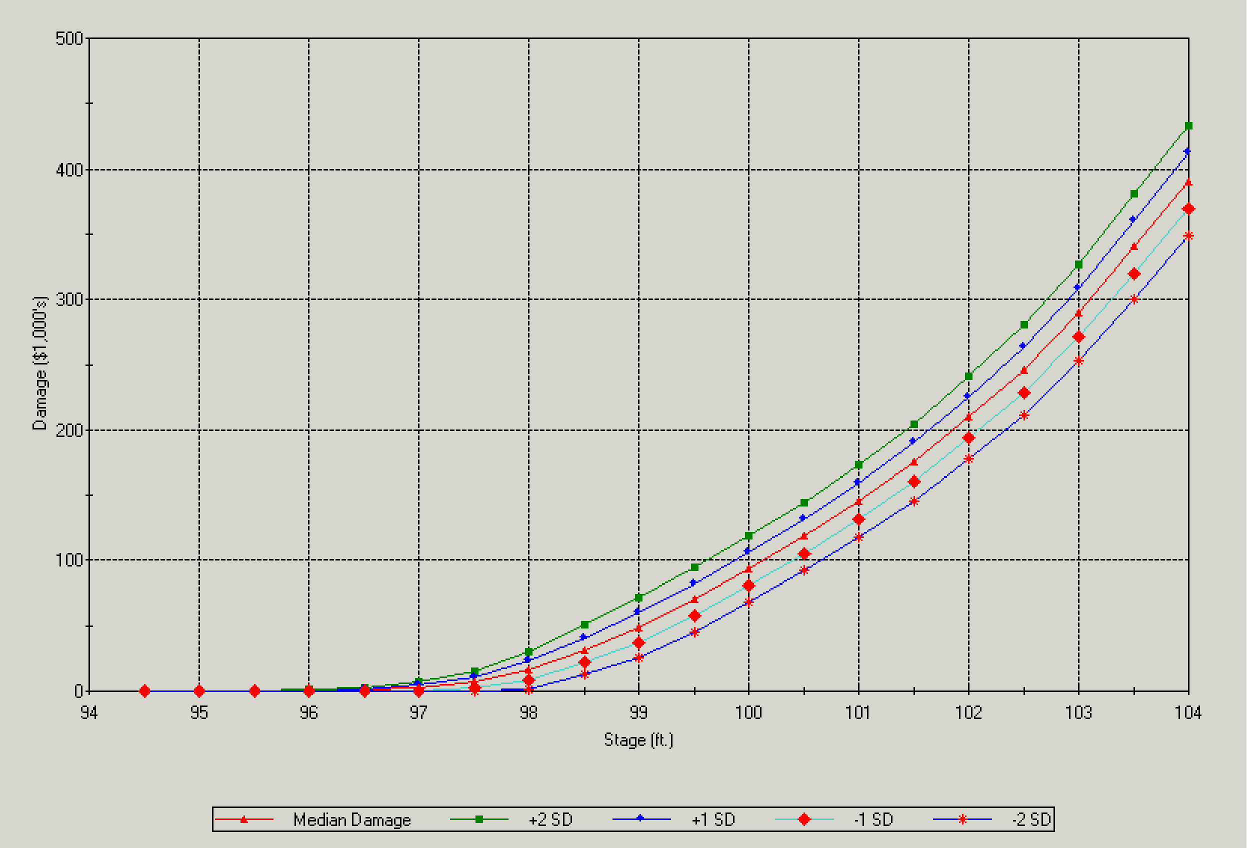


Figure D6: Existing Aggregate Stage-Damage Curve for Residential Structures at XS 296768

D.4 Alternative Descriptions

Besides the “without project” condition, eight flood reduction alternatives were created for testing with the HEC-FDA model. Six alternatives are channel widening projects, while the remaining two are detention only or detention/diversion options. Channel widening projects will need easements from the top of both banks for construction and maintenance access. The descriptions for these alternatives are shown below in Table D2.

Table D2: Flood Reduction Alternative Descriptions

Alternative Name	Description
Without	Without project or existing conditions: reflects current damages without flood reduction measures.
25yr_Earth	25-yr capacity channel: Channel improvements to increase channel capacity to hold the 25-yr flow (4:1 side slope and 45 ft. bottom width) extending from Bus. 59 to CR 406. Channel to remain earthen.
50yr_Earth	50-yr capacity channel: Channel improvements to increase channel capacity to hold the 50-yr flow (4:1 side slope and 60 ft. bottom width) extending from Bus. 59 to CR 406. Channel to remain earthen.
100yr_Earth	100-yr capacity channel: Channel improvements to increase channel capacity to hold the 100-yr flow (4:1 side slope and 80 ft. bottom width) extending from Bus. 59 to CR 406. Channel to remain earthen.
100yr_Conc	100-yr capacity channel: Channel improvements to increase channel capacity to hold the 100-yr flow (1.5:1 side slope and 40 ft. bottom width) extending from Bus. 59 to CR 406. Channel to be concrete lined.
250yr_Conc	250-yr capacity channel: Channel improvements to increase channel capacity to hold the 250-yr flow (1.5:1 side slope and 55 ft. bottom width) extending from Bus. 59 to CR 406. Channel to be concrete lined.
500yr_Conc	500-yr capacity channel: Channel improvements to increase channel capacity to hold the 500-yr flow (1.5:1 side slope and 70 ft. bottom width) extending from Bus. 59 to CR 406. Channel to be concrete lined.
Alt2_Det	Detention Option: Two detention ponds are used to reduce flow downstream of each pond to 10-yr flow. Probable locations are on El Campo Tributary somewhere upstream of South Meadow Lane and on the mainstem somewhere upstream of Bus. 59.
Alt3_Det_Div	Detention/Diversion Option: One detention pond on El Campo Tributary with a probable location somewhere upstream of South Meadow Lane to reduce flow downstream of pond to 10-yr flow. Water also to be diverted from El Campo Tributary to Stage Stand Creek through bypass channel.

D.5 Expected Annual Damage and Damage Reduction

After hydraulic and economic data with associated uncertainties was entered into HEC-FDA for “without project” option and all alternatives, the expected (average) annual damage (EAD) calculation process was begun. In this study, it was assumed that economic growth in the El Campo area would be slow with overall structure value and stream hydraulics remaining roughly the same. Therefore, no changes were made to the hydraulic or economic data sets to reflect future conditions.

Expected annual damage is calculated using a Monte Carlo simulation to create possible flooding and damage scenarios. The Monte Carlo simulation uses normally distributed errors and probabilities associated with the input data to create thousands of trials containing different flooding scenarios. The damage from these scenarios is then averaged on an annual basis as the expected annual damage. Expected annual damage and damage reduced over the "without project" condition for flood reduction alternatives is shown in Table D3.

Table D3: Expected Annual Damage and Damage Reduction (Damage in $1,000's per Year)

Alternative	Description	Expected Annual Damage			Probability Damage Reduced Exceeds Indicated Values		
		Total Without Project	Total With Project	Damage Reduced	0.75	0.5	0.25
Without	Without Project Condition	426.78	426.78	0.00	0.00	0.00	0.00
25yr_Earth	25yr Earthen Channel	426.78	254.48	172.3	77.63	140.83	236.80
50yr_Earth	50yr Earthen Channel	426.78	240.67	186.11	82.49	150.84	255.79
100yr_Earth	100yr Earthen Channel	426.78	232.34	194.44	85.92	157.37	267.1
100yr_Conc	100yr Concrete Channel	426.78	231.43	195.35	86.67	158.21	267.97
250yr_Conc	250yr Concrete Channel	426.78	216.68	210.1	96.85	168.7	288.59
500yr_Conc	500yr Concrete Channel	426.78	212.31	214.47	92.24	171.95	294.73
Alt2_Det	Detention Option	426.78	352.26	74.52	29.36	58.73	104.21
Alt3_Det_Div	Detention/Diversion Option	426.78	357.47	69.31	26.64	54.23	97.36

Once expected annual damages were calculated, damage reduction results were brought to present value based on a 50-yr project life and 3% discount rate. This discount rate is based off of the real interest rates published in Office of Management and Budget Circular No. A-94 Appendix C for use in cost-effectiveness analysis. The reduction in damages for each alternative should be considered the benefit of building that project. Also shown in Table B4 are probabilities that the indicated damage reductions for each alternative are exceeded. For example, there is a 25% chance that the annual damage reduction for the 25-yr earthen channel is greater than $236,800.

D.6 Benefit-Cost Analysis

To complete the benefit-cost analysis, cost estimates were created by HDR: Claunch and Miller for each flood reduction alternative. Details for these cost estimates can be seen in Appendix A. After cost estimates and flood damage reduction calculations were completed, comparisons were made to develop a recommendation for flood reduction on the Tres Palacios through El Campo, TX. The benefit to cost (B/C) ratio is calculated by dividing present benefits by present costs. It should be noted that the cost estimates do not include maintenance costs. The economic viability of each project is reflected by its B/C ratio. If the B/C ratio is less than 1, the costs of the project outweigh the benefits indicating a project that is not economically viable. Cost, benefit, and B/C ratios for all El Campo flood reduction alternatives are shown in Table D4.

Table D4: El Campo Costs, Benefits, and B/C Ratios (Costs and Benefits are Present Value)

Alternative Name	Cost	Benefit	B/C Ratio
25yr_Earth	$ 3,446,248	$4,433,245	1.29
50yr_Earth	$ 4,067,275	$4,788,573	1.18
100yr_Earth	$ 5,225,610	$5,001,873	0.96
100yr_Conc	$ 9,408,059	$5,026,316	0.53
250yr_Conc	$ 9,966,240	$5,405,831	0.54
500yr_Conc	$10,627,305	$5,518,270	0.52
Alt2_Det	$13,089,980	$1,917,385	0.15
Alt3_Det_Div	$ 7,318,280	$1,783,332	0.24

The results of the B/C analysis show that the 25yr_Earth and 50yr_Earth flood reduction alternatives have a B/C ratio greater than one. Of these two alternatives the 25-yr earthen channel is slightly more cost effective and is therefore the recommended alternative. However, both the 25-yr and 50-yr earthen channel alternative are economically viable.

D.7 El Campo Tributary Drainage Issues

The main issue along the El Campo Tributary is poor drainage due to siltation for most of the channel downstream of BUS 59. A field investigation was performed to determine the possible causes and locations of the siltation problem.

As a result of the field investigation, it was discovered that the deposition is likely due to a combination of sand and silty sand soils that naturally occur in this region of the watershed, as well as poor maintenance of existing drop structures and tributary inlets to the main channel. All existing drop pipes and tributaries including the main channel are privately owned with no public drainage easement available for county and city personnel to access. A list of the identified drop pipes and tributary inlets to the main channel were identified in GIS and can be seen in Figure D7. Pictures of sediment in the channel upstream and downstream of South Meadow Lane can be seen in Figures D8 and D9.

Improvement recommendations for this problem include easement acquisition, drop pipe construction, re-channelization, and construction of a backslope drainage system. The recommendations and preliminary quantities required to implement the improvements are as follows.

1. Coordinate with landowners
2. Obtain Easements (100 ft wide)
3. Construction of Drop Pipe Structures (~26)
4. Construct a Channel Backslope Drain System (6,400 LF)
5. Clean Creek to original capacity (4:1 Side Slope / 10 ft BW)

The excavation includes laying side slopes back 4 to 1 and maintaining a 0.04% invert slope starting at the confluence channel invert. No cost estimate was developed for this recommended improvement, as it is likely to be considered a maintenance issue and no outside funding will likely be available to aid in the implementation. It is assumed that County and/or City personnel will be used to construct these recommended improvements.

**Figure D7.
El Campo Tributary
Sedimentation
Problem Locations**

Figure D7: Ponded water upstream of South Meadow Lane

Figure D8: Sediment in channel downstream of South Meadow Lane

D.8 Matagorda County Flood Reduction Alternative Analysis

Downstream of SH 35 in Matagorda County, the channel is large and the flood volumes are high. Therefore, any structural alternative, such as channelization or storage, can safely be assumed to be substantial in size and cost. To show how high the cost of storage will be, storage options were analyzed for different levels of flood reduction. Eight storage scenarios were analyzed, each one representing a reduction of a higher flood frequency to a lower flood frequency. For example, the "50 to 25" alternative stores the volume required to reduce the existing 50-yr peak to the 25-yr peak. The rest of the alternatives follow this same logic. Table D5 shows the storage volume and area (based on average 10 ft. depth) required for each alternative. The relative impact of each alternative is shown in the "# Homes Out" column of Table D6. This column reflects the number of homes removed from the larger floodplain for each alternative. For example, 26 homes were removed from the 50-yr floodplain for the "50 to 25" alternative. Also, note that the difference in detention volume is much greater for the "10 to 2" compared to the 100 to 25. This means that more volume must be detained to reduce the 10-yr to the 2-yr peak flow than to reduce the 100-yr to the 25-yr peak flow.

Table D5: Volume and Area Calculations for Matagorda Detention Alternatives

Alternative	# Homes Out	Volume Required (ac-ft)	Area (acres)
100 to 50	14	4037	404
100 to 25	40	11595	1159
50 to 25	26	4005	400
50 to 10	49	14042	1404
25 to 10	23	6001	600
25 to 5	32	14605	1460
10 to 5	9	4278	428
10 to 2	24	18663	1866

A preliminary opinion of probable cost was calculated for each alternative to illustrate the extremely high cost of detention. The cost estimate was very basic including only land, excavation, and mobilization costs as well as a 20% contingency cost. Excavation costs were based on the required detention volumes in Table D5, therefore the excavation cost for the "10 to 2" is greater than for the "50 to 25", for example. Not included in the cost estimates are engineering fees, cost of environmental work and permits, and cost of constructing the outflow structure for the detention pond. Table D6 shows the included cost as well as the total cost for each alternative. Note how high the total costs are even without the excluded costs. The most reasonable alternative that removes the most houses from flooding is the "50 to 25" alternative.

Table D6: Preliminary Opinion of Probable Cost for Matagorda Detention Alternatives

Alternative	Land Cost	Excavation Cost	15% Mobilization.	20% Contingency	Total Cost
100 to 50	$1,211,094	$32,564,973	$5,066,410	$7,768,495	$46,610,973
100 to 25	$3,478,451	$93,531,673	$14,551,519	$22,312,329	$133,873,971
50 to 25	$1,201,469	$32,306,153	$5,026,143	$7,706,753	$46,240,518
50 to 10	$4,212,529	$113,270,233	$17,622,414	$27,021,035	$162,126,212
25 to 10	$1,800,244	$48,406,567	$7,531,022	$11,547,567	$69,285,399
25 to 5	$4,381,489	$117,813,380	$18,329,230	$28,104,820	$168,628,920
10 to 5	$1,283,405	$34,509,340	$5,368,912	$8,232,331	$49,393,988
10 to 2	$5,598,968	$150,550,033	$23,422,350	$35,914,270	$215,485,622

A channel widening alternative was also tested to reduce flood elevations in the Tres Palacios Oaks sub-division. The alternative consisted of approximately doubling the bottom width of the channel and laying the banks back at a 3:1 slope on both sides. Total excavation volume and probable cost are 607,527 CY and $3,037,600 respectively. Even though the widening and excavation of the channel was substantial, the reduction in the 100-yr flood elevation was only 0.7 ft or less. Figure D10 shows the 100-yr profiles for both the existing and widened channels. It is not expected that this decrease in flood elevation will result in significant flood damage reduction in the affected subdivisions.

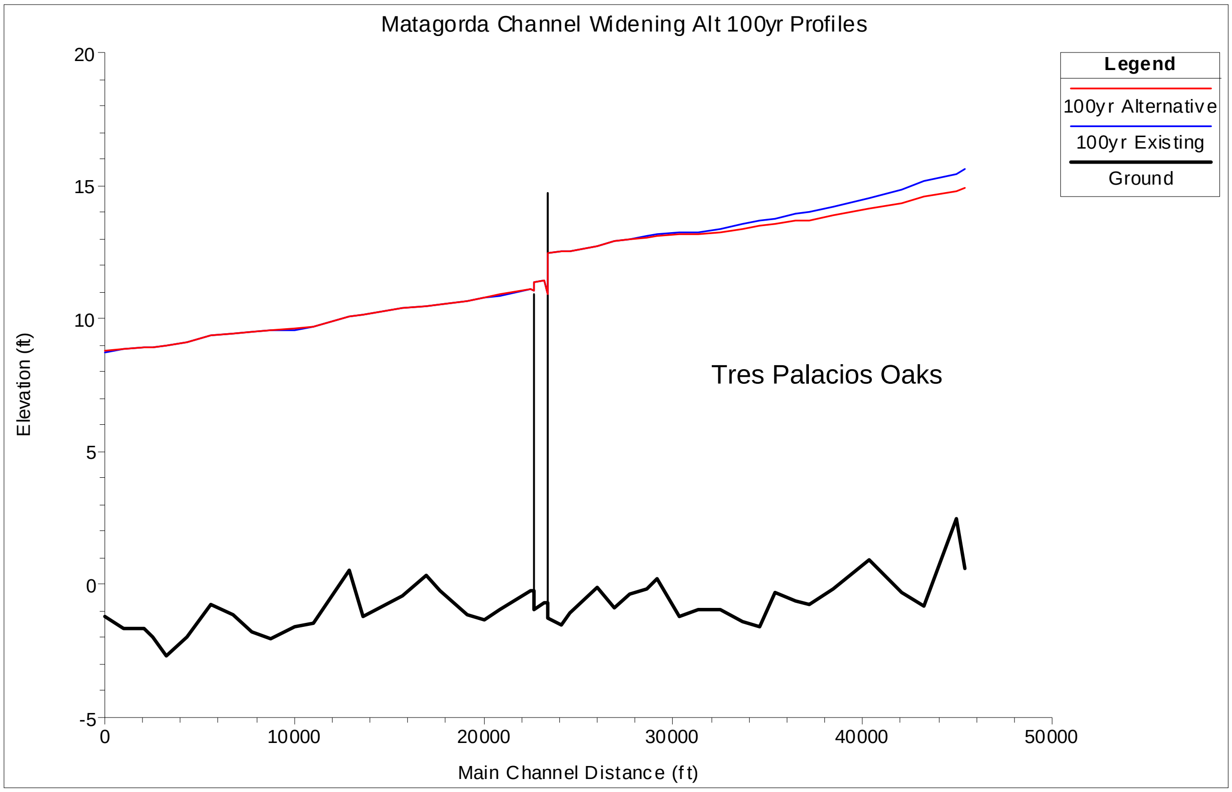


Figure D9: Existing vs. Channel Widening at Tres Palacios Oaks Subdivision

Flood reduction benefits for structural alternatives are most likely much lower than costs judging from the number and value of homes in the affected neighborhoods. There is also some uncertainty in determining the impact of flooding on existing structures. Field reconnaissance revealed elevated homes in the Tidewater Oaks subdivision which would reduce the extent of flood damage (i.e. benefits) to those structures. Tres Palacios Oaks is a gated community and it was not conclusively determined whether any homes there were elevated as well. If homes are elevated, flood reduction benefits of structural alternatives will be reduced even further.

APPENDIX F: Environmental Constraints Summary

F.1 Introduction

The study area encompasses the Tres Palacios River watershed from El Campo to approximately 7 miles north of Palacios. The records review of potential environmental constraints in the study area consisted of the following: socioeconomic, threatened and endangered species (elements of occurrence), species habitat, protected areas, national wetland inventory, hazardous materials, roads, railroads, utility lines, national register properties, cemeteries, and historical markers. These occurrences of these constraints are displayed spatially in Figure F1.

F.2 Socio-Economic Constraints

The study area is located in Census Tracts 73.06, 73.07, 74.07, 74.08, 74.09, 74.10, and 74.11, as defined by the 2000 U.S. Census. These Census Tracts have a total population of 29,224 while Matagorda and Wharton Counties have a combined total population of 79,145. According to the Texas Almanac, the primary industries in Matagorda and Wharton Counties are oil, agribusiness, petrochemicals, and hunting leases. The median household income for both counties is approximately $32,200 and the average median household income for the study area Census Tracts is $32,254. Demographic data was reviewed to determine if a disproportionate number of minority or low-income persons have the potential to be adversely affected by the proposed project. The 2009 U.S. Department of Health and Human Services (DHHS) poverty guideline for a family or household of four is $22,050. The most recent poverty information was collected in 1999. The 1999 DHHS poverty guideline for a family or household of four is $16,700. Block group data show that the median household income in 1999 for all block groups is greater than the 1999 DHHS poverty guideline. However, the data indicate that low-income individuals live in the project area. Block group data indicate that minorities live in the project area. Socio-economic data was retrieved from the US Census Bureau on July 26, 2010. 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 in Matagorda and Wharton Counties.

F.3 Biological Constraints

U.S. Fish and Wildlife Service (USFWS) lists 14 federal threatened and endangered species in Matagorda County, and the Texas Parks and Wildlife Department (TPWD) lists 30 state threatened and endangered species in Matagorda County. USFWS lists five federal threatened and endangered species in Wharton County, and TPWD lists 18 state threatened and endangered species in Wharton County. This data was retrieved from TPWD's county lists of Texas special species for Wharton County, revised on March 12, 2010. In addition, a database search for protected species was conducted using the Texas Natural Diversity Database (TXNDD) on July 27, 2010. The search revealed 12 Element Occurrence Records (records of sightings of rare or endangered species) or managed areas within 1.5 miles of the study area, which are shown in Figure F1. Given the small proportion of public versus private land in Texas, the TXNDD does not include a representative inventory of rare resources in the state. Although it is based on the best data available to TPWD regarding rare species, these data cannot provide a definitive statement as to the presence, absence, or condition of special species, natural communities, or other significant features in any area. Nor can these data substitute for on-site evaluation by qualified biologists. The TXNDD information is intended to assist users in avoiding harm to rare species or significant ecological features. Refer all requests back to the TXNDD to obtain the most current information. The Texas General Land Office (GLO) has delineated species habitats and protected areas that are shown in Figure F1. A field visit by a qualified biologist is recommended to determine the presence or absence of suitable habitat for these protected species.

F.4 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 national wetland inventory (NWI) database indicates that there are several wetlands in the study area. These wetlands may be jurisdictional under Section 404 of the Clean Water Act and may require a permit prior to filling or dredging. Figure 1 shows NWI locations within the Tres Palacios watershed. 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 U.S.

F.5 Hazardous Materials

Texas Commission of Environmental Quality (TCEQ) hazardous materials were reviewed for this project. The data includes superfund sites, municipal solid waste sites, and permitted industrial hazardous waste sites and are included in Figure F1. A Phase I Environmental Assessment is recommended prior to construction.

F.6 Physical Constraints

Physical constraints, such as railroads and roads, are depicted in Figure F1 according to Texas Natural Resource Information Systems (TNRIS) data. Other constraints, such as cemeteries, national register properties, and historical makers were reviewed with Texas Historical Commission data, and are also shown Figure F1. It is recommended that a site visit be performed for cultural resources by an architectural historian and an archeologist to determine the likelihood of impacts. 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.

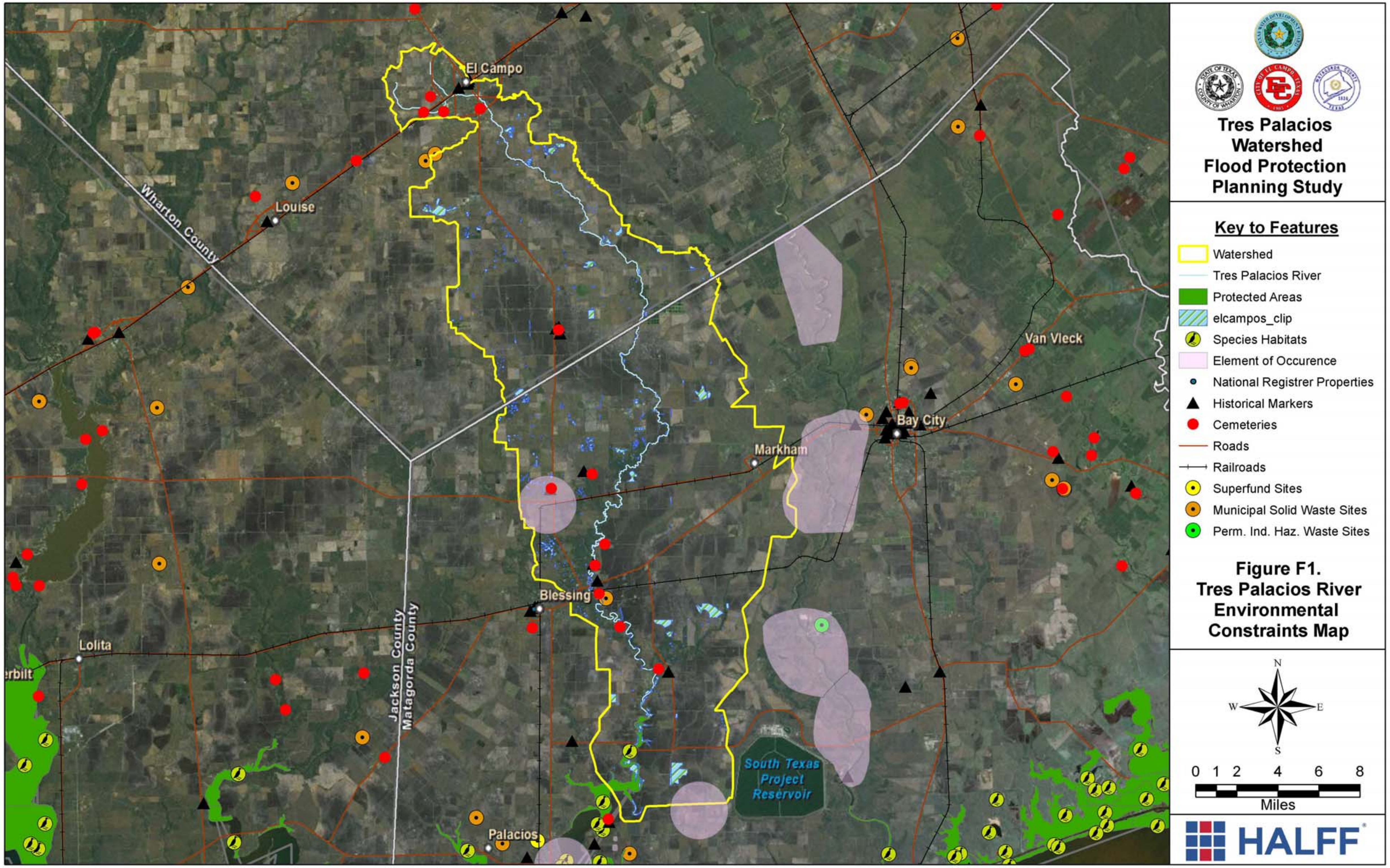


Figure F1.
Tres Palacios River Environmental Constraints Map