CAMERON COUNTY DRAINAGE DISTRICT 5
TEXAS WATER DEVELOPMENT BOARD
FLOOD PROTECTION PLANNING STUDY
FINAL REPORT

September 13, 2019

PO 00111

PREPARED FOR:

Cameron County
Drainage District 5

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ACRONYMS

1D – One Dimensional
2D – Two Dimensional
ACS – American Community Survey
AMC – Antecedent Moisture Condition
Cameron CAD – Cameron County Appraisal District
CN – Curve Number
CCCD5 – Cameron County Drainage District 5
DEM – Digital Elevation Model
DMP – Drainage Master Plan
EMC – Emergency Management Coordinator
FEMA – Federal Emergency Management Agency
FEWS – Flood Early Warning System
FPP – Flood Protection Planning
GIS – Geographic Information System
GLO – Texas General Land Office
HIDCC1 – Harlingen Irrigation District Cameron County #1
HSG – Hydrologic Soil Group
IHWCA – Industrial and Hazardous Waste Correction Action
LiDAR – Light Detection and Ranging
LAS – Log Ascii Standard
LPST – Leaking Petroleum Storage Tank
MOE – Margin of Error
NAVD 88 – North American Vertical Datum 88
NOAA – National Oceanic and Atmospheric Agency
NRCS – Natural Resource Conservation Service
NWI – National Wetland Inventory
NWS – National Weather Service
P.T. – Pressure Transducer
QC – Quality Control
RMSE – Root Mean Square Error
Tc – Time of Concentration
TCEQ – Texas Commission of Environmental Quality
THC – Texas Historical Commission
Tlag – Lag Time
TNRIS – Texas Natural Resource Information System
TPWD – Texas Parks and Wildlife Department
TR-55 – NRCS Technical Release 55
TRC – Texas Railroad Commission
TWDB – Texas Water Development Board

TxDOT – Texas Department of Transportation
TXNDD – Texas Natural Diversity Database
UH – Unit Hydrograph
USCB – United States Census Bureau
USDHHS – United States Department of Health and Human Services
USGS – United States Geological Survey
USGS HIF – USGS Hydrologic Instrumentation Facility
USFWS – United States Fish and Wildlife Service

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EXECUTIVE SUMMARY

Cameron County Drainage District 5 (CCDD5), located in Cameron County, TX, has been the source of frequent flooding for decades. Heavy rainfall coupled with the flat coastal prairielands and a significant population boom have resulted in extreme flooding in unincorporated portions of the County, as well as the Cities of Harlingen, Combes, Primera, and Palm Valley. As a result of these known flooding issues, CCDD5 developed a district-wide hydrologic and hydraulic model and evaluated flood reduction alternatives throughout the district. This initial effort was partially funded through a TWDB Flood Protection Planning Grant, and the study was completed in 2008. At the completion of this initial study, CCDD5 began implementing drainage improvement projects (including regional detention facilities and channel improvement projects), as well as managing development based on this new regional model. Under this initial study, the modeling performed focused on a 1-dimensional, steady-state, modeling approach focused on developing peak water surface elevations and peak flow rates throughout the district's various drainage channels. The results of this initial effort were helpful in providing a good understanding of the main drainage channel capacities but provided only limited value for the more extreme flooding scenarios (when flood waters far exceed the capacity of the given drainage network). To help the district better manage and prepare for extreme flood events, an updated hydrologic and hydraulic model was needed. CCDD5 applied for another Flood Protection Planning Grant (in 2016) to aid in the creation of updated hydrologic and 1D/2D hydraulic modeling, flood damage reduction alternative analyses, and an analysis of the existing flood early warning system to aid in developing long-term solutions to the more extreme flooding events that plague this part of the State.

Hydrologic and hydraulic 1D/2D modeling was performed on North Main, Stuart Place, Dixieland, and Southwest drains, as well as several lateral drains. Detailed LiDAR elevation data as well as cross-section and bridge/culvert surveys where available were used to enhance the accuracy of the models. The modeling resulted in updated and more accurate flows and water surface elevations for the 100- and 500-yr events. The resulting hydrologic and hydraulic data was then used to analyze various flood reduction alternatives for CCDD5 throughout the study area with a regional perspective in mind.

Several flood reduction alternatives were analyzed during the flood damage reduction analysis portion of the study. Each alternative was evaluated by cost and potential for producing a favorable cost-benefit ratio. Alternatives were recommended that consist of regional detention, channel improvements, and improving roadway bridge/culvert capacity. In some cases, non-structural alternatives, such as buyouts, were also recommended where costs far outweighed the flood reduction benefits. In addition to flood reduction alternatives, the existing flood early warning system was analyzed in detail and recommendations for improvement were made.

1.0 INTRODUCTION AND BACKGROUND

Located in deep south Texas, to the west and north of Harlingen, in Cameron County, Cameron County Drainage District 5 (CCDD5) contains four main channels that drain into the Arroyo Colorado. These four main drains, North Main, Stuart Place, Dixieland, and Southwest Drains drain approximately 43 square miles of very flat, poorly draining Gulf Coastal plain (see **Figure 1**). This region has a long history of documented extreme flood events, ranging from Hurricane Beulah in 1967, the flood events of the 1980s, and Hurricane Dolly of 2008. The documented extreme weather combined with the ever-increasing development throughout this region has created a very serious drainage situation for the local community manage. CCDD5 was formed in 1993 to help manage these main drainage networks and implement new flood reduction improvements throughout the district. In 2008, the first comprehensive watershed protection plan to define flood risk within the district was completed. The 2008 study was a flood protection planning (FPP) study funded by the Texas Water Development Board (TWDB). As the study was concluding, Hurricane Dolly made landfall causing major flooding throughout the district. Methodologies used in the 2008 FPP study included one-dimensional (1D) steady-state hydraulic modeling, which was standard methodology at that time. Limitations to these methods include using static flow data in an area that is highly impacted by dynamic two-dimensional (2D) flow lateral to the channel as well calculating a single water surface elevation at each cross-section location representing both channel and overbanks.

Aware of the dynamic nature of 2D flow occurring during flood events and the need for more accurate flood information, CCDD5 obtained a second Flood Protection Planning Grant (circa 2016) from TWDB to update and expand the modeling performed in the 2008 FPP study. Other stakeholders in the FPP study include City of Harlingen, City of Primera, City of Palm Valley, and Cameron County. The goals of the study are as follows:

- Update the comprehensive basin-wide hydrology models with more detailed inputs as well as create 1D/2D dynamic hydraulic models for all study streams. In addition to the mainstems of North Main, Stuart Place, Dixieland, and Southwest Drains, several laterals and connectors were also included for a total of 54.7 stream miles.

- Analyze the existing system of flood early warning stage gages along Stuart Place and North Mains and develop recommendations for improving the infrastructure and more effective and useful display and dissemination of data during and post flood events.

To accomplish these goals, CCDD5 contracted with Scheibe Consulting to complete the FPP study. Extensive survey data was acquired by Brown and Leal Engineering under separate contract outside of the FPP grant funding. Input on the study process and results was obtained through a series of stakeholder meetings as well as three public meetings. The first public meeting was held in October 2018 followed by a second meeting in March 2019 and a final meeting in July 2019. Notices for these public meetings as published in the Valley Star newspaper are provided in **Figure 2**. The following report details the analysis and findings of the CCDD5 Flood Protection Planning Study.

NOTICE OF PUBLIC MEETING

Cameron County Drainage District #5 Flood Protection Plan

Thursday, October 19, 2017
6:00 to 7:00 p.m.
Primera City Hall
22893 N Stuart Place Rd., Primera, TX 78552

The purpose of this meeting is to solicit input from the public regarding drainage and flooding problem areas within Cameron County Drainage District #5 (CCDD5). This information will be considered in the CCDD5 Flood Protection Plan to further develop an early warning system and flood response implementation plan. The public is invited to attend and provide written and oral comments.

For more information please contact Mr. Alan Moore at (956) 423-6411 or alan@hidcc1.org.

NOTICE OF PUBLIC MEETING

Cameron County Drainage District #5 Flood Protection Plan

Wednesday, March 27, 2019
6:00 to 7:00 p.m.
Primera City Hall
22893 N Stuart Place Rd., Primera TX 78552

The Purpose of this meeting is to solicit input from the public regarding drainage and flooding problem areas within Cameron County Drainage District #5 (CCDD5), as well as present the preliminary flood risk inundation maps developed as part of this study. This information will be considered in the CCDD5 Flood Protection Plan to further develop an early warning system and flood response implementation plan. The public is invited to attend and provide written and oral comments.

For more information please contact Mr. Alan Moore at (956) 423-6411 alan@hidcc1.org.

NOTICE OF PUBLIC MEETING

THE CAMERON COUNTY DRAINAGE DISTRICT NO. 5 WILL HOLD A MEETING FOR PUBLIC REVIEW AND COMMENT ON THE RESULTS OF A FLOOD PROTECTION PLAN FOR PORTIONS OF ITS SERVICE AREA, AS FUNDED IN PART BY THE TEXAS WATER DEVELOPMENT BOARD. THE MEETING WILL TAKE PLACE ON JULY 10, 2019 AT 6:00 PM AT PFC. ADAN NAJAR COMMUNITY CENTER, 16603 COMMUNITY DRIVE, PRIMERA, TEXAS. ALL INTERESTED PERSONS ARE INVITED TO ATTEND A PRESENTATION AND QUESTION/ANSWER SESSION GIVEN BY THE DISTRICT'S CONSULTANTS. PERSONS REQUIRING ACCESSIBILITY SERVICES PLEASE CONTACT PRIMERA CITY HALL AT (956) 423-9654 AT LEAST 24 HOURS IN ADVANCE OF THE MEETING. FOR FURTHER INFORMATION PLEASE CONTACT THE DISTRICT OFFICE AT 423-6411.

CAMERON COUNTY DRAINAGE DISTRICT NO. 5
ALAN MOORE, PE, GENERAL MANAGER
221 E. FILMORE
HARLINGEN, TEXAS 78550

Figure 2: Public meeting notices

2.0 TERRAIN DEVELOPMENT

Sub-basins and floodplain delineations were developed using the most recent Light Detection and Ranging (LiDAR) elevation dataset. The primary sources of terrain data used were developed from the 2006 and 2011 International Boundary Waters Commission (IBWC) LiDAR datasets available for download on the Texas Natural Resources Information System (TNRIS) website. These LiDAR datasets have an average point spacing of 70 cm and vertical accuracy meeting the FEMA standard 18.5 RMSE (root mean square error) criteria. The LiDAR data was received from TNRIS as log ascii standard (LAS) files, the standard open format for storing LiDAR point records.

The LAS data was processed by Scheibe Consulting to create a seamless topographic dataset for the study area. During the processing it was noticed that there were many isolated locations where the 2006 and 2011 datasets had elevation differences great than 1 foot. It was assumed that these differences could likely be attributed to differences in point classification between the datasets and advances in LiDAR data collection between 2006 and 2011. Overall the two data sets merged well; however, it should be noted that the area of the district west of US 77 is covered by the higher quality 2011 data and the area east of US 77 is covered by the 2006 data.

A 3 ft. X 3 ft. digital elevation model (DEM) was created for use in developing inputs for the hydrologic modeling, hydraulic modeling, and floodplain mapping. The LiDAR DEM was also updated and enhanced using construction plan sets for constructed channel modifications and survey data for constructed regional pond structures. More information on these data sources is provided in Section 4.

3.0 HYDROLOGIC ANALYSIS

A detailed hydrologic analysis was performed on the four CCDD5 watersheds with the goal of providing a validated existing base conditions model. These models were used in developing flood mitigation alternatives and quantifying the impacts of these alternatives to the surrounding area. The new, georeferenced, hydrologic analysis was performed using the US Army Corps of Engineers HEC-HMS software, version 4.2. Flow hydrographs for input into 1D/2D dynamic hydraulic models, which were developed for the 100- and 500-yr events. A 48-hr storm duration was utilized to remain consistent with the 2008 FPP study. Frequency rainfall data for the 100-yr and 500-yr events was derived from the Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas (SIR 2004-5041) and is provided in **Table 1**. The new Atlas 14 rainfall data was not available for use when this study was initiated.

Table 1: 100-yr and 500-yr rainfall data for CCDD5 watersheds

Duration	Recurrence Interval	
	100-yr	500-yr
	Depth (inches)	
5 min	1.37	1.66
15 min	2.32	2.94
1 hr	4.54	6.01
2 hr	5.89	8.00
3 hr	6.15	8.48
6 hr	7.69	10.83
12 hr	8.87	12.59
24 hr	10.16	13.70
48 hr	11.64	15.33

Sub-basins for CCDD5 watersheds were delineated from the 2006/2011 IBWC LiDAR data for CCDD5 using geographic information system (GIS) based tools. Sub-basins were delineated with the target of about 0.25 sq. mi. for urbanized areas and 1 sq. mi. for non-urbanized areas. Final sub-basin areas ranged from 0.02 to 1.67 sq. mi. for a total of 136 sub-basins. Initial sub-basin delineations were checked against stormdrain GIS data and previous study sub-basin delineations obtained from CCDD5 and City of Harlingen and corrected accordingly to accurately reflect the existing drainage patterns. **Figure 3** illustrates the overall watershed and sub-basin layout for the study. Sub-basin areas are provided in the hydrologic parameters table in **Appendix A**.

Runoff losses were computed using the US Department of Agriculture Natural Resource Conservation Service (NRCS) curve number (CN) method. This method considers factors such as soil characteristics, land use, hydrologic land condition, and antecedent moisture conditions (AMC) to establish rainfall/runoff relationships within an area. The base CN for each drainage area was assumed based on Hydrologic Soil Group (HSG) and a land use of open space in fair condition. Percent impervious cover was developed based on existing land use for each sub-basin. An existing land use dataset was developed from a land use dataset produced as part of the 2008 Harlingen Drainage Master Plan (DMP). The dataset was checked against 2018 aerial imagery and updated as needed to form a current land use dataset. The complete land use dataset is illustrated in **Figure 4**. The NRCS Web Soil Survey for Cameron County was used to determine the spatial distribution of HSG within the watershed. HSG for soils within the study area is illustrated in **Figure 5**. Base curve numbers (AMC type II), land use, and corresponding % impervious cover assumptions are provided in **Table 2**. Final curve numbers were calculated by converting AMC II to AMC I curve numbers to be consistent with the previous 2008 FPP study and 2008 Harlingen DMP. Final curve numbers and % impervious cover for each sub-basin are provided in the hydrologic parameters table in **Appendix A**.

Table 2: Land use category, AMC II curve numbers, and % impervious cover

Land Use Category	Hydrologic Soil Group			%IC
	B	C	D	
Commercial	69	79	84	80%
Industrial	69	79	84	65%
Institutional	69	79	84	40%
Multi-Family Residential	69	79	84	50%
Parks/Open Space	69	79	84	5%
Pasture	69	79	84	0%
Low Density Residential	69	79	84	25%
Rural Residential	69	79	84	10%
Medium Density Residential	69	79	84	45%
Transportation	69	79	84	90%
Woods/Brush	58	71.5	78	0%
Water	98	98	98	0%

The NRCS unit hydrograph (UH) method was used to generate runoff hydrographs for each sub-basin. The lag time inputs for the NRCS UH method were calculated using the Kerby-Kirpich method to be consistent with the 2008 FPP Study. First, longest flow paths were delineated for each sub-basin using GIS tools and available LiDAR topographic data. The longest flowpath is the runoff path from the most hydrologically remote point to the outlet for each sub-basin. Next, the flowpaths were divided into sheet, shallow concentrated, and channel flow segments and travel time for each segment was computed using the Kerby-Kirpich methodology. The Kerby-Kirpich method consists of using the Kerby equation for overland flow (sheet plus concentrated shallow) travel time and the Kirpich equations for stormdrain/channel flow travel time. Maximum sheet flow length was assumed to be 200 feet, after which it is assumed to be shallow concentrated flow. The transition from shallow concentrated flow to channel flow was assumed to occur when the flowpath entered the stormdrain or channel section. Channel flow was usually a combination stormdrain and natural channel flow. Stormdrain slopes and sizes were taken from GIS data provided by the City of Harlingen or TxDOT plan sets. Time of concentration (Tc) or total travel time for each sub-basin was calculated by summing the travel times of the flowpath segments. The final Tc values were converted to lag times using the equation Tlag = 0.6*Tc. A NRCS UH peaking factor of 150 was applied to all sub-basins to be consistent with peaking factors used in the previous 2008 FPP study. Final lag times for each sub-basin are included in the hydrologic parameters table in **Appendix A**.

Most routing reaches were not included in the hydrologic modeling, as routing is naturally accounted for in the 1D/2D unsteady hydraulic modeling. A total of three Muskingum-Cunge 8-point routing reaches (2 in Stuart Place watershed and 1 in North Main watershed) were included where routing was required to route the flow to a hydraulically modeled stream. The only other output required from the hydrologic models are sub-basin hydrographs, which are used as inputs into the hydraulic model. These input hydrographs were included in the hydraulic flow files for each model as inflow hydrographs either directly at the upstream end of the study reaches, as lateral point inflows, or uniformly spread over several cross-sections that represent the corresponding sub-basins.

4.0 HYDRAULIC ANALYSIS

New geo-referenced, unsteady 1D/2D analyses were performed for 54.7 stream miles using US Army Corps of Engineers HEC-RAS software, version 5.0.6. Four separate hydraulic models were created to cover all study streams. One model per stream was created for Stuart Place Tributary 1, Stuart Place Tributary 2, Dixieland Drain, and Southwest Drain. North main drain and Stuart Place Drain networks were modeled as one complete system due to three locations within the network that are connected between the two drains. Cross-section layouts were based on layouts from the 2008 FPP study trimmed down to represent the channel section only. During cross-section layout development, cross-sections were added to ensure proper modeling of bridges and culverts as well as other bends and transitions along the study streams. Cross-section spacing varied depending on location with larger spacing in rural areas and smaller spacing in urbanized areas. 2D areas were added to model overbank areas and connected to the 1D channel sections with lateral weirs. The 2D areas were also connected with 2D connectors, which operate similarly to lateral weirs. The cross-section and 2D area layouts for the study streams are provided in **Figure 6**.

Cross-section station and elevation data was extracted using GIS tools and a 3 ft. X 3 ft. DEM created from LiDAR data. Once the cross-sections were imported into the hydraulic model, as-built plan data and field survey data were incorporated, where available. Field survey sources include new survey collected by Brown and Leal Engineers and Surveyors as well as survey data taken from the 2008 FPP study. All survey data were collected using the North American Vertical Datum of 1988 (NAVD 88) with current geoid, which aligned well with the LiDAR data used in the study. Additional bridge, culvert, and channel data was incorporated from CCDD5 and Texas Department of transportation (TXDOT) project plans sets. As-built topography from the plan sets and survey data was digitized and used to update the LiDAR DEMs and hydraulic geometries, where needed, due to recent channel improvement and regional detention construction projects. A list of incorporated topographic data is provided in **Table 3** and illustrated along with survey data locations in **Figure 7**.

Table 3: Sources for topography updates

Data Type	Data Source	Description
Contours	CCDD5 Plans	Modification of Southwest Drain channel
Contours	CCDD5 Plans	Modification of Wilson Tract Lateral channel

Data Type	Data Source	Description
Contours	TXDOT Plans	Primera Road Stormdrain and road widening
Survey Points	Brown and Leal	Dual Ponds at North Main and Las Palmas Lateral
Survey Points	Brown and Leal	Pond on North Main near Brazil Rd.
Survey Points	Brown and Leal	Ponds Upstream and Downstream of Breedlove Rd.
Survey Points	Brown and Leal	New channel between Wilson Tract and David Stephenson Laterals
Survey Points	Brown and Leal	Topo update at upstream end of Carters Lateral

2D areas and existing storage areas were delineated in GIS and added manually to the HEC-RAS geometry along with the lateral weirs and connectors. A base computation cell size of 40 feet X 40 feet was used in the 2D areas. Additional detail was added using breaklines with reduced cell size for roadside ditches and drainage channels within the 2D areas. Outlet pipes were added to storage areas according to field survey data and elevation-storage curves extracted from terrain data reflecting the existing storage areas.

Once cross-section and 2D area/storage area layouts were complete and updated with survey data, hydraulic model parameters were added such as n-values, ineffective areas, weir coefficients, and downstream boundary conditions. Manning's "n" roughness values ranging from 0.03 to 0.12 were assigned to channel and overbanks. Channel n-values were initially assigned using site visits, survey photos, and 2017 aerial imagery and later updated as a result of model validation to the recent June 2018 flood event. 2D area n-values were assigned by land use type and adjusted where needed based on 2017 aerial imagery. **Table 4** contains the land use types and assigned overbank n-values used in this study. Downstream boundary conditions were set to normal depth for each model with the appropriate friction slope. Normal depth 2D boundary conditions were set at several locations where 2D flow reached a limit of study. This usually occurred at the upstream end of a study stream or a transition location from one model section to another.

Table 4: Land use category and associated overbank Manning's n-values

Land Use Category	Overbank N-value
Commercial	0.12
Industrial	0.12
Institutional	0.12
Multi-Family Residential	0.12
Parks/Open Space	0.06
Pasture	0.06
Low Density Residential	0.09
Rural Residential	0.07
Medium Density Residential	0.12
Transportation	0.03
Woods/Brush	0.10
Water	0.03

The following is a list of assumptions made and/or modeling issues related to hydraulic model development.

- Survey channel flowlines were generally lower than LiDAR flowlines indicating that the LiDAR data does not accurately reflect channel flowlines likely due to water or vegetation in the channel. Therefore, pilot channels were added in all models between survey locations to more accurately reflect channel capacity and flowline elevations.
- The existing culverts with flap gates at Acacia Dr. on the connector between North Main and Stuart Place were modeled as a gated inline structure. The rules for gate opening and closing reflect the operation of the existing flap gates.
- Model stabilization issues were resolved at locations such as large slope changes where culvert drop structures join a tributary to a lower main channel by raising n-values and setting initial flows and elevations. These adjustments for stabilization did not have a significant impact on final results.

5.0 HYDROLOGIC AND HYDRAULIC MODELING RESULTS

Validation

To ensure the accuracy and validity of our modeling results, data for the June 2018 and June 2019 flood events were run and compared to best available high-water mark data. While extensive data was collected during the 2008 Hurricane Dolly event, it was not able to be used for calibration/validation due to extensive modifications to the drainage system that CCDD5 has implemented, post 2008. Model results were also reviewed by CCDD5 staff to ensure consistency with staff experience of flooding issues. Rainfall data for the June 2018 and June 2019 events were obtained from the National Weather Service (NWS) in XMRG format, the standard format for 4 km gridded rainfall data. Sub-basin hyetographs for the events were created by processing the XMRG datasets using HEC-MetVue software recently developed by the U.S. Army Corps of Engineers.

Hydrology runs were created with the rainfall data producing model flows for the June 2018 and June 2019 events, which were then input into the hydraulic models for CCDD5. There are currently 10 telemetered gages recording stage and rainfall data along Stuart Place and North Main drains. However, the data from both events seems to be inconsistent and not reflective of what actually occurred. A review of how these gauges operate revealed that all of the sonar stage gauges in the system are set at roughly the same elevation as the top of deck of the roadway; meaning if the roadway is overtopped, the sonar gauge is submerged and cannot produce a value. Post flood, high-water mark data for the June 2018 event was collected by Cameron County at many locations throughout the county and included only two locations along North Main drain at Wilson Rd./US 77 and FM 508. The dataset included a surveyed high-water mark near US 77 but only a sketch and description of high-water at CR 508. High-water mark data for the June 2019 event was collected by CCDD5 and includes 14 surveyed points in North Main watershed, 4 surveyed points in Stuart Place watershed, and 1 surveyed point in Southwest Drain watershed. Model water surface elevation results for the June 2019 were on average 0.5 ft. off from observed high-water elevations. These June 2018 and June 2019 high-water marks along with review of results by CCDD5 staff served as validation of the model results. **Table 5** shows a comparison of model results to the June 2018 and 2019 high-water marks.

Table 5: June 2018 and June 2019 high water mark comparison

Event	Watershed	Location	Source	Observed	Model
June 2018	North Main	US 77/I 69	Survey	38.08 ft.	38.4 ft.
June 2018	North Main	FM 508	Sketch	Approx. 30.3 ft.	31.5 ft.
June 2019	North Main	Primera Rd.	Survey	40.81	40.08
June 2019	Stuart Place	Garrett Rd.	Survey	40.36	41.55
June 2019	Stuart Place	S Palm Blvd.	Survey	41.75	42.55
June 2019	Stuart Place	Beckham Rd.	Survey	47.23	46.84
June 2019	Stuart Place	Beckham Rd.	Survey	46.15	47.2
June 2019	Southwest	S Atlas Palmas Rd.	Survey	43.59	43.63
June 2019	North Main	Stuart Place Rd.	Survey	43.58	43.02
June 2019	North Main	Aubrey Dr.	Survey	43.70	43.01
June 2019	North Main	New Combes Hwy.	Survey	35.89	35.3
June 2019	North Main	New Combes Hwy.	Survey	34.72	34.33
June 2019	North Main	New Combes Hwy.	Survey	34.35	34.79
June 2019	North Main	N Breedlove Rd.	Survey	33.85	33.78
June 2019	North Main	N Breedlove Rd.	Survey	34.47	33.72
June 2019	North Main	N Breedlove Rd.	Survey	35.07	34.23
June 2019	North Main	Briggs Coleman Rd.	Survey	33.38	33.25
June 2019	North Main	Briggs Coleman Rd	Survey	33.18	32.91
June 2019	North Main	Briggs Coleman Rd	Survey	33.17	32.9
June 2019	North Main	FM 508	Survey	33.04	32.59
June 2019	North Main	FM 507	Survey	32.92	30.96

A second validation of model results was performed by comparing 100-yr frequency flow results to those from the 2008 FPP study on a 100-yr discharge per drainage area basis. A figure showing the comparison to these previous studies is provided in **Figure 8**.

Hydrologic Results

The validated hydrology model was utilized to produce flows for the 100- and 500-yr frequency flood events. Areal reduction of point rainfall was applied to North Main as a result of a storm centering analysis. Following guidance from HMR-51, concentric oval rings representing rainfall reduction were aligned with the centroid of the North Main watershed and oriented according to the predominant rainfall orientation for the study area. The point rainfall for North Main was reduced and weighted according to the selected storm centering distribution and applied to the hydrology model. Reduction of point rainfall was not applied to Stuart Place, Dixieland or Southwest drains as they all have cumulative drainage areas less than 10 square miles. Final existing conditions 100-yr flows along the study streams were taken from the unsteady hydraulic modeling results. A summary of existing conditions 100-yr peak flow results at key locations along the study streams is provided in **Appendix B**. All hydrologic modeling and associated GIS data for the frequency runs, as well as the June 2018 event, used in the model validation are included with the digital data located in **Appendix E**.

Hydraulic Results

The 100-yr and 500-yr flow hydrographs produced from the hydrologic modeling were input into unsteady 1D-2D hydraulic models for the study streams. The 500-yr event results are provided within the model while water surface elevation contours and depth grids were produced for the 100-yr event using the RAS mapper tool in the HEC-RAS program. The resulting water surface elevation contours and depth grids for the 100-yr event are provided on the hydraulic workmaps included in **Appendix B**. All hydraulic modeling and associated GIS data for the frequency runs, as well as the June 2018 event used in the model validation, are included with the digital data located in **Appendix E**.

6.0 FLOOD DAMAGE REDUCTION ALTERNATIVES

Alternative Analysis

The alternative analysis for CCDD5 included flood damage reduction alternatives focusing on problem areas within the North Main watershed affecting the Cities of Primera, Palm Valley, and Harlingen. Consultations were held with CCDD5 to determine key flooding areas and potential alternatives to reduce flooding in those areas. The types of alternatives analyzed are as follows:

- Regional Detention – The goal of regional detention options is to detain water at an upstream location to reduce flooding in downstream reaches. Regional detention can either be inline or offline. Offline detention options are more efficient at reducing flood peaks as they require less volume to produce similar results to inline options. The objective of detention alternatives analyzed was to determine the impact of existing detention ponds and optimize them by adjusting overflow weirs and adding additional storage where needed.
- Channel Modification – Increasing channel conveyance reduces the amount of overbank storage required to pass a given flood flow, thus reducing flood elevations. Channel modification options were assumed to be simple trapezoidal cuts lined with concrete, if necessary. Channel cuts were made to avoid impacting existing structures adjacent to the channel, while optimizing reduction in flood elevations.
- Culvert/Bridge Improvements – Undersized bridges and culverts can cause upstream flooding due to high headwater elevations. Options to remove or enlarge these structures can provide relief from flooding in the upstream area, but such improvements can also result in increased flow and flood elevations downstream. Impacts of these improvements were quantified by updating the hydraulic modeling and comparing to the existing conditions results. Detention storage was added or further optimized to mitigate for any negative downstream impacts.

A total of five alternatives were fully analyzed and are presented in detail in **Appendix C** of this report, including flood reduction results and detailed opinions of probable cost. The alternatives are listed below in **Table 6** with descriptions, value of structures removed, and total opinion of probable cost. The color coding in **Table 6** indicates the level of priority associated with the alternative as determined by CCDD5 (green = high priority, yellow = medium priority, red = low priority). **Figure 9** shows the location of each alternative analyzed within the watershed. Structure values were determined from improvement values taken from Cameron County Central Appraisal District (Cameron CAD) property records. Opinion of probable cost for each alternative is based on construction elements with unit costs derived from the TXDOT average low bid data and a 25% contingency. Probable costs also include potential land acquisition and engineering costs. Land acquisition and easement costs are very preliminary and should be used with caution when developing future Capital Improvement Plan (CIP) budgets. It should be noted that the benefit and cost of Alternative 1 will depend on needed improvements through the City of Palm Valley that were not analyzed under this FPP study; therefore, structures removed and total cost could not be calculated for Alternative 1 and "N/A" was entered into **Table 6**.

Table 6: Summary of flood reduction alternatives

Alt #	Stream Name	Description	#/Value of Structures Removed	Total Probable Cost
1	Sibley Lateral	Optimize detention at location upstream of Wilson Road.	N/A	N/A
2	North Main	Ditch lining and improvement from Wilson Road to Commerce Street.	203/$9,076,277	$2,840,438
3	North Main	Optimize existing detention ponds at conf. with Las Palmas Lateral and near Brazil Road with culvert improvements at Chester Park Road and irrigation canal	88/$2,531,449	$5,404,402
4	South Fork Lateral.	Culvert improvement at railroad and detention downstream of railroad.	60/$4,811,058	$2,420,758
5	Murphy Lateral	Culvert improvement at railroad and Primera Road with detention upstream of railroad.	207/$12,861,745	$3,855,652

Environmental Constraints Summary

A desktop level environmental constraints investigation was performed for this project area. The intent of this environmental constraint investigation was to identify any key, known, environmental constraints that could impact various alternatives that were evaluated. This investigation is not a comprehensive environmental assessment and did not include any field investigations. For the purposes of the environmental constraints review, the project area includes the entire CCDD5 study area. CCDD5 is located entirely within Cameron County and includes the cities of Primera, Palm Valley, Combes, and Harlingen. Numerous sources were reviewed to identify potential environmental constraints in the study area. Items included: socio-economic data, Texas Parks & Wildlife threatened and endangered species by county & element of occurrence locations, United States Fish & Wildlife Service (USFWS), Texas Parks and Wildlife Department (TPWD) and Texas General Land Office (GLO) species habitat, protected areas and national wetland inventory, Texas Commission of Environmental Quality (TCEQ) hazardous materials including leaking petroleum storage tank locations (LPST), cultural resources data from the Texas Historical Commission (THC), and other spatial information including roads, railroads, and water wells. An online Texas Railroad Commission (TRC) mapper was utilized to extrapolate the locations of various well data including shut-in oil/gas, oil, gas, plugged oil/gas, permitted locations, injection/disposal, and dry wells. Oil and gas pipeline data was also gathered from the TRC. The occurrences of these constraints are displayed in **Figure 10**.

Socioeconomics/Environmental Justice:

Executive Order (EO) 12898 "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" requires each Federal agency to "make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies and activities on minority populations and low-income populations."

The study area is associated with 9 Census Tracts within Cameron County, as defined by the United States Census Bureau (USCB) 2010 Census. These Census Tracts have a total population of 66,268 while Cameron County has a combined total population of 406,220 indicating about 16% of the County population lives within CCDD5. According to the Texas Almanac, the primary industries in Cameron County vary, but include manufacturing, agribusiness, seafood processing, shipping, and tourism. Demographic data was reviewed to determine if minority or low-income persons have the potential to be adversely affected by the proposed project. The data was retrieved from the USCB on June 11, 2019. Block group data from the 2010 Census indicates that approximately 88 percent of the population in the project area is comprised of minorities. Although income data is not available in the 2010 Census, the American Community Survey (ACS) provides a 5-year average of income and poverty information for the investigated geographies. The ACS is an ongoing nationwide survey that provides social, economic, and housing data every year. All ACS data are estimates; therefore, the USCB provides a margin of error (MOE) for every ACS estimate. The 2019 United States Department of Health and Human Services (USDHHS) poverty guideline for a family or household of four is $24,600. The ACS data for 2013-2017 indicate that the median household income for Cameron County is $36,095 (MOE +/- 962). Therefore, the County data shows that the median household income for all investigated geographies is greater than the 2019 USDHHS poverty guideline; however, the 2013-2017 ACS data indicates that low-income individuals live in the project area.

Although minority and low-income persons are located within the project area, the proposed action is not expected to have adverse or disproportionate impacts on minority or low-income populations. The benefits of the flood control project are expected to equally benefit residents of all socio-economic backgrounds. Public outreach planning for any future public involvement activities should take into consideration low-income and minority population.

Biological Resources:

USFWS lists 17 federal threatened and endangered species in Cameron County; however, TPWD lists 48 state threatened and endangered species. This data was retrieved from the USFWS and TPWD county lists of Texas special species for Cameron County on June 11, 2019. It is recommended that a search of the Texas Natural Diversity Database (TXNDD) be performed to determine if there are any recorded sightings of any of these endangered species within the project area. 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, the 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. The data cannot 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

Wetlands:

Wetlands are identified as those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. A search of the USFWS national wetland inventory (NWI) database indicates that there are numerous 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 10** shows NWI locations within the CCDD5 study area. It is recommended that a jurisdictional determination be performed in the field prior to construction in order to determine potential impacts to the waters of the United States.

Potential Hazardous Materials:

The Texas Commission of Environmental Quality known hazardous materials database was reviewed for the study area. The data includes superfund sites, municipal solid waste sites, industrial and hazardous waste correction action (IHWCA) locations, and leaking petroleum storage tank (LPST) locations. 1 superfund site, 3 IHWCA sites and 5 LPST locations (LPSTs documented within last 15 years) were identified within the study area. The level of contamination at the LPST sites range from "minor soil contamination" to "ground water impacts". One of the LPST sites is currently in active status and have not been resolved. Texas Railroad Commission (TRC) data was used to determine location of oil and gas wells and pipelines within the study area. According to TRC data, there are gas transmission pipelines within the watershed but no known wells. TRC and TCEQ data are included in **Figure 10**. Once the perimeters of the projects are established during future design phase, a comprehensive database review and site visit are recommended to determine the level of assessment necessary. A Phase I Environmental Assessment may be needed prior to construction.

Physical Constraints:

Physical constraints, such as railroads and roads, are depicted in **Figure 10** according to Texas Natural Resource Information Systems (TNRIS) data. Other constraints, such as water wells, are also shown. A field reconnaissance is recommended prior to construction to determine any conflicts with existing infrastructure.

Cultural Resources:

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

Implementation

Potential funding sources for recommended alternatives can include FEMA grant programs such as the Hazard Mitigation Grant Program, Severe Repetitive Loss Grants, and Flood Mitigation Assistance Grants. These grants must involve a project with a benefit to cost ratio greater than one and be combined with matching local funds from the affected communities. Other sources of funding include local drainage utility fees or portions of city budgets allocated to drainage capital improvement projects as well as tax revenue allotted to CCDD5 for management of the district's drainage ways. In addition, the State of Texas has recently passed bills in 2019 that allow for approximately $3 Billion in funds from the "Rainy Day Fund" to be allocated to drainage and flood control projects via loans and grants to help fund studies, designs, and construction projects needed to mitigate flood risk throughout the State. It is recommended that that CCDD5 and local stakeholders keep a close watch on these funds over the coming months.

7.0 FLOOD EARLY WARNING SYSTEM FEASIBILITY STUDY

Cameron County has been subjected to frequent flooding associated with both localized heavy rainfall events, as well as large regional flood events and Hurricanes. Recent catastrophic flooding events within CCDD5 jurisdiction include the June 25th, 2019 Flood (with record rainfall at 12.5" in 3-hrs) and Hurricane Dolly of 2008 (equivalent to a 100-yr synthetic storm). Both storm events listed, as well as innumerable other events, have resulted in extreme local flooding situations, displacing many citizens and putting the public at risk. The CCDD5 has sought to build on the experience of these past and recent catastrophic events by advancing the state-of-the-art in hydraulic/flood modeling, aggressively implementing flood reduction projects, collaborating with local/regional political entities, partnering with funding agencies, collaborating with resources agencies, and partnering with the general public. CCDD5 has also implemented a broad stage and rain gauge network, but also desires to explore the state-of-the-art in flood early warning systems (FEWS), with the goal of improving on the recent efforts already implemented.

CCDD5 requested, as part of this TWDB FPP study, that a FEWS feasibility study be conducted to help provide the district with guidance and direction on potential future enhancements to the existing flood warning system. One of the goals of this feasibility study is to provide overall direction for the potential enhancement of the existing CCDD5 FEWS. This feasibility study was focused on the following:

- Identification of existing rain and stage gauge network;
- Identification of regional trends in gauge equipment;
- Identification of gauge network deficiencies and recommendations for improvements;

Existing Rain and Stage Gauge Assessment

As part of this feasibility study, an inventory of existing rain and stage gauges was obtained and reviewed. This assessment included the type and location of gauges currently in-place, a review of available rain/stream gauge equipment on the market, identification of additional rain/stream gauge needs for CCDD5, consideration of ancillary communications equipment needs for CCDD5, and review of other rain/stream gauge FEWS elsewhere in the State.

The existing loose "network" of gauges throughout CCDD5 consists of a matrix of dual stage/rain gauges installed by the district for flood monitoring and recording purposes. **Figure 11** illustrates the locations of the various gauges installed and maintained by the district. **Figure 12** illustrates the known USGS gauge network in Texas (including webcams [camera symbol], rain gauges [diamond symbol], and stage/flow gauges [dot symbol]). Interestingly, the USGS gauge network density seems to mimic regional population density, except for in South Texas.

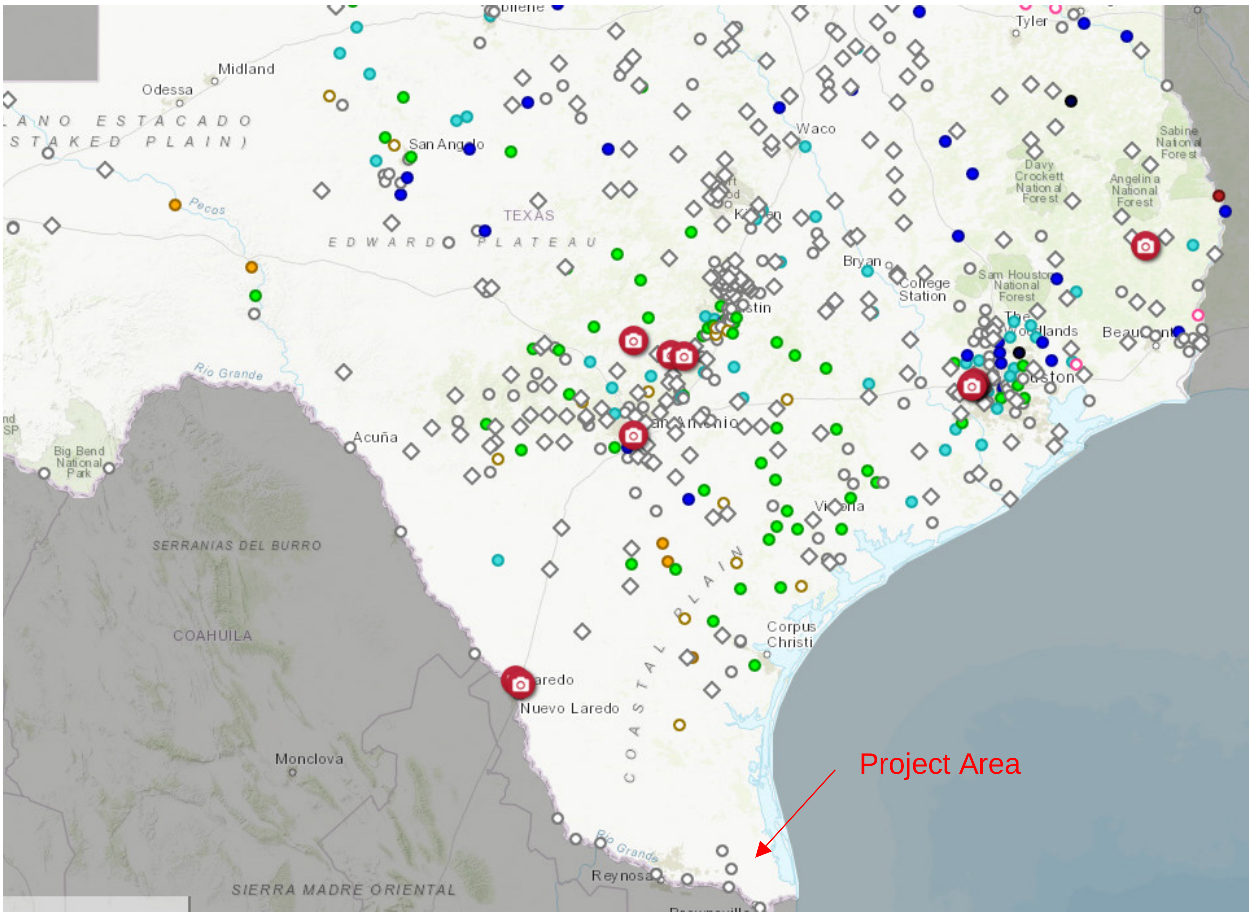


Figure 12: USGS Gauge Network (*https://txpub.usgs.gov/txwaterdashboard/index.html*)

Additional rain gauges existing in proximity to the district, including the Harlingen International Airport Gauge, and roughly five (5) COCORAHS 24-hr rain gauges.

The rain gauges currently maintained by CCDD5 are all standard tipping bucket rain gauges. Details on manufacturer, diameter, or quality were not obtained. **Figure 13** illustrates a typical CCDD5 rain gauge setup at the top of a pole adjacent to the telemetry box, solar panel, and radio antenna.

Figure 13: Typical CCDD5 Rain Gauge Setup

The stage gauges currently maintained by CCDD5 are all standard non-contact radar gauges mounted on the side of county or state-maintained bridges. Typically, these radar gauges are placed flush with the top of deck of the bridge, as local farm equipment often cross these bridges and at times have wide harvesting machines that would otherwise knock down a radar gauge that is mounted any higher. This approach helps with maintained gauge equipment longevity, relative to roadway traffic, but creates a situation where once a bridge is overtopped, the gauge is no longer of any use, as non-contact gauges cannot provide an accurate reading if they come into contact with the flood waters. **Figure 14** illustrates a typical CCDD5 stage gauge setup mounted to the side of a bridge, with telemetry equipment in the background.

Figure 14: Typical CCDD5 Stage Gauge Setup

As previously illustrated in **Figure 11**, there are a total of ten (10) dual stage/rain gauges within the district's network. These gauges use radio telemetry that transmit the data to a central server managed by Harlingen Irrigation District Cameron County #1 (HIDCC1). It is unclear if this current system uses 'ALERT 1' or 'ALERT 2' protocols to transmit data.

The existing rain/stage gauges currently report at a minimum interval of 15-minutes, but tend to report inconsistently, based on a review of the recent June 2019 rainfalls. The recorded data is made available via the HIDCC1 website, and all historic archived data can be retrieved via this website. It is unclear if recorded data is reviewed for quality control (QC) purposes and edited once archived, but it appears it is likely not. A review of a recent dataset for the Dilworth North rain gauge (with a date range from May 1, 2019 to June 26, 2019) revealed that that rain gauge was reporting constant rainfall intensities for the same time over and over. It is unclear why this may have occurred, but this illustrates that lack of QC of the recorded and archived datasets.

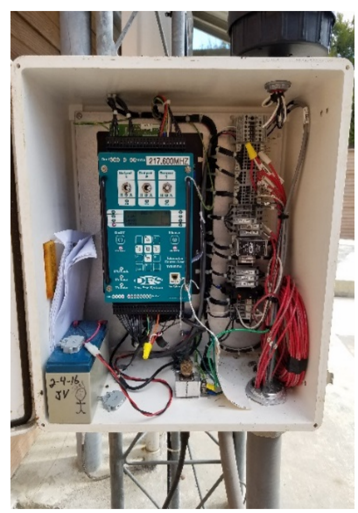


Figure 15: Example Gauge Telemetry & Battery Setup (courtesy Scheibe, 2018)

Review of Regional Trends in Gauge Equipment

Scheibe Consulting conducted a review of available rain/stream gauge equipment that may be of interest to CCDD5, when implementing FEWS improvements. An introduction to the main stage gauge and rain gauge equipment on the market is important to understanding the best direction forward for the district.

Following is a review of both stage and rain gauge systems that are typically used. To optimize our research, we initially focused on recent stage gauge research efforts conducted by the USGS [1], which illustrate the typical stage-gauge systems used on the market and also worthy of consideration by the USGS. Other systems (less commonly used) are available on the market but are not discussed in detail in this report. No past research documents could be readily found for rain gauge systems typically used, so this effort was focused on equipment type currently used or under serious consideration by regional FEWS owner/operators that were interviewed during the course of this feasibility study.

Stage Gauges:

Numerous stage gauges exist on the market and include traditional stage gauges, modern electronic stage gauges, and noncontact stage gauges. The traditional stage gauges consist primarily of a stilling basin coupled with a float to measure stage. The modern electronic stage gauges can be further broken down into bubbler gauges with non-submersible pressure transducers (P.T.s), and submersible pressure transducers (P.T.s). The modern electronic stage gauges appear to be the most commonly used systems (Based on interviews with regional owner/operators). The noncontact stage gauges can be further broken down into radar gauges, acoustic gauges, and laser gauges. Schematics of each of the basic systems are provided below in **Figures 16-19** (courtesy of the USGS [1]) for illustrative purposes.

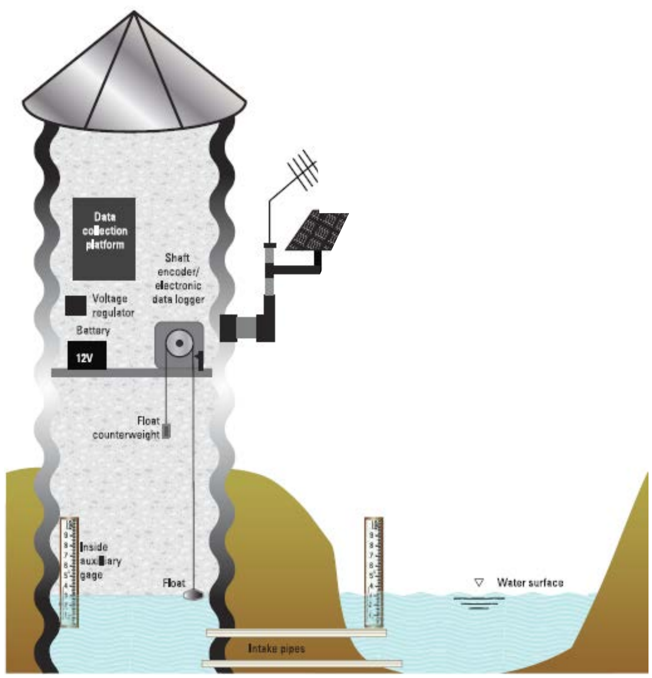


Figure 16: Basic Stilling Well Float System Schematic (Courtesy USGS [1])

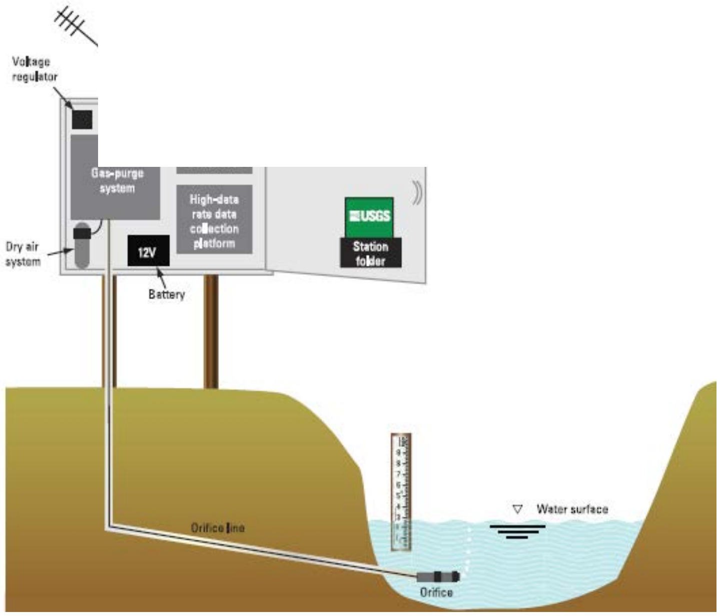


Figure 17: Bubble Gauge with Non-Submersible Pressure Transducer Schematic (Courtesy USGS [1])

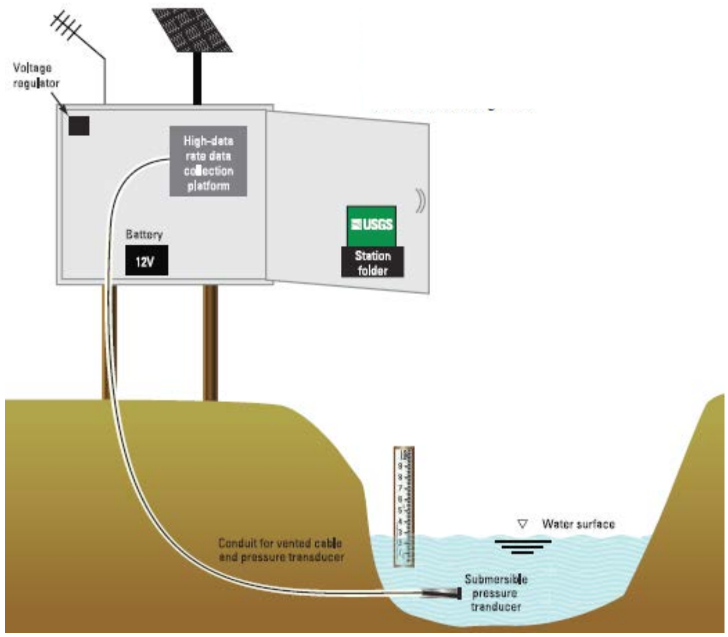


Figure 18: Submersible Pressure Transducer Schematic (Courtesy USGS [1])

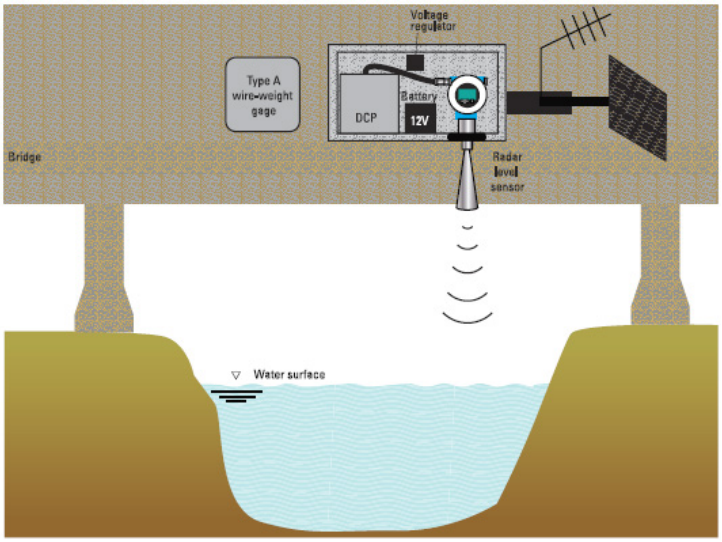


Figure 19: Noncontact Stage Gauge Schematic (Courtesy USGS [1])

It is important to discuss stage gauge accuracy. As per the USGS [1] stage gauges (to be used for flow measurements) should have an accuracy of 0.01 ft or 0.2% of the effective stage. This translates to an accuracy of 0.01 ft +/- during typical low-flow scenarios, and during flood stage (i.e. 30+ feet) the accuracy may diminish to ~0.1 ft +/-. This is important, as stage gauges setup for stage readings only, may not always meet these standards, which can have an impact on real-time stage reporting accuracy, potential real-time inundation mapping accuracy, model calibration accuracy (especially unsteady models), and potential future predictive stage accuracy. Typical sources of error for stage gauges include datum error (such as movement of the gauging device by nature or man) and instrument error (including clogged P.T. pipe or bubbler, animal/insect impacts/clogging, wind/vibrational effects on noncontact stage gauges, dust, and temperature effects).

Standard Still Well Float Gauges have several sources of potential error, ranging from poor stilling basin placement to tape errors, and other human errors. Since this type of system is a lot more expensive to install relative to other systems available on the market, not much emphasis was made on detailing the accuracy range or cost for this type system. Emphasis was instead focused on Bubbler P.T.s, Submersible P.T.s, and noncontact gauges.

Sutron Accubar Bubbler 5600-0131 P.T. (courtesy Sutron [2])

Bubbler P.T.s on the market have accuracy ranges on the order of 0.05% [2] and appear to be relatively reliable systems often employed by agencies. These systems can operate in a wide temperature range, and have less risk of damage to the P.T. than submersible P.T.s.

Submersible P.T.s tend to have accuracy issues with large fluctuations in water temperature, and most cannot operate in freezing conditions [1]. The ideal conditions for this type of unit is in a deep stream or water body that has a minimal temperature change throughout the year. It should be noted that freezing temperatures can damage and destroy some of these sensors, and these sensors are subject to movement during large geomorphologically changing events, if not well anchored. These units are also subject to clogging when high sediment loads are experienced. Some units do exist on the market that meet USGS standards, including the YSI Model 600XL submersible P.T., which has an accuracy of 0.01 ft for up to 30 ft in depth.

YSI Model 600XL Submersible P.T. (courtesy USGS [1])

Radar Gauges are a newer system (when compared to P.T.s) to the market, but the USGS Hydrologic Instrumentation Facility (HIF) has done some testing of products available [1]. These systems use electro-magnetic (radio) waves traveling at the speed of light to measure distance from the unit to the water surface. Error can occur with these units due to debris in the water column being measured as opposed to the actual water surface; thus, placement of these devices is critical to providing accurate readings during flood events that may result in debris floating down a river. Typically, these types of units are mounted on bridge railings, and should be mounted high enough to measure flood waters that may overtop a bridge structure. In rural areas mounting considerations should account for potential conflicts with wide agricultural equipment that may utilize a bridge structure. Units tested by the USGS HIF have accurate distance ranges on the order of 0.75 ft to 72 ft, while still maintaining an accuracy of +/- 0.01 ft [1]. Care must also be taken to ensure insects and other debris like dust do not clog or interfere with the radio wave emitted from the unit, thus routine maintenance is needed. Interviews with the CCDD5 manager, suggest that a rigorous monthly maintenance schedule for each device be conducted. These radar units are relatively new to CCDD5, and thus as time passes, they may pull back on the frequency of maintenance inspections.

VegaPuls62 Radar Gauge (Courtesy Vega [3])

Interviews with Hays County Flood Early Warning Staff revealed that the recently installed stage gauges at various low-water crossings are within a standard error of ~0.5 ft +/-, which is deemed acceptable for road closure notifications, but would not be sufficient for developing flow measurements and may prove problematic if used for other purposes than their original intent of identifying "generally" when roads need to be closed.

Rain Gauges:

Rain gauges have been used for a very long time (dating back to the fourth century BC in India [4]) and include very simple buckets with depth markers on the side, to complex and highly sophisticated electronic devices. Modern rain gauges include weighing, tipping bucket, capacitance, drop-counting, optical, and acoustic rain gauges. As per the National Weather Service (NWS), the primary equipment used for precipitation observations is the 8-inch standard rain gauge and the Fischer & Porter weighing rain gauge [5]. Interviews with various local FEWS owner/operators indicate that the tipping bucket and weighing rain gauges are the most frequently used systems. These interviews also indicated some local interest in the use of capacitance rain gauges, due to their ability to more accurately measure higher intensity rainfall events. As a result of these interviews, the focus of this feasibility study is on the weighing, tipping bucket, and capacitance rain gauges. Photos of these three (3) rain gauge systems are provided below.

Figure 20: Example Capacitance Rain Gauge, Model 50202 Rain Gauge (Courtesy [6])

Figure 21: Example Weighing Rain Gauge, Fischer & Porter Rain Gauge (Courtesy NOAA, NWS)

Figure 22: Example Tipping Bucket Rain Gauge (Courtesy SARA, 2018)

Similar to stage gauges, rain gauges have accuracy limitations that should be considered when selecting equipment. A review of several manufacturers of tipping bucket rain gauges, coupled with research performed for the American Meteorological Society indicates that measurement error is generally on the order of +/-1.5% for up to 2 inches per hour [7], and beyond that point the tipping bucket gauge tends to underestimate rainfall intensity [8]. The tipping bucket rain gauge also has limitations with measurement intervals on the order of 1-minute (ranging as high as +/- 20% error), and high winds can also play a role in inaccuracies with this type of gauge [7, 8]. Measurement durations on the order of 5-minute intervals can result in error on the order of +/- 10%, and with durations on the order of 15-minutes the error is much more acceptable (being on the order of +/- 2%) [8]. The weighing gauge has relatively accurate readings for both high intensity and low intensity rainfall events, and also tends to function well at measurement intervals on the order of 1-minute; but this gauge has a tendency to fail during longer duration events due to automatic siphon failure which can lead to significant data loss issues [8]. Newer models of the weighing rain-gauge developed by OTT, appear to resolve this siphon failure issue. The capacitance rain gauge performed similar to the weighing gauge for both high intensity and low intensity rain events. Capacitance gauges are also subject to error in high wind conditions, resulting in "instrument noise". Also, capacitance gauges tend to have some extra error during extremely low rainfall intensity (on the order of 0.08 inches/hr or less), and measurements taken during extremely low intensity events should be interpreted with caution [8].

Interviews with regional owner/operators of gauge equipment

As part of this feasibility study, an effort was made to interview regional owner/operators of rain and stream gauge equipment, with the goal of identifying preferences for the various systems under consideration by CCDD5. This interview process was actually done in conjunction with several other regional FEWS studies conducted simultaneously, and the results of this interview process are published in other reports developed by Scheibe Consulting, LLC. Regional partners that were interviewed include the Harris County Flood Control District (H.C.F.C.D.), Hays County, U.S. Geological Survey (U.S.G.S.), Lower Colorado River Authority (L.C.R.A.), City of Belton, City of Austin, San Antonio River Authority (S.A.R.A.), and Cameron County Drainage District #5 (C.C.D.D. #5). As noted elsewhere in this report, there has already been some mention of owner/operator preference to various gauging system types, so an attempt was made in this section to summarize the overall opinions of the various entities interviewed, with the goal of documenting general preference trends. **Table 7** shows the matrix results from the interviews with the various gauge operators in the region.

Table 7: Owner/Operator equipment preference interview results

Gauge Owner/Operator	Preferred Equipment Type[1]					
	Traditional Stage Gauges[2]	Modern Electronic Stage Gauges[3]	Noncontact Stage Gauges[4]	Tipping Bucket Rain Gauge	Capacitance Rain Gauge	Weighing Rain Gauges
H.C.F.C.D.		X	X	X		X
Hays Co.		X		X		
U.S.G.S.	X	X	X	X	X	X
L.C.R.A.		X	X	X		
City of Belton		X	X			
City of Austin		X				
S.A.R.A.		X	X	X	X	
C.C.D.D. #5			X	X	X	

1. Preferred equipment type is marked with an "X".
2. Basic Stilling-well float system;
3. Modern electronic stage sensors (including bubble gauges with non-submersible pressure transducers (P.T.), & submersible P.T.s)
4. These type of stage gauges include radar, acoustic, and laser methods;

A summary of the detailed findings of these interviews can be obtained from the City of San Marcos Flood Early Warning System (FEWS) Feasibility Study Report (*Scheibe, 2019*).

Rain/Stream Gauge Cost Analysis

A cost analysis was performed to assist the district with potential selection of future rain and stream gauging equipment, as well as the potential of upgrading existing equipment. A select number of units and manufacturers were used in the analysis, based on owner/operator interviews, as well as research noted in previous sections of this report. The results of this cost analysis are by no means exhaustive; and are intended to provide a general range of costs that the district should expect when trying to implement upgrades or new installations of gauging equipment. Some consideration was also taken with regard to collaboration with the USGS on installation and maintenance of gauging equipment, which is also described further in the section of the report. To help illustrate cost ranges, **Tables 8 and 9** were developed to illustrate the various equipment types and cost considerations in the feasibility study.

Table 8: Summary of cost analysis for rain gauge equipment (*Scheibe, 2019*)

Manufacturer	Model	Gauge Type	Accuracy1	Cost	Ancillary Equipment needs	Ancillary Equipment Costs	Total Cost2
Texas Electronics	TR-525USW	8" Tipping Bucket	+/- 1% (at 0 – 2 in./hr.)	$450.00	Dual Reed Switch, Siphon, data logger, bird spikes, field calibration device, Solar panel, sapphire jewel option, battery, solar panel, transmission antenna, cabling, & enclosure box	$3,050.00	$18,500.00
SUTRON	5600-0525-6	~8" Tipping Bucket	+/- 2% (at 0 – 10 in./hr.	$1,250.00	Assuming cellular data logger/telemetry (X link 500), Siphon, cell service, battery, solar panel, transmission antenna, cabling, & enclosure box	$3,650.00	$19,900.00
SUTRON	OTT Pluvio[2]	8" Weighing	+/- 0.002"	$4,300.00	Assuming cellular data logger/telemetry (X link 500), cell service, battery, solar panel, transmission antenna, cabling, & enclosure box	$3,650.00	$22,950.00
Young	50202	5.5" Capacitive	+/- 0.04"	$1,600.00	Meteorological translator, mounting panel, gauge calibrator, battery, solar panel, transmission antenna, & cabling	$3,500.00	$20,100.00

1. Accuracy is as per manufacturer and is not necessarily based on independent test results.
2. Total cost includes equipment costs and assumed installation costs. Installation costs are assumed to be $15k per unit. Annual maintenance costs are not provided herein. Annual maintenance may be on the order of $4,000.00 for bi-annual maintenance (every 4 sites) (*courtesy of sales rep. for Sutron, 2019*). Use of trained in-house district staff will likely result in lower maintenance costs.

Table 9: Summary of cost analysis for stage gauge equipment (*Scheibe, 2019*)

Manufacturer	Model	Gauge Type	Accuracy[1]	Cost	Ancillary Equipment needs	Ancillary Equipment costs	Total Cost[2]
SUTRON	Single Orifice Constant Flow Bubble Gauge	Bubble w/ non-submersible P.T.	+/- 0.05%	$4,000.00	100 LF PVC orifice line (data logger not needed), battery, solar panel, transmission antenna, & cabling	$1,700.00	$23,700.00
SUTRON	OTT RLS	Radar Gauge	+/- 0.1% (@ 115 ft)	$2,900.00	Assuming cellular data logger/telemetry (X link 500), cell service, battery, solar panel, transmission antenna, & cabling	$3,650.00	$24,550.00
SUTRON	OTT PLS	Submersible P.T.	+/- 0.1% (at full range)	$2,100.00	Humidity absorber box, cartridge, data logger/telemetry (X link 500), cell service, battery, solar panel, transmission antenna, & cabling	$3,800.00	$23,900.00

1. Accuracy is as per manufacturer and is not necessarily based on independent test results.
2. Total cost includes equipment costs and assumed installation costs. Installation costs are assumed to be $18k per unit. Annual maintenance costs are not provided herein. Annual maintenance may be on the order of $4,000.00 for bi-annual maintenance (every 4 sites) (*courtesy of sales rep. for Sutron, 2019*). Use of trained in-house district staff will likely result in lower maintenance costs.

In summary, the district should expect to spend on the order of $18,000 to $23,000 per rain gauge (equipment and labor), and $23,000 to $25,000 per stage gauge. There is some cost savings in equipment if one data logger is used for multiple gauges, and/or dual rain and stream gauges are installed at each site. More refined costs based on site specific short-term and long-term goals may also reveal some cost savings per site.

The USGS was interviewed to discuss the potential to have them purchase, install, and maintain rain/stream gauges for the district. The cost for this type of system is on the order of $30,000 to $80,000 per new gauge. These systems are uniquely setup with satellite telemetry (thus reducing the risk of data loss due to power outages) and include U.S. Geological Survey (USGS)/National Oceanic Atmospheric Administration (NOAA) grade equipment, maintenance, verification field measurements during flood events, and data post-processing through the USGS website. It should be noted that many times the USGS uses a dual P.T. with radar stage gauge setup, which may be a large part of the reason for the higher system cost. USGS installed and maintained gauges also offer the opportunity to be tied into the National Weather Service (NWS) forecasting system.

Identification of Gauge Network Deficiencies and Recommendations for Improvements

Following a cursory review of the existing gauge network, including density, telemetry, equipment, procedures, maintenance, and data management; the following general recommendations have been developed:

1. CCDD5 should consider implementing a standardized maintenance plan that is in writing, so that it can be passed down to future district managers and maintenance personnel. This maintenance plan should illustrate equipment manufacturer, contact information, inspection log, and equipment specifications needed for replacements. The maintenance plan should list the minimum maintenance interval and provide inspection procedures and checklists.

2. CCDD5 should consider implementing a data management policy and QC process for archived rain and stage gauge information. This will greatly aid with identifying when equipment has failed and will also make historic/archived data much more useful and reliable. Internal staff or a sub-organization should be considered to help manage this data and provide consistent QC reviews.

3. CCDD5 should consider installing weighing rain gauges and replacing tipping buckets with weighing rain gauges. As illustrated in the recent June 25th, 2019 Flood, rainfall intensities were recorded on the order of 8 inches in 2.5 hrs, and 27 inches in 6 hrs. These intensities are not accurately recorded using a standard tipping bucket rain gauge, and the district would be better served with upgrades to a weighing gauge network.

4. CCDD5 should consider installing video cameras with staff gauges adjacent to the radar gauges to aid with estimating flood depths that overtop bridges and submerge radar gauges. This extra level of data collection would be very beneficial when trying to estimate peak flood depths during extreme events and could also serve as a road closure alert system to other regional partners. The USGS has had success with installing real-time cameras at select gauges that report at the same 15-minute interval as the other equipment.

5. CCDD5 should conduct an internal review of the existing radar stage gauge equipment's accuracy. If radar gauges are deemed insufficient due to accuracy issues, then the district should consider implementing a rehabilitation program for the existing stage gauge equipment.

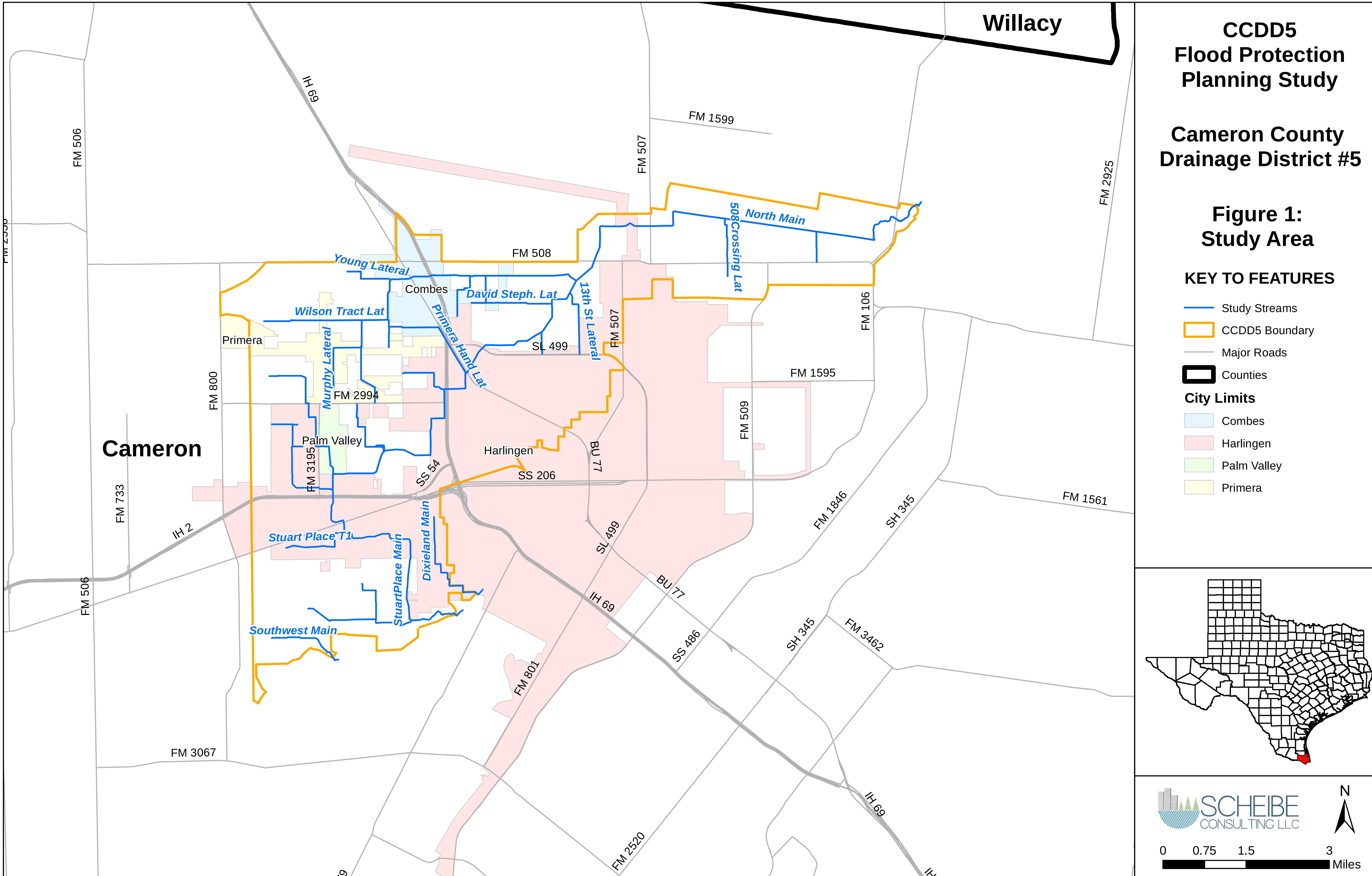
6. CCDD5 should consider implementing a real-time inundation mapping system similar to the Harris County Flood Control District. This information could be used by local offices of emergency management, as well as the local community with regard to road flooding and high-risk areas during heavy rainfall events. To implement a system of this type, the District may need to increase its stage gauge density to accommodate a more accurate real-time inundation mapping network.

FEWS Feasibility Study Footnotes

1. Sauer, V. B.; Turnipseed, D. P.; Stage Measurement at Gaging Stations, Chapter 7 of Book 3, Section A, Techniques and Methods 3-A7, US Department of Interior, USGS, 2010

2. www.sutron.com; Sutron Accubar Bubbler 5600-0131, 2019.
3. https://www.vega.com/en/Products/Product-catalog/Level/Radar/VEGAPULS-62; VegaPuls 62, 2019.
4. Strangeways, I.; A History of Rain Gauges, Royal Meteorological Society (RMetS), Weather, Vol. 65, No. 5, 2010.
5. NDSPD 10-13, National Weather Service, Surface Observing Program, 2018.
6. Model 50202 Precipitation Gauge, R. M. Young Company, 2001.
7. Ciach, G.J.; Local Random Errors in Tipping-Bucket Rain Gauge Measurements, Journal of Atmospheric and Oceanic Technology, Vol. 20, Pg. 752, 2002.
8. Nystuen, J. A.; Relative Performance of Automatic Rain Gauges under Different Rainfall Conditions, American Meteorological Society, 1999.

FIGURES


CCDD5
Flood Protection
Planning Study
Cameron County
Drainage District #5
Figure 1:
Study Area
KEY TO FEATURES
Study Streams
CCDD5 Boundary
Major Roads
Counties
City Limits
Combes
Harlingen
Palm Valley
Primera
SCHEIBE CONSULTING LLC
N
0 0.75 1.5 3 Miles
Willacy
Cameron
Combes
Primera
Palm Valley
Harlingen
North Main
508Crossing Lat
Young Lateral
David Steph. Lat
Wilson Tract Lat
13th St Lateral
Primera Hand Lat
Murphy Lateral
Stuart Place T1
StuartPlace Main
Dixieland Main
Southwest Main
IH 69
IH 2
FM 506
FM 507
FM 508
FM 1599
FM 2925
FM 106
FM 1595
FM 509
FM 800
FM 2994
FM 3195
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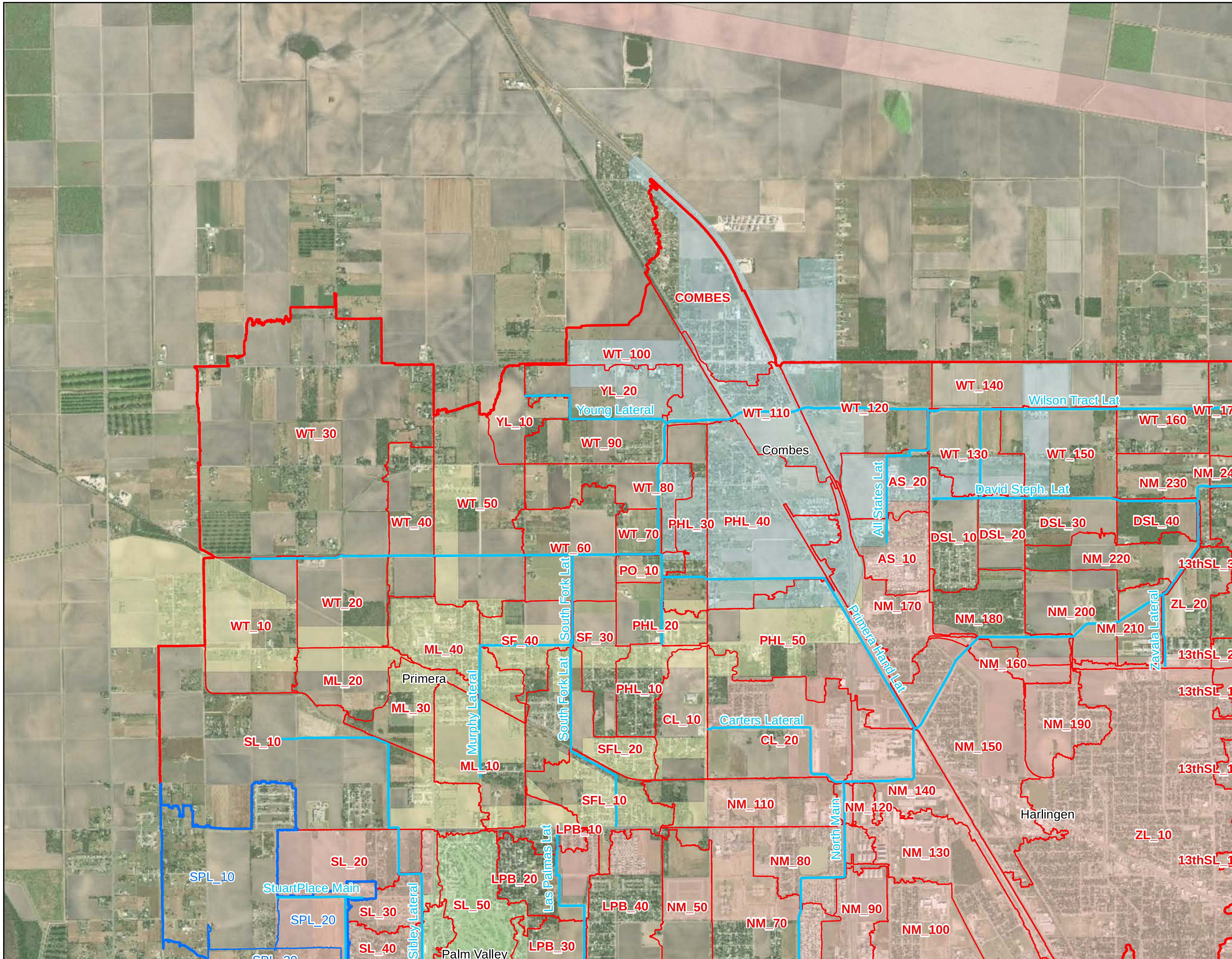
FM 2520



CCDD5 Flood Protection Planning Study

Cameron County Drainage District #5

Figure 3: Sub-basin Layout Map 1 of 3

KEY TO FEATURES

- Study Streams
- North Main Watershed
- Dixieland Watershed
- Stuart Place Watershed
- SW Drain Watershed
- North Main Sub-basins
- Dixieland Sub-basins
- Stuart Place Sub-basins
- SW Drain Sub-basins

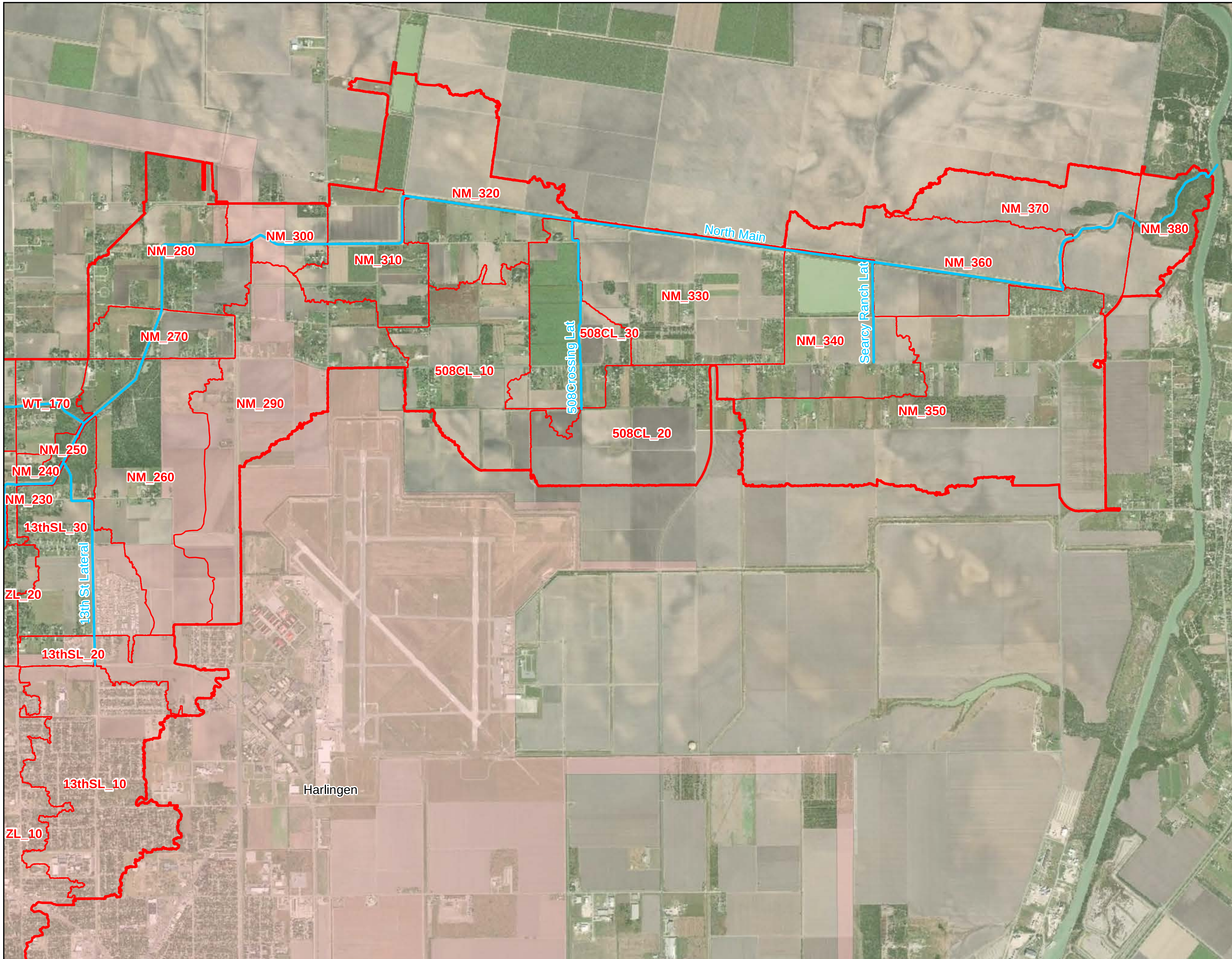
City Limits

- Combes
- Harlingen
- Palm Valley
- Primera

SCHEIBE CONSULTING LLC

N

0 0.25 0.5 1 Miles



CCDD5 Flood Protection Planning Study

Cameron County Drainage District #5

Figure 3: Sub-basin Layout Map 2 of 3

KEY TO FEATURES

- Study Streams
- North Main Watershed
- Dixieland Watershed
- Stuart Place Watershed
- SW Drain Watershed
- North Main Sub-basins
- Dixieland Sub-basins
- Stuart Place Sub-basins
- SW Drain Sub-basins

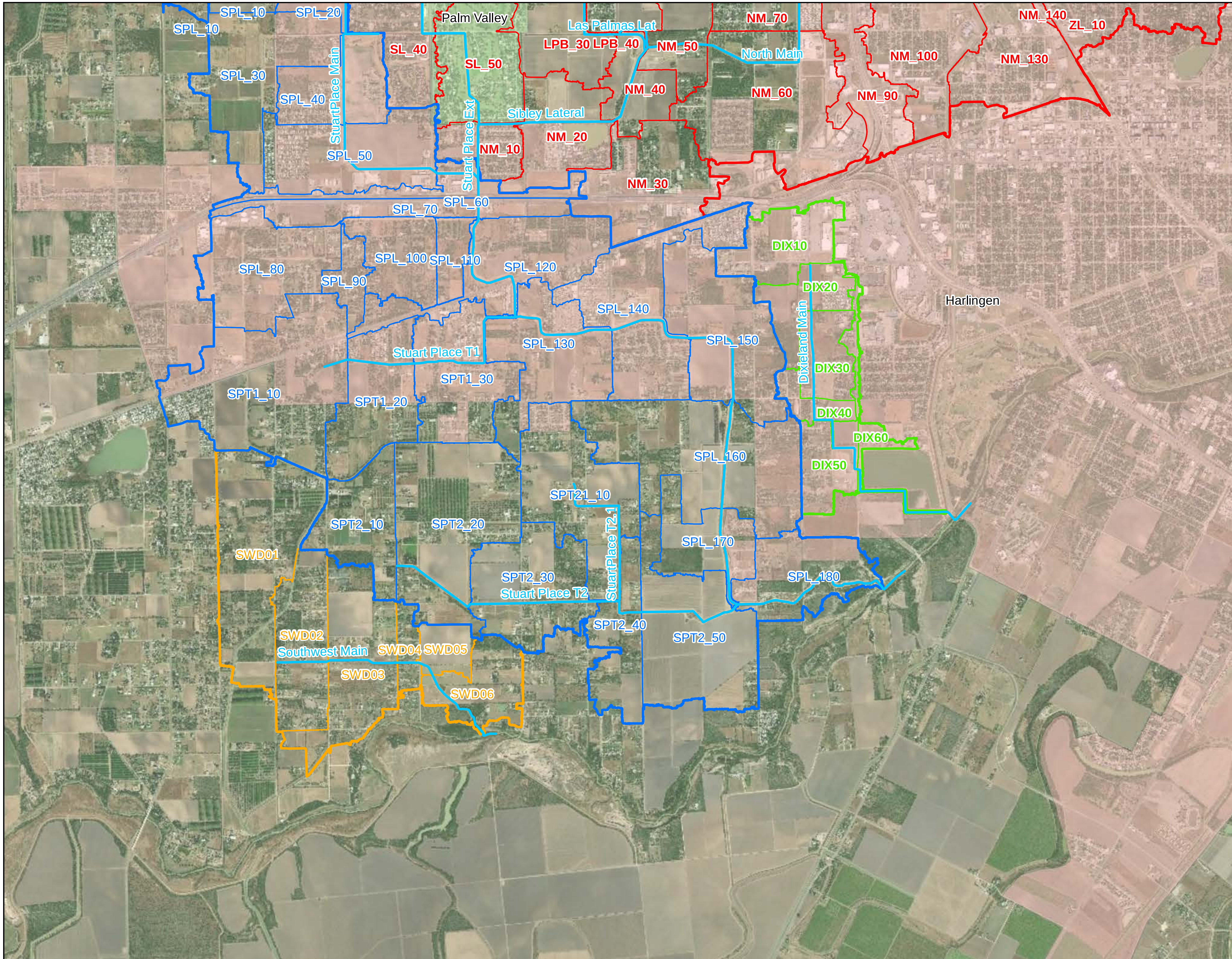
City Limits

- Combes
- Harlingen
- Palm Valley
- Primera

SCHEIBE CONSULTING LLC

N

0 0.25 0.5 1 Miles



CCDD5
Flood Protection Planning Study

Cameron County Drainage District #5

Figure 3: Sub-basin Layout Map 3 of 3

KEY TO FEATURES

- Study Streams
- North Main Watershed
- Dixieland Watershed
- Stuart Place Watershed
- SW Drain Watershed
- North Main Sub-basins
- Dixieland Sub-basins
- Stuart Place Sub-basins
- SW Drain Sub-basins

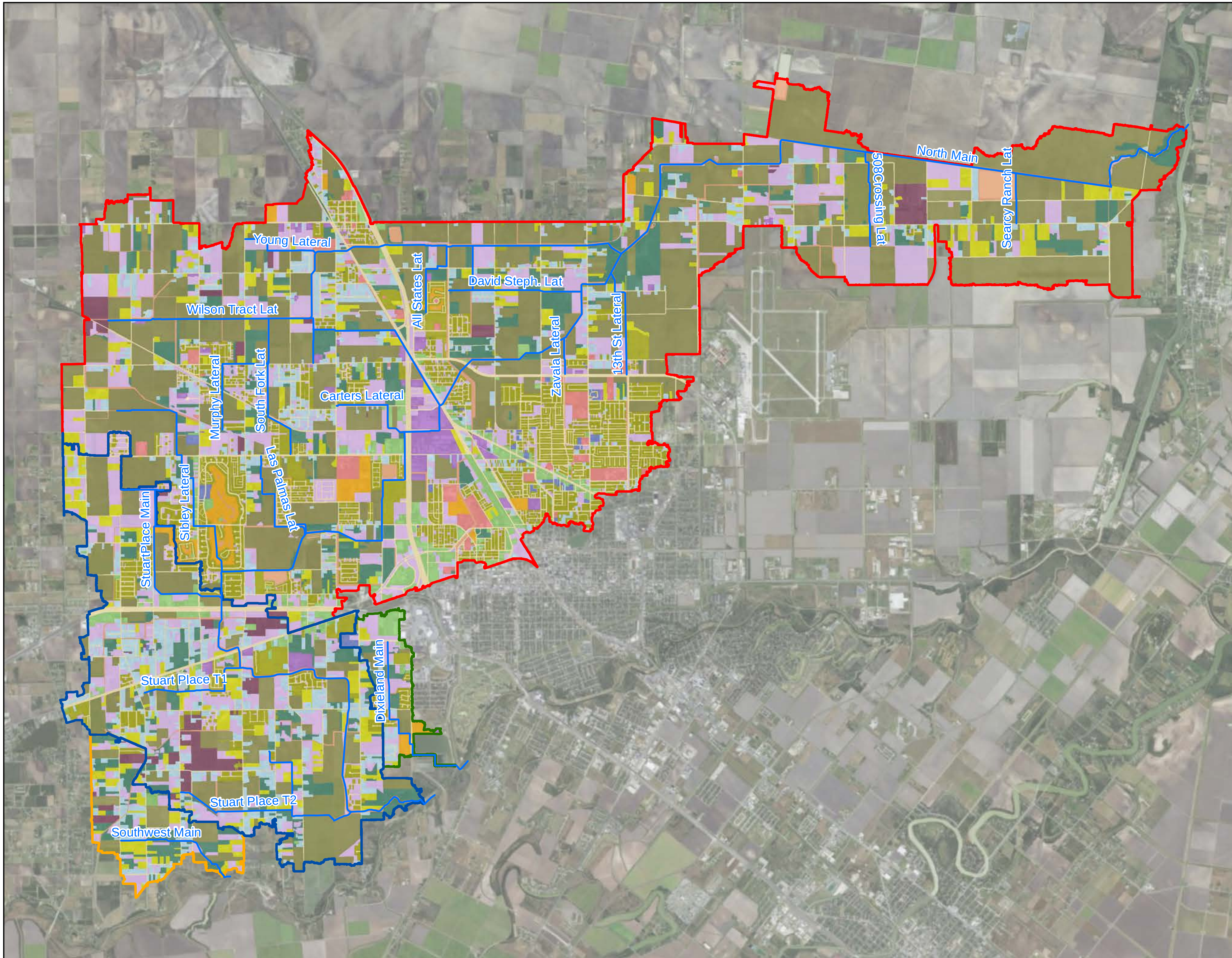
City Limits

- Combes
- Harlingen
- Palm Valley
- Primera

SCHEIBE CONSULTING LLC

N

0 0.25 0.5 1 Miles



CCDD5 Flood Protection Planning Study

Cameron County Drainage District #5

Figure 4: Land Use

KEY TO FEATURES

- Study Streams
- Stuart Place Watershed
- Dixieland Watershed
- SW Drain Watershed
- North Main Watershed

Land Use

- Commercial
- Crop
- Industrial
- Institution
- Low-Density Residential
- Multi-Family Residential
- Orchard
- Park
- Pasture
- Rural Residential
- High-Density Residential
- Transportation
- Water
- Woods/Brush

SCHEIBE CONSULTING LLC

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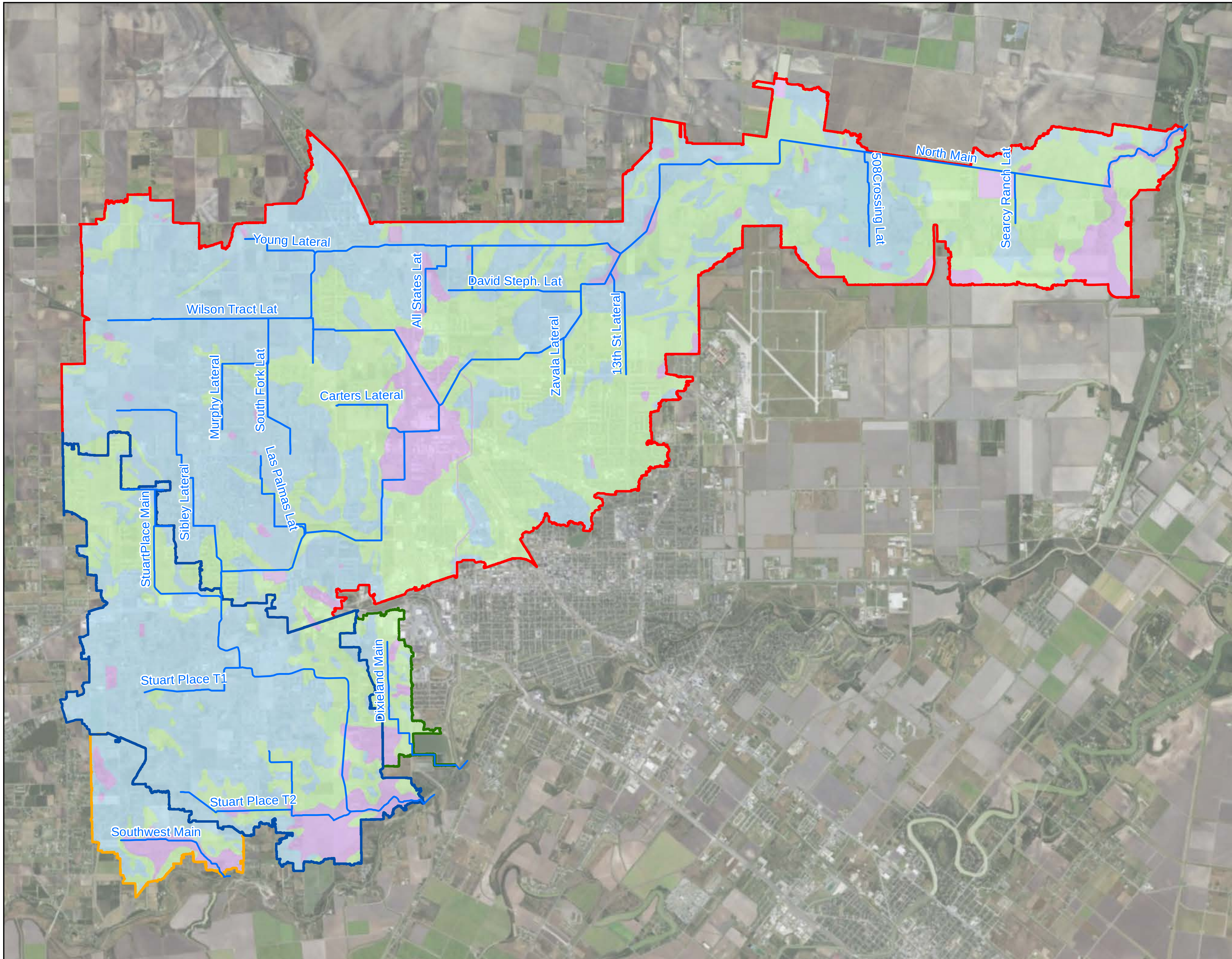


CCDD5 Flood Protection Planning Study

Cameron County Drainage District #5

Figure 5: Soil Types

KEY TO FEATURES

- Study Streams
- Stuart Place Watershed
- Dixieland Watershed
- SW Drain Watershed
- North Main Watershed

Hydrologic Soil Group

- B
- C
- D

SCHEIBE CONSULTING LLC

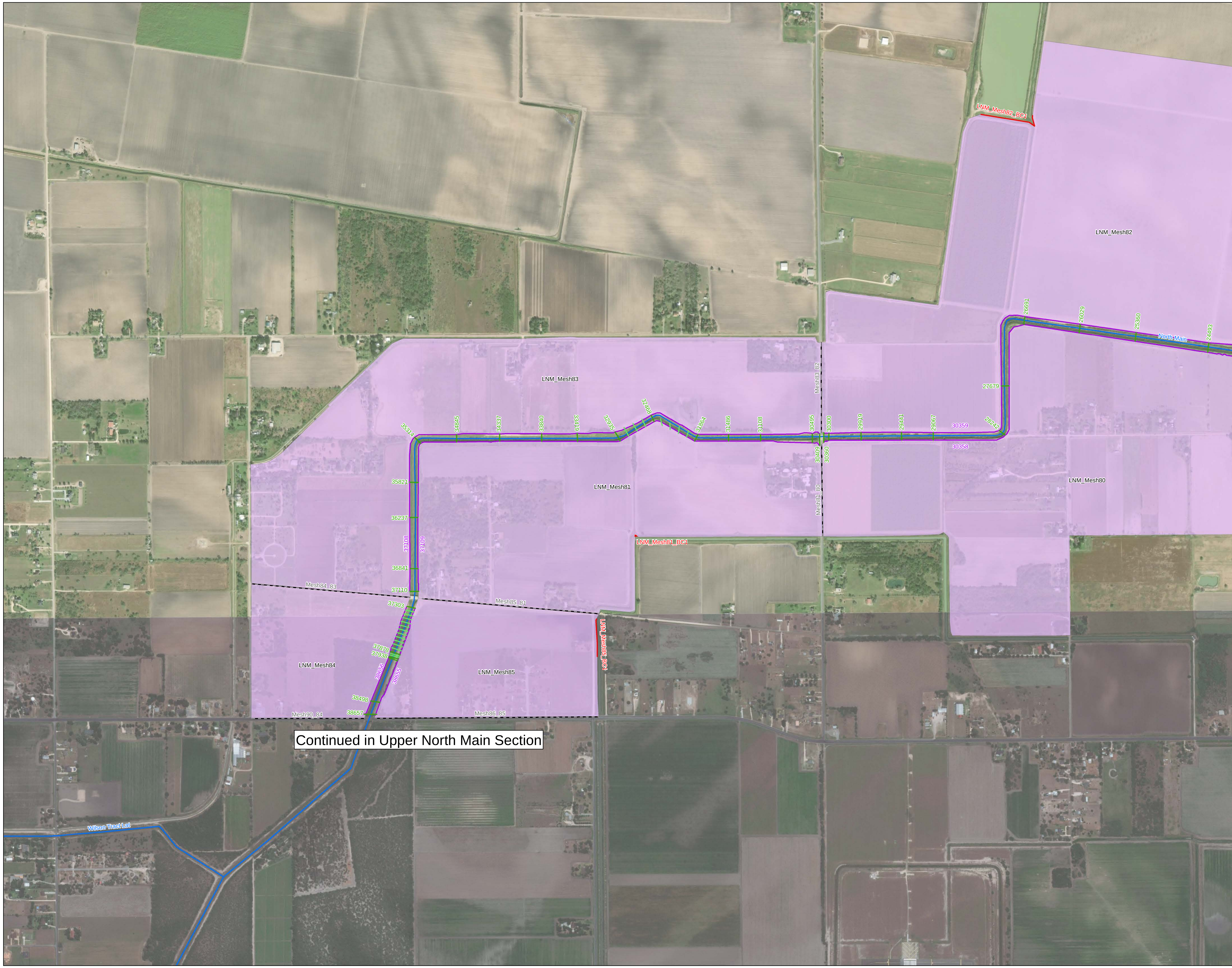
N

0 0.5 1 2 Miles

CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Lower North Main Map 1 of 3



KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- Storage Area
- 2D Flow Area

SCHEIBE CONSULTING LLC

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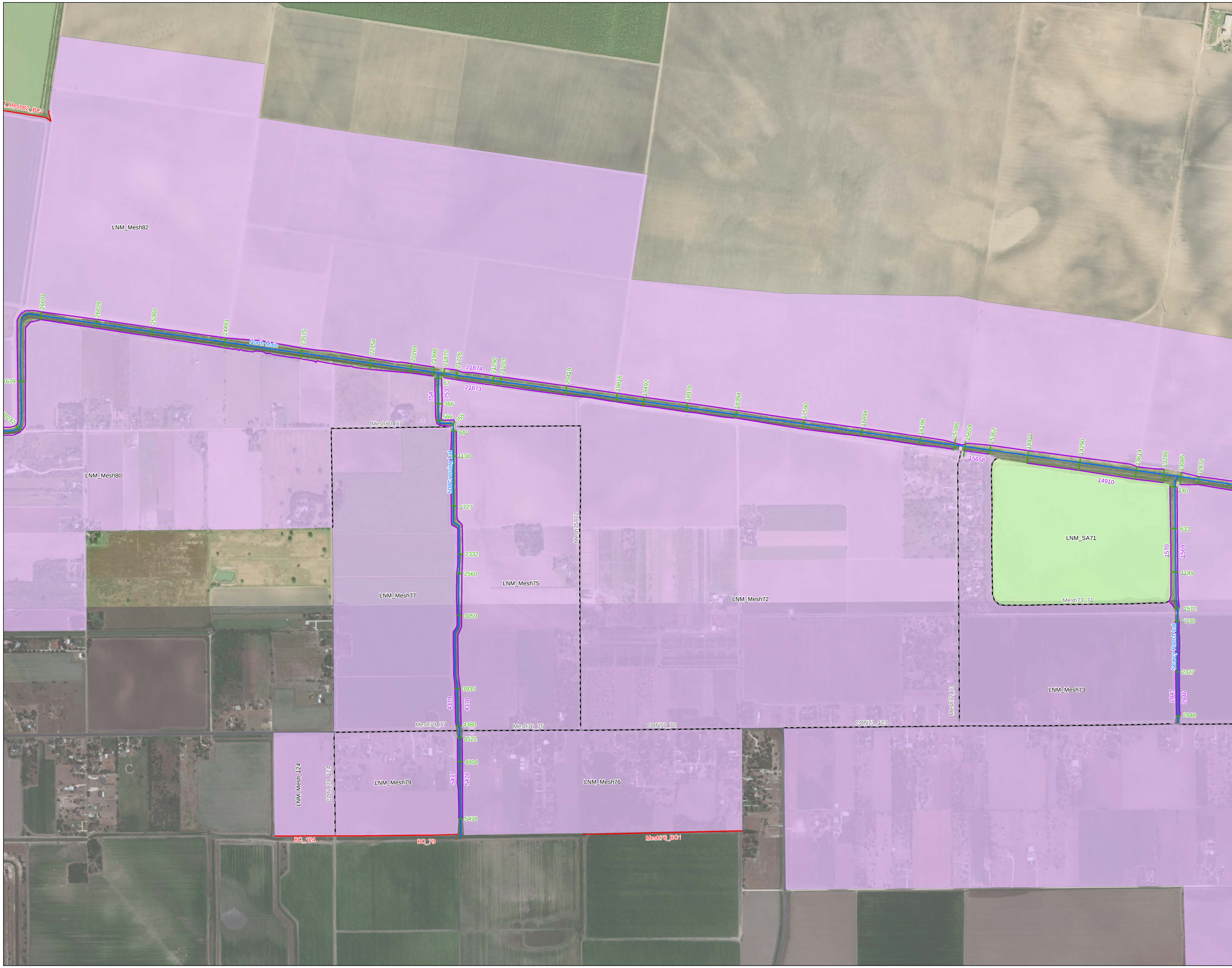

CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Lower North Main Map 2 of 3

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- Storage Area
- 2D Flow Area

SCHEIBE CONSULTING LLC

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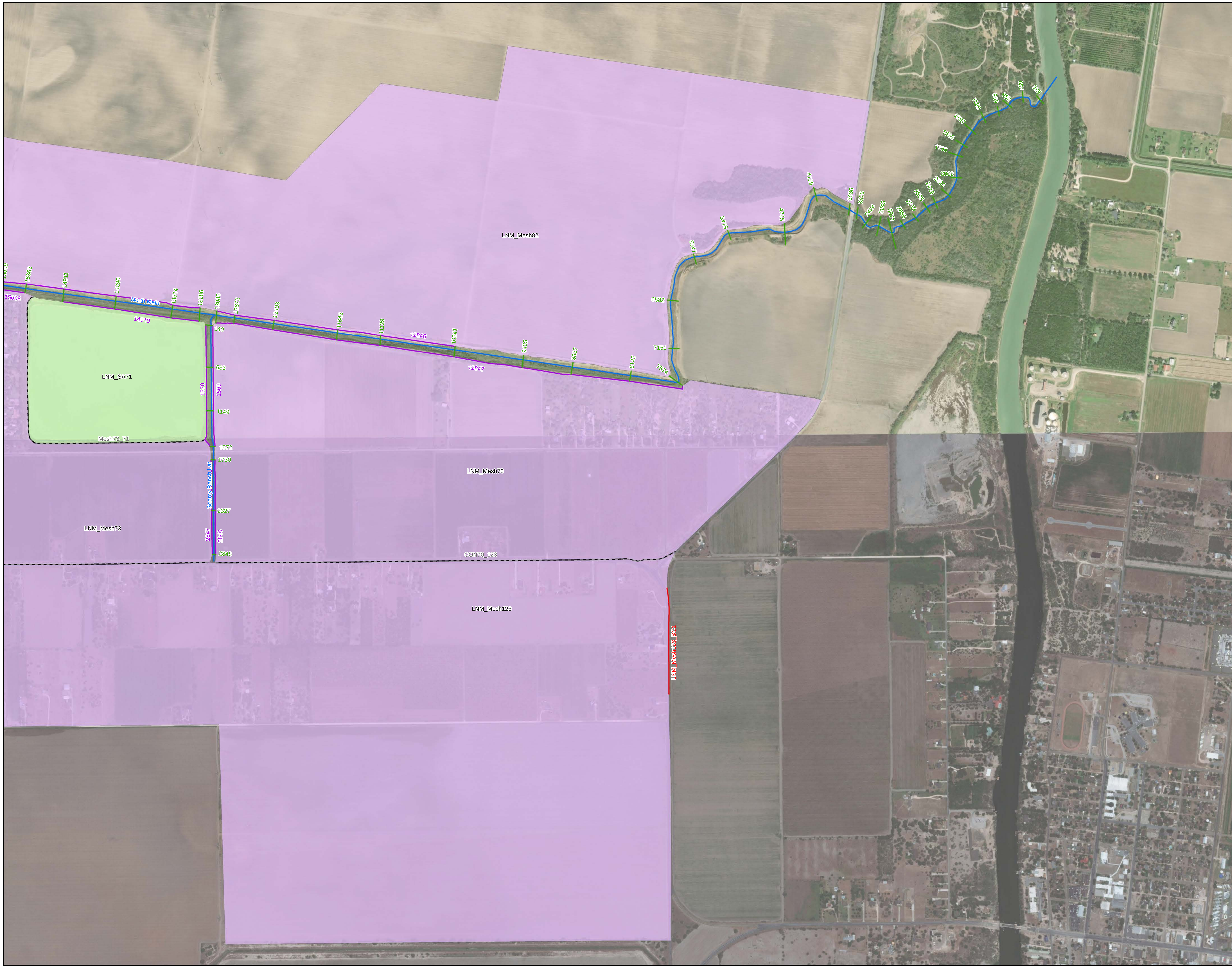
0 500 1,000 2,000 Feet



CCDD5
Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Lower North Main Map 3 of 3

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- Storage Area
- 2D Flow Area

SCHEIBE CONSULTING LLC

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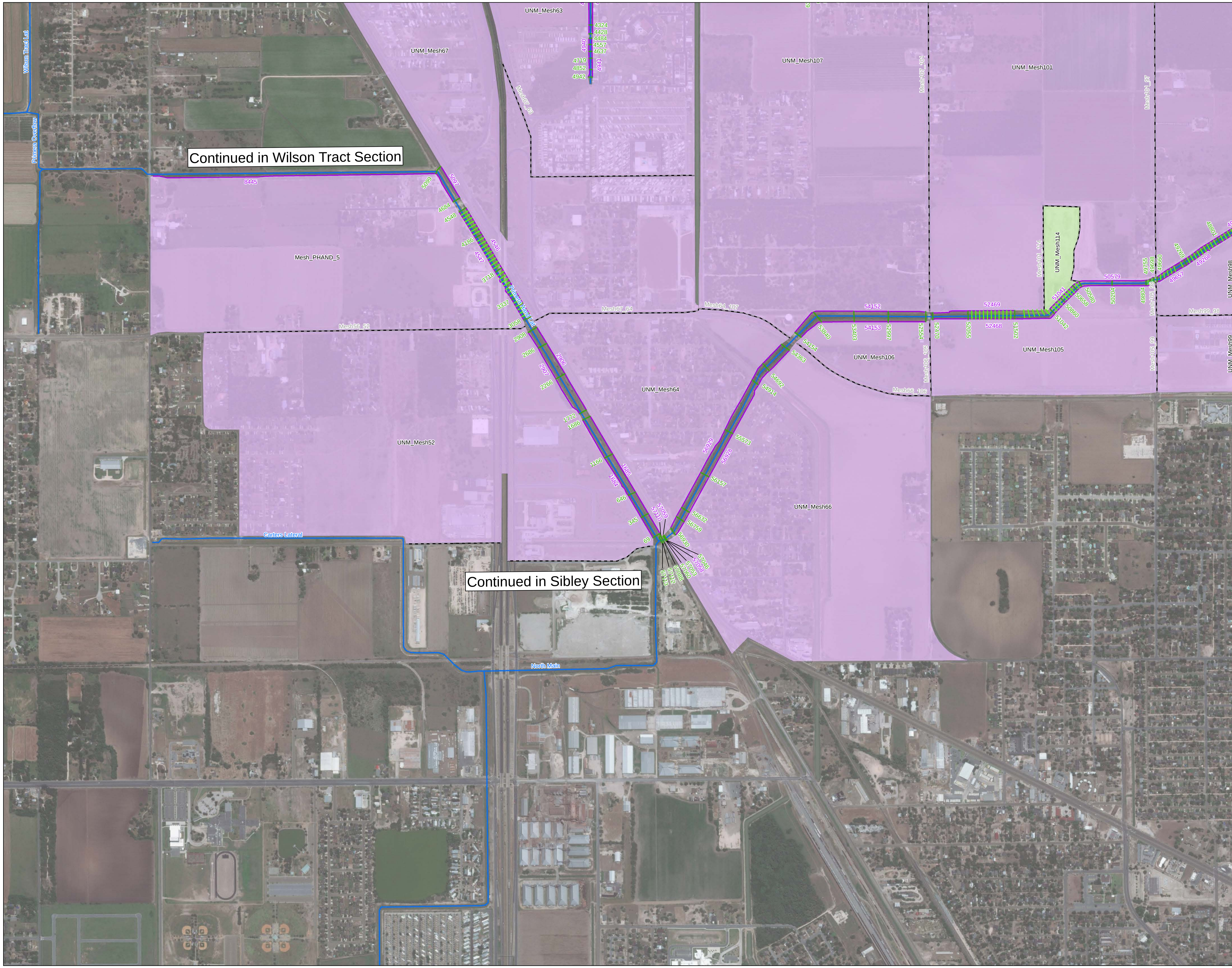

CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Upper North Main Map 1 of 3

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- Storage Area
- 2D Flow Area

SCHEIBE CONSULTING LLC

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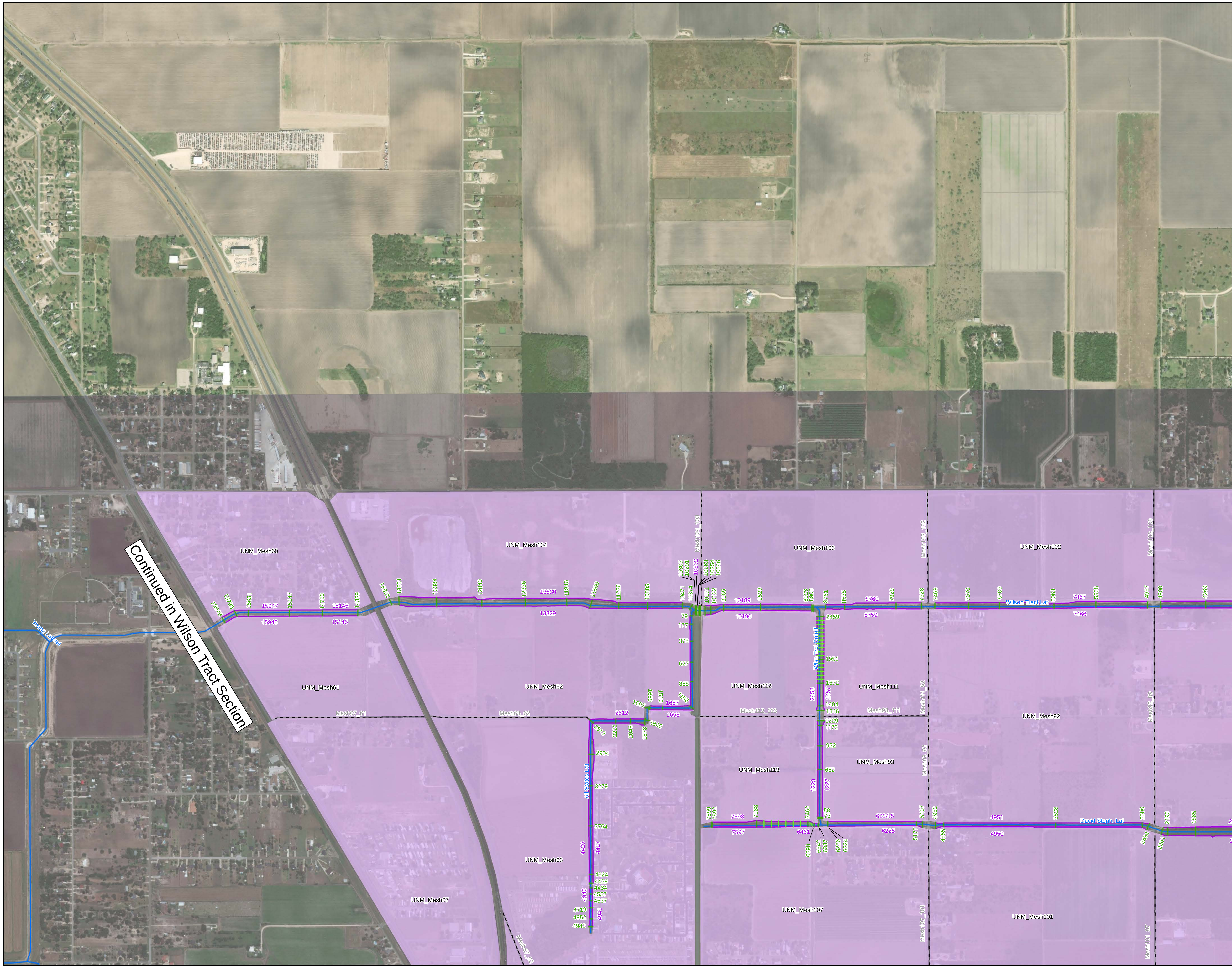

CCDD5
Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Upper North Main Map 2 of 3

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- Storage Area
- 2D Flow Area

SCHEIBE CONSULTING LLC

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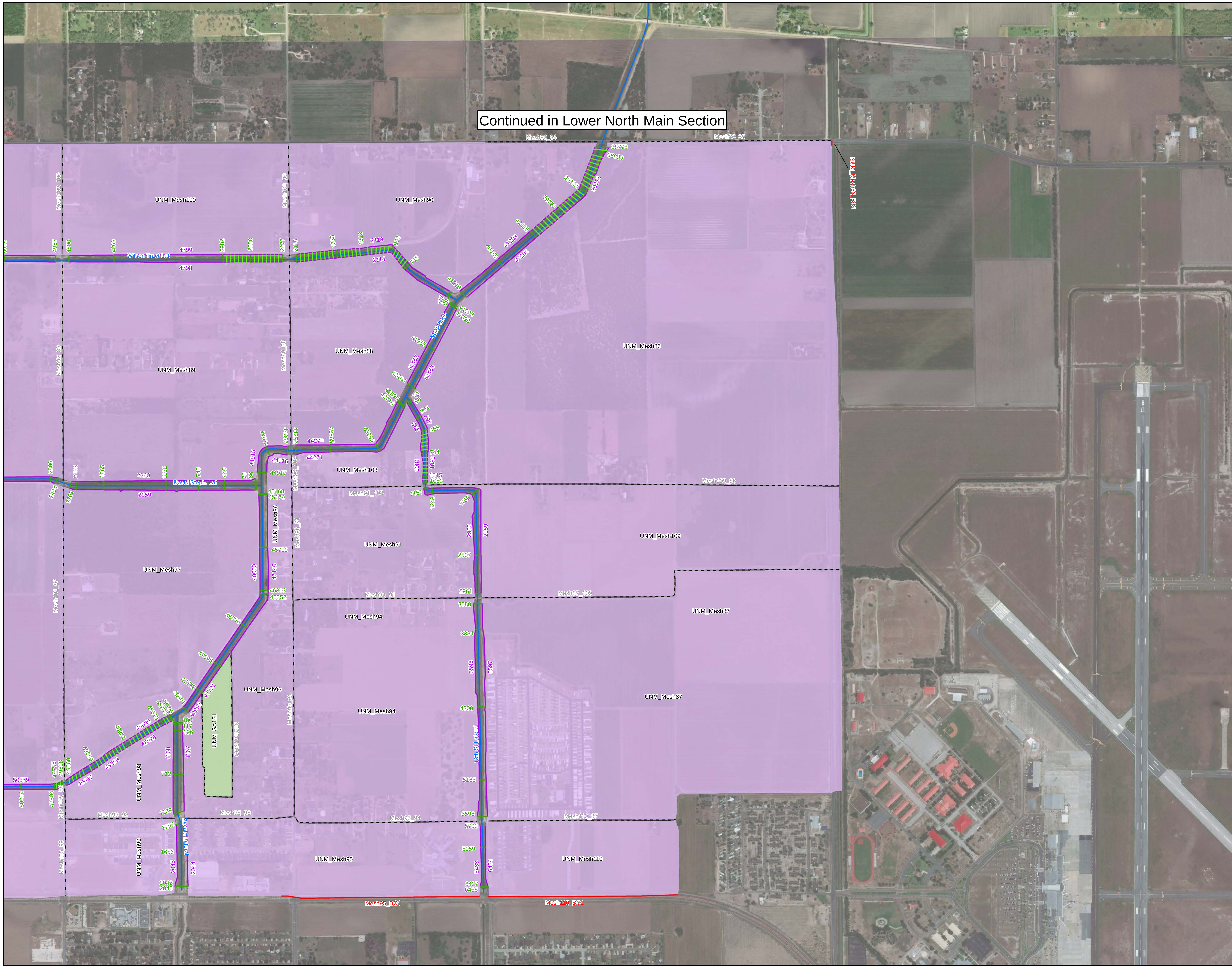

CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Upper North Main Map 3 of 3

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- Storage Area
- 2D Flow Area

SCHEIBE CONSULTING LLC

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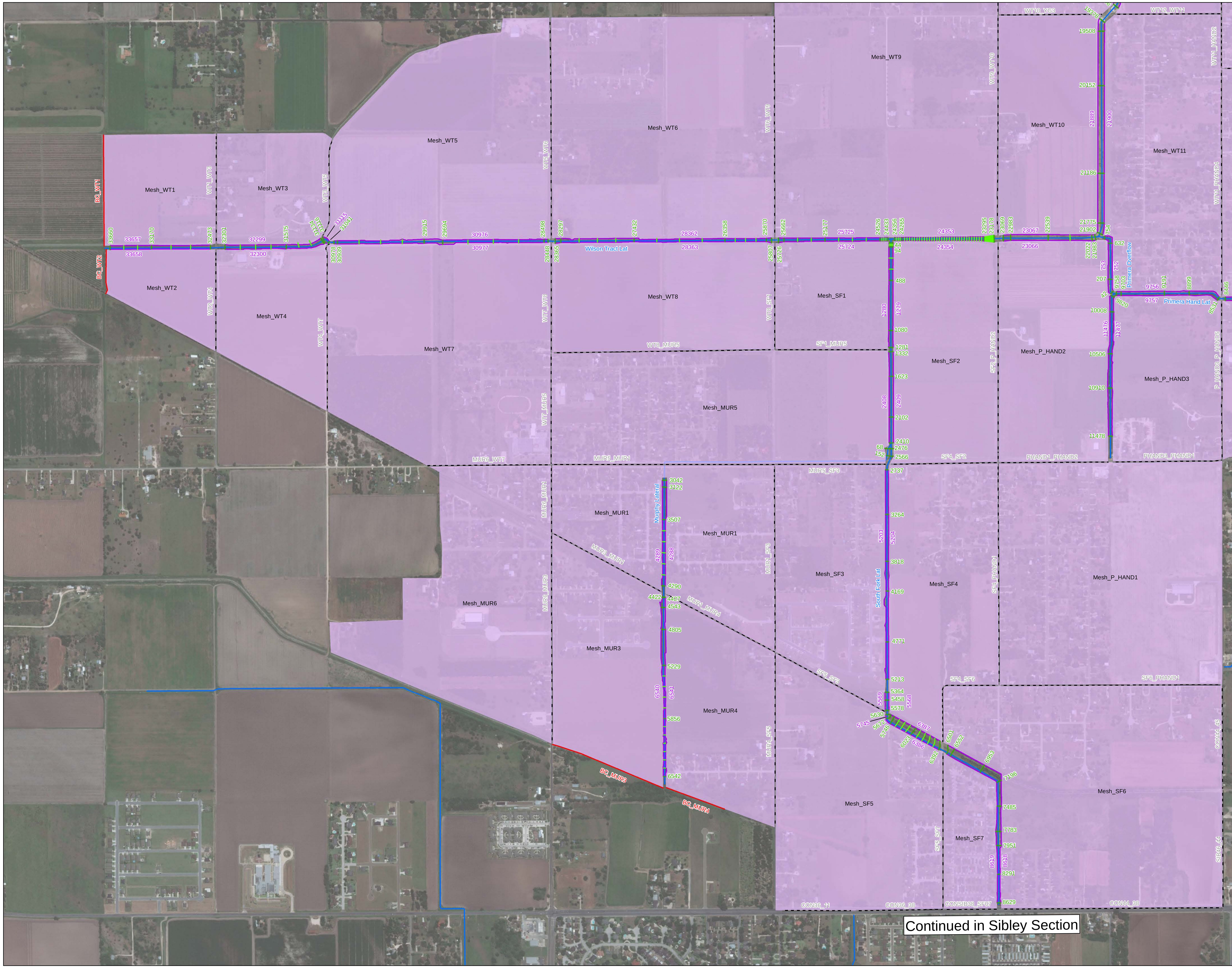

CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Wilson Tract Lateral Map 1 of 2

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- 2D Flow Area

SCHEIBE CONSULTING LLC

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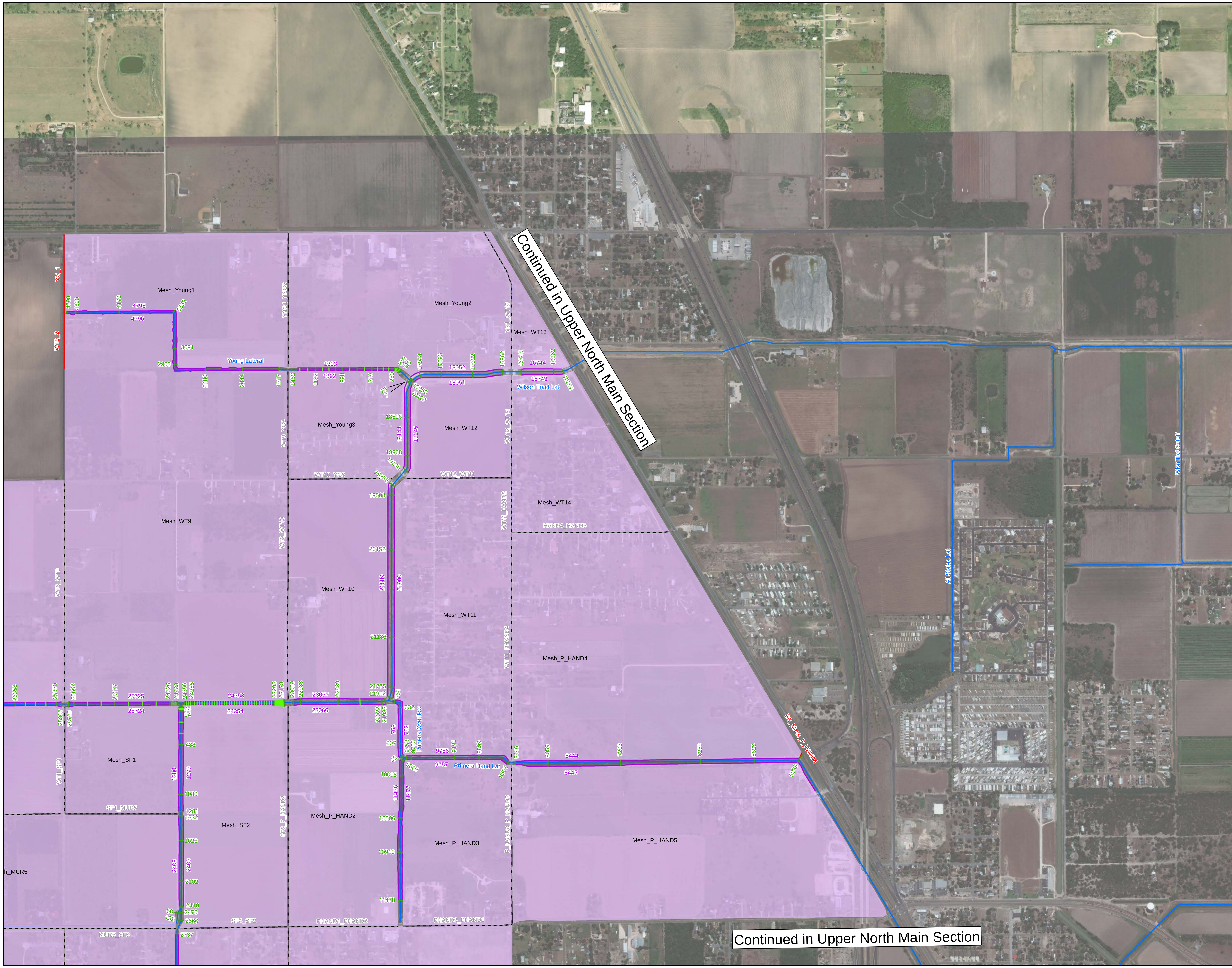

CCDD5
Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Wilson Tract Lateral Map 2 of 2

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- 2D Flow Area

SCHEIBE CONSULTING LLC

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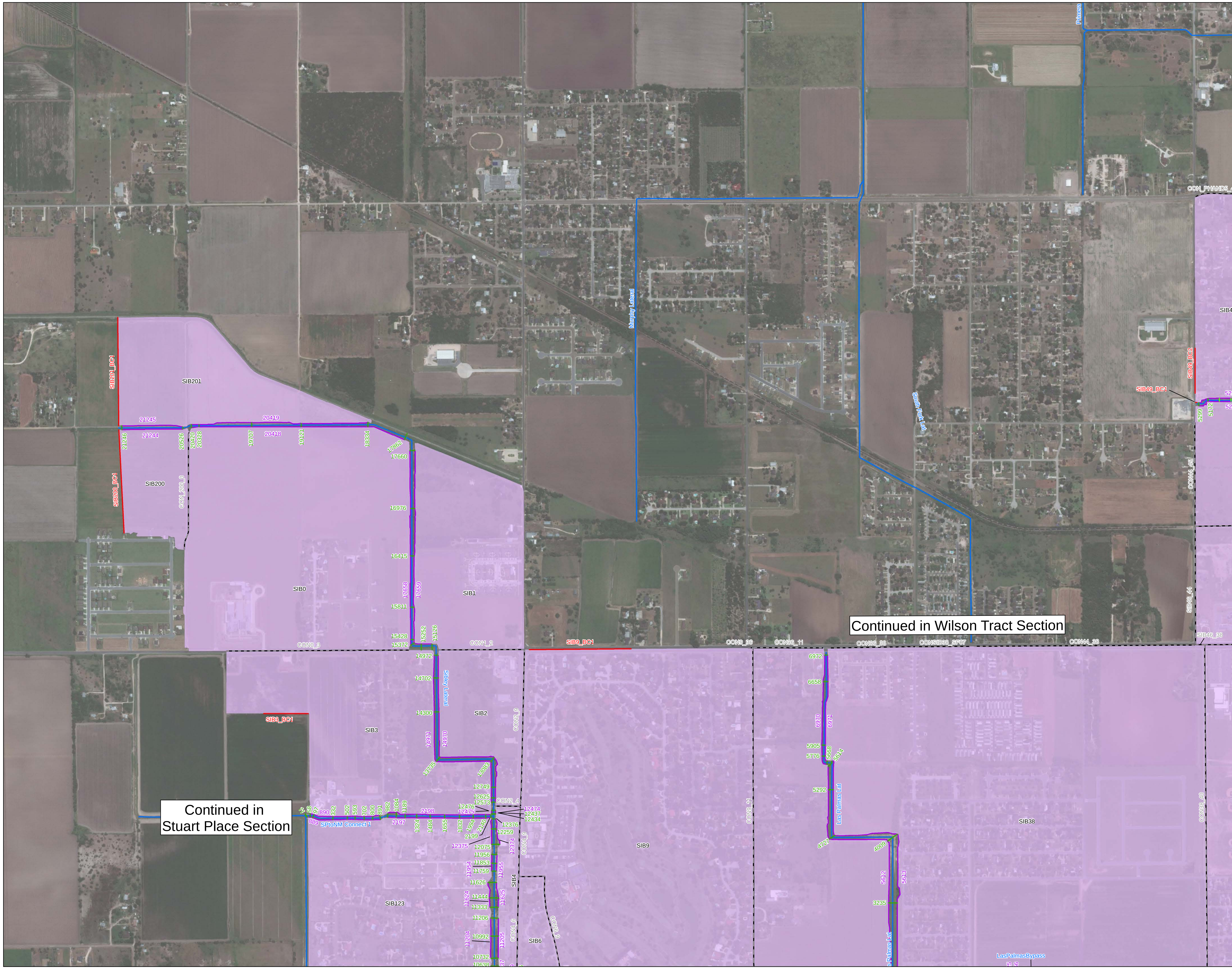

CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Sibley Lateral Map 1 of 3

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- Storage Area
- 2D Flow Area

SCHEIBE CONSULTING LLC

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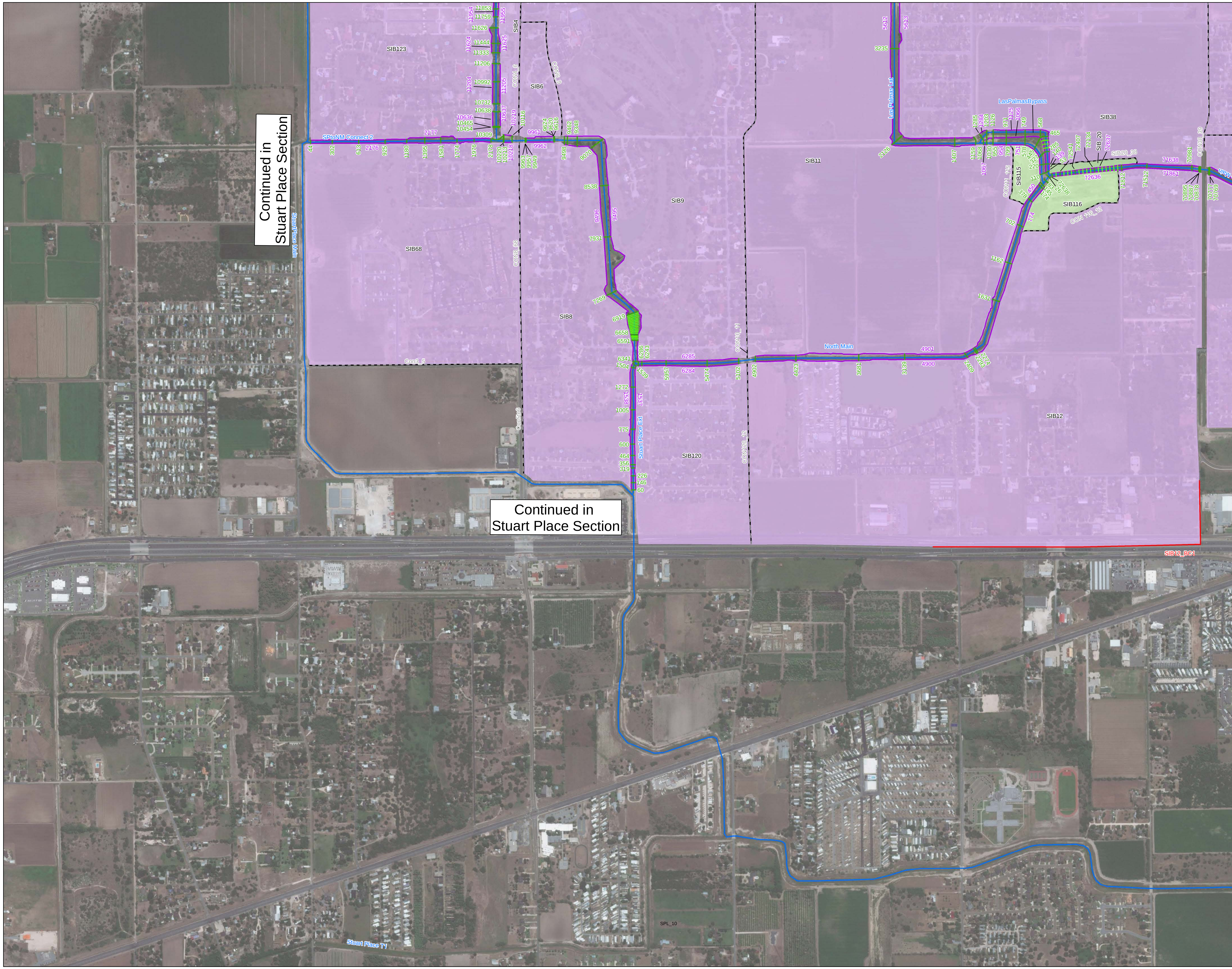

CCDD5
Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Sibley Lateral Map 2 of 3

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- Storage Area
- 2D Flow Area

SCHEIBE CONSULTING LLC

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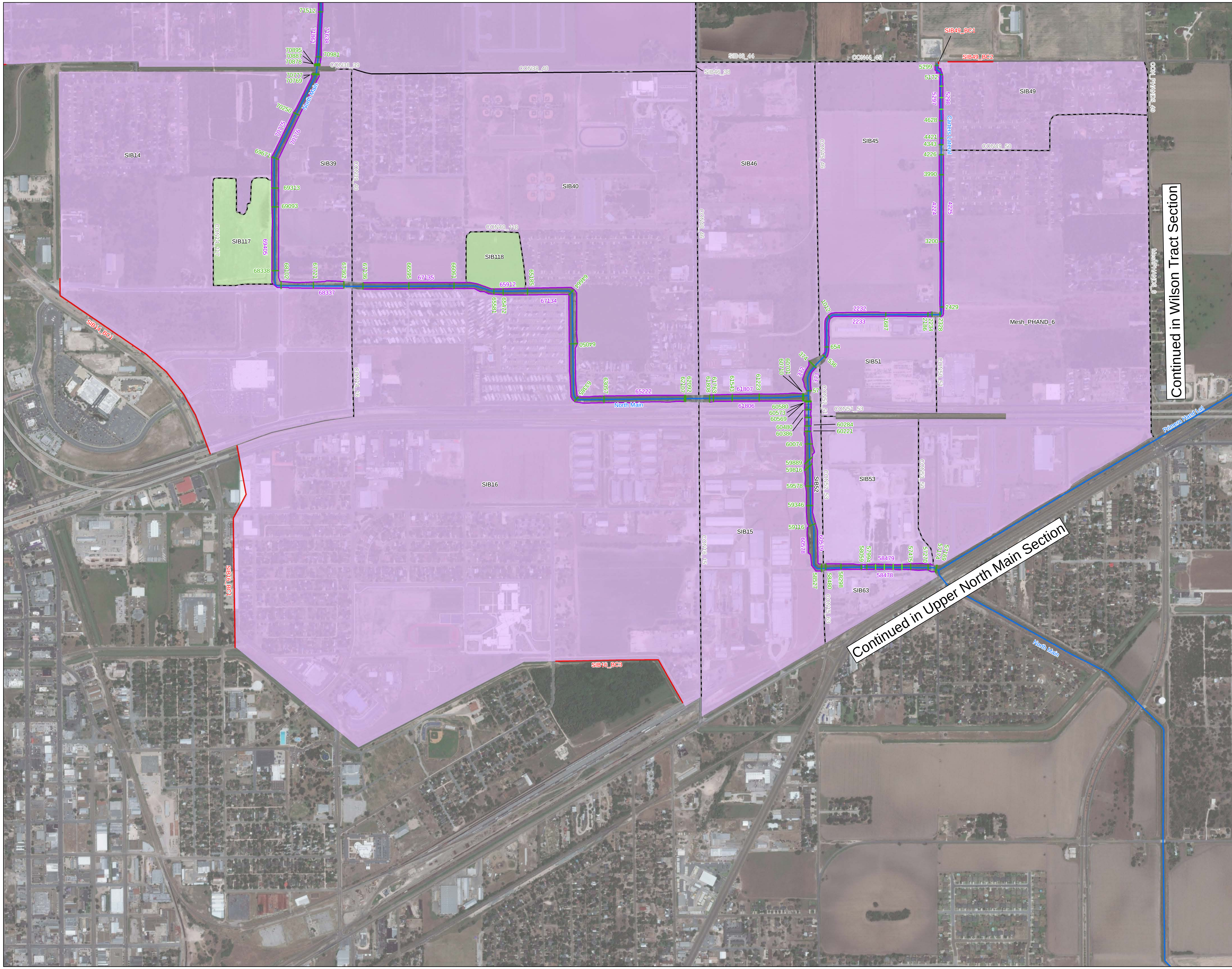
0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

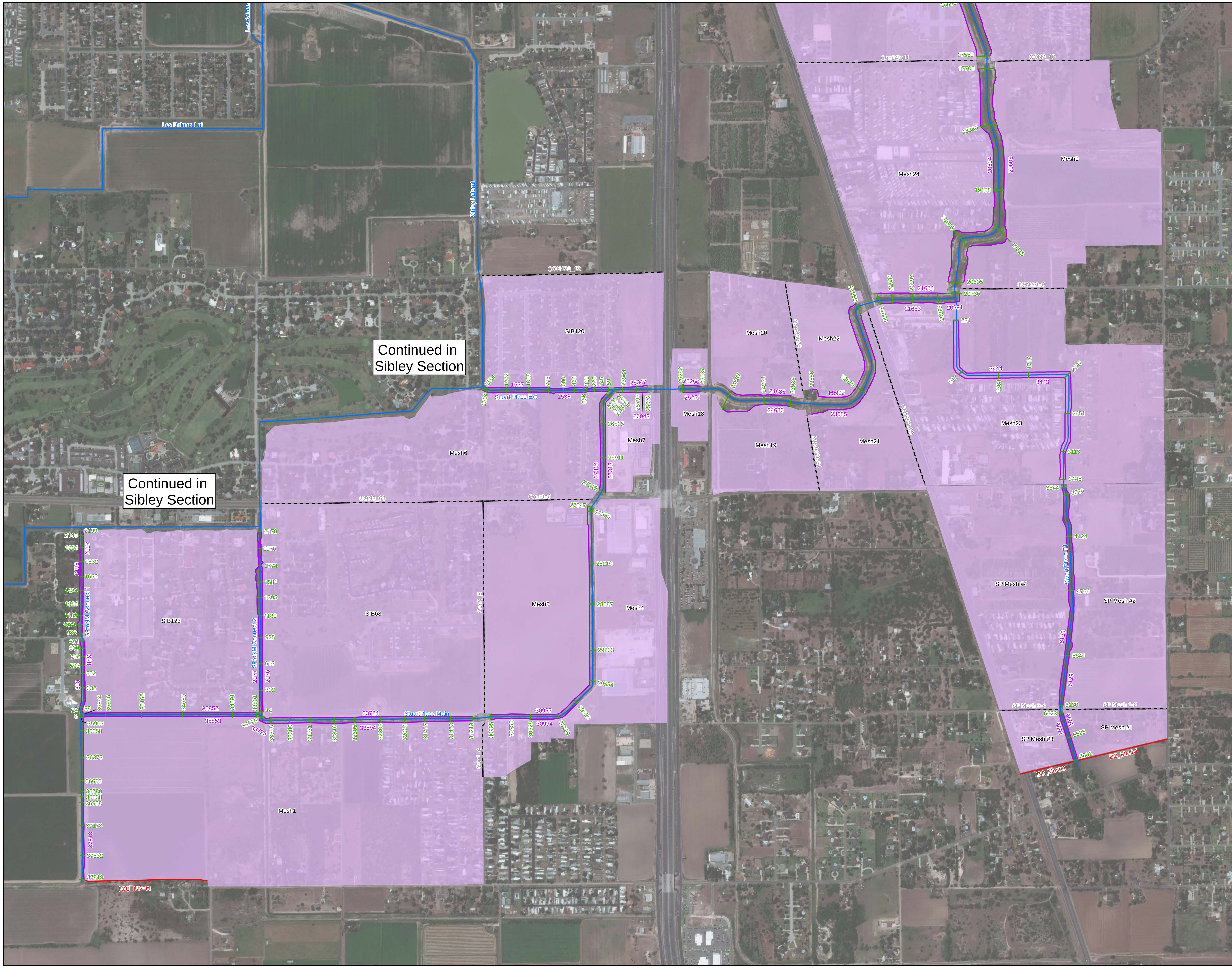
Figure 6: Cross-Section Layout Sibley Lateral Map 3 of 3

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- Storage Area
- 2D Flow Area

SCHEIBE CONSULTING LLC

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Stuart Place Stuart Place Trib 1 Dixieland Map 1 of 2

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- 2D Flow Area

SCHEIBE CONSULTING LLC

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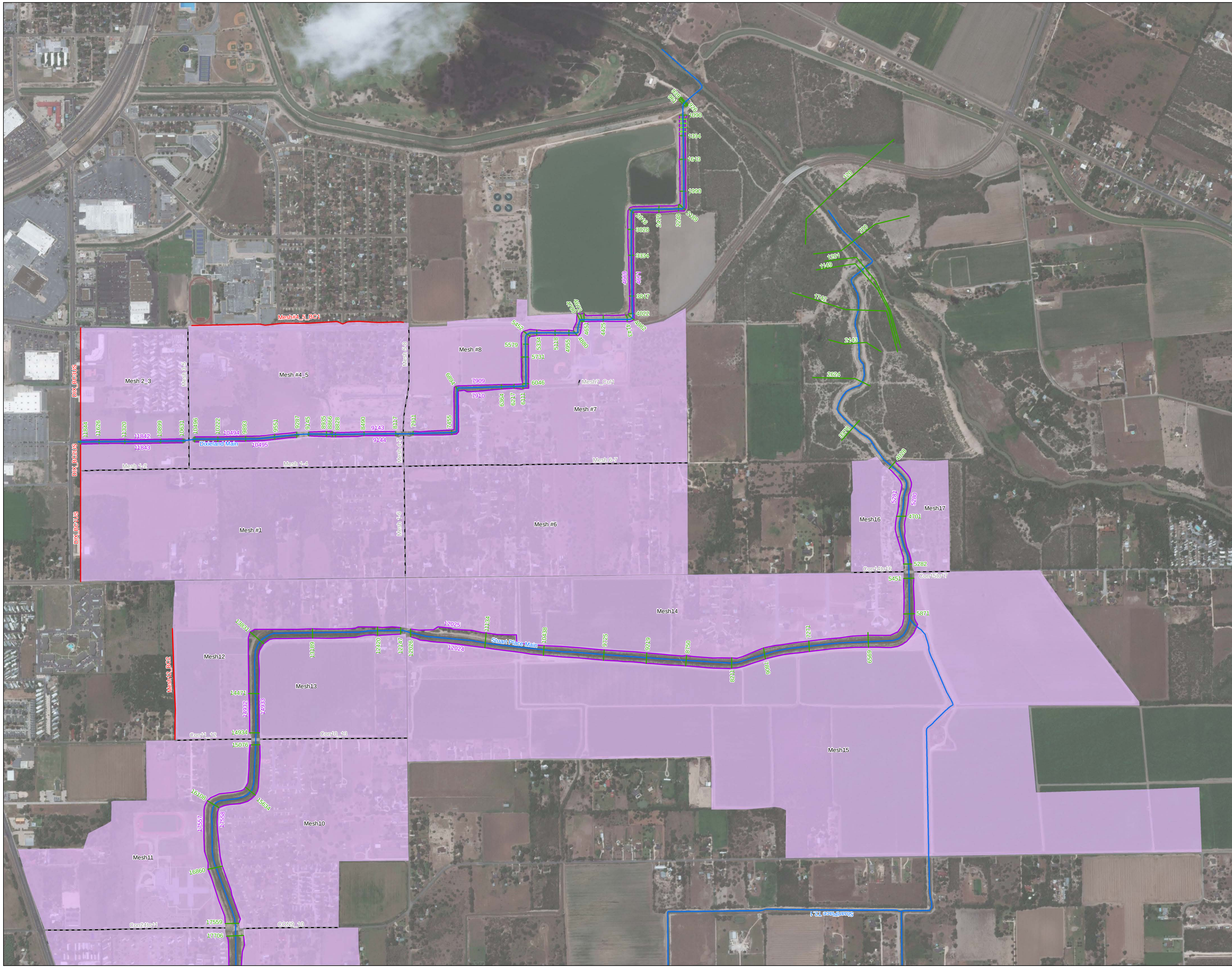
0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

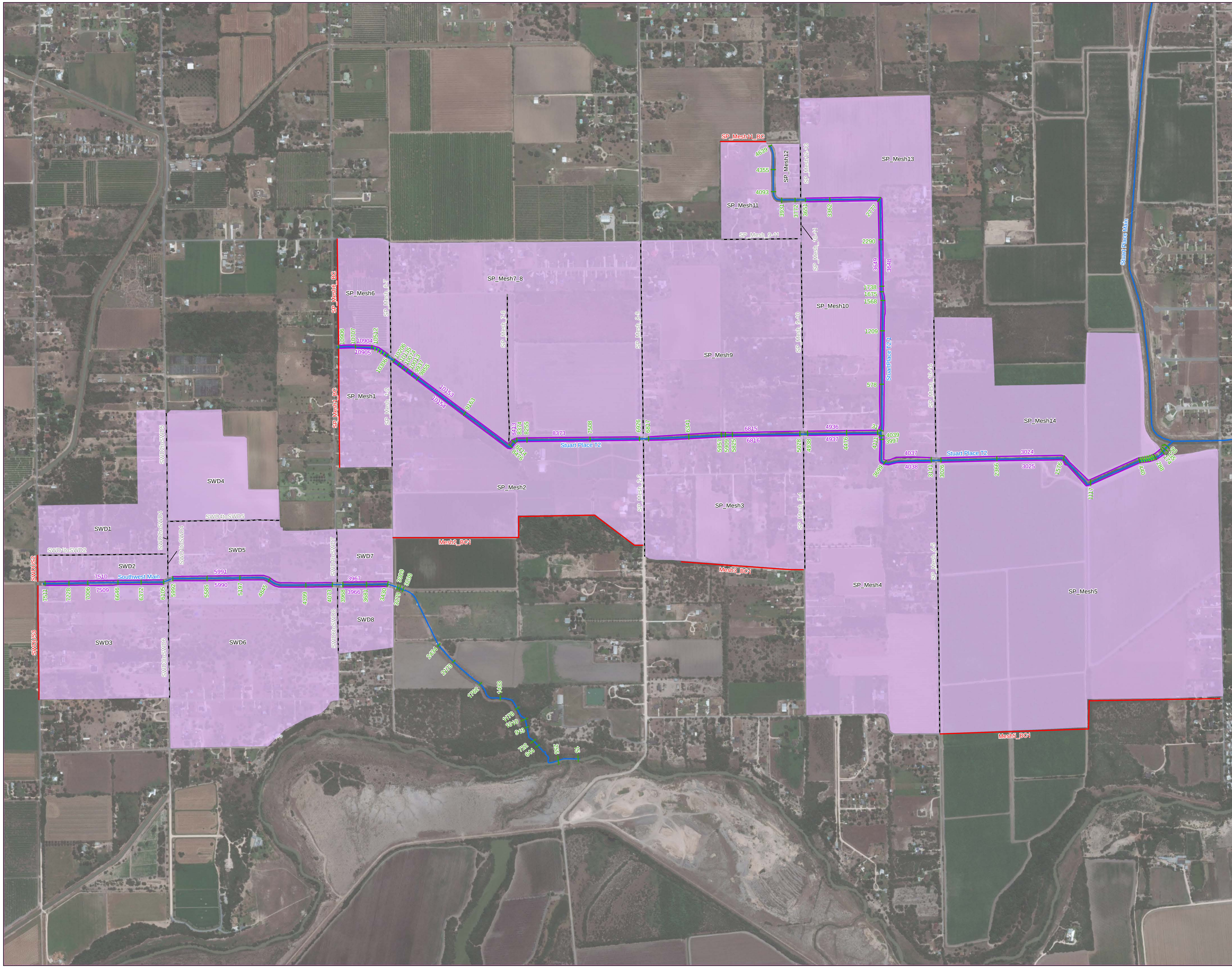
Figure 6: Cross-Section Layout Stuart Place Stuart Place Trib 1 Dixieland Map 2 of 2

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- 2D Flow Area

SCHEIBE CONSULTING LLC

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

Figure 6: Cross-Section Layout Stuart Place Trib 2 Southwest Drain Map 1 of 1

KEY TO FEATURES

- XS
- Interpolated XS
- 2D Area Connection
- Lateral Structure
- Boundary Condition
- Study Streams
- 2D Flow Area

SCHEIBE CONSULTING LLC

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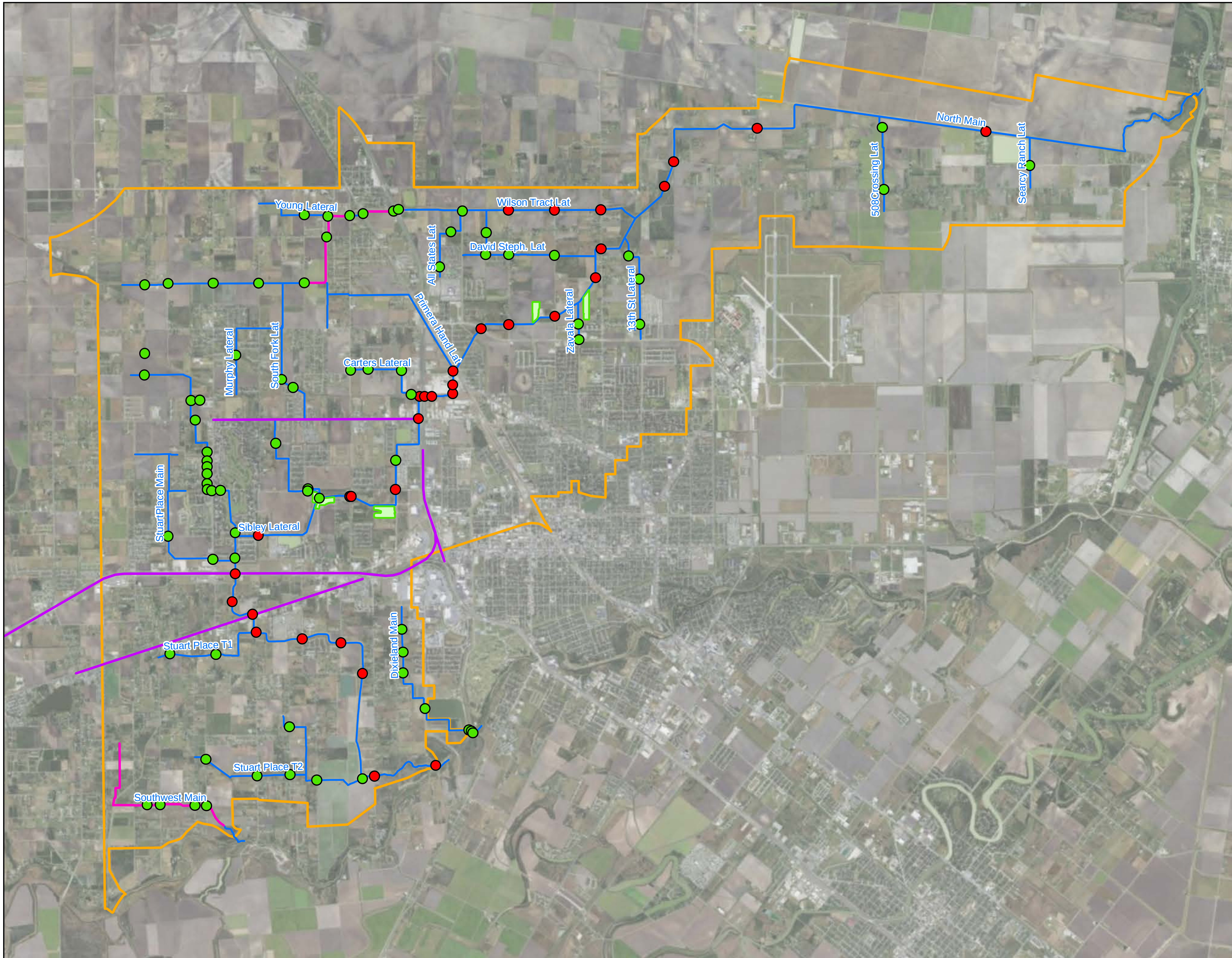


CCDD5 Flood Protection Planning Study

Cameron County Drainage District #5

Figure 7: Survey Locations

KEY TO FEATURES

- Study Streams
- New Structure Survey
- 2008 Model Survey
- New Pond Survey
- TxDOT Plans
- CCDD5 Plans
- CCDD5 Boundary

N

0 0.5 1 2 Miles

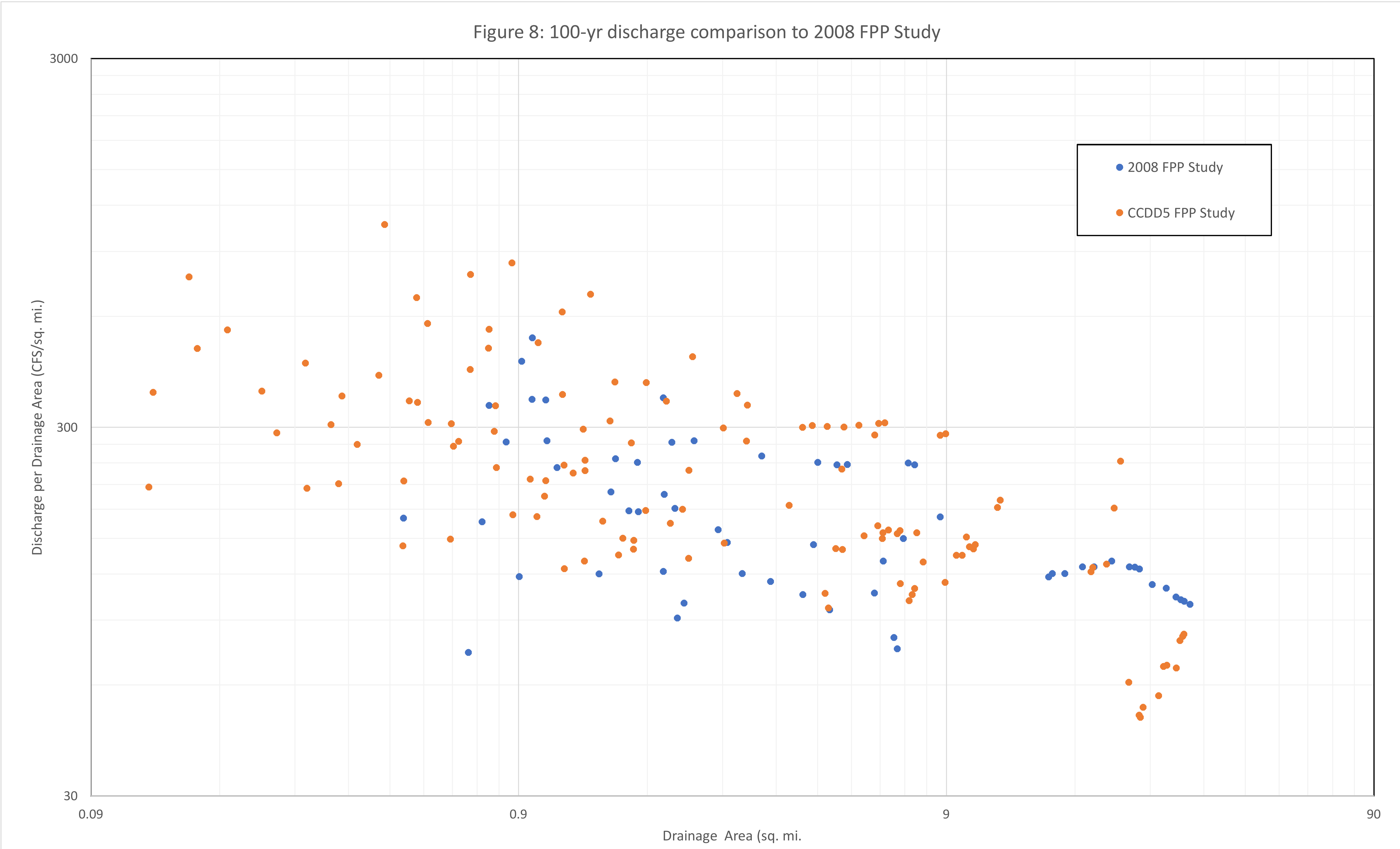
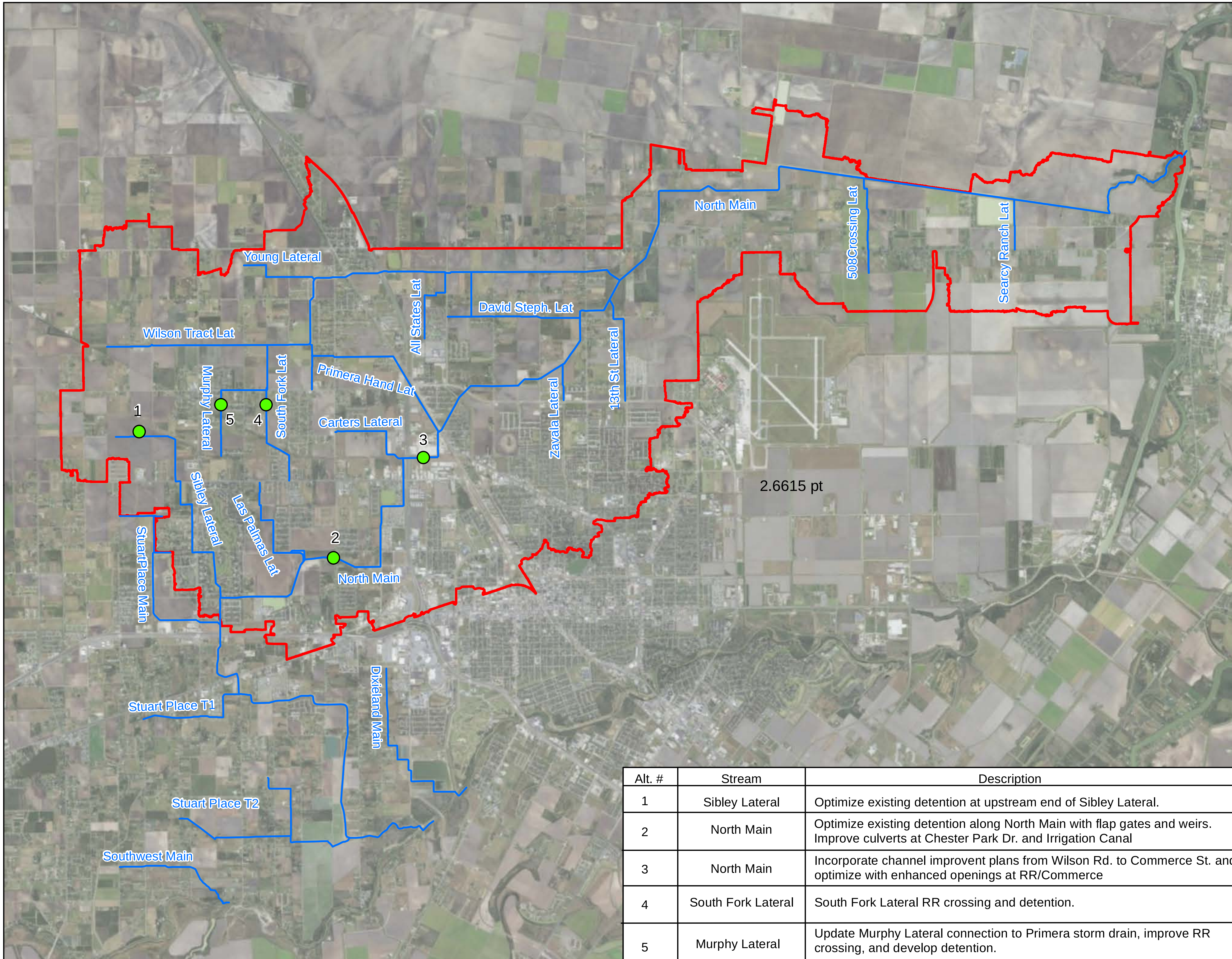


Figure 8: 100-yr discharge comparison to 2008 FPP Study
3000
300
30
0.09
0.9
9
90
Discharge per Drainage Area (CFS/sq. mi.)
Drainage Area (sq. mi.
2008 FPP Study
CCDD5 FPP Study

CCDD5
Flood Protection Planning Study

Cameron County Drainage District #5

Figure 9: Location of Alternatives



KEY TO FEATURES

- Alternatives
- Study Streams
- North Main Watershed

Alt. #	Stream	Description
1	Sibley Lateral	Optimize existing detention at upstream end of Sibley Lateral.
2	North Main	Optimize existing detention along North Main with flap gates and weirs. Improve culverts at Chester Park Dr. and Irrigation Canal
3	North Main	Incorporate channel improvent plans from Wilson Rd. to Commerce St. and optimize with enhanced openings at RR/Commerce
4	South Fork Lateral	South Fork Lateral RR crossing and detention.
5	Murphy Lateral	Update Murphy Lateral connection to Primera storm drain, improve RR crossing, and develop detention.

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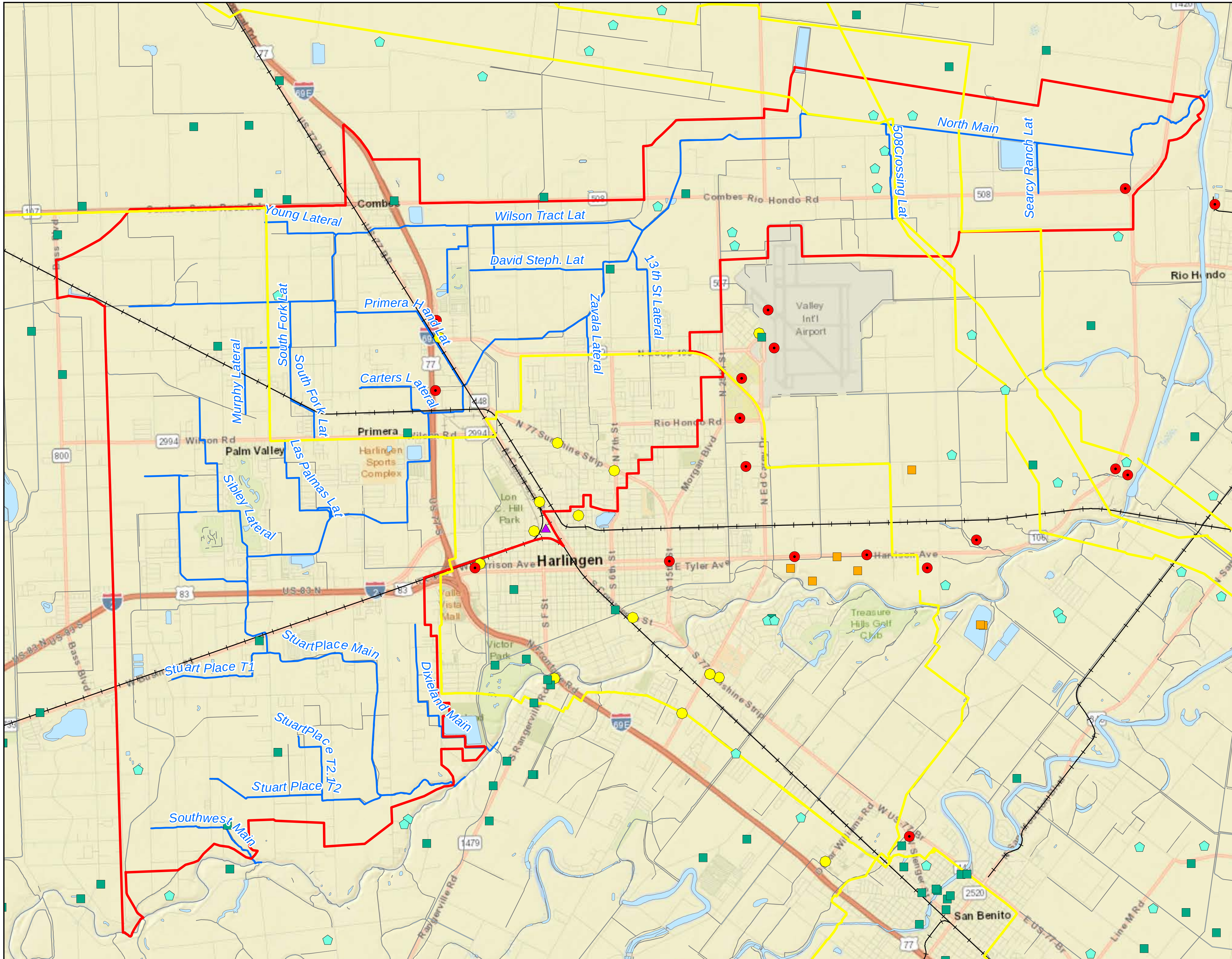

CCDD5 Flood Protection Planning Study

Cameron County Drainage District #5

Figure 10: Environmental Constraints Map

KEY TO FEATURES

- Oil/Gas Wells
- TWDB Water Wells
- Superfund
- TCEQ IHWCA
- MSW Sites
- TCEQ LPST
- Gas Transmission Lines
- National Wetland Inventory
- CCDD5 Boundary
- Railroad
- Study Streams

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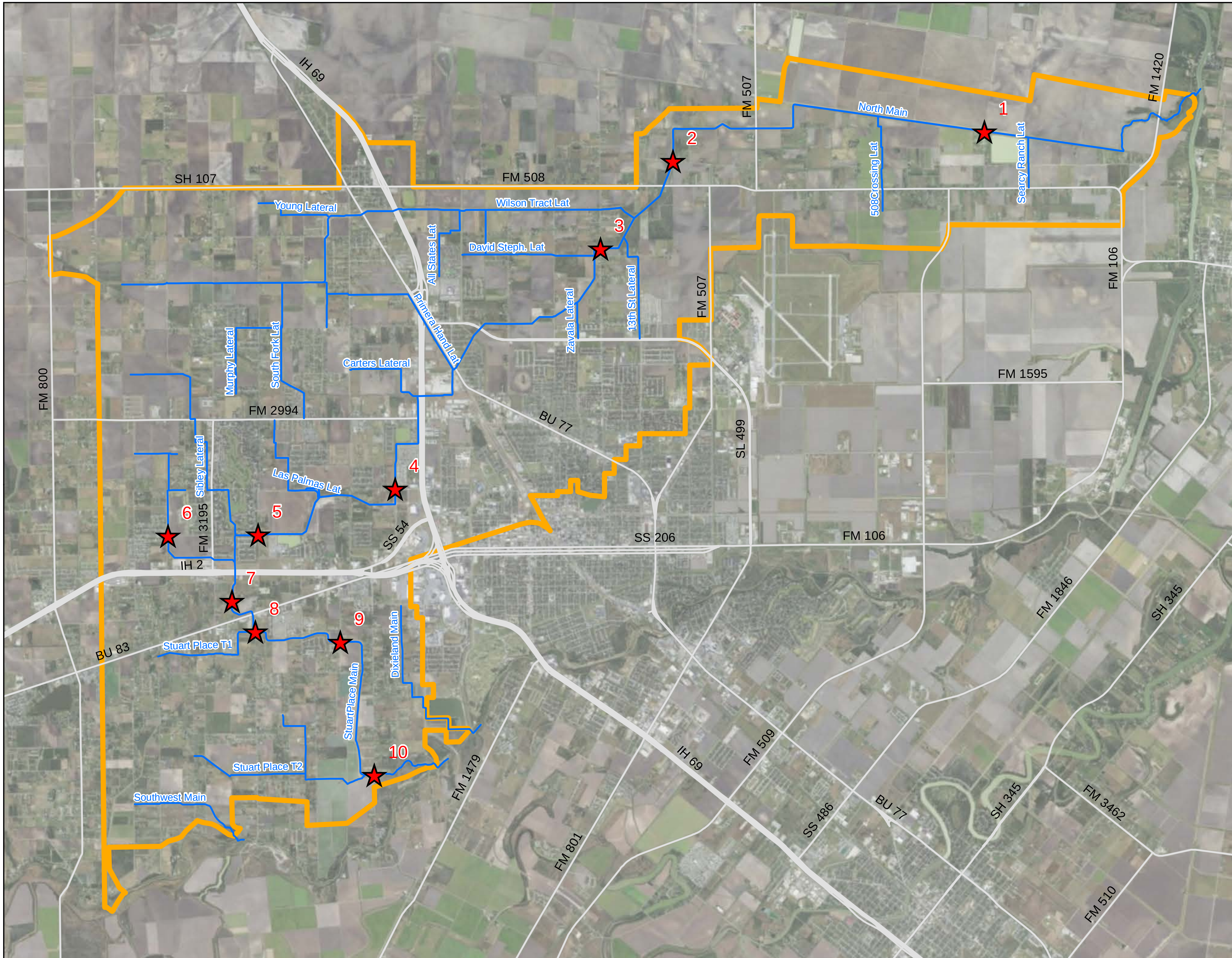
N

0 0.5 1 2 Miles

CCDD5 Flood Protection Planning Study

Cameron County Drainage District #5

Figure 11: CCDD5 Flood Gages



KEY TO FEATURES

- CCDD5 Flood Gages
- Study Streams
- Major Roads
- CCDD5 Boundary

CCDD5 Gauges	
#	Name
1	Sercy Rd
2	Hoenig
3	Briggs Coleman
4	Teege
5	Dilworth North
6	Queen Sago
7	Brennaman
8	Dilworth South
9	Paloma Lane
10	Palm Court

SCHEIBE CONSULTING LLC

N

0 0.5 1 2 Miles

APPENDIX A:
HYDROLOGIC PARAMETERS

Hydrologic Parameters Summary Table

Southwest Drain					
Name	Area (sq. mi.)	Area (ac.)	CN AMC I	% Imperv.	Lag time (min.)
SWD01	0.5219	334.0	47.8	9.30	195.25
SWD02	0.2677	171.3	53.1	15.10	121.54
SWD03	0.3598	230.3	56.0	12.70	99.2
SWD04	0.0580	37.1	56.6	22.20	59.04
SWD05	0.0786	50.3	52.8	1.50	83.86
SWD06	0.1872	119.8	57.0	3.00	120.43

Dixieland					
Name	Area (sq. mi.)	Area (ac.)	CN AMC I	% Imperv.	Lag time (min.)
DIX10	0.2060	131.8	54.0	43.47	54.55
DIX20	0.1420	90.9	56.0	15.75	106.37
DIX30	0.1370	87.7	58.0	19.36	89.68
DIX40	0.0660	42.2	59.0	23.75	65.32
DIX50	0.1420	90.9	65.0	17.21	98.87
DIX60	0.0720	46.1	62.0	36.86	113.79

Stuart Place					
Name	Area (sq. mi.)	Area (ac.)	CN AMC I	% Imperv.	Lag time (min.)
SPL_10	0.5000	320.0	59.5	59.50	156.68
SPL_20	0.1342	85.9	56.5	56.50	131.54
SPL_30	0.4081	261.2	56.9	56.90	138.89
SPL_40	0.2334	149.4	55.7	55.70	87.33
SPL_50	0.3746	239.7	54.0	54.00	147.12
SPL_60	0.1401	89.7	45.1	45.10	81.81
SPL_70	0.2054	131.5	50.5	50.50	98.74
SPL_80	0.3681	235.6	50.3	50.30	136.56
SPL_90	0.0784	50.2	47.3	47.30	58.70
SPL_100	0.1912	122.4	46.3	46.30	105.97
SPL_110	0.0768	49.2	47.7	47.70	79.55
SPL_120	0.3747	239.8	35.9	35.90	116.74
SPL_130	0.3684	235.8	49.2	49.20	104.87

Stuart Place					
Name	**Area (sq. mi.)**	**Area (ac.)**	**CN AMC I**	**% Imperv.**	**Lag time (min.)**
SPL_140	0.4443	284.3	52.6	52.60	172.35
SPL_150	0.4414	282.5	56.6	56.60	110.95
SPL_160	0.6314	404.1	55.8	55.80	121.51
SPL_170	0.2029	129.9	58.2	58.20	130.85
SPL_180	0.2666	170.6	61.8	61.80	116.82
SPT1_10	0.6522	417.4	46.1	46.10	126.47
SPT1_20	0.3065	196.1	49.1	49.10	155.93
SPT1_30	0.3305	211.5	49.9	49.90	131.02
SPT2_10	0.2454	157.1	46.4	46.40	129.20
SPT2_20	0.5528	353.8	48.7	48.70	187.09
SPT2_30	0.3538	226.4	53.7	53.70	118.14
SPT2_40	0.2078	133.0	54.7	54.70	115.66
SPT2_50	0.4659	298.2	61.2	61.20	119.81
SPT21_10	0.4239	271.3	52.5	52.50	91.52

North Main					
Name	**Area (sq. mi.)**	**Area (ac.)**	**CN AMC I**	**% Imperv.**	**Lag time (min.)**
13thSL_10	0.7675	491.2	61.0	42.04	115.24
13thSL_20	0.2328	149.0	58.0	23.29	103.12
13thSL_30	0.5123	327.9	56.0	14.92	137.91
508CL_10	0.6122	391.8	55.0	5.34	72.92
508CL_20	0.5277	337.7	55.0	6.44	163.79
508CL_30	0.4026	257.7	50.0	5.24	131.50
AS_10	0.1596	102.1	60.0	40.06	63.95
AS_20	0.1682	107.6	53.0	16.26	124.17
CL_10	0.1876	120.1	55.0	14.41	77.12
CL_20	0.4386	280.7	61.0	23.30	96.67
COMBES	0.3822	244.6	48.0	33.90	103.56
DSL_10	0.1526	97.7	60.0	23.28	75.40
DSL_20	0.1004	64.3	58.0	10.47	84.39
DSL_30	0.1171	75.0	57.0	5.64	103.04
DSL_40	0.0986	63.1	47.0	1.76	86.25
LPB_10	0.0891	57.0	48.0	29.55	44.23
LPB_20	0.1967	125.9	51.0	21.07	78.83
LPB_30	0.2344	150.0	51.0	7.22	101.04
LPB_40	0.2750	176.0	53.0	33.95	113.13

North Main					
Name	Area (sq. mi.)	Area (ac.)	CN AMC I	% Imperv.	Lag time (min.)
ML_10	0.2879	184.2	49.0	13.79	93.50
ML_20	0.1751	112.1	48.0	5.55	123.70
ML_30	0.1602	102.5	47.0	20.66	99.05
ML_40	0.2493	159.6	49.0	36.55	129.47
NM_10	0.1207	77.2	60.0	38.43	52.96
NM_20	0.2670	170.9	58.0	15.62	89.61
NM_30	0.3536	226.3	56.0	38.78	108.84
NM_40	0.1505	96.3	51.0	2.28	68.71
NM_50	0.2864	183.3	51.0	9.61	102.78
NM_60	0.6181	395.6	53.0	25.13	90.12
NM_70	0.3581	229.2	53.0	26.62	90.50
NM_80	0.2169	138.8	67.0	36.34	93.83
NM_90	0.3278	209.8	62.0	52.63	117.31
NM_100	0.4509	288.6	62.0	42.21	158.24
NM_110	0.2584	165.4	57.0	22.88	107.95
NM_120	0.0205	13.1	69.0	55.76	39.03
NM_130	0.6516	417.0	59.0	42.68	175.81
NM_140	0.2693	172.3	68.0	65.01	87.46
NM_150	0.5606	358.8	61.0	35.52	108.23
NM_160	0.0689	44.1	60.0	32.44	69.62
NM_170	0.2372	151.8	60.0	45.24	124.27
NM_180	0.2155	137.9	57.0	9.54	144.73
NM_190	0.1715	109.7	55.0	28.70	84.62
NM_200	0.2173	139.0	53.0	8.97	129.98
NM_210	0.1077	68.9	57.0	10.91	74.67
NM_220	0.1885	120.7	48.0	3.45	153.67
NM_230	0.1436	91.9	54.0	9.84	118.17
NM_240	0.0347	22.2	57.0	4.36	70.65
NM_250	0.0216	13.8	57.0	0.40	60.71
NM_260	0.7867	503.5	53.0	3.39	173.89
NM_270	0.2058	131.7	55.0	9.38	132.95
NM_280	0.5230	334.7	51.0	5.95	120.63
NM_290	0.8407	538.1	56.0	7.10	155.34
NM_300	0.1714	109.7	54.0	3.35	101.06
NM_310	0.3727	238.5	56.0	4.32	94.25
NM_320	0.7367	471.5	55.0	1.85	99.75
NM_330	0.7364	471.3	55.0	5.09	200.79
NM_340	0.5535	354.2	64.0	6.14	113.01
NM_350	1.5422	987.0	59.0	5.40	206.63

North Main					
Name	**Area (sq. mi.)**	**Area (ac.)**	**CN AMC I**	**% Imperv.**	**Lag time (min.)**
NM_360	0.5871	375.8	59.0	0.46	207.13
NM_370	0.4655	297.9	56.0	1.28	196.30
NM_380	0.2153	137.8	55.0	1.13	101.45
PHL_10	0.1259	80.6	57.0	38.38	172.60
PHL_20	0.1323	84.7	50.0	9.31	99.26
PHL_30	0.1786	114.3	51.0	12.86	122.35
PHL_40	0.5040	322.6	53.0	20.68	114.21
PHL_50	0.5084	325.4	60.0	24.22	138.60
PO_10	0.0523	33.5	50.0	12.15	60.27
SFL_10	0.2260	144.6	47.0	24.65	91.80
SFL_20	0.2567	164.3	50.0	19.44	158.37
SFL_30	0.1418	90.7	53.0	14.92	136.84
SFL_40	0.1751	112.1	48.0	15.86	79.38
SL_10	1.0355	662.7	51.0	8.13	206.01
SL_20	0.2483	158.9	50.0	7.16	140.23
SL_30	0.1312	84.0	50.0	28.90	73.79
SL_40	0.2557	163.7	50.0	43.21	75.86
SL_50	0.5052	323.3	53.0	32.19	113.65
WT_10	0.3771	241.4	52.0	6.34	141.15
WT_20	0.2503	160.2	48.0	8.01	132.28
WT_30	1.4080	901.1	50.0	6.06	189.30
WT_40	0.2106	134.8	49.0	8.30	105.15
WT_50	0.4778	305.8	48.0	6.39	146.90
WT_60	0.2903	185.8	48.0	3.81	87.49
WT_70	0.0621	39.7	54.0	4.71	60.59
WT_80	0.2158	138.1	51.0	12.96	65.87
WT_90	0.1831	117.2	48.0	11.65	93.25
WT_100	0.2517	161.1	49.0	16.68	120.38
WT_110	0.1916	122.6	50.0	35.50	91.69
WT_120	0.3666	234.6	53.0	10.01	84.14
WT_130	0.2027	129.7	53.0	6.28	83.00
WT_140	0.2553	163.4	54.0	4.65	137.06
WT_150	0.2845	182.1	51.0	8.81	83.51
WT_160	0.2569	164.4	56.0	9.09	74.31
WT_170	0.1742	111.5	53.0	8.51	90.58
YL_10	0.1229	78.7	48.0	4.15	92.55
YL_20	0.2184	139.7	49.0	14.02	77.46
ZL_10	1.6652	1065.7	58.0	49.74	168.36
ZL_20	0.1888	120.8	60.0	22.67	84.28

APPENDIX B:

HYDROLOGIC AND HYDRAULIC RESULTS

North Main Drain Sub-Basin Peak Inflows				
Sub-basin	Drainage Area (sq.mi.)	100-yr Peak Discharge (CFS)	500-yr Peak Discharge (CFS)	June 2018 Peak Discharge (CFS)
13thSL_10	0.768	330	487	230
13thSL_20	0.233	93	142	66
13thSL_30	0.512	149	235	116
508CL_10	0.612	243	394	148
508CL_20	0.528	111	182	68
508CL_30	0.403	86	147	55
AS_10	0.160	107	158	72
AS_20	0.168	50	81	43
CL_10	0.188	81	130	68
CL_20	0.439	196	299	158
COMBES	0.382	134	210	113
DSL_10	0.153	81	123	59
DSL_20	0.100	47	74	36
DSL_30	0.117	40	65	33
DSL_40	0.099	27	47	23
LPB_10	0.089	58	91	38
LPB_20	0.197	80	128	67
LPB_30	0.234	68	116	62
LPB_40	0.275	102	158	85
ML_10	0.288	88	147	79
ML_20	0.175	37	64	34
ML_30	0.160	48	79	42
ML_40	0.249	77	120	66
NM_10	0.121	90	135	60
NM_20	0.267	110	176	94
NM_30	0.354	377	566	194
NM_40	0.151	55	96	49
NM_50	0.286	86	145	78
NM_60	0.618	254	398	205
NM_70	0.358	149	232	120
NM_80	0.217	116	170	86
NM_90	0.328	151	221	114
NM_100	0.451	157	232	125
NM_110	0.258	98	153	82
NM_120	0.020	23	33	12
NM_130	0.652	201	299	163

North Main Drain Sub-Basin Peak Inflows				
Sub-basin	Drainage Area (sq.mi.)	100-yr Peak Discharge (CFS)	500-yr Peak Discharge (CFS)	June 2018 Peak Discharge (CFS)
NM_140	0.269	170	242	116
NM_150	0.561	248	371	189
NM_160	0.069	41	62	29
NM_170	0.237	99	146	78
NM_180	0.215	59	95	51
NM_190	0.171	79	122	59
NM_200	0.217	58	95	50
NM_210	0.108	49	78	37
NM_220	0.189	35	61	32
NM_230	0.144	43	70	35
NM_240	0.035	42	65	17
NM_250	0.022	11	17	7
NM_260	0.787	155	256	125
NM_270	0.206	57	91	42
NM_280	0.523	135	222	100
NM_290	0.841	202	324	150
NM_300	0.171	53	86	37
NM_310	0.373	127	206	85
NM_320	0.737	226	371	151
NM_330	0.736	129	212	81
NM_340	0.553	513	779	182
NM_350	1.542	289	464	172
NM_360	0.587	105	172	64
NM_370	0.466	80	134	49
NM_380	0.215	61	102	35
PHL_10	0.126	37	55	32
PHL_20	0.132	39	65	36
PHL_30	0.179	48	79	44
PHL_40	0.504	164	261	144
PHL_50	0.508	171	262	145
PO_10	0.052	23	38	19
SFL_10	0.226	78	126	67
SFL_20	0.257	59	95	53
SFL_30	0.142	37	61	34
SFL_40	0.175	60	100	53
SL_10	1.036	164	277	153

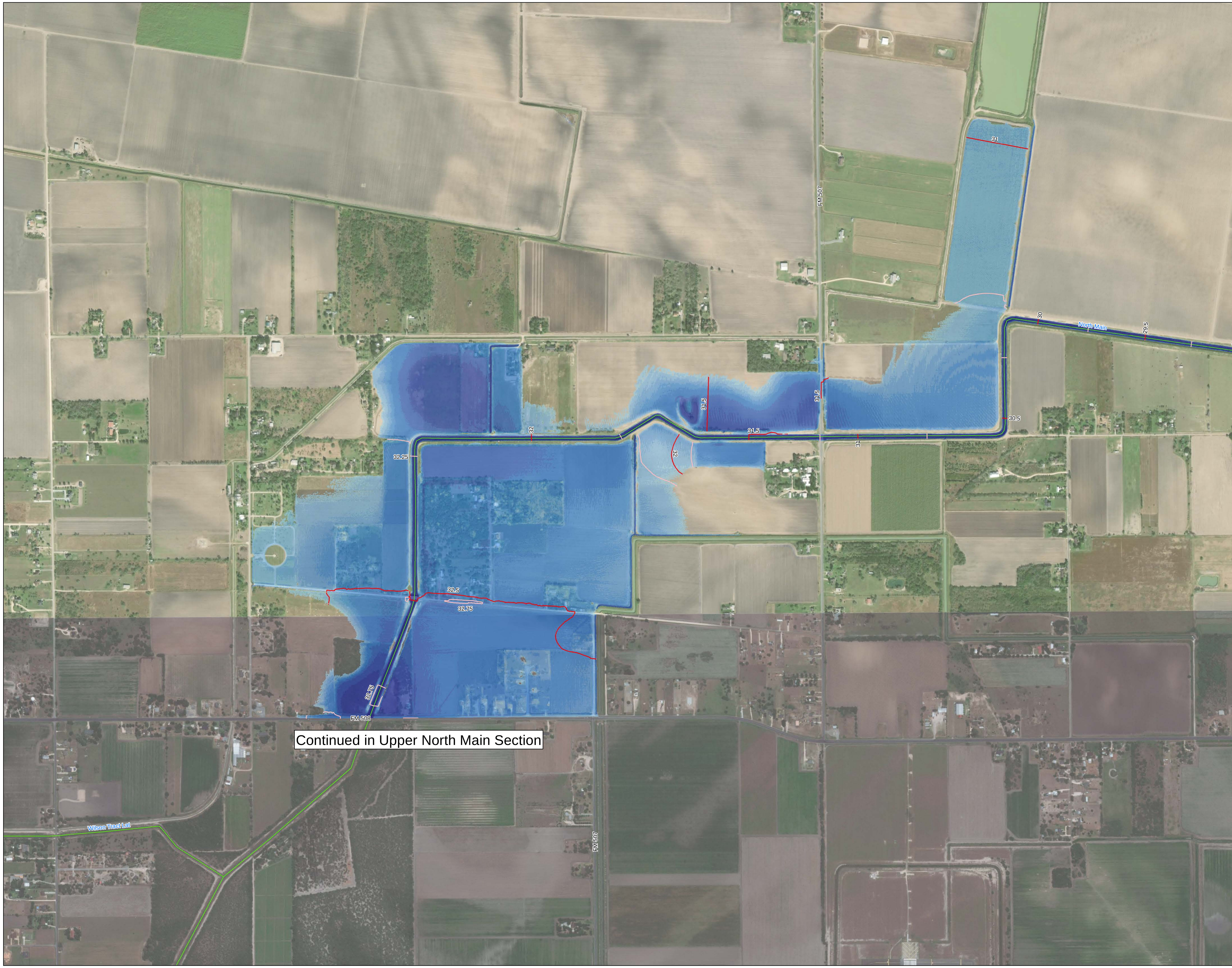
North Main Drain Sub-Basin Peak Inflows				
Sub-basin	Drainage Area (sq.mi.)	100-yr Peak Discharge (CFS)	500-yr Peak Discharge (CFS)	June 2018 Peak Discharge (CFS)
SL_20	0.248	52	89	48
SL_30	0.131	58	92	47
SL_40	0.256	128	195	100
SL_50	0.505	465	712	275
WT_10	0.377	81	137	76
WT_20	0.250	54	94	50
WT_30	1.408	222	379	196
WT_40	0.211	54	92	49
WT_50	0.478	89	154	85
WT_60	0.290	78	138	75
WT_70	0.062	28	46	23
WT_80	0.216	90	147	76
WT_90	0.183	53	89	49
WT_100	0.252	66	109	61
WT_110	0.192	79	122	65
WT_120	0.367	135	221	114
WT_130	0.203	197	315	91
WT_140	0.255	64	106	55
WT_150	0.284	100	166	80
WT_160	0.257	114	182	83
WT_170	0.174	61	100	46
YL_10	0.123	31	55	30
YL_20	0.218	76	127	67
ZL_10	1.665	549	805	421
ZL_20	0.189	92	140	66

Stuart Place Drain Sub-Basin Peak Inflows				
Sub-basin	Drainage Area (sq. mi.)	100-yr Peak Discharge (CFS)	500-yr Peak Discharge (CFS)	June 2018 Peak Discharge (CFS)
SPL_10	0.500	137	217	115
SPL_20	0.134	37	60	31
SPL_30	0.408	115	184	97
SPL_40	0.233	99	155	80
SPL_50	0.375	113	175	96

Stuart Place Drain Sub-Basin Peak Inflows				
Sub-basin	Drainage Area (sq. mi.)	100-yr Peak Discharge (CFS)	500-yr Peak Discharge (CFS)	June 2018 Peak Discharge (CFS)
SPL_60	0.140	72	106	54
SPL_70	0.205	90	136	73
SPL_80	0.368	98	159	91
SPL_90	0.078	40	63	31
SPL_100	0.191	55	91	51
SPL_110	0.077	27	44	24
SPL_120	0.375	83	139	78
SPL_130	0.368	112	183	109
SPL_140	0.444	121	185	112
SPL_150	0.441	153	242	141
SPL_160	0.631	193	311	192
SPL_170	0.203	61	98	61
SPL_180	0.267	95	149	88
SPT1_10	0.652	177	287	171
SPT1_20	0.306	68	112	70
SPT1_30	0.330	93	149	90
SPT2_10	0.245	55	94	59
SPT2_20	0.553	98	165	107
SPT2_30	0.354	106	172	106
SPT2_40	0.208	64	104	66
SPT2_50	0.466	156	248	155
SPT21_10	0.424	155	249	151

Dixieland Drain Sub-Basin Peak Inflows				
Sub-basin	Drainage Area (sq.mi.)	100-yr Peak Discharge (CFS)	500-yr Peak Discharge (CFS)	June 2018 Peak Discharge (CFS)
DIX10	0.206	149	221	97
DIX20	0.142	51	81	46
DIX30	0.137	60	93	51
DIX40	0.066	39	59	30
DIX50	0.142	65	98	55
DIX60	0.072	31	47	26

Southwest Drain Sub-Basin Peak Inflows				
Sub-basin	**Drainage Area (sq. mi.)**	**100-yr Peak Discharge (CFS)**	**500-yr Peak Discharge (CFS)**	**June 2018 Peak Discharge (CFS)**
SWD01	0.522	86	147	92
SWD02	0.268	81	130	76
SWD03	0.360	132	211	121
SWD04	0.058	35	54	27
SWD05	0.079	27	45	26
SWD06	0.187	56	91	56



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Lower North Main Map 1 of 3

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet

CCDD5
Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Lower North Main Map 2 of 3

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

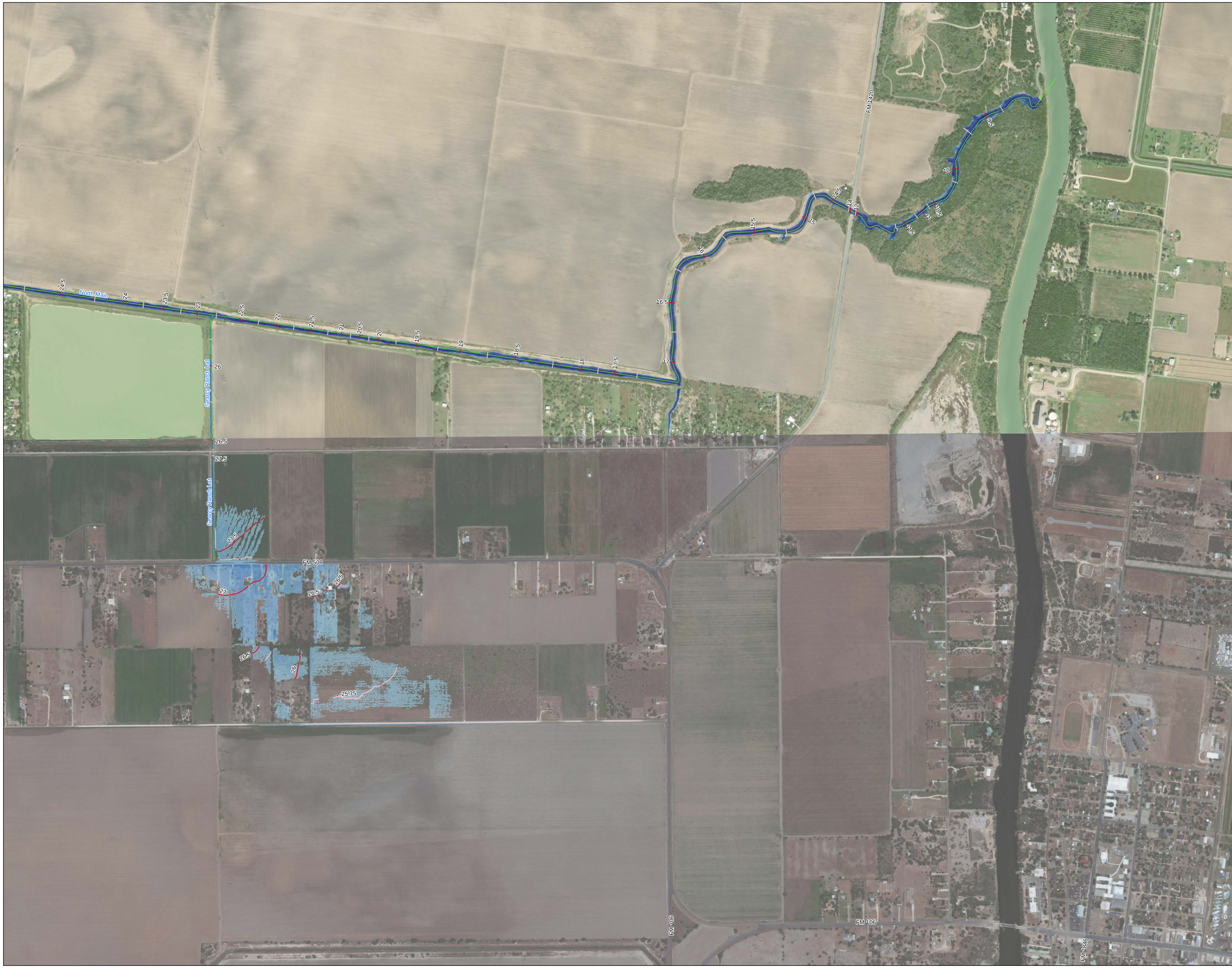
100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Lower North Main Map 3 of 3

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet

CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Upper North Main Map 1 of 3

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

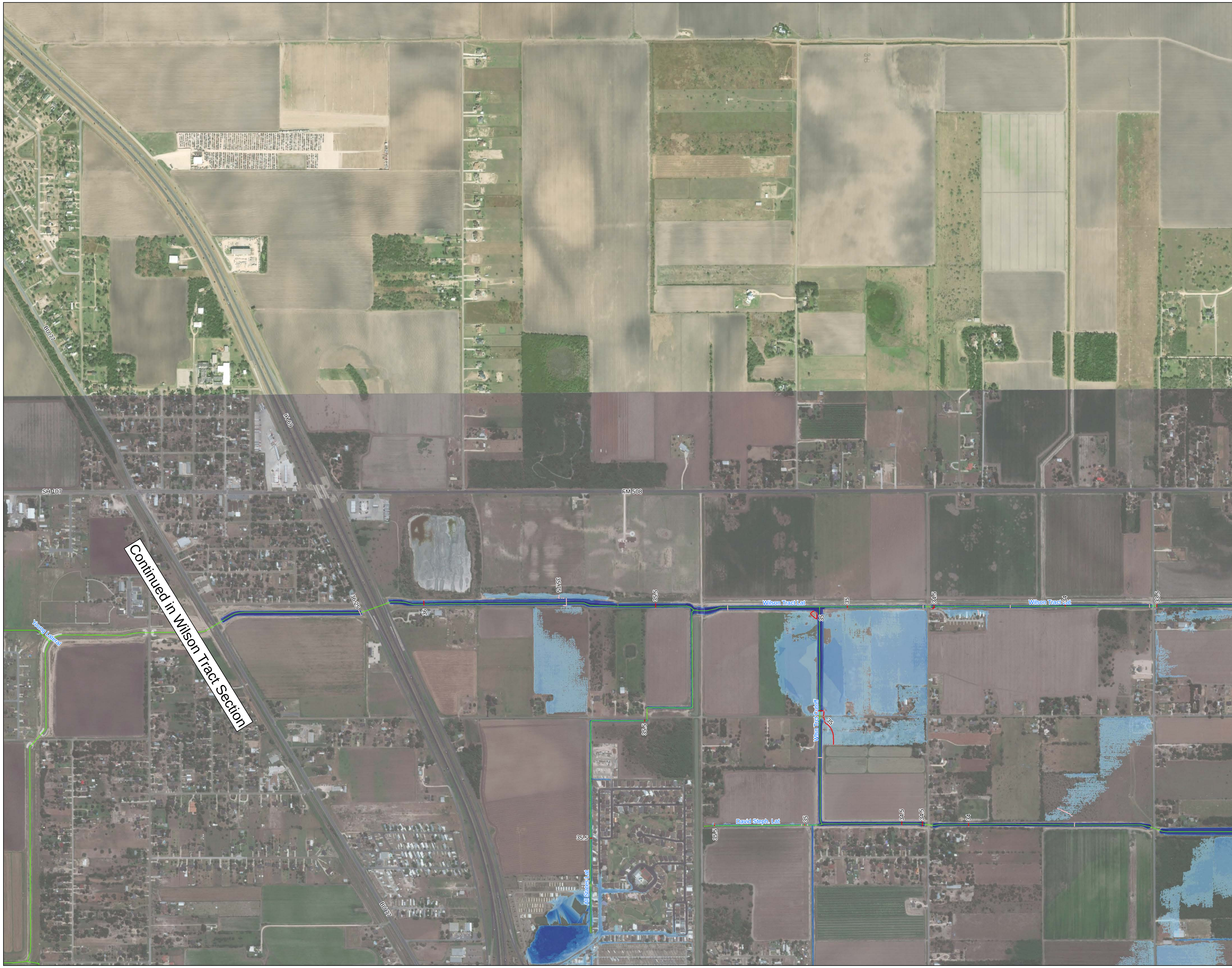
100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Upper North Main Map 2 of 3

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

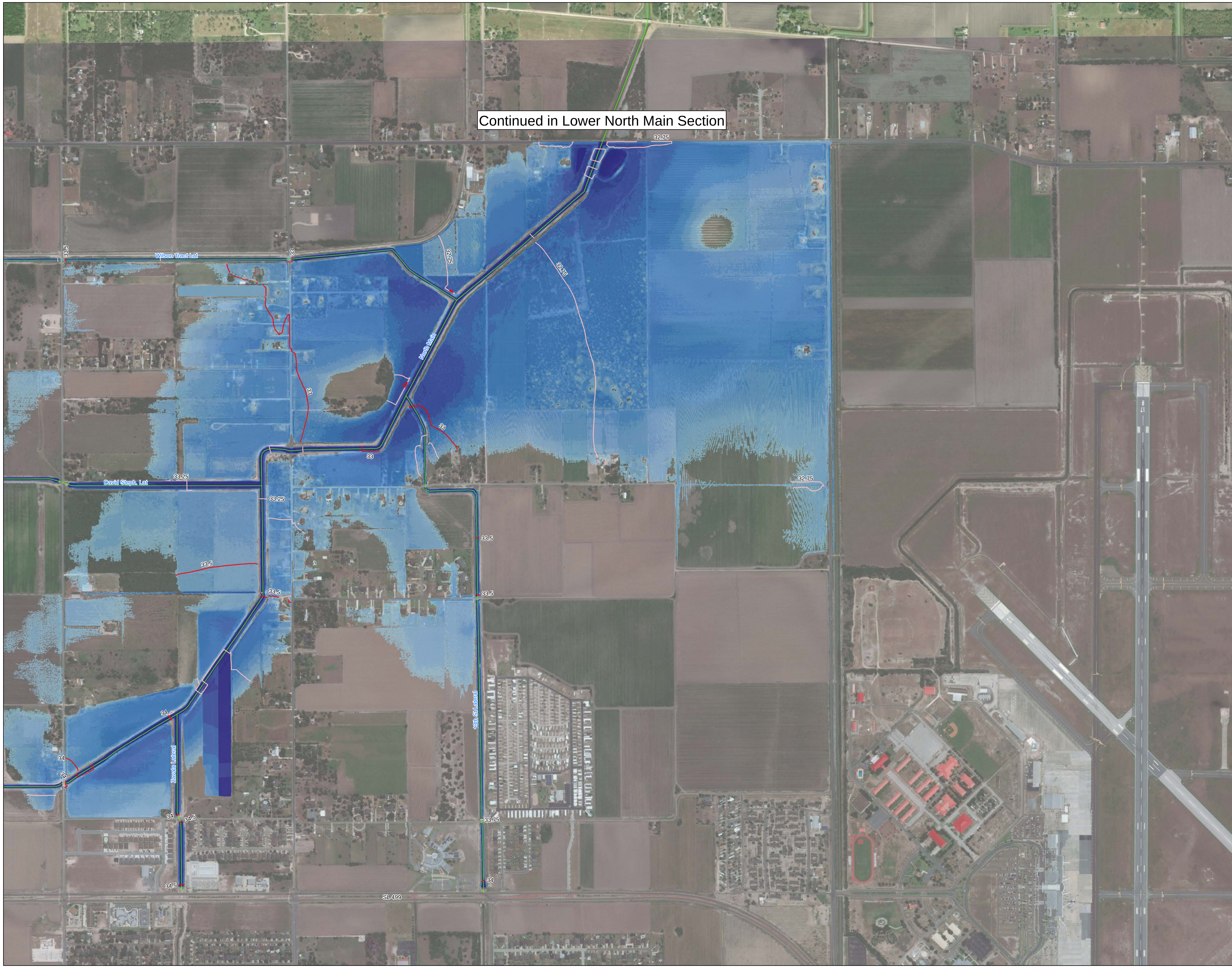
100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Upper North Main Map 3 of 3

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

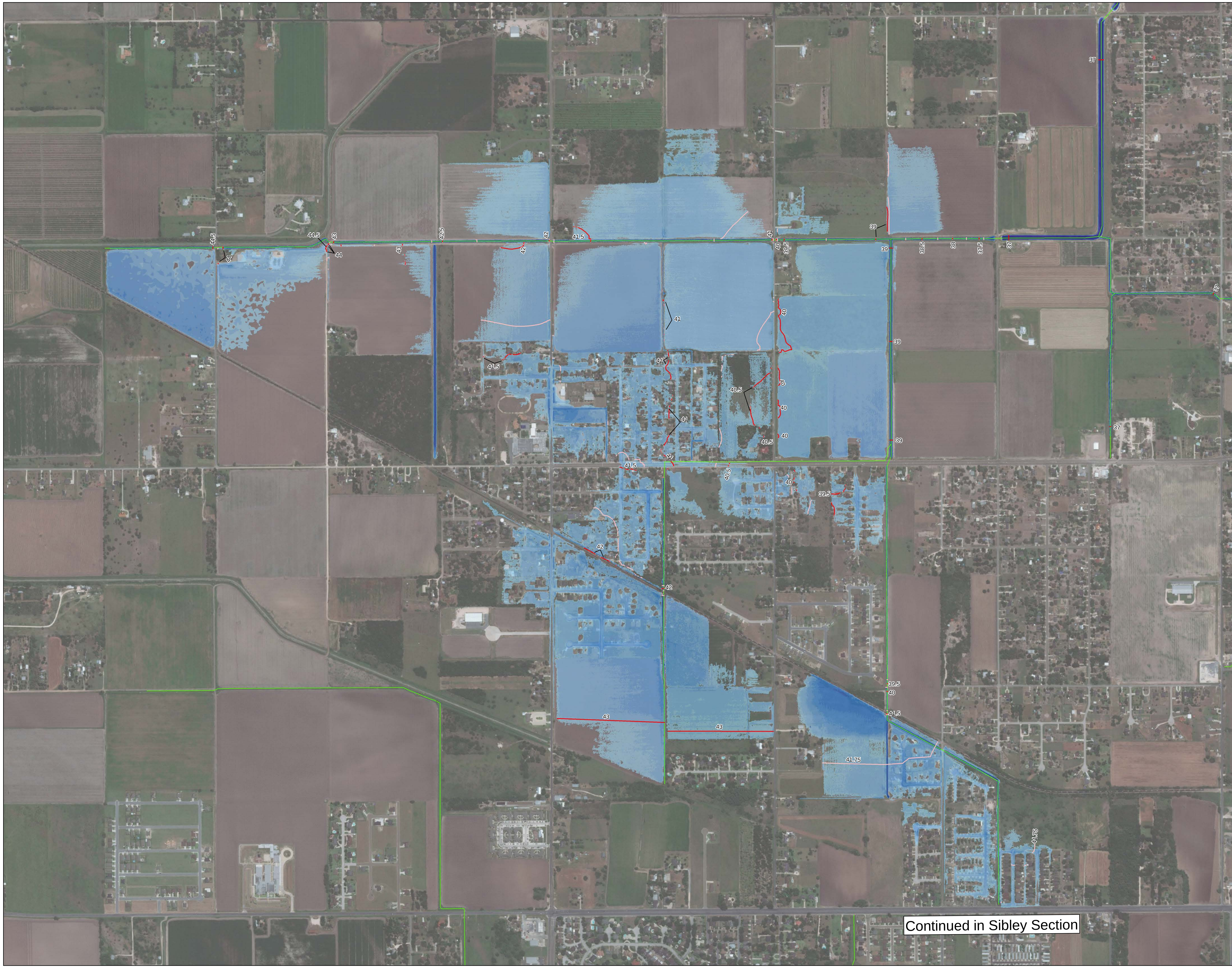
100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Wilson Tract Lateral Map 1 of 2

KEY TO FEATURES

Study Streams

0.5 ft WSE Contours

0.25 ft WSE Contours

100-Yr Floodplain Depths

0.0 - 0.25

0.25 - 0.5

0.5 - 1.0

1.0 - 1.5

1.5 - 2.0

2.0 - 3.0

3.0 - 4.0

4.0 - 6.0

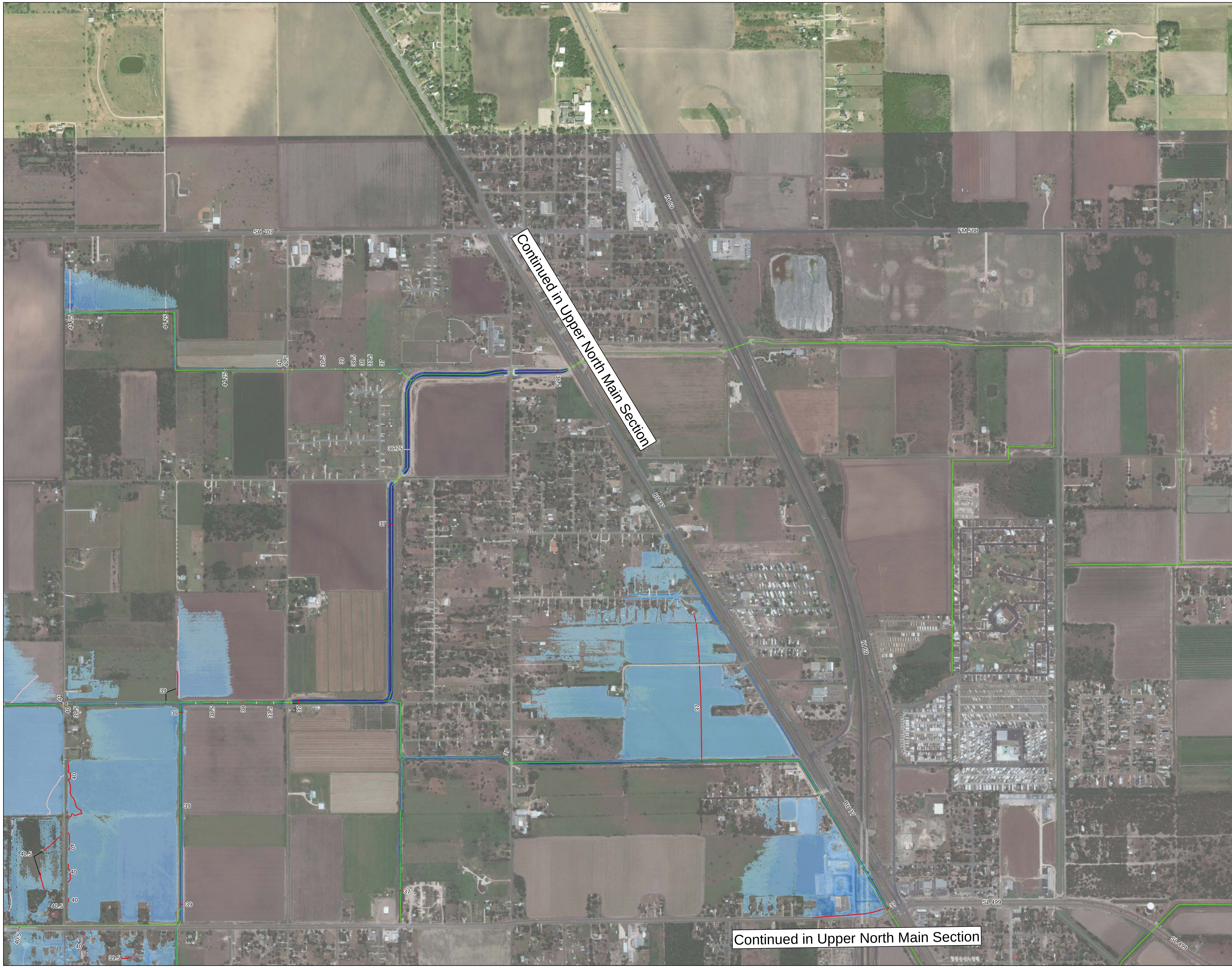
6.0 - 8.0

8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Wilson Tract Lateral Map 2 of 2

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

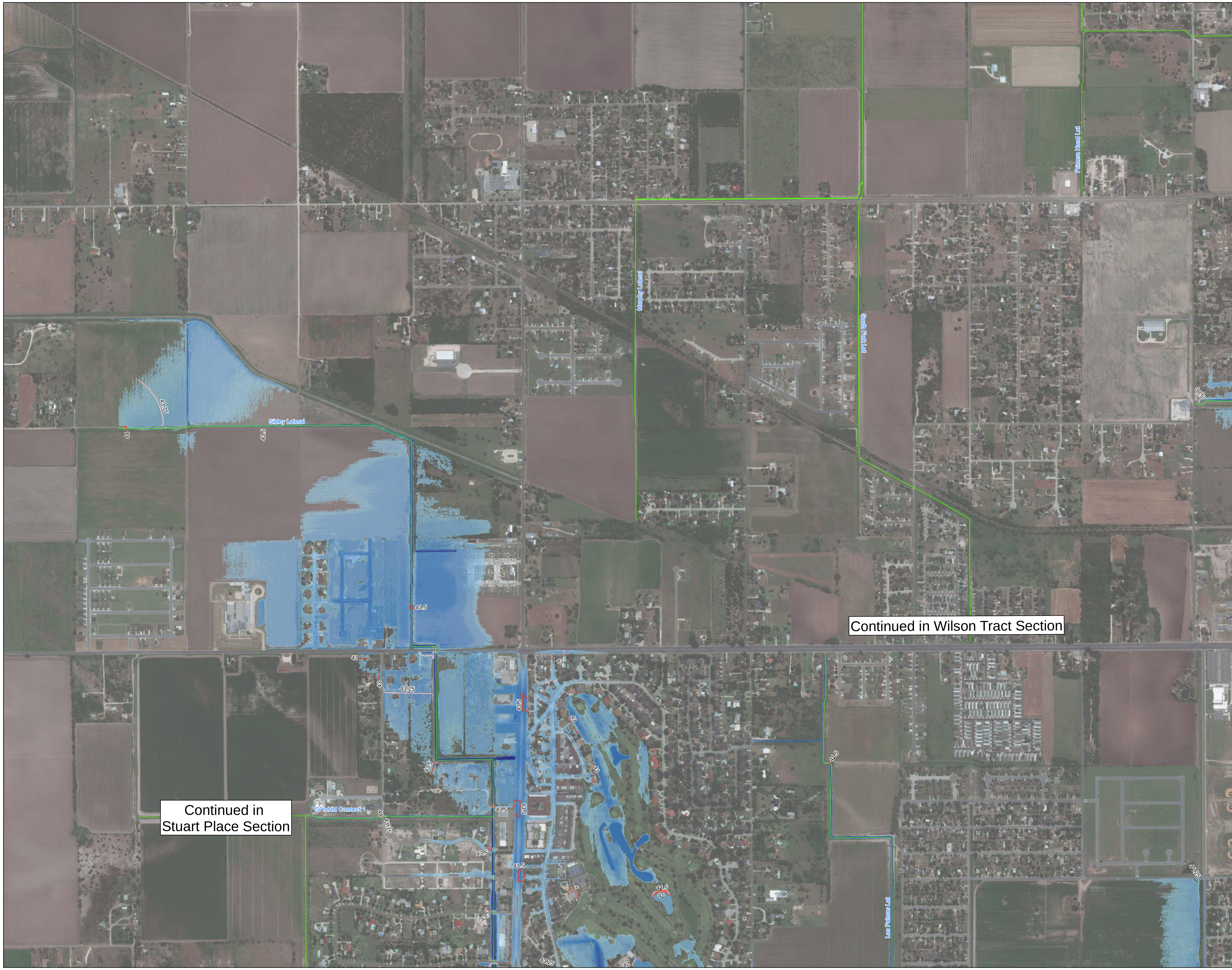
100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5
Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Sibley Lateral Map 1 of 3

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

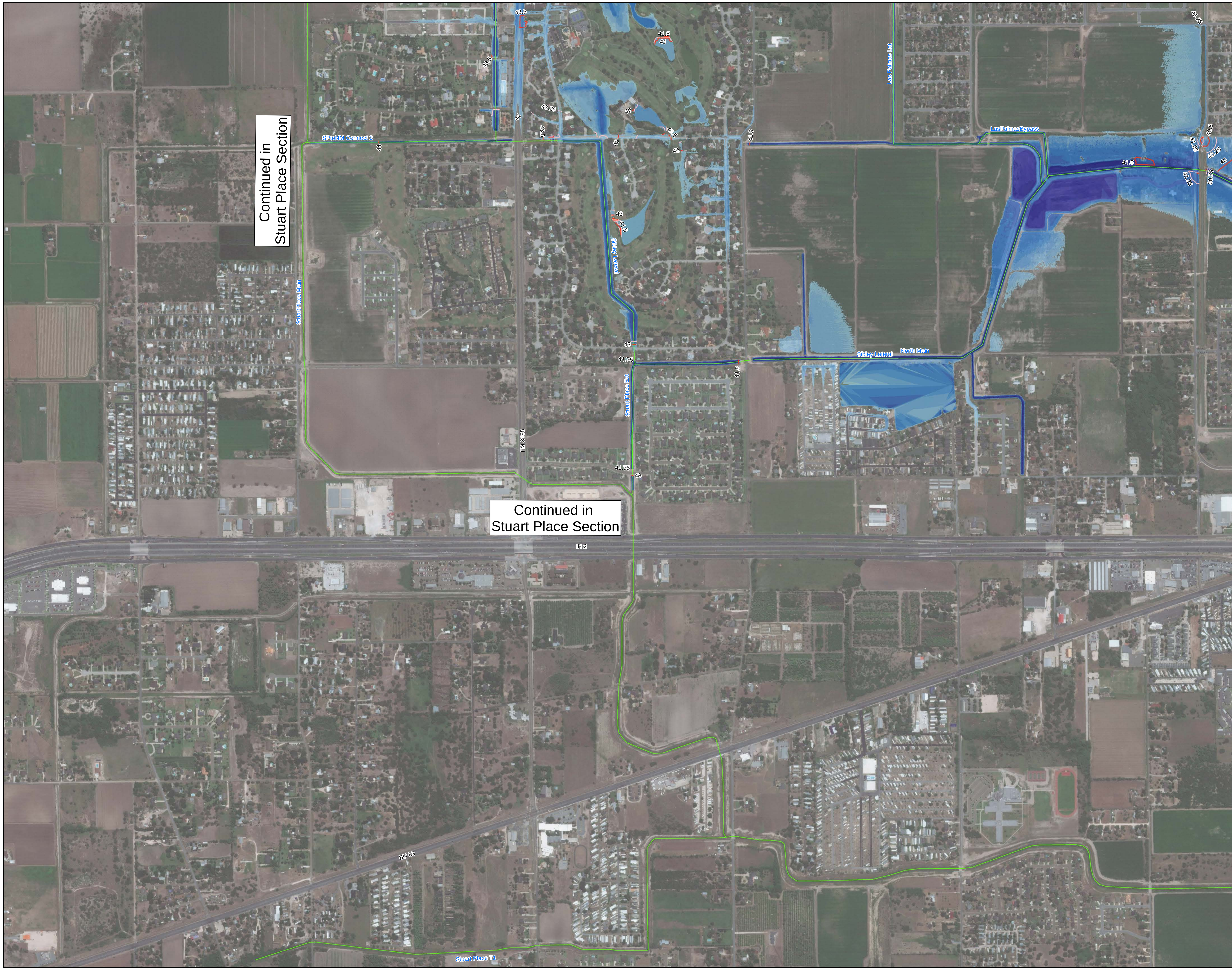
100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Sibley Lateral Map 2 of 3

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

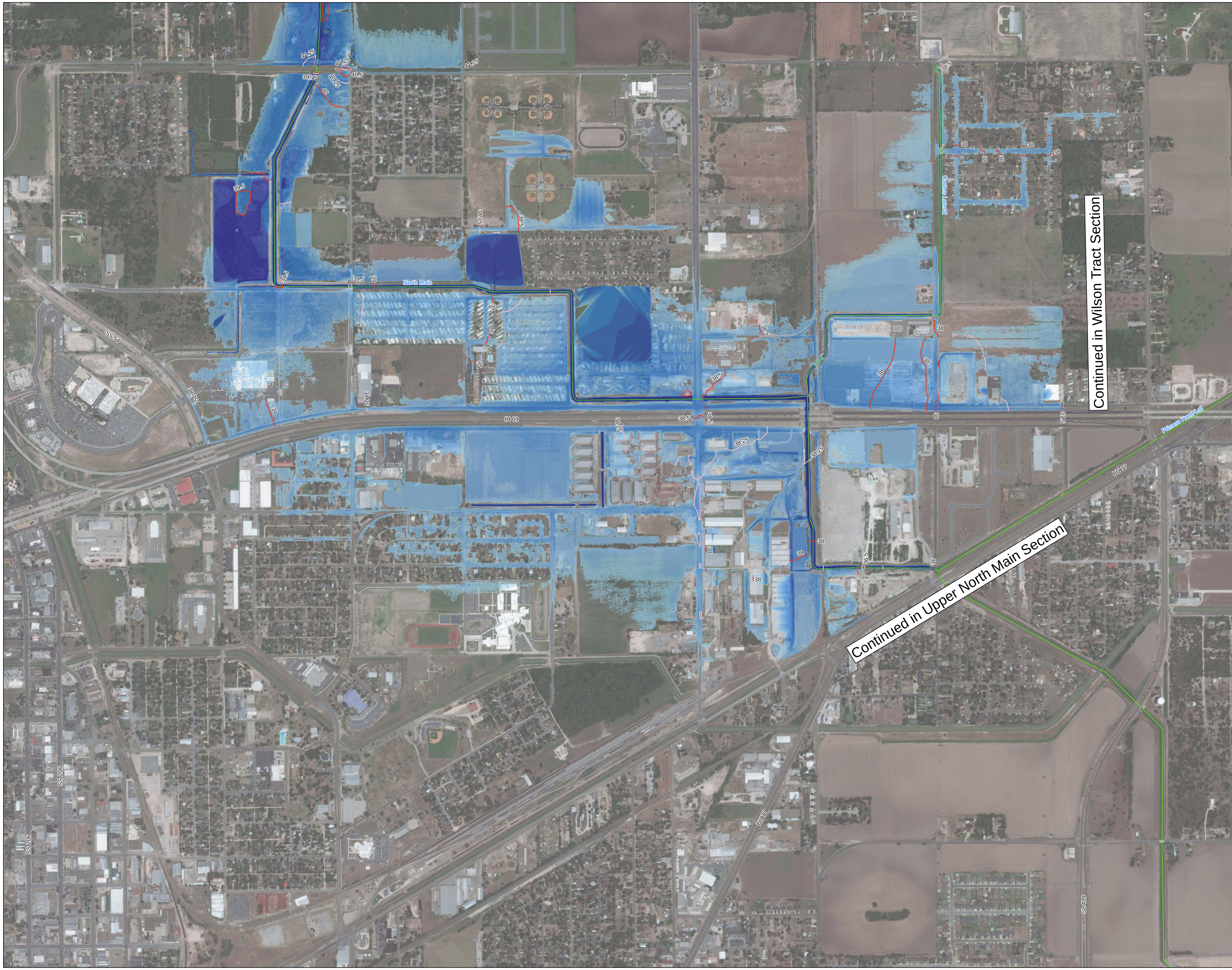
100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Sibley Lateral Map 3 of 3

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

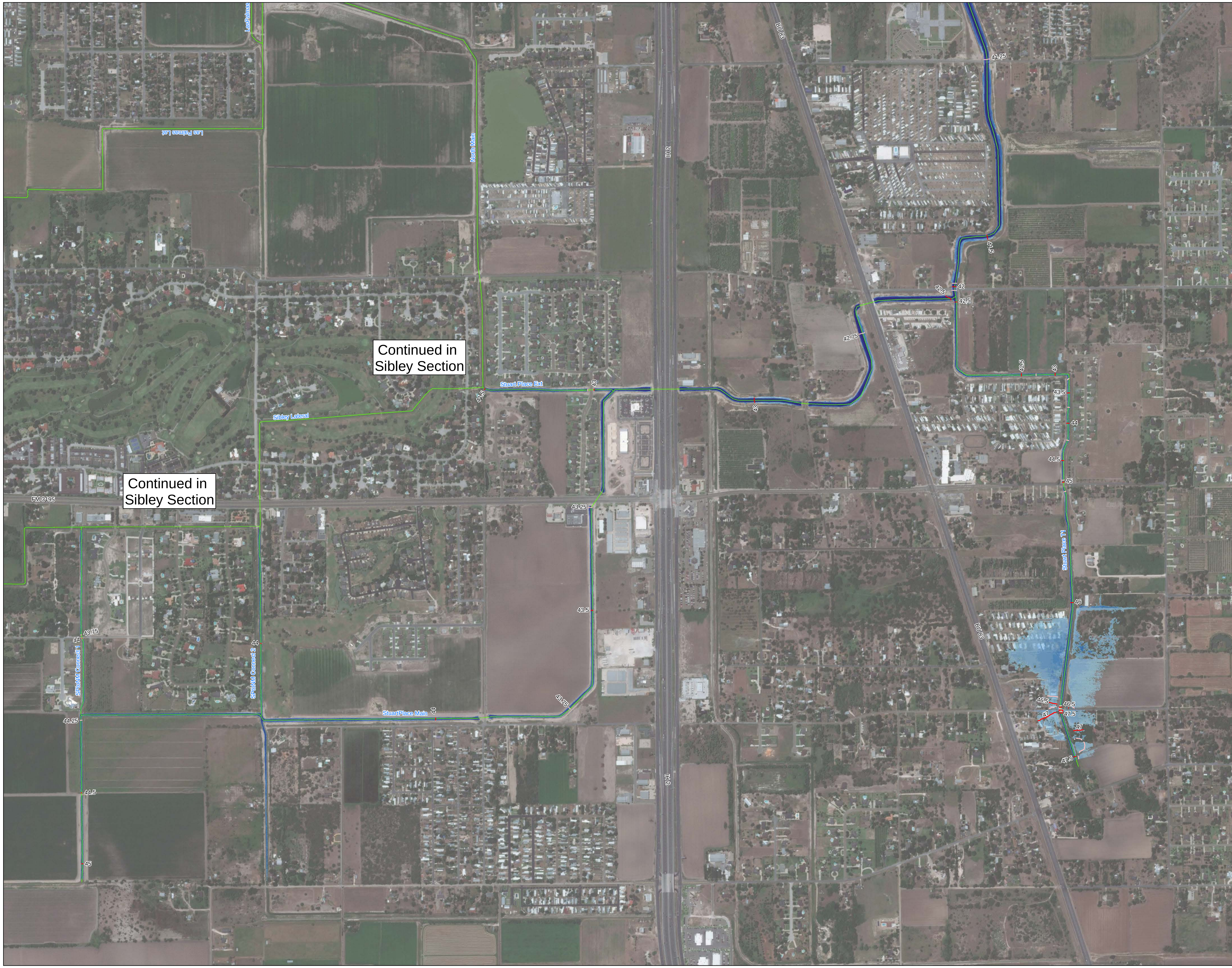
100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5
Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Stuart Place Stuart Place Trib 1 Dixieland Map 1 of 2

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet

CCDD5
Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Stuart Place Stuart Place Trib 1 Dixieland Map 2 of 2

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

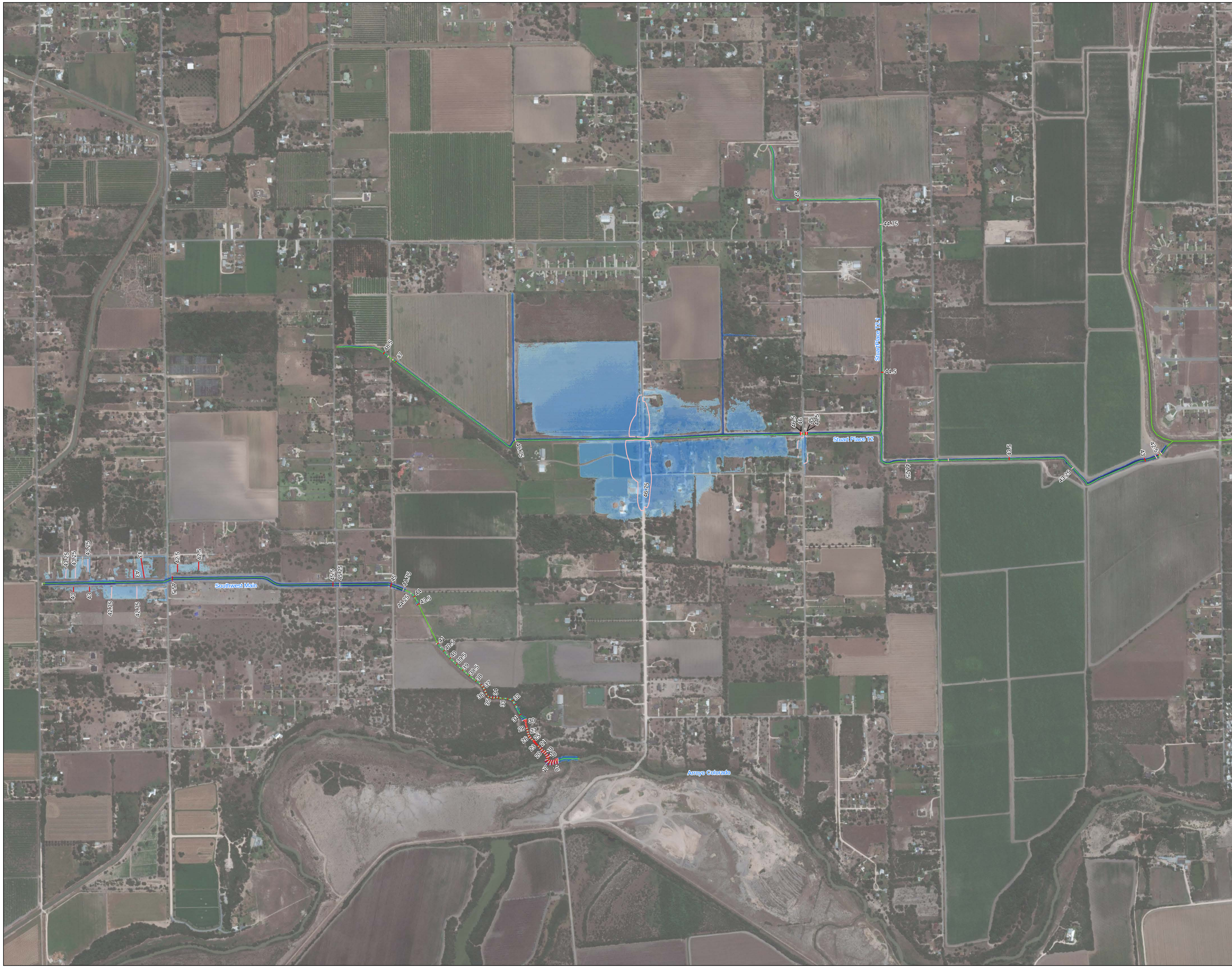
100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet



CCDD5 Flood Protection Planning Study

Cameron County Drainage Distict #5

100-yr Floodplain Depths & Water Surface Elevation Contours Stuart Place Trib 2 Southwest Drain Map 1 of 1

KEY TO FEATURES

- Study Streams
- 0.5 ft WSE Contours
- 0.25 ft WSE Contours

100-Yr Floodplain Depths

- 0.0 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 6.0
- 6.0 - 8.0
- 8.0 - 10.0

SCHEIBE CONSULTING LLC

N

0 500 1,000 2,000 Feet

APPENDIX C:

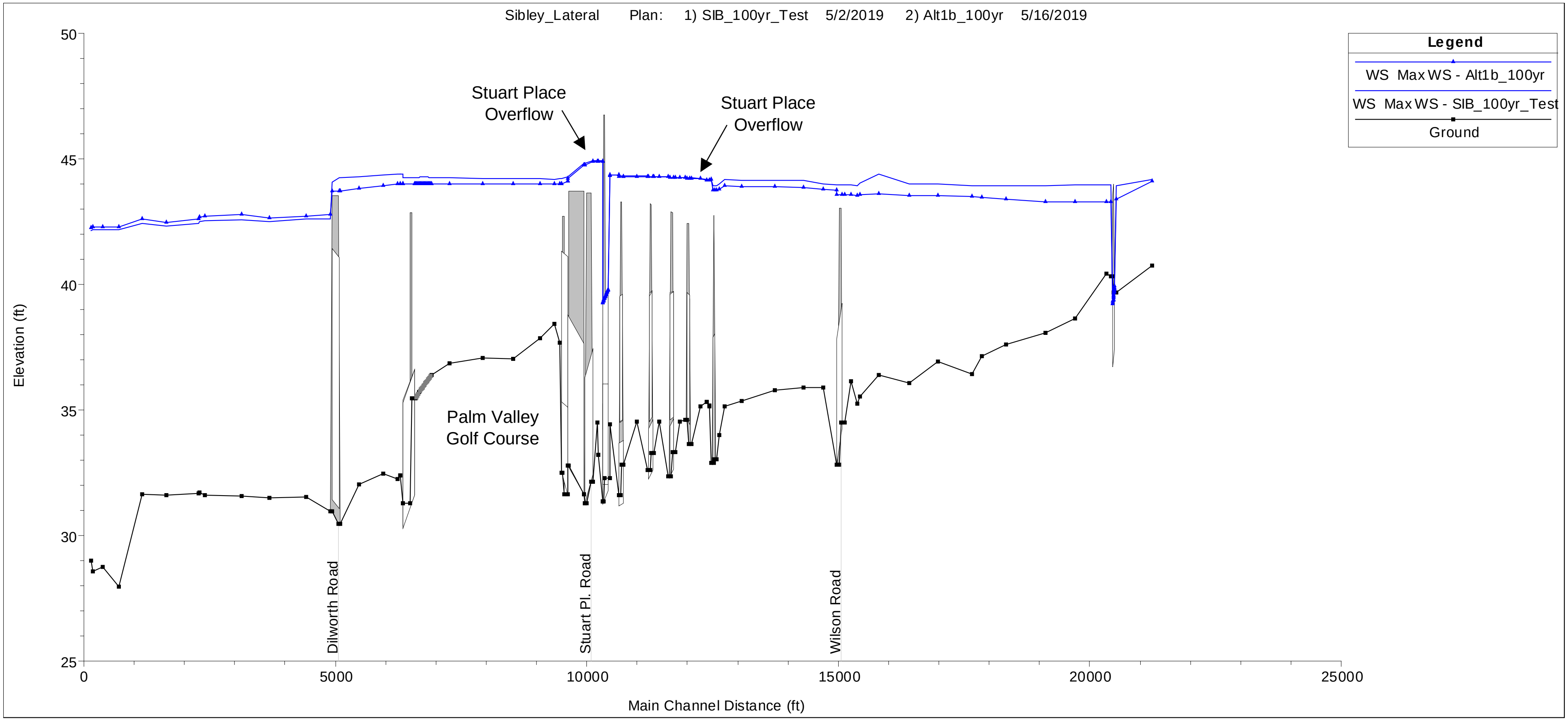
ALTERNATIVE ANALYSIS DETAILS

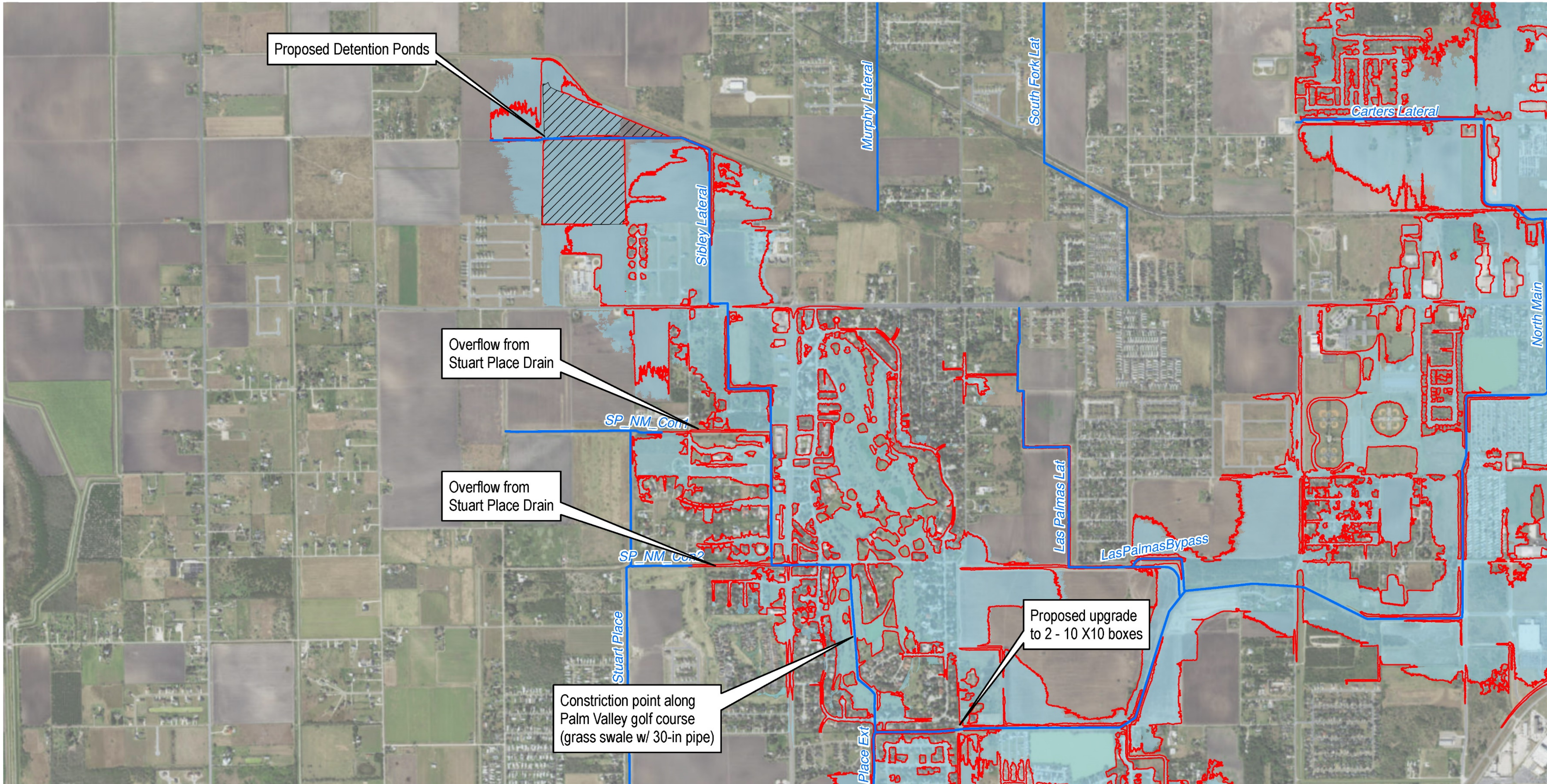
Alternative 1 – Optimize Regional Detention Pond on Sibley Lateral Upstream of Wilson Road

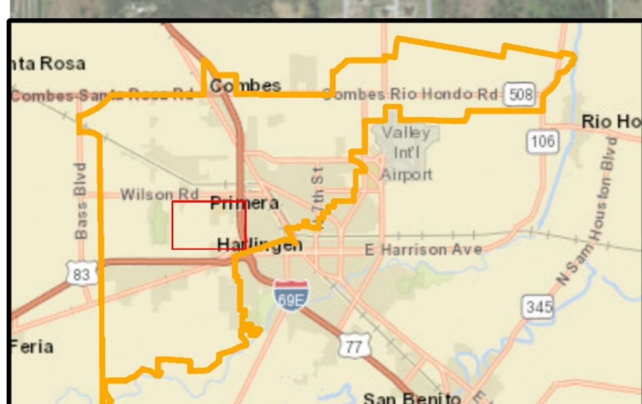
The goal of this alternative is to reduce flooding downstream of Wilson road through the City of Palm Valley. This alternative consists of optimizing and expanding an existing 52.9 acre-foot offline detention pond currently located upstream of Wilson Road. Optimization options analyzed include (1) expanding the existing pond located on the north side of Sibley lateral to 112.4 acre-feet and adding a 250 ft. lateral weir with a 24 inch drain pipe with flap gate and (2) adding additional 201.9 acre-foot pond on the south side of Sibley lateral with 1150 foot lateral weir with a 24 inch drain pipe. During simulations, it was noticed that the existing culvert at Dilworth Road creates a hydraulic head difference of over 2.5 feet. Therefore, the final alternative configuration also included adding an additional 10 ft. X 10 ft. box to this crossing.

It was evident from the analysis of these options that a constriction in flow capacity associated with the existing grassy swale and 30-inch storm drain located along the Palm Valley golf course combined with additional flow coming in from Stuart Place drain through connecting ditches upstream of Stuart Place Road was not allowing the optimized pond to have a significant impact through the City of Palm Valley. The profile provided below shows the impact of the Stuart Place Drain overflows and Palm Valley constriction on the alternative results. Note that the profile is higher along the Palm valley golf course and Stuart Place Road and decreases upstream and downstream.

A detailed probable cost estimate was not determined at this time due to the minimal flood reduction impact of this alternative under current conditions. It is recommended that this alternative be reanalyzed at a future time when drainage capacity improvements have been made along the Palm Valley golf course. For this reason. Alternative1 has been given a low priority until additional downstream improvements can be analyzed as discussed. A map is included below showing details of the analysis for Alternative 1 and the location of the current flow capacity constriction.


Sibley_Lateral Plan: 1) SIB_100yr_Test 5/2/2019 2) Alt1b_100yr 5/16/2019
Legend
WS Max WS - Alt1b_100yr
WS Max WS - SIB_100yr_Test
Ground
Stuart Place Overflow
Stuart Place Overflow
Palm Valley Golf Course
Dilworth Road
Stuart Pl. Road
Wilson Road
Elevation (ft)
Main Channel Distance (ft)
50
45
40
35
30
25
0
5000
10000
15000
20000
25000





Legend

- Study Streams
- Proposed 100-YR Floodplain
- Proposed Detention Basin
- Prelimary 100-yr Floodplain

N

SCHEIBE CONSULTING LLC

0 1,500 3,000 4,500 Feet

Sibley Lateral - Alternative 1

CAMERON COUNTY DRAINAGE DISTRICT #5
FLOOD PROTECTION PLANNING STUDY

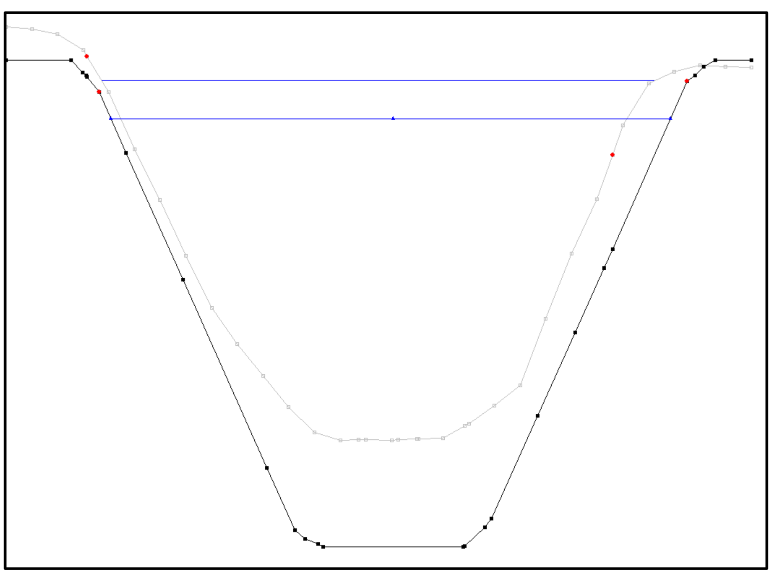
DETENTION BASIN UPSTREAM OF
WILSON ROAD AND CULVERT
IMPROVMENT AT DILWORTH ROAD

Alternative 2 – Channel Lining and Improvements from Wilson Road to Commerce Street

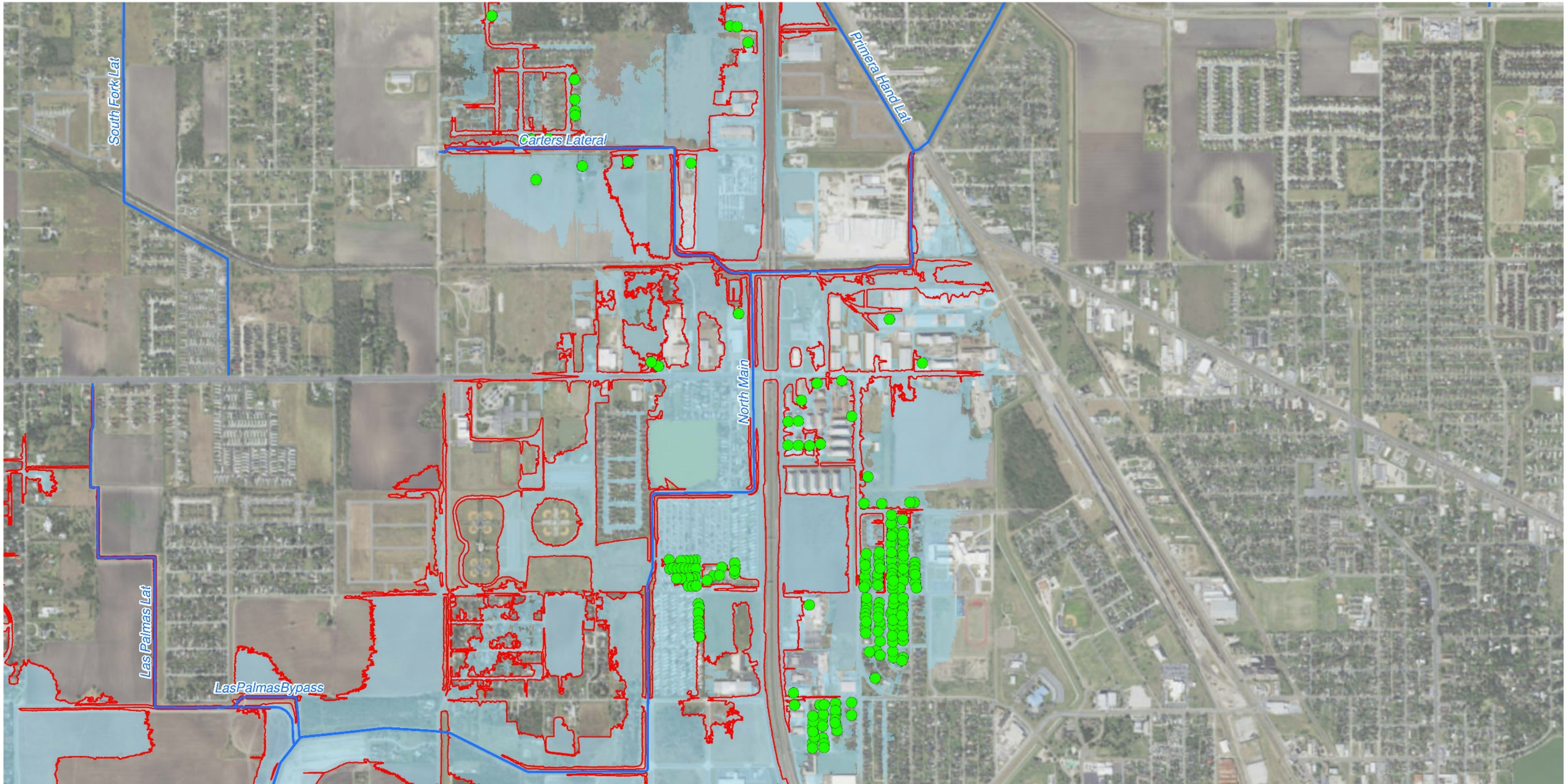
The goal of this alternative is to reduce flooding between Wilson Road and Commerce Street by adding concrete lined channel improvements and a conversion of the railroad trestle to a box culvert crossing. Dimensions and layout for this alternative were taken from an existing plan set for the proposed project obtained from CCDD5. The typical dimensions of the channel improvement cut consist of a 20 ft. bottom width with 1 to 1 side slopes with concrete lining. A typical section is shown below. The culvert upgrade for the current railroad trestle was not included in the existing plan set but was assumed to be three 10 ft. X 8 ft. boxes based on information from CCDD5 staff. Downstream impacts for this alternative were also analyzed and were determined to be negligible. Prior to construction, utility conflicts will need to be addressed if needed. This alternative resulted in a maximum 1.2 ft. reduction in 100-yr flood elevations in the project area removing 203 structures from the existing 100-yr floodplain. The total value (from appraisal district data) of structures removed from the floodplain and reduced 100-yr flooding extents are provided in the map below.

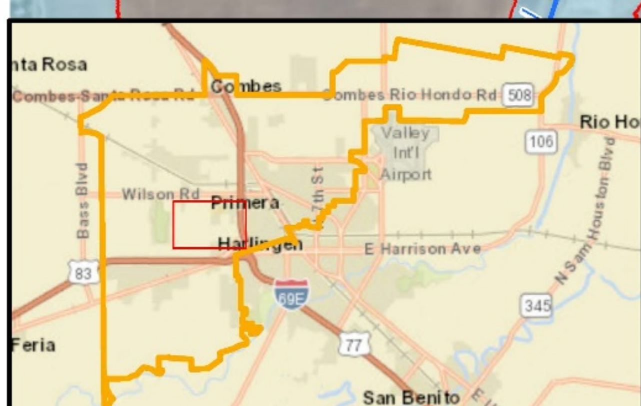
A probable cost estimate was obtained from CCDD5 for the channel lining and improvement as this alternative is already in the design stage. However, the probable cost of the culvert upgrade to the railroad has not yet been developed by CCDD5. Therefore, a detailed probable cost estimate for the railroad culvert upgrade is included below. The total probable cost estimate for the channel lining and improvement is $2,246,699 for a total project probable cost of $2,840,438 when the railroad culvert upgrade is included. This project will result in removal of $9,076,277 of structures from the 100-yr floodplain. The benefits for this project are high when compared to cost and it has a positive impact on the area between Wilson Road and Commerce St., which contains a key industrial area for the City of Harlingen. Due to the positive cost-benefit ratio and high level of positive impact of this alternative, it was given a high priority.

Typical Section of Channel Modification



North Main - Alternative 2 - RR Culverts				
Quantity	**Unit**	**Item Description**	**Unit Price**	**Amount**
25	LF	Remove Structure (RR Track)	$ 21	$ 525
1	EA	Remov Str (Bridge 100 -499 FT length)	$ 100,000	$ 100,000
75	LF	Conc Box Culv (8 FT x 10 FT)	$ 873	$ 65,475
4	EA	Wingwall (FW-0) (HW=8 FT)	$ 13,451	$ 53,804
6400	CY	Embankment (Final) (Ord Comp)(TY C)	$ 26.88	$ 172,032
4000	SY	Broadcast Re-seeding	$ 0.30	$ 1,200
1	LS	Temporary Erosion Control	$ 20,000	$ 20,000
		SUBTOTAL		$ 413,036
1	LS	Engineering Design (approx. 10% of construction subtotal)	$ -	$ 41,304
1	LS	Total Mobilization Payment (approx. 5% of construction subtotal)	$ -	$ 20,652
		CONSTRUCTION SUBTOTAL		$ 474,991
		25% CONTENGENCIES		$ 118,748
		GRAND TOTAL		$ 593,739





Legend

- Structures_Removed
- Study Streams
- Proposed 100-YR Floodplain
- Preliminary 100-YR Floodplain

Structure Counts

Flood Event	Structures Impacted	Value of Structures
Proposed 100-YR Floodplain	883	$81,836,761
Preliminary 100-YR Floodplain	1,077	$90,332,111
Structures Removed From 100-YR Floodplain	203	$9,076,277

N

0 1,200 2,400 3,600 Feet

SCHEIBE CONSULTING LLC

North Main Drain - Alternative 2

CAMERON COUNTY DRAINAGE DISTRICT #5
FLOOD PROTECTION PLANNING STUDY

CHANNEL LINING AND IMPROVEMENTS
FROM WILSON RD. TO COMMERCE ST.

NOTE: Details for this alternative were derived from an exisiting plan set developed by CCDD5.

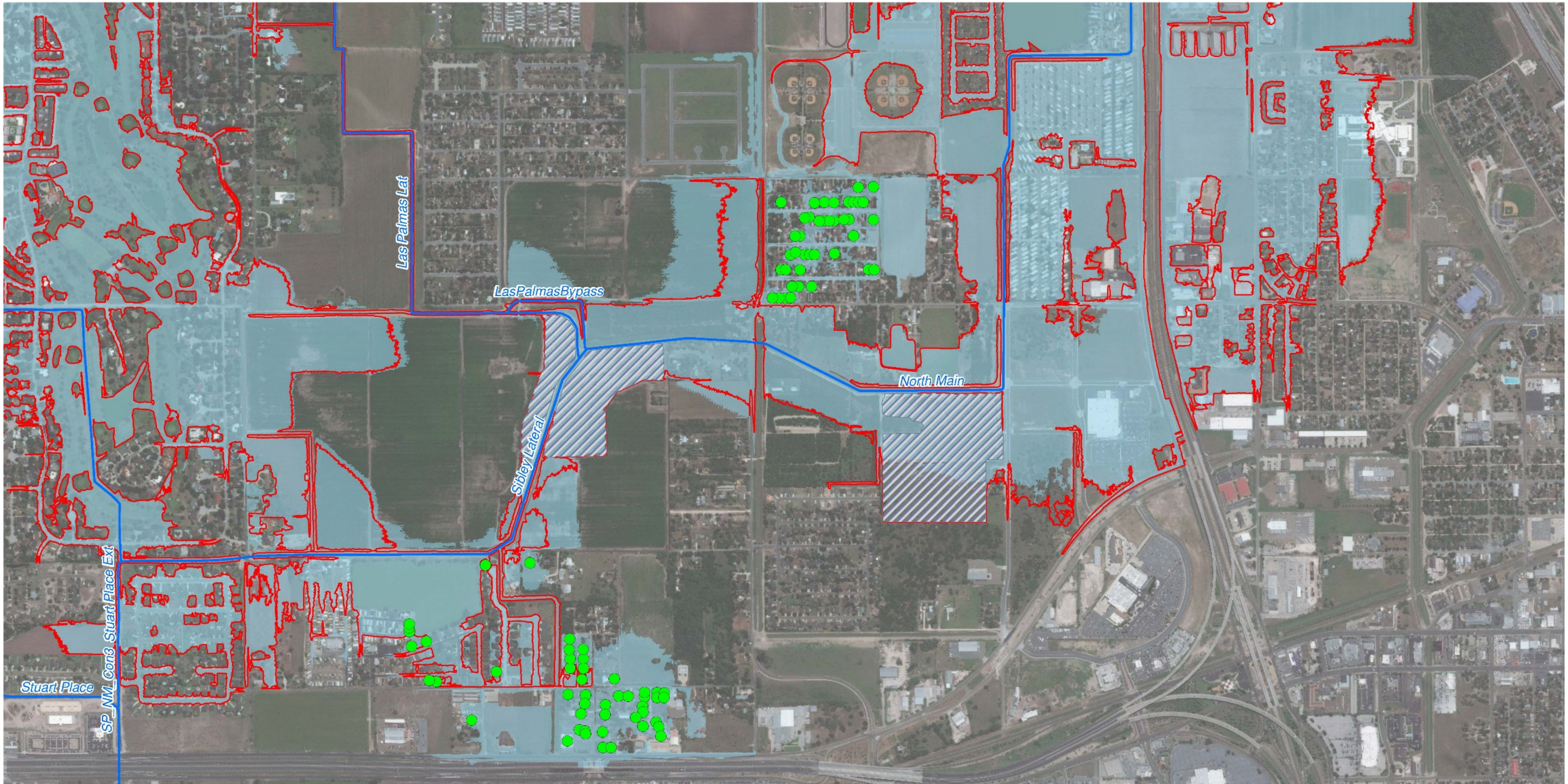
Alternative 3 – Optimize Regional Detention Ponds and Increase Culvert Capacity at Chester Park Road and Irrigation Canal

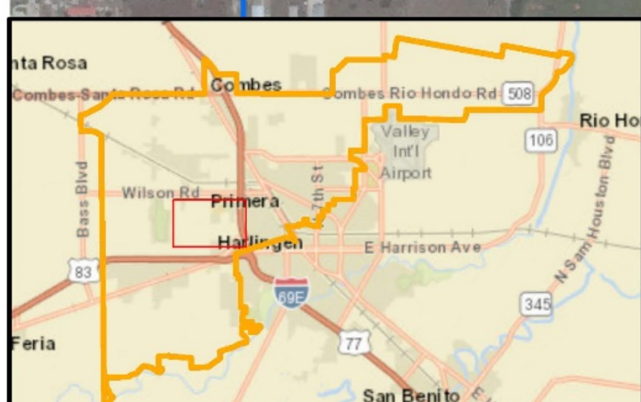
The goal of this alternative is to reduce flooding on North Main Drain upstream and downstream of Chester Park Road. This alternative consists of optimizing and expanding existing 18.7 acre-foot and 41.1 acre-foot offline detention ponds currently located upstream of Chester Park Road at the confluence with Las Palmas Lateral as well as the existing 122.3 acre-foot detention pond downstream of Chester Park Road near Brazil Road. All three ponds have pipe culvert drains but no flap gates. This alternative also consists of expanding the existing culvert capacity at Chester Park Road (currently 1 – 10 X 10 box) and the parallel irrigation canal just downstream (currently 2 – 5 X 5 boxes).

The ponds were optimized first by adding flap gates to pipe drains to prevent filling of the pond at lower flows. In addition to flap gates, each pond volume was optimized bot vertically and horizontally by dropping the bottom of each pond to the minimum elevation along the main channel and expanding the footprint of each pond. The ponds upstream of Chester Park Road were increased to 73.3 acre-feet and 176.0 acre-feet and the Brazil Rd. pond was increased to 361.9 acre-feet. Minimum elevation of the lateral overflow structures was also optimized to achieve the maximum peak shaving effect. Culverts at Chester Park Road and the irrigation canal were both increased to two 10 ft. X 10ft. boxes. Utility conflicts were not analyzed as part of this alternative and will need to be addressed during a future design phase.

This alternative resulted in a maximum 0.96 ft. reduction in 100-yr flood elevations along North Main drain and removal of 88 structures from the existing 100-yr floodplain upstream and downstream of Chester Park Road. The total value (from appraisal district data) of structures removed from the floodplain and reduced 100-yr flooding extents are provided in the map below. A detailed opinion of probable cost is also provided and includes typical construction component costs, engineering fee, land acquisition cost, and a 25% contingency. The total opinion of probable cost for this project is $5,404,402 and will result in removal of $2,531,449 of structures from the 100-yr floodplain. Although this project has a positive impact on existing structures, the cost of construction is high. If additional benefits can be derived from this alternative it may have a more favorable comparison of costs to benefits. Due to the low cost-benefit ratio, this alternative was given a medium priority.

North Main - Alternative 3				
Quantity	**Unit**	**Item Description**	**Unit Price**	**Amount**
143	SY	Removing Stab Base and Asph Pavement (6")	$ 30	$ 4,290
6400	CY	Excavation (Channel)	$ 6.00	$ 38,400
423263	CY	Excavation (Detention)	$ 6.00	$ 2,539,578
208	LF	Conc Box Culv (10 FT x 10 FT)	$ 836	$ 173,888
4	EA	Wingwall (FW-0) (HW=10 FT)	$ 17,250	$ 69,000
17	TON	D-GR HMA (SQ) TY-C SAC-A PG64-22	$ 103	$ 1,751
72	LF	Remov Str (Box Culvert)	$ 52	$ 3,744
144	LF	Jack Bor Tun Box Culv (10 FT x 10 FT)	$ 3,000	$ 432,000
192991	SY	Soil Retention Blankets (CL 1)(TY C)	$ 1	$ 183,341
3000	SY	Geotextile Fabric (Est. installation cost at $.21 per SF)	$ 2.20	$ 6,600
277	CY	RipRap (Stone Common) (Dry) (12 in)	$ 30	$ 8,310
168432	SY	Broadcast Re-seeding	$ 0.30	$ 50,530
1	LS	Temporary Erosion Control	$ 20,000	$ 20,000
1	LS	Land Acquisition	$ 228,152	$ 228,152
		SUBTOTAL		$ 3,759,584
1	LS	Engineering Design (approx. 10% of construction subtotal)	$ -	$ 375,958
1	LS	Total Mobilization Payment (approx. 5% of construction subtotal)	$ -	$ 187,979
		CONSTRUCTION SUBTOTAL		$ 4,323,522
		25% CONTENGENCIES		$ 1,080,880
		GRAND TOTAL		$ 5,404,402





Legend

- Structures_Removed
- Study Streams
- Optimized Detention Basins
- Proposed Floodplain
- Preliminary 100-YR Floodplain

Structure Counts

Flood Event	Structures Impacted	Value of Structures
Proposed 100-YR Floodplain	989	$87,800,662
Preliminary 100-YR Floodplain	1,077	$90,332,111
Structures Removed From 100-YR Floodplain	88	$2,531,449

N

0 1,000 2,000 3,000 Feet

SCHEIBE CONSULTING LLC

North Main Drain - Alternative 3

CAMERON COUNTY DRAINAGE DISTRICT #5
FLOOD PROTECTION PLANNING STUDY

OPTIMIZE REGIONAL DETENTION PONDS AND IMPROVE CULVERTS AT CHESTER PARKK RD. AND RAILROAD

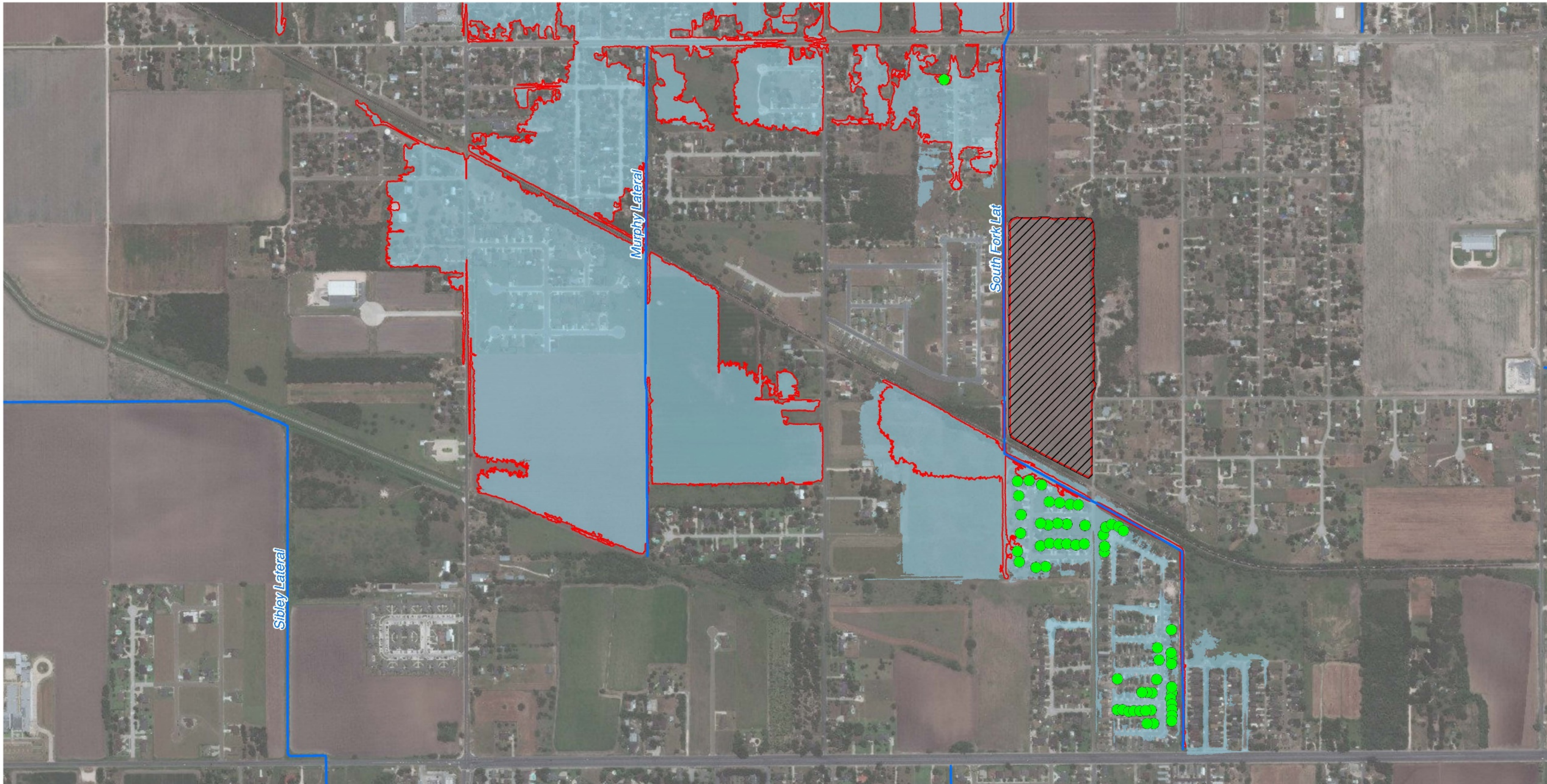
NOTE: Storage analysis is preliminary & subject to change in final design.

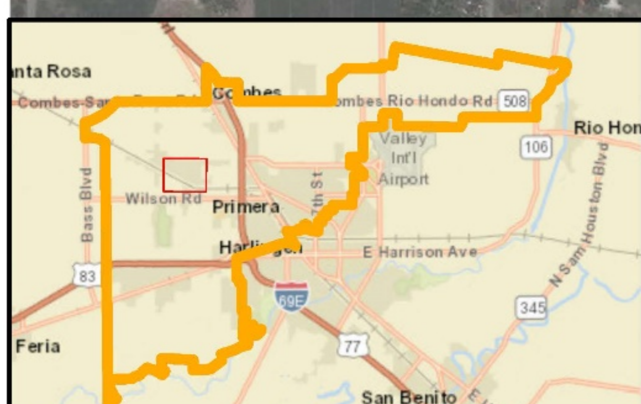
Alternative 4 – Increase Culvert Capacity at Railroad and Mitigate with Offline Detention on South Fork Lateral

The goal of this alternative is to reduce flooding on South Fork Lateral in the City of Primera upstream and downstream of the existing railroad crossing. This alternative consists of increasing culvert capacity at the railroad and private crossing just downstream of it from one 18-inch pipe to three 30-inch pipes to relieve upstream flooding. In addition to the culvert upgrades, this alternative includes an 85.4 acre-foot offline pond downstream on the railroad to mitigate for downstream increases discharge due to the increased culvert capacity and also provide additional flood reduction downstream of the railroad. The lateral overflow structure optimized to ensure maximum storage and consists of a 400-foot lateral weir with two 24-inch drainpipes with flap gates. Utility conflicts were not analyzed as part of this alternative and will need to be addressed during a future design phase.

This alternative resulted in a maximum 1.4 ft. reduction in 100-yr flood elevations along South Fork Lateral and removal of 60 structures from the existing 100-yr floodplain upstream and downstream of the existing railroad. The total value (from appraisal district data) of structures removed from the floodplain and reduced 100-yr flooding extents are provided in the map below. A detailed opinion of probable cost is also provided and includes typical construction component costs, engineering fee, land acquisition cost, and a 25% contingency. The total opinion of probable cost for this project is $2,420,758 and will result in removal of $4,811,058 of structures from the 100-yr floodplain. The benefits for this project are high when compared to costs and it has a positive impact on the area upstream of the railroad. Due to the positive cost-benefit ratio and high level of positive impact of this alternative, it was given a high priority.

South Fork Lateral - Alternative 4				
Quantity	**Unit**	**Item Description**	**Unit Price**	**Amount**
12	EA	Tree Removal (4" - 12" DIA)	$ 236.00	$ 2,832
120	LF	Remove & Re-lay Pipe (30 in)	$ 49.00	$ 5,880
144	LF	Jack Bor or Tun Pipe (30 IN)(RC)(CL V)	$ 1,000.00	$ 144,000
13	CY	Excavation (Channel)	$ 7.43	$ 97
264	LF	RC Pipe (CL III)(30 IN)	$ 115	$ 30,360
160	LF	RC Pipe (CL III)(24 IN)	$ 70	$ 11,200
2	EA	Flap Gate (approx. 50% installation cost)	$ 1,800	$ 3,600
219,062	CY	Excavation (Special:Detention Basin)	$ 6.00	$ 1,314,372
1,148	SY	Geotextile Fabric (Est. installation cost at $.21 per SF)	$ 2.20	$ 2,526
957	CY	RipRap (Stone Common) (Dry) (12 in)	$ 30.00	$ 28,710
9,600	SY	Soil Retention Blankets (CL 1) (TY C)	$ 0.95	$ 9,120
200	SY	Broadcast Re-seeding	$ 0.30	$ 60
1	LS	Temporary Erosion Control	$ 20,000	$ 20,000
1	LS	Land Acquisition	$ 179,829	$ 179,829
		SUBTOTAL		$ 1,752,585
1	LS	Engineering Design (approx. 10% of construction subtotal)	$ -	$ 175,259
1	LS	Total Mobilization Payment (approx. 5% of construction subtotal)	$ -	$ 8,763
		CONSTRUCTION SUBTOTAL		$ 1,936,607
		25% CONTENGENCIES		$ 484,152
		GRAND TOTAL		$ 2,420,758





Legend

- Structures Removed
- Study Streams
- Proposed Detention Basin
- Proposed 100-YR Floodplain
- Preliminary 100-YR Floodplain

N

Structure Counts

Flood Event	Structures Impacted	Value of Structures
Proposed 100-YR Floodplain	296	$17,779,233
Preliminary 100-YR Floodplain	356	$22,590,291
Structures Removed From 100-YR Floodplain	60	$4,811,058

0 700 1,400 2,100 Feet

SCHEIBE CONSULTING LLC

South Fork Lateral - Alternative 4

CAMERON COUNTY DRAINAGE DISTRICT #5
FLOOD PROTECTION PLANNING STUDY

OFFLINE DETENTION BASIN AND
RAILROAD CULVERT IMPROVEMENT

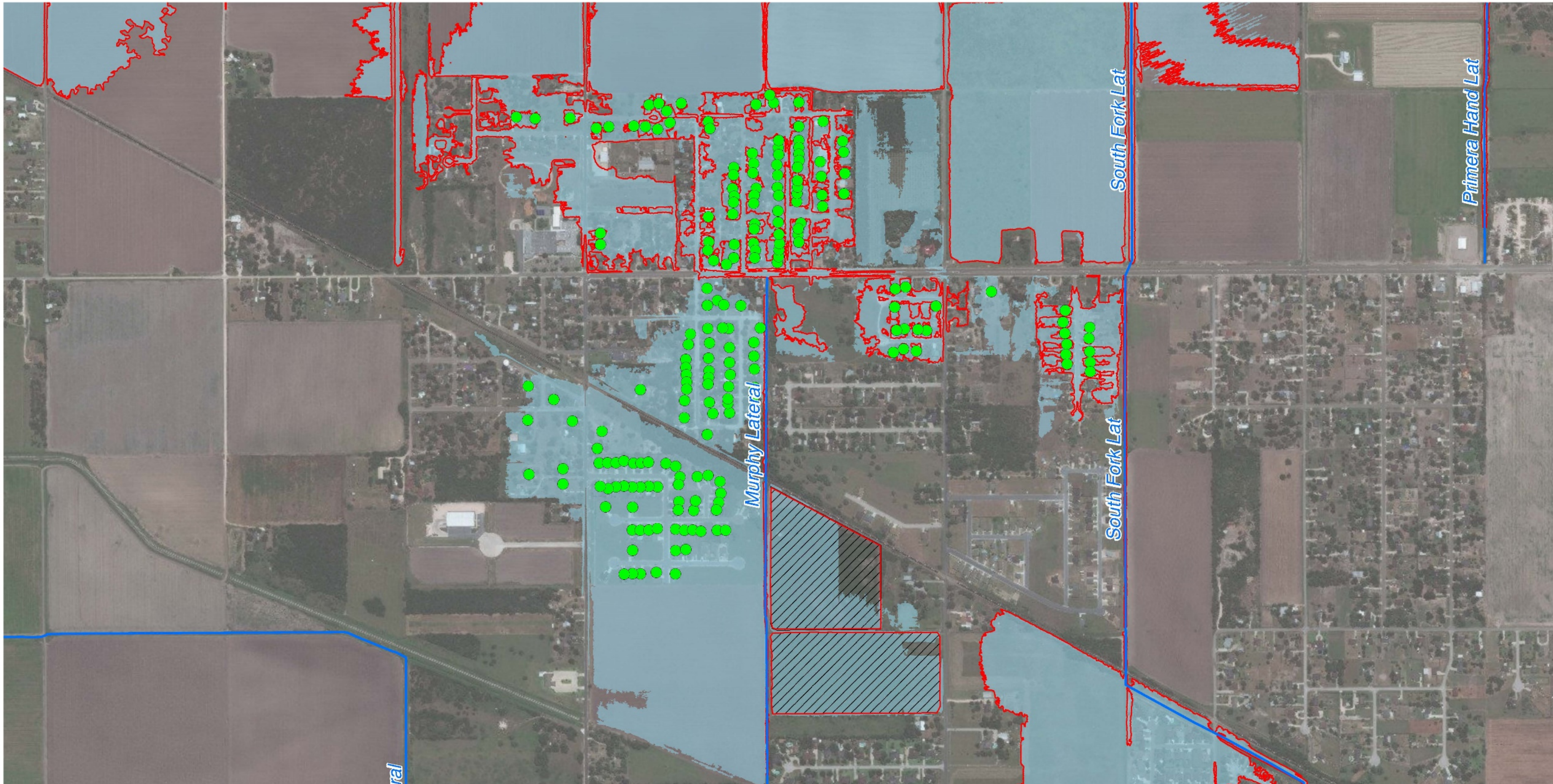
NOTE: Storage analysis is preliminary & subject to change in final design.

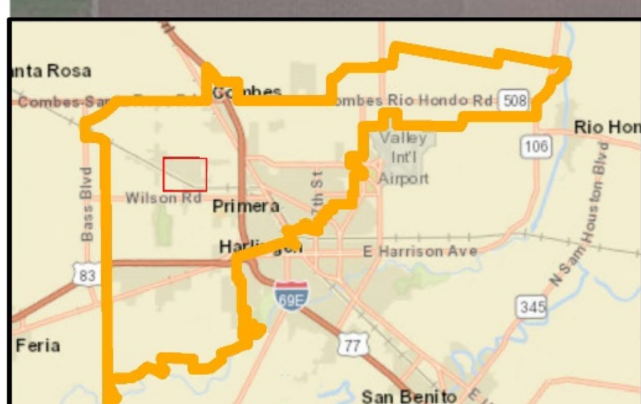
Alternative 5 – Increase Culvert Capacity at Railroad and Primera Road with Offline Detention on Murphy Lateral

The goal of this alternative is to reduce flooding on Murphy Lateral in the City of Primera upstream and downstream of the existing railroad crossing. This alternative consists of increasing culvert capacity at the railroad from one 24-inch pipe to three 30-inch pipes and at Primera road by increasing the 4 ft. X 2 ft. box connecting to the Primera Road storm drain to two 6 ft. X 2 ft. boxes to relieve upstream flooding. In addition to the culvert upgrades, this alternative includes a 153.4 acre-foot offline pond downstream on the railroad to mitigate for downstream increases discharge due to the increased culvert capacity and also provide additional flood reduction downstream of the railroad. The lateral overflow structure optimized to ensure maximum storage and consists of a 710-foot lateral weir with a 24-inch drainpipe with flap gate. Utility conflicts were not analyzed as part of this alternative and will need to be addressed during a future design phase.

This alternative resulted in a maximum 2 ft. reduction in 100-yr flood elevations along Murphy Lateral and removal of 207 structures from the existing 100-yr floodplain upstream and downstream of the existing railroad. The total value (from appraisal district data) of structures removed from the floodplain and reduced 100-yr flooding extents are provided in the map below. A detailed opinion of probable cost is also provided and includes typical construction component costs, engineering fee, land acquisition cost, and a 25% contingency. The total opinion of probable cost for this project is $3,885,652 and will result in removal of $12,861,745 of structures from the 100-yr floodplain. The benefits for this project are very high when compared to cost and it has a positive impact on the area upstream of the railroad as well as a portion of the City of Primera north of Primera Road. Due to the very high cost-benefit ratio and high level of positive impact of this alternative, it was given a high priority.

Murphy Lateral - Alternative 5				
Quantity	**Unit**	**Item Description**	**Unit Price**	**Amount**
105	SY	Cut & Restore Asph Paving	$ 69.49	$ 7,296
2	EA	Remov Str (Wingwall)	$ 1,146.71	$ 2,293
1	CY	Removing Conc (Riprap)	$ 28.35	$ 40
393	LF	Conc Box Culv (6 FT X 2 FT)	$ 427.00	$ 167,811
2	EA	Wingwall (FW - 0) (HW = 3 Ft)	$ 6,000.00	$ 12,000
222	CY	Excavation (Roadway)	$ 6.00	$ 1,329
197	LF	Trench Excav. Prot.	$ 2.84	$ 558
218	SY	Geotextile Fabric (Est. Installation Cost At $.21 Per Sf)	$ 2.20	$ 480
1	CY	Riprap (Conc) (CL B) (5")	$ 486.20	$ 681
1	MO	Barricades, Signs, & Traffic Handling	$ 7,517.10	$ 7,517
197	LF	Remove Str (Box Culvert)	$ 37.22	$ 7,314
333	SY	Broadcast Re-seeding	$ 0.30	$ 100
778	CY	Excavation (Channel)	$ 7.43	$ 5,779
122	LF	Jack Bore or Tunnel Pipe (30") (RC) (CL V)	$ 1,000.00	$ 121,800
343026	CY	Excavation (Special: Detention Basin)	$ 6.00	$ 2,058,156
12004	SY	Soil Retention Blankets (CL 1) (TY C)	$ 0.95	$ 11,404
171820	SY	Broadcast Re-seeding	$ 0.30	$ 51,546
1	LS	Land Acquisition	$ 274,800	$ 274,800
1	LS	Temporary Erosion Control	$ 20,000	$ 20,000
		SUBTOTAL		$ 2,750,904
1	LS	Engineering Design (approx. 10% of construction subtotal)	$ -	$ 220,072
1	LS	Total Mobilization Payment (approx. 5% of construction subtotal)	$ -	$ 137,545
		CONSTRUCTION SUBTOTAL		$ 3,108,521
		25% CONTENGENCIES		$ 777,130
		GRAND TOTAL		$ 3,885,652





Legend

- Structures Removed
- Study Streams
- Proposed 100-YR Floodplain
- Proposed Detention Basin
- Preliminary 100-YR Floodplain

Structure Counts

Flood Event	Structures Impacted	Value of Structures
Proposed 100-YR Floodplain	149	$9,728,546
Preliminary 100-YR Floodplain	356	$22,590,291
Structures Removed From 100-YR Floodplain	207	$12,861,745

N

0 800 1,600 2,400 Feet

SCHEIBE CONSULTING LLC

Murphy Lateral - Alternative 5

CAMERON COUNTY DRAINAGE DISTRICT #5
FLOOD PROTECTION PLANNING STUDY

OFFLINE DETENTION BASIN AND CULVERT IMPROVEMENT AT RAILROAD/PRIMERA RD.

NOTE: Storage analysis is preliminary & subject to change in final design.

APPENDIX D:
DIGITAL DATA