Identify, Interpret, Integrate

Lower Frio Watershed, TX
Base Level Engineering (BLE) Results

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Executive Summary

FEMA Region 6 contracted Compass to complete a Base Level Engineering (BLE) analysis for the Lower Frio HUC-8 in Central Texas, to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHAs). This BLE study will provide significant data for several Texas counties previously lacking modernized flood models.

The BLE process involves using best available data and incorporating automated techniques with traditional model development procedures to produce regulatory-quality flood hazard boundaries for the 1-percent annual chance event as well as estimates of flood hazard boundaries for multiple recurrence intervals.

The source digital terrain data used for surface model development in support of hydrologic and hydraulic analysis as well as mapping activities were leveraged from various local, State, and Federal partners. Details regarding the different datasets used are provided below in Section 1.1.

Flood discharges for this study were calculated using both the United States Geological Survey (USGS) regression equations and gage analysis, where stream gages with sufficient record exist. Regression equations were obtained from the USGS Scientific Investigations Report (SIR) 2009-5087, *Regression Equations for Estimation of Annual Peak-Streamflow Frequency for Undeveloped Watersheds in Texas Using an L-moment Based, PRESS-Minimized, Residual-Adjusted Approach* (2009).

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) program version 5.0.5 was used to compute water surface elevations on a stream by stream basis. All hydraulic models were computed using 1-D steady state analysis.

The stream mile network that was validated for these watersheds was compiled using FEMA's Community Needs Management Strategy (CNMS) inventory. CNMS is an inventory of flood hazard studies and flood hazard mapping needs for areas where a study is needed. This data is helpful for community officials in analyzing and depicting flood hazards to enhance the understanding of flood risks. Communities may use this information to make informed decisions on their planning and flood mitigation efforts. Table ES-1 lists the Zone A stream miles associated with this validation analysis.

Table ES-1: Summary of Stream Miles

Source	Lower Frio Stream Miles
CNMS	305.77

The full inventory of Zone A studies in the watershed were classified in CNMS. Total miles validated in CNMS are summarized in

Table ES-2 and illustrated in Figure ES-1 below.

Table ES-2: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	8.6
UNVERIFIED	BEING STUDIED	297.1

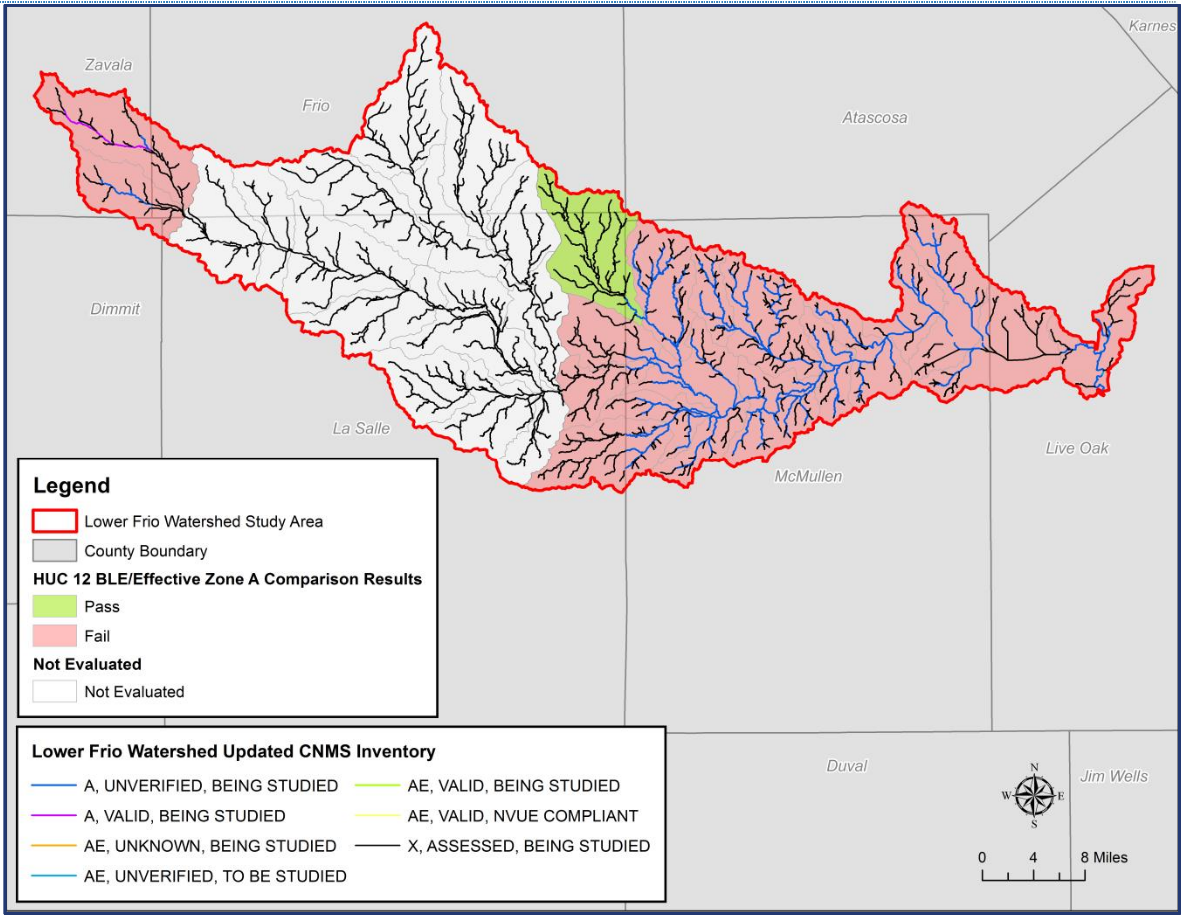

Figure ES-1: Lower Frio Watershed CNMS Validation Results

An overall risk for each HUC-12 watershed was calculated using the National Flood Risk Percentages Dataset and its proportional area. The weighted risk was multiplied by the percentage of points in the watershed that failed the CNMS comparison to effective to determine the priority score. Figure ES-2 below shows the range of the Lower Frio HUC-8 priority scores which can be used to initiate discussions during the Discovery phase.

Sevenmile Creek-Frio River HUC-12 was determined to have the highest priority score and the most need while Upper Esperanza CreekHUC-12 had the lowest scores.

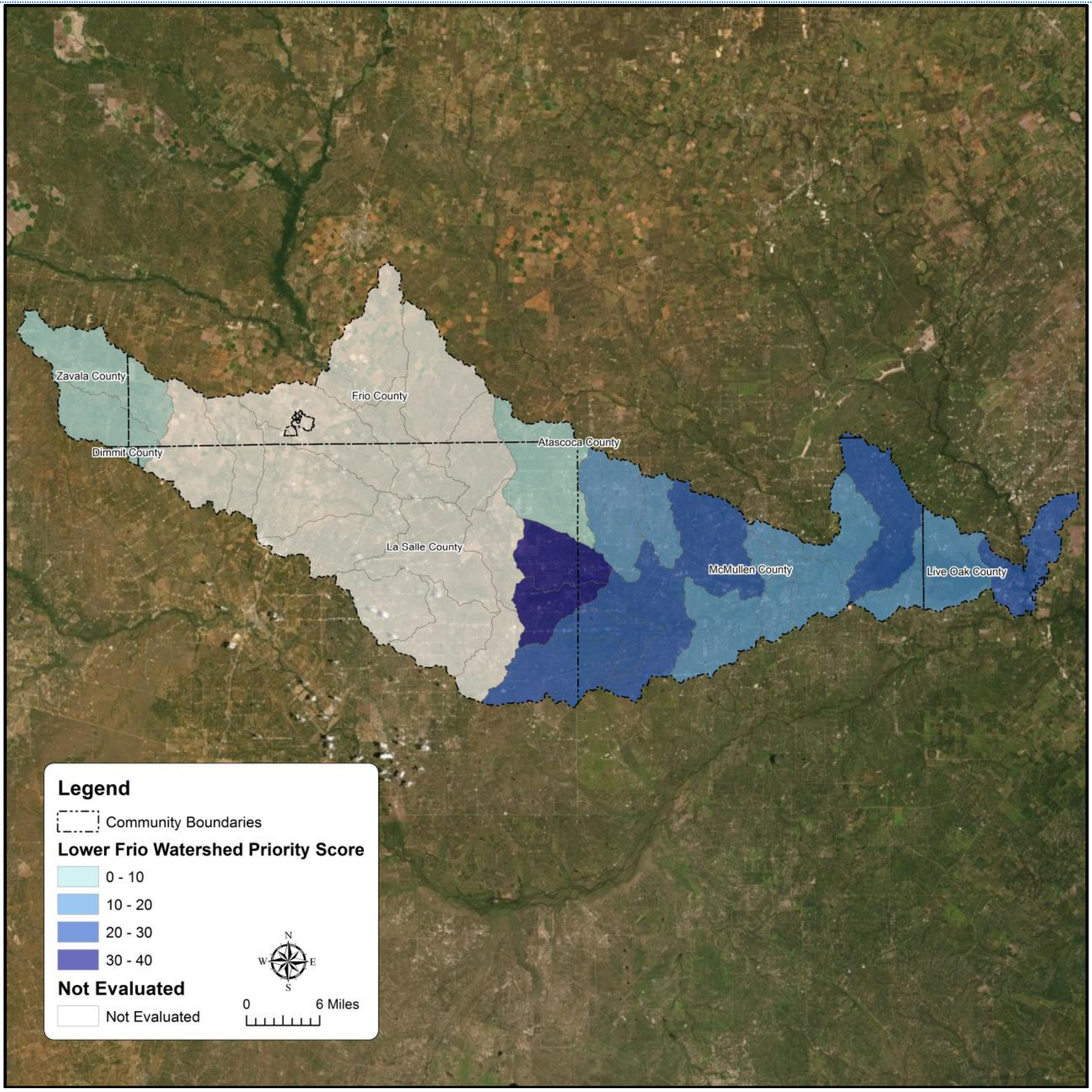

Figure ES-2: Ranking of Lower Frio Watershed HUC-12s

Base Level Engineering (BLE) Methodology

Recent innovations and efficiencies in floodplain mapping have allowed the U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) to develop a process called Base Level Engineering (BLE), which can be used to address current program challenges, including the validation of Zone A studies and the availability of flood risk data in the early stages of a Flood Risk Project. The BLE process involves using best available data and incorporating automated techniques with traditional model development procedures to produce regulatory quality flood hazard boundaries for the 1-percent annual chance event as well as estimates of flood hazard boundaries for multiple recurrence intervals. The cost for developing the data and estimates resulting from the BLE process are lower than standard flood production costs. The BLE results may be used for eventual production of regulatory and non-regulatory products.

As described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e), once every five years, FEMA must evaluate whether the information on Flood Insurance Rate Maps (FIRMs) reflects the current risks in flood-prone areas. FEMA makes this determination of flood hazard data validity by examining flood study attributes and change characteristics, as specified in the Validation Checklist of the Coordinated Needs Management Strategy (CNMS) Technical Reference. The CNMS Validation Checklist provides a series of critical and secondary checks to determine the validity of flood hazard areas studied by detailed methods (e.g., Zone AE, AH, or AO). While the critical and secondary elements in CNMS provide a comprehensive method of evaluating the validity of Zone AE studies, a cost-effective approach for evaluating Zone A studies has been lacking.

In addition to the need for Zone A validation guidance, FEMA standards require flood risk data to be provided in the early stages of a Flood Risk Project. FEMA Program Standard SID #29 requires that during Discovery, data must be identified that illustrates potential changes in flood elevation and mapping that may result from the proposed project scope. If available data does not clearly illustrate the likely changes, an analysis is required that estimates the likely changes. This data and any associated analyses should be shared and results should be discussed with stakeholders.

An important goal of the BLE process is the scalability of the results. Scalability means that the results of a BLE analysis can not only be used for CNMS evaluations of Zone A studies, but can also be leveraged throughout the Risk MAP program. The data resulting from a BLE analysis can be updated as needed and used for the eventual production of regulatory and non-regulatory products, outreach and risk communication, and MT-1 processing. Leveraging this data outside the Risk MAP program may also be valuable to external stakeholders.

FEMA Region 6 contracted Compass to complete a BLE analysis for the Lower Frio Watershed in Central Texas to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHA). The study extents include portions of Atascosa, Dimmit, Frio, La Salle, Live Oak, McMullen, and Zavala Counties, and include the following communities: the Cities of Dilley and Three Rivers. The study area consists of five HUC-10 basins: Esperanza Creek-Frio River, Martin Branch-Frio River, San Miguel Creek-Frio River, Snake Creek-Cibolo Creek, and Yeager Creek-Cibolo Creek. Figure 1 shows the orientation of the Lower Frio HUC-10 basins with respect to the counties.

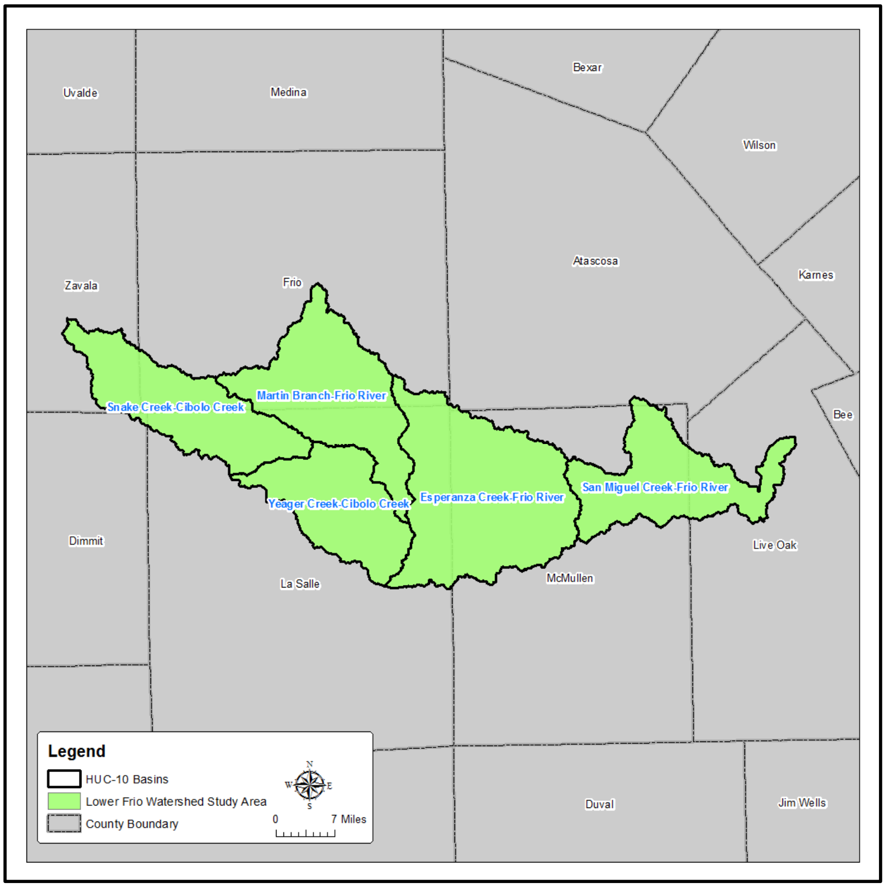

Figure 1: Lower Frio Watershed HUC-10 Basins

AECOM studied approximately 1,400 miles of stream reaches within the Lower Frio Watershed with a minimum drainage area tolerance of one square mile outside of population centers and half a square mile inside population centers. The selection and extent of stream reaches studied were based upon the number of stream miles with a minimum drainage area of one square mile (or half a square mile, where appropriate) and not the number of effective Zone A stream miles. Study reaches were extended above this threshold as appropriate to ensure all effective Zone A flood areas received an updated analysis. Topographic data from multiple sources were used to determine the hydrologic and hydraulic characteristics of the watershed. The following sections summarize the BLE process and discuss the results along with their recommended use.

1.1 Topographic Data

Topographic data from multiple sources were used to determine the hydrologic and hydraulic characteristics of the watershed. Topographic data were obtained from the Texas Natural Resources Information System (TNRIS), and the United States Geological Survey (USGS).

All available metadata, survey reports, and other leverage documentation are available with the source dataset. Figure 2 shows the extents of the source Digital Terrain Model (DTM) data used for the Lower Frio Watershed.

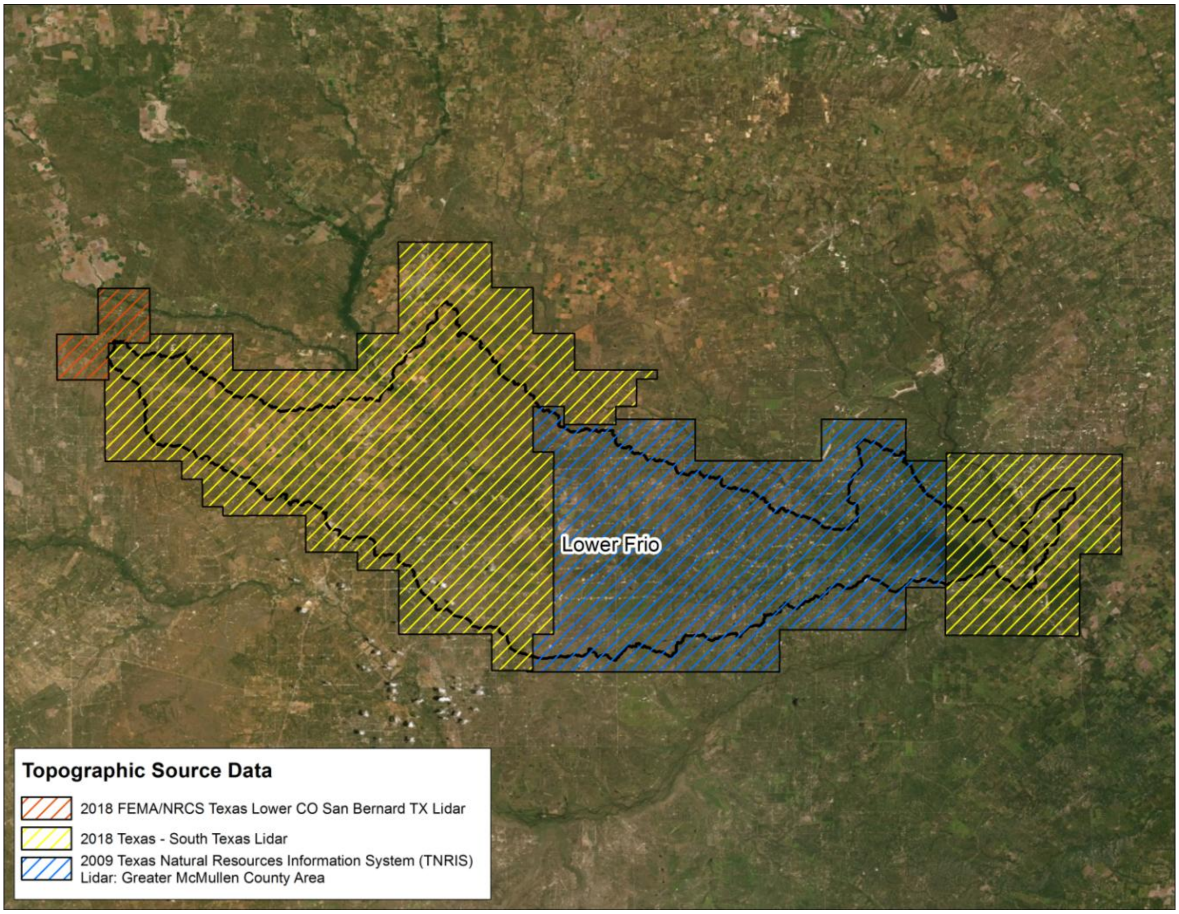

Figure 2: Extent of LiDAR Data for Lower Frio Watershed

1.1.1 Source Terrain Data

Three topographic datasets were used in the development of the BLE hydraulic models. Details on each dataset are outlined below.

1.1.1.1 2018 FEMA/NRCS Texas Lower CO San Bernard TX LiDAR

The 2018 FEMA/NRCS Texas Lower CO San Bernard TX LiDAR was acquired from the United States Geological Survey (USGS). The LiDAR data was collected from February 12th to April 22nd of 2018. The acquisition task order required LiDAR data to be acquired over approximately 17,942 square miles of LiDAR, for the area of interest (AOI) collected at a nominal pulse spacing (NPS) of

0.571 meters. The LiDAR data was acquired and processed in compliance with U.S. Geological Survey (USGS) National Geospatial Program LiDAR Base Specification version 1.2. The Root Mean Square Error (RMSE)z reported for the dataset was 4.9 cm at the 95% confidence level which meets project accuracy specifications of the National Standard for Spatial Data (NSSDA). The data in Figure 2 shows the Lower Frio Watershed extent of the 2018 FEMA/NRCS Texas Lower CO San Bernard TX LiDAR data leveraged for this study.

1.1.1.2 2018 Texas - South Texas LiDAR

The USGS LiDAR project covers Dimmit, Frio, La Salle, Live Oak and Zavala counties. The project was developed to create a consistent and accurate surface elevation dataset for the USGS FEMA VI Red River, Texas Project Area. The acquisition was conducted from January 4, 2018 to January 22, 2018. Dewberry served as the prime contractor for the project and was responsible for LAS classification, all LiDAR products, breakline production, DEM production, and quality assurance.

LiDAR acquired from this project was to be used for floodplain management and planning, feature extraction, water quality modeling, stream restoration potential analysis, change detection, 9-1-1, wildfire mitigation, habitat identification/modeling for endangered species, and hurricane recovery projects.

Further details regarding this acquisition can be found by downloading the USGS 2018 South Central Project Reports.

1.1.1.3 2009 Texas Natural Resources Information System (TNRIS) LiDAR: Greater McMullen County Area

The StratMap LiDAR collection covers portions of Atascosa, Frio, La Salle, Live Oak and McMullen counties, Texas. Data was captured by Photoscience, Inc. from June 19-20, 2009. The purpose of this project was to develop new flood hazard information that would be used in the update and creation of accurate flood zone maps in support of the National Flood Insurance Program.

The data products became part of ongoing data collection by the State of Texas to support mapping and modeling of floodplains, hydrography, and terrain. This project was procured through the Council on Competitive Government's HPIDS contract.

1.1.2 Terrain Data Processing

The LiDAR data were processed in Environmental System Research Institute (ESRI) ArcGIS software to create a composite Digital Terrain Model (DTM) dataset for the project area. The outputs from the processing described below were used during the hydrology, hydraulics, floodplain mapping and CNMS processes and validations.

The Watershed Information System (WISE) software platform was utilized in order to create a digital surface model for the Lower Frio Watershed project area. This module allows source data from a variety of sources to be prioritized based on level of accuracy or preference of the user. The 2018 FEMA/NRCS Texas Lower CO San Bernard TX LiDAR dataset was prioritized as the best data source for the Lower Frio Watershed followed by the 2018 Texas - South Texas LiDAR, and lastly the 2009 TNRIS LiDAR: Greater McMullen County Area.

The 10-foot DEMs created from the LiDAR datasets described above were compiled in order of vertical accuracy into a mosaic dataset using ArcMap. From this mosaic, a tile index was created for the project area and the mosaic was clipped into 40,000-foot tiles, converted to asciis and imported into Wise Terrain Analyst (WTA). Visual inspection of the 10-foot DEMs was performed to ensure no voids and/or artifacts were present. The DEM surface model was affirmed to be suitable for hydraulic takeoffs and supporting other hydraulic analyses.

Stream centerlines were manually digitized using the 10-foot DEMs as a source for horizontal alignment and vertical elevation. These stream centerlines are created for use in the hydraulic analysis-and hydro-enforcement of the 50-foot DEMs. Several routines were then used to take localized elevations from the source topographic data and apply them to the streams. This gave the stream vertices elevation information along the Z axis. The resulting elevations ensure that the streams are lower in elevation than any overbank sumps. A separate routine was then used to ensure that the elevations of these vertices descend in height down to an outfall. The final streams file is then "burned" into the 50-foot DEMs to force flow through structures while preventing it from "jumping" out of the channel banks.

After the DEM was imported, an additional 50-foot DEM was created from the same mosaic and tile index used for the 10-ft DEM. This 50-foot DEM was used for hydro enforcement of the project area. Proprietary software was used to identify natural sinks, peaks and flat areas in the 50-foot DEM surface. Elevations of the cells in the DEM were algorithmically calculated and the best path to route flow was determined without filling sinks in the DEM. Once all calculations were completed, the flow was checked confirming that all drainage flowed downstream correctly and routed to outside of the project area.

In addition to the quantitative assessment of the source digital terrain, a qualitative visual inspection of the composite DEM was performed using a hillshade derived from the 10-foot DEM. The visual inspection indicated no unusual or non-terrestrial features were observed in the composite DEM assuring the surface files used for hydrologic and hydraulic analyses and floodplain mapping activities are sufficient for BLE analysis.

1.2 Hydrology

Flood discharges for this study were calculated using both the United States Geological Survey (USGS) regression equations and gage analysis, where stream gages with sufficient record exist. Regression equations obtained from the USGS Scientific Investigations Report (SIR) 2009-5087, *Regression Equations for Estimation of Annual Peak-Streamflow Frequency for Undeveloped Watersheds in Texas Using an L-moment Based, PRESS-Minimized, Residual-Adjusted Approach* (2009) contain the most recent regression equations for Texas.

The Watershed Information System (WISE) software was used to delineate drainage basins in shapefile format using the 50-foot DEM. WISE was also used to calculate the main-channel slope for each basin. The basin shapefile attribution was automated by WISE with drainage area, main-channel slope, precipitation, and OmegaEM.

Table 1 shows the published equations used in this study. In these equations, Q_i represents peak streamflow for i-recurrence interval (annual chance exceedance (a.c.e.)) in cubic feet per second (cfs), P represents mean annual precipitation in inches, S represents dimensionless main-channel slope, Ω represents the OmegaEM parameter, and A represents cumulative drainage area in square miles.

Table 1: Summary of Regression Equations in Texas (SIR 2009-5087)

Recurrence Interval	Equation[1]
$Q_{10\%}$	$PREC^{1.203}S^{0.403}*10^{[0.908*\Omega + 13.62 - 11.97*CONTDA\wedge(-0.0289)]}$
$Q_{4\%}$	$PREC^{1.140}S^{0.446}*10^{[0.945*\Omega + 11.79 - 9.819*CONTDA\wedge(-0.0374)]}$
$Q_{2\%}$	$PREC^{1.105}S^{0.476}*10^{[0.961*\Omega + 11.17 - 8.997*CONTDA\wedge(-0..0424)]}$
$Q_{1\%}$	$PREC^{1.071}S^{0.507}*10^{[0.969*\Omega + 10.82 - 8.448*CONTDA\wedge(-0.0467)]}$
$Q_{0.2\%}$	$PREC^{0.988}S^{0.569}*10^{[0.976*\Omega + 10.40 - 7.605*CONTDA\wedge(-0.0554)]}$

Variables:

Q_i, peak flow for i recurrence interval (a.c.e.), in cubic feet per second;
PREC, mean annual precipitation, in inches;
S, Main-channel slope (dimensionless);
Ω, OmegaEM parameter;
CONTDA, Contributing Drainage Area in square miles;

Discharges for the 1-percent plus and 1-percent minus a.c.e. were calculated as well. These values were computed as $Q_{1\%+/-} = Q_{1\%} \times (10^{\pm 0.30})$ where 0.30 is the residual standard error in $\log_{10}$-unit of cubic feet per second for the $Q_{1\%}$ equation (Table 3 in SIR 2009-5087). In other words, these values were computed by multiplying the $Q_{1\%}$ discharges by 1.995 and 0.501 respectively, which account for the log10 format residual standard error of 0.30 associated with the $Q_{1\%}$ regression equation.

The mean annual precipitation values were determined based on a shapefile coverage obtained from the Texas Water Development Board (TWDB) and is available for download at the following location: https://www.twdb.texas.gov/mapping/gisdata.asp

The annual precipitation values reflect data for the climatological period 1981-2010 as recorded by the Natural Resources Conservation Service (NRCS).

Main-channel slope was calculated in WISE. An automated routine determined the longest flowpath from upstream of a reach to the outlet of the sub-basin of interest. Two points along the channel, one at 0 percent and the other at 100 percent of the channel length, determined the endpoints of the segment used in the main-channel slope calculation. The elevations for those endpoints were based on the 10-foot DEM developed from the LiDAR.

From SIR 2009-5087, the OmegaEM parameter is a generalized terrain and climate index that expresses relative differences in peak-streamflow potential. A shapefile was developed and populated with OmegaEM values based on Figure 2 in SIR 2009-5087. This shapefile was used to determine Omega EM values on a sub-basin basis. For sub-basins spanning more than one OmegaEM grid, the sub-basin's centroid determined its OmegaEM parameter.

Drainage area for each sub-basin was determined based on automated basin delineations performed by WISE. Basin break points were set by the user with a sub-basin target size of one square mile. This criterion was adjusted for the main stem of the Lower Frio River to avoid excessive and unnecessary discharge breaks. Break points were also set immediately upstream of stream confluences. Cumulative drainage area was determined based on these automated delineations performed by WISE in combination with a stream connectivity routine that defined the stream reach segments with upstream and downstream neighbors.

The sub-basin shapefile was attributed with the computed discharges, and those discharges were incorporated into the HEC-RAS 5.0.5 models using an automated routine in WISE. Discharges, as well as water surface elevation results, were associated with the hydraulic cross sections prior to generation of floodplain boundaries and grid mapping. Those results are available in GIS format as part of this BLE submittal package.

1.2.1 Stream Gage Analysis

Figure 3 shows the location of the three (3) USGS stream gages on the Lower Frio River and one (1) USGS stream gage on the Nueces River used to develop discharges for the Lower Frio River main stem (see

Table 2). Flood frequency analyses (FFA) were performed for these gages, according to Bulletin 17C guidelines.

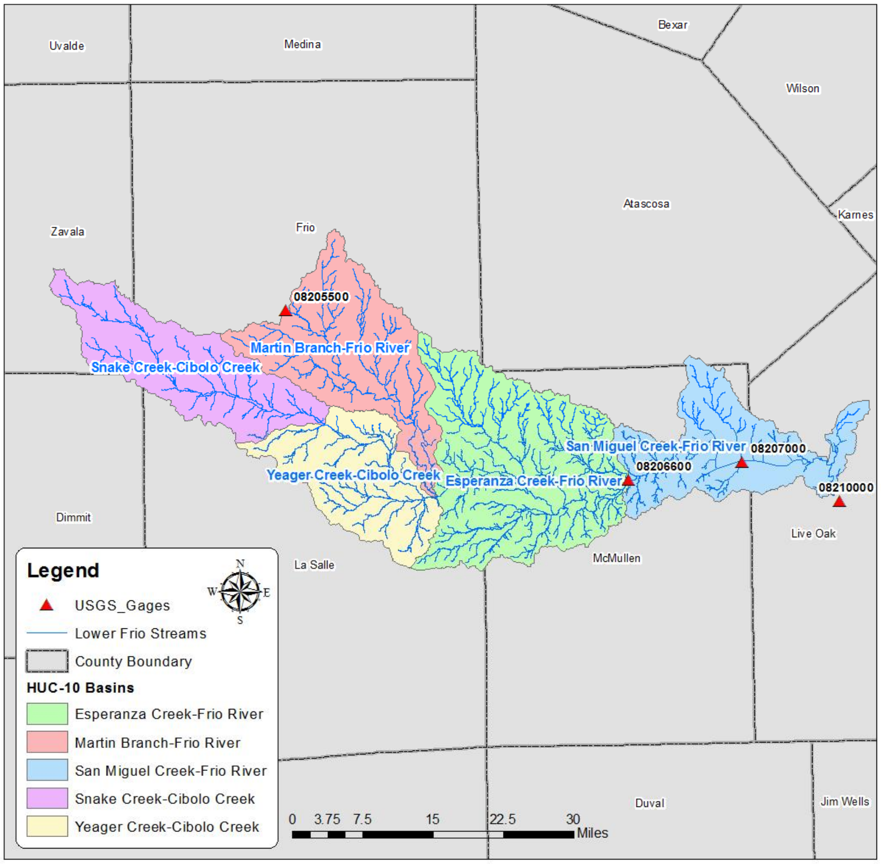

Figure 3: Locations of USGS Gages Utilized in Flood Frequency Analyses

Table 2: USGS Stream Gages in Lower Frio River Watersheds

Gage ID	Flooding Source and Location	Computed Drainage Area (mi.^{2})	Published Drainage Area (mi.^{2})	Period of Record
08205500	Frio River near Derby, TX	3,429	3,429	1916-2018
08206600	Frio River at Tilden, TX	4,447	4,493	1932-2018
08207000	Frio River at Calliham, TX	5,491	5,491	1925-1980
08210000	Nueces River Near Three River, TX	N/A	15,427	1915-2020

Stream gage analyses were performed for Frio River mainstem with the following procedures:

First, determine the frequency discharges at above mentioned gages (from upstream to downstream) using flood frequency analysis (FFA), according to Bulletin 17C (EMA) guidelines. Table 3 lists the FFA flows for USGS gages with red color text.

(1). Lower Frio River near Derby (08205500),
(2). Lower Frio River at Tilden (08206600),
(3). Lower Frio River at Calliham (0207000)
(4). Nueces River near Three River (08210000).

Second, the discharges for the reaches between gages were calculated using the flowing equation.

$$Q_{ungaged} = Q_{USgage}\ x10\text{^}(((\log(DA_{ungage})-\log(DA_{USgage}))*(\log(Q_{DSgage})-\log(Q_{USgage}))/(\log(DA_{DSgage})-\log(DA_{USgaged}))).$$

The upstream gage and downstream gage are the nearest gages from the study reach. The FFA analysis was performed using USGS computer program PeakFQ version 7.3; and a spreadsheet is available to determine the discharges for un-gaged stream reaches.

Table 3: Final Discharges at Lower Frio River in Frio River Watershed

RAS Station	Cum DA (mi^2)	10PCT (cfs)	4PCT (cfs)	2PCT (cfs)	1PCT (cfs)	0.2PCT (cfs)
641147 (Gage 08205500)	3,429	27,500	48,700	69,100	93,500	166,000
594940 (Middle of Basin1)	3,558	24,644	42,859	60,049	80,299	138,944
542886 (Basin2)	3,686	22,195	37,940	52,518	69,442	117,245
408016 (Basin3)	4,077	16,442	26,750	35,770	45,793	72,065
404831 (Basin4)	4,232	14,721	23,516	31,047	39,278	60,229
318792 (Basin5)	4,343	13,624	21,489	28,118	35,277	53,122
262817 (Gage 08206600)	4,447	12,700	19,800	25,700	32,000	47,400

RAS Station	Cum DA (mi^2)	10PCT (cfs)	4PCT (cfs)	2PCT (cfs)	1PCT (cfs)	0.2PCT (cfs)
197356 (Gage 08207000)	5,491	22,200	34,300	45,600	58,800	98,700
90527 (Choke Canyon Res)	5,530	22,274	34,422	45,768	59,025	99,101
59119 (Choke Canyon Dam)	5,574	22,355	34,556	45,953	59,271	99,539
(Gage 08210000 at Nueces River)	15,427	35,900	57,300	77,600	102,000	177,000

Figure 4 shows the relationships curves between discharges in cubic feet per second and the drainage area in square miles.

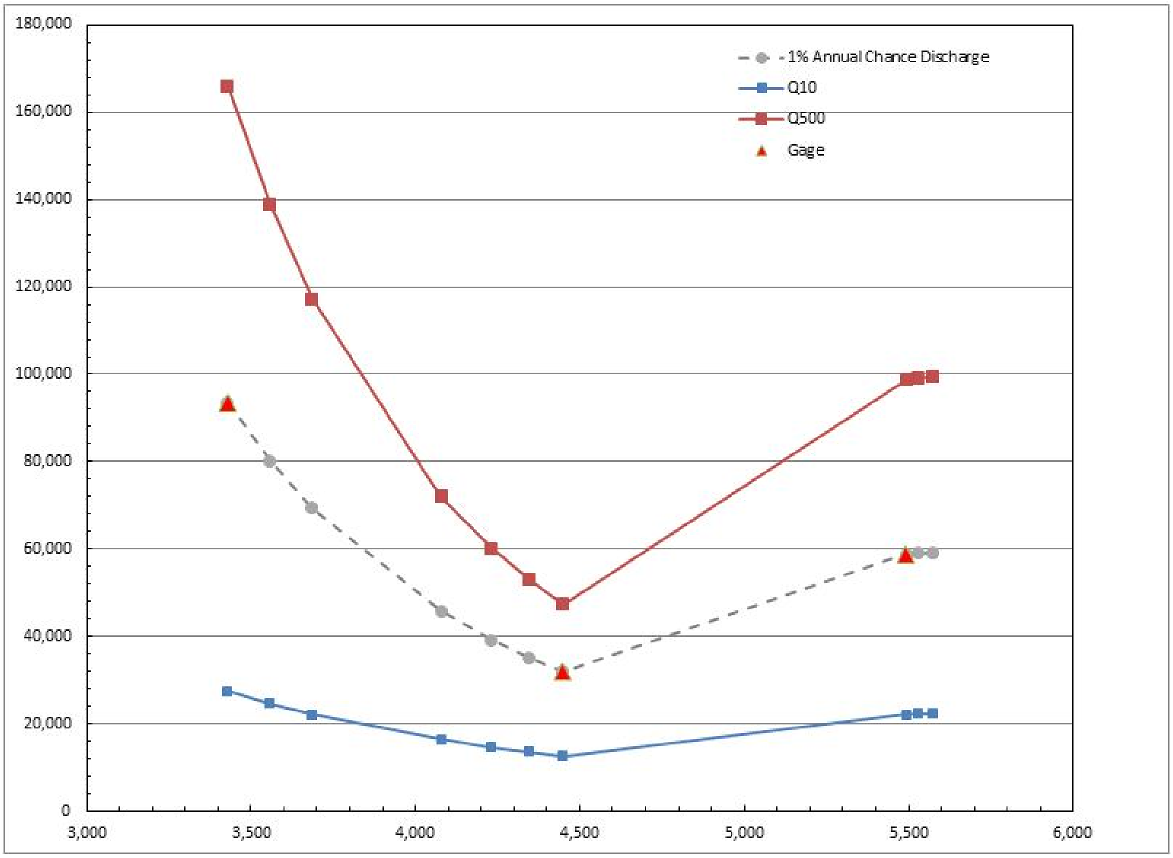

Figure 4: Discharges vs. Drainage area curves for Lower Frio River Watershed

1.2.2 Special Considerations

One issue note while applying gage analysis was that downstream of Choke Canyon Reservoir there are no USGS gages located along the Frio River. In order to estimate reasonable discharges downstream of Choke Canyon Reservoir, a USGS Gage 0821000 (Nueces River Near Three River, TX) was selected for the FFA, and application of a drainage area (DA) ratio was used to estimate the discharges for Frio River main stem basins downstream of Choke Canyon Reservoir.

It was also noted that the discharges are reduced with the drainage increased for stream reaches from USGS Gage 08205500 to USGS Gage 08206600, the reason is explained from USGS Water-Year Summary 2019, "*PART OF THE FLOW OF FRIO RIVER AND ITS HEADWATER TRIBUTARIES ENTERS THE EDWARDS AND ASSOCIATED LIMESTONES IN THE BALCONES FAULT ZONE UPSTREAM FROM U.S. HIGHWAY 90. THERE IS CONSIDERABLE LOSS OF FLOW INTO VARIOUS PERMEABLE FORMATIONS DOWNSTREAM FROM BALCONES FAULT ZONE*".

1.3 Hydraulics

The hydraulic approach for this BLE analysis of the Lower Frio Watershed consisted of using the terrain model described in Section 1.1 in combination with the hydrologic outputs from Section 1.2 to establish water surface elevations using 1-D steady state analysis. The Hydrologic Engineering Center's River Analysis System (HEC-RAS) program version 5.0.5 was chosen as the computer model to compute water surface elevations on a stream by stream basis. The WISE software was used to establish model stream orientation, generate initial hydraulic cross section layout and stationing, assign n-values to cross sections, and develop all input files for the HEC-RAS program. ESRI's ArcMap program was used to review and refine cross-section layout orientation.

First pass cross-section layout was performed using an automated routine in WISE that varies cross section spacing based on the cumulative drainage area at the cross section location. A first draft model was created based on this initial cross-section layout, and draft boundaries were developed. Next, a second pass inspection for cross-section placement and alignment occurred. Significant refinement occurred during this step. To improve the hydraulic models, additional cross-sections were added as needed to better define the BLE floodplain boundary. Cross-sections were extended in locations where overtopping occurred. Orientation of cross-sections was refined to improve on the perpendicular orientation to flow. Additional cross-sections were added at floodplain constrictions and at downstream portions of tributaries to ensure a proper tie-in with receiving streams. Cross-sections were adjusted to remove sections that intersected hydraulic crossings in the floodplain. For some of the largest studied streams, cross-sections were laid out manually in order to have more reasonable spacing and better capture the constrictions in the floodplain.

Cross-sections were not drawn on top of roadways or railroads but were placed at the upstream and downstream face of major roads and railroads. Ineffective flow stations were placed in the hydraulic models as appropriate to account for flow constrictions and other locations deemed by the engineer to be ineffective at conveying flow downstream.

Cross-sections were drawn on dam crests for dams with well-defined spillways in order to better represent ponded water upstream of the structures. In so doing, it was assumed that the vast majority of the flow during a flood event would pass the spillway and that the hydraulic model would reasonably estimate flow across the spillway as represented in the hydraulic cross-section. The elevations used in the modeling were checked against effective Zone A boundaries, and the results were deemed reasonable.

The relationship between cumulative drainage area and assigned channel geometry is shown in Table 4. These default values for dimensions and spacing were subject to change based on engineering judgment.

Table 4: Cross-Section Default Parameters

Drainage area (upper limit)	XS Spacing	Channel Top Width	Channel Bottom Width	Channel Depth
1	300	7	6	0.8
2	300	8	7	0.8
4	300	11	10	0.8
8	400	12	11	0.8
10	500	13	12	0.8
15	500	18	13	0.8
20	500	19	14	0.8
25	500	20	15	0.8
30	500	21	16	0.8
40	500	25	17	0.8
50	600	28	18	0.8
75	600	30	19	1
100	750	33	20	1
150	750	36	21	1
250	1000	38	22	2
500	1500	40	23	2
1000	2500	100	50	3
2000	2500	150	75	3
5000	2500	200	100	3

In typical BLE projects, Manning's roughness coefficients (n-values) are determined using the 2016 National Land Cover Data (NLCD) dataset in combination with n-values from Chow (1959) and Calenda et al. (2005). For this watershed, the n-values for the developed areas indicated an underestimation of the roughness coefficients when compared to the aerial imagery and were adjusted accordingly. The association between the n-values and the NLCD Classification is shown in Table 5. Manning's n-value takeoffs are performed by WISE (default values taken from the "Normal" column). N-values within channel banks are constrained by the automated routine to a range of 0.030 to 0.070. Then, overbank and channel n-values are manually adjusted in certain locations based on engineering judgment.

Table 5: Manning's "n" Roughness Based on 2016 NLCD Classification (Moore, 2011)

NLCD Classification	Selected Manning's N	Minimum	Normal	Maximum	Source
Open Water	0.033	0.025	0.03	0.033	Chow 1959
Developed, Open Space	0.04	0.01	0.013	0.016	Calenda et al. 2005
Developed, Low Intensity	0.08	0.038	0.05	0.063	Calenda et al. 2005
Developed, Medium Intensity	0.1	0.056	0.075	0.094	Calenda et al. 2005
Developed, High Intensity	0.15	0.075	0.1	0.125	Calenda et al. 2005
Barren Land	0.025	0.025	0.03	0.035	Chow 1959
Deciduous Forest	0.16	0.1	0.12	0.16	Chow 1959
Evergreen Forest	0.16	0.1	0.12	0.16	Chow 1959
Mixed Forest	0.16	0.1	0.12	0.16	Chow 1959

NLCD Classification	Selected Manning's N	Minimum	Normal	Maximum	Source
Scrub/Shrub	0.1	0.035	0.05	0.1	Chow 1959
Grassland/Herbaceous	0.035	0.025	0.03	0.035	Chow 1959
Pasture/Hay	0.03	0.03	0.04	0.05	Chow 1959
Cultivated Crops	0.035	0.025	0.035	0.045	Chow 1959
Woody Wetlands	0.12	0.08	0.1	0.12	Chow 1959
Emergent Herbaceous Wetland	0.07	0.07	0.1	0.15	Chow 1959

The boundary condition used for the majority of the study streams was normal depth with a default value of 0.005 ft/ft. For streams with large drainage areas (generally greater than 8 square miles), the normal depth slope was calculated based on the channel inverts of the downstream cross sections.

In cases where streams tie in to a lake, a normal depth slope was calculated based on the channel inverts of the downstream cross sections (typically between 0.0001 and 0.001 ft/ft). Several HUC-10s within this watershed are located in urban areas with storm drain systems, which are unaccounted for in the BLE models. Implications of these systems may considerably affect risk.

1.4 Quality Control

Following the initial hydraulic model analysis in each watershed, the resulting flood hazard area delineations were reviewed for areas where the results were not ideal.

QC results indicated that some of the models should be extended to cover the scope of effective flood hazard data. Those streams were extended farther upstream to match the extents of the effective SFHA data.

Typical revisions resulting from reasonability checks included adding cross-sections, adjusting orientation of cross-sections, trimming cross-sections and reduction of the default "V" angle of cross-sections. Examples of default "V" angled cross-sections are shown in Figure 5Error! Reference source not found.. It is estimated that 75 percent of cross-sections were adjusted in some work areas while other areas did not require as much editing. Other examples of manual editing included the addition of cross-sections at confluence areas (see Figure 5Error! Reference source not found. below), modifications to improve perpendicular orientation at the channel, adjustment of discharge breaks to better represent flow addition points, revisions to cross sections at dams, additional cross-sections bounding major hydraulic structures, and revisions to n-values.

A major component of the QC process was an automated check that identified locations where the 1-percent a.c.e profile was crossed by any other frequency profile. Significant effort was made to reasonably resolve all of these instances. Another automated check identified locations where there was a drawdown of greater than 0.5 foot on the 1-percent a.c.e. water surface profile. This check is particularly useful for identifying errors in the model such as a channel that is too wide, a poorly placed cross-section, or a need for additional cross-sections. Again, significant effort was made to reasonably resolve these drawdown situations.

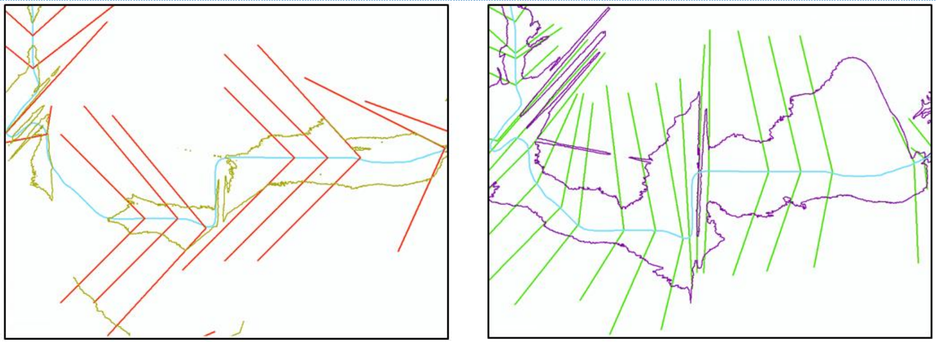

Figure 5: Default "V" angle cross-sections automated by WISE (left). Manually edited cross-sections to more accurately capture terrain (right). Resulting flood boundaries shown in gold (left) or purple (right) for clarity.

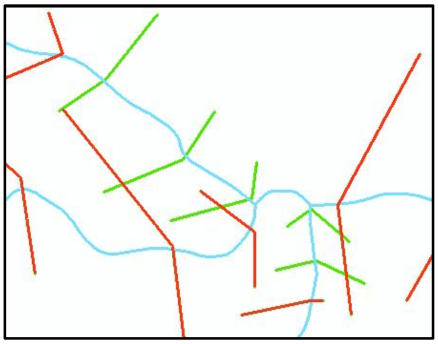

Figure 6: Manually added cross-sections (green) to improve accuracy of tie-ins at confluences.

1.5 One-percent Special Flood Hazard Area Delineation

The 1-percent and 0.2-percent boundaries were mapped using a routine that develops water surface elevation grids based on the 10-foot cell size DEM developed from the LiDAR dataset used for this project (see Section 1.1). This product was converted to a polygon for cleaning. The cleaning routine involved manual inspection of the polygons to identify and remove areas of disconnected flooding. In general, all polygons greater than 5,000 square feet are investigated, but all polygons, including those less than 5,000 square feet that intersect the stream lines were included in the final output. This investigation was aided by the ground DEM and aerial imagery. Manual adjustments to the polygons were made to account for spillways on dams which could not be accurately modeled using HEC-RAS as well as disconnected areas along the flooding source that should reasonably be connected.

Following the removal of disconnected flooding areas and other boundary adjustments, the small islands in the floodplain were filled. In general, islands less than 2 acres were inspected and filled.

Once the island filling process was complete, the water surface raster mapping routine was run and set to conform to the polygon boundary. This ensures that the water surface raster and the floodplain boundary are consistent with each other. The depth raster product was created at the end of the process by performing a raster subtraction with the water surface elevation raster and the ground DEM.

Challenges

The Lower Frio Watershed is located in Central Texas, an area known for flat terrain. In some of the wide and flat floodplains, small tributaries run parallel to large streams. Parallel streams with shared floodplains were modeled by moving the combined discharge upstream to the cross-section that begins the shared floodplain.

A significant effort was made to achieve proper 1%-acf water surface elevation tie-ins at stream confluences. Cross-sections were manually added on the downstream end of nearly every stream, some of which traverse the receiving stream; so that the water surface elevation of the tributary would be lower than that of the receiving stream.

There are a significant number of dams of varying sizes throughout the watershed. Discharges calculated with the regression equations do not take into account the impact of these structures. There may be need for further investigation, particularly for those dams designed for flood control, when upgrading these models for detailed studies.

There are a few containment issues across the study area. In some areas the 0.2%-acf flows overtopped cross section. For these situations, additional investigation is recommended when upgrading these models for detailed study.

The Three River Levee is located the downstream end of the Frio River Mainstem near the City of Three Rivers. This levee is non-accredited as it does not meet the 44 CFR Part 65.10. BLE mapping reflects a natural valley floodplain approach. Further detailed analysis may be required to determine the levee's impact on the flooding.

Coordination efforts were made with the Lower Nueces BLE and Atascosa BLE studies to ensure a tie-in. Incorporating the tie-ins from these watersheds may result in water surface elevation data within the modeling to be less than what is shown in the grids/floodplain results.

For the Frio River mainstem hydraulic model, the Choke Canyon Dam is located approximately 4 miles west of Three Rivers in Live Oak County, on the Frio River. The modeled 100-year WSEL within the dam is 225.42'. This 100-yr WSEL was deemed reasonable for this BLE study as it is higher than both the conservation pool elevation of 220.58, and the recorded historical high water surface of 222.36 (2007-07-10); it is also lower than maximum design elevation of 232.26 (https://www.waterdatafortexas.org/reservoirs/individual/choke-canyon.csv). In order to achieve reasonable WSELs within the lake, the lake inverts were manually estimated below the water surface that was picked up by the LiDAR data (RS 59119 to RS 146755). The top of dam cross section at station 57800 was adjusted to include the emergency spillway which is approximately 400 feet wide. Ineffective flow areas were added to the lake cross sections (set everything below the normal/conservation pool elevation to ineffective) to ensure all modeled elevations are estimated at or above the conservation pool elevation.

In Esperanza Creek-Frio River HUC-10, there are several locations where the hydrastreams are inconsistent with the hydrostreams, thus the basin boundaries have to be changed manually to follow the hydrastreams. For example, Basin 290 (UNT148 in EspCr Watershed), if flows the hydrostream, the water would flow to south to the downstream basin 309; however, the hydrastream shows the flow path should be toward to east, and flows into the downstream Basin 493. The final basin delineation was followed the hydrastreams. Manual changes did result in additional modeling time.

Because of the dramatic terrain change at some locations, the mapping rasters had gaps between cross sections, thus more cross sections are needed to fill the mapping gaps. An example is the UNT150 in EspCr Watershed, cross section XS36610 upstream to XS38862, the cross section spacings have to be close to below 100ft to achieve the reasonable mapping.

In Yeager Creek watershed, UNT 208 in Yeager Cr Watershed has an area where the stream runs parallel with Cibolo Creek, another stream with higher drainage area. This makes it harder to find a high ground to tie in the cross sections. UNT 212 in Yeager Cr Watershed and UNT 219 in Yeager Cr Watershed contain area in which the channel is shallow to carry enough water, causing a spread in flood waters.

In Martin Branch HUC-10 watershed, multiple streams require further study. UNT 025 in Martin Branch watershed is located in an urban area. Mule Creek and UNT 001 require further study due to overflow between these two streams. This same situation is observed between streams UNT 050 and UNT 046.

Results and Recommendations

The BLE results for this study produced a SFHA that compares favorably with the effective SFHA. These boundaries provide an estimated SFHA in areas that have not been previously studied and therefore do not currently have an SFHA mapped. These results provide context for flood risk communication as part of the Discovery process, and should be verified through community work map meetings before being applied to a regulatory product.

A map showing the BLE results is included as Appendix A.

3.1 CNMS Validation of Effective Zone A SFHA

The inventory of Zone A studies (305.77 miles) in the Lower Frio Watershed were classified in CNMS with validation status of “UNVERIFIED” (297.1 miles) or “VALID” (8.6 miles), and with status type of “BEING STUDIED.” The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A3 were evaluated for the CNMS inventory of Zone A studies.

INITIAL ASSESSMENT A1 – SIGNIFICANT TOPOGRAPHY UPDATE CHECK

This check involves determining whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. For the study area in the Lower Frio Watershed, the effective Zone A topographic data leveraged was based upon United States Interagency Elevation Inventory. The LiDAR sources discussed in Section 1.1 are a significant improvement from the effective Zone A topographic source for the entire study area. Therefore, all reaches failed this check.

INITIAL ASSESSMENT A2 – CHECK FOR SIGNIFICANT HYDROLOGY CHANGES

This check involves first determining if regression equations were used for the effective study. Next, it must be determined whether new regression equations have become available from the USGS since the date of the effective Zone A study. If newer regression equations exist for the area of interest, then an engineer must determine whether these regression equations would significantly affect the 1-percent annual chance flow.

Regression equations were not used for any effective Zone A study areas located in the Lower Frio watershed and, therefore, pass this assessment check.

INITIAL ASSESSMENT A3 – CHECK FOR SIGNIFICANT DEVELOPMENT

This check involves using the National Urban Change Indicator (NUCI) dataset to assess increased urbanization in the watershed of the Zone A study. If the percentage of urban area within the HUC-12 watershed containing the effective Zone A study is 15% or more, and has increased by 50% or more since the effective analysis, the study would fail this check. Although the NUCI data provide year-to-year changes in urbanization, the NLCD also is needed to establish a baseline of urban land cover for this analysis. The check for significant development in this watershed was completed by evaluating percentage of urban change at the HUC-12 level. The entire study area is still classified as rural, so all reaches pass this check.

All of the initial assessment results are shown in Table 6.

Table 6: Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Fail	LiDAR sources available are a significant improvement from effective topography
A2 – Hydrology	Pass	Regression equations not used in effective study
A3 – Development	Pass	HUC-12 watershed does not meet urban threshold

VALIDATION CHECK A4 – CHECK OF STUDIES BACKED BY TECHNICAL DATA

Zone A studies that pass all initial assessment checks described above may be categorized as “Valid” in the CNMS Inventory only if the effective Zone A study is supported by modeling or sound engineering judgment and all regulatory products are in agreement. If the effective Zone A study passes all initial assessment checks, but is not supported by modeling, or if the original engineering method used is unsupported or undocumented, a comparison of the BLE results and effective Zone A’s is performed. All Zone A studies within the Lower Frio Watershed are not model-backed studies and, therefore, fail this check.

VALIDATION CHECK A5 – COMPARISON OF BLE AND EFFECTIVE ZONE A

The BLE /effective Zone A comparison method leverages the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach uses the 1-percent plus and 1-percent minus flood profiles and horizontal and vertical tolerances described in FEMA’s Automated Engineering guidance document dated May 2016. For the comparison of BLE and effective Zone A in the Texas study area, the following vertical and horizontal tolerances were used to conduct the modified FBS procedure. One point was placed every 200 feet along the floodplain boundaries for comparison.

- Vertical Tolerance: +/- 10 feet (one-half contour interval of assumed effective topographic source).

- Horizontal Tolerance: +/- 75 feet (standard horizontal tolerance for BLE comparison testing).

Comparison results for these streams were grouped at the HUC-12 level and are summarized in Table 7 to better understand the general health of the HUC-12 watershed, but the validation check was performed at the stream level. Streams where the percentage of passing FBS sample points is greater than or equal to 85% are marked as “Pass”, otherwise marked as “Fail”.

Table 7: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Lower Frio Watershed	All Streams	18,442	7,186	11256	61%	FAIL	
Black Hill Hollow-Frio River	121101080502	1293	500	793	61%	FAIL	19.3
Elm Creek-Galinda Creek	121101080405	914	394	520	57%	FAIL	21.6
Galinda Creek-Frio River	121101080407	1508	786	722	48%	FAIL	26.1
Hackberry Creek-Frio River	121101080506	305	159	146	48%	FAIL	26.1
Headwaters Cibolo Creek	121101080201	556	90	466	84%	FAIL	8.1
Javelina Hollow-Frio River	121101080408	1396	551	845	61%	FAIL	19.7
Lower Esperanza Creek	121101080404	101	67	34	34%	FAIL	33.2
Lower Leoncita Creek	121101080410	2806	1168	1638	58%	FAIL	20.8
Middle Esperanza Creek	121101080403	2262	709	1553	69%	FAIL	15.7
Muerto Creek-Galinda Creek	121101080406	1044	487	557	53%	FAIL	23.3
Opossum Creek-Frio River	121101080504	1519	660	859	57%	FAIL	21.7
Opossum Hollow-Frio River	121101080505	578	231	347	60%	FAIL	20.0
Salt Branch-Frio River	121101080501	1126	365	761	68%	FAIL	16.2
Sevenmile Creek-Frio River	121101080401	94	66	28	30%	FAIL	35.1
Snake Creek	121101080202	368	72	296	80%	FAIL	9.8
Upper Esperanza Creek	121101080402	297	38	259	87%	PASS	6.4
Upper Leoncita Creek	121101080409	1541	563	978	63%	FAIL	18.3
Yarbrough Lake-Frio River	121101080503	734	280	454	62%	FAIL	19.1

VALIDATION RESULTS

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Lower Frio Watershed has been updated as summarized in Table 8 and illustrated in Figure 7 below.

Table 8: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	8.6
UNVERIFIED	BEING STUDIED	297.1

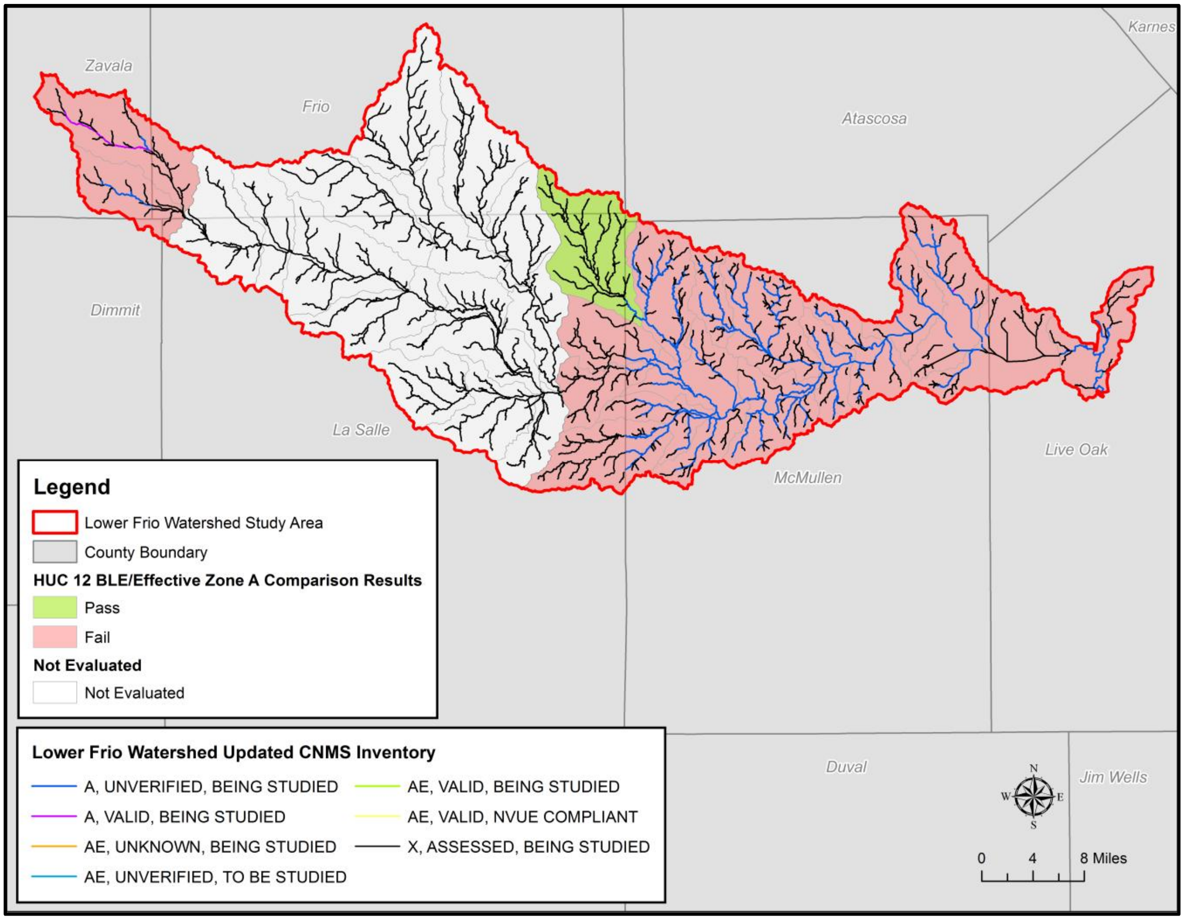

Figure 7: Lower Frio Watershed CNMS Validation Results

An overall risk for each HUC-12 watershed was calculated using the National Flood Risk Percentages Dataset and its proportional area. The weighted risk was multiplied by the percentage of points in the watershed that failed the CNMS comparison to effective to determine the priority score. Figure 8 below shows the range of the HUC-12 priority scores which can be used to initiate discussions during the Discovery phase.

Sevenmile Creek-Frio River HUC-12 was determined to have the highest priority score and the most need while Upper Esperanza Creek HUC-12 had the lowest scores.

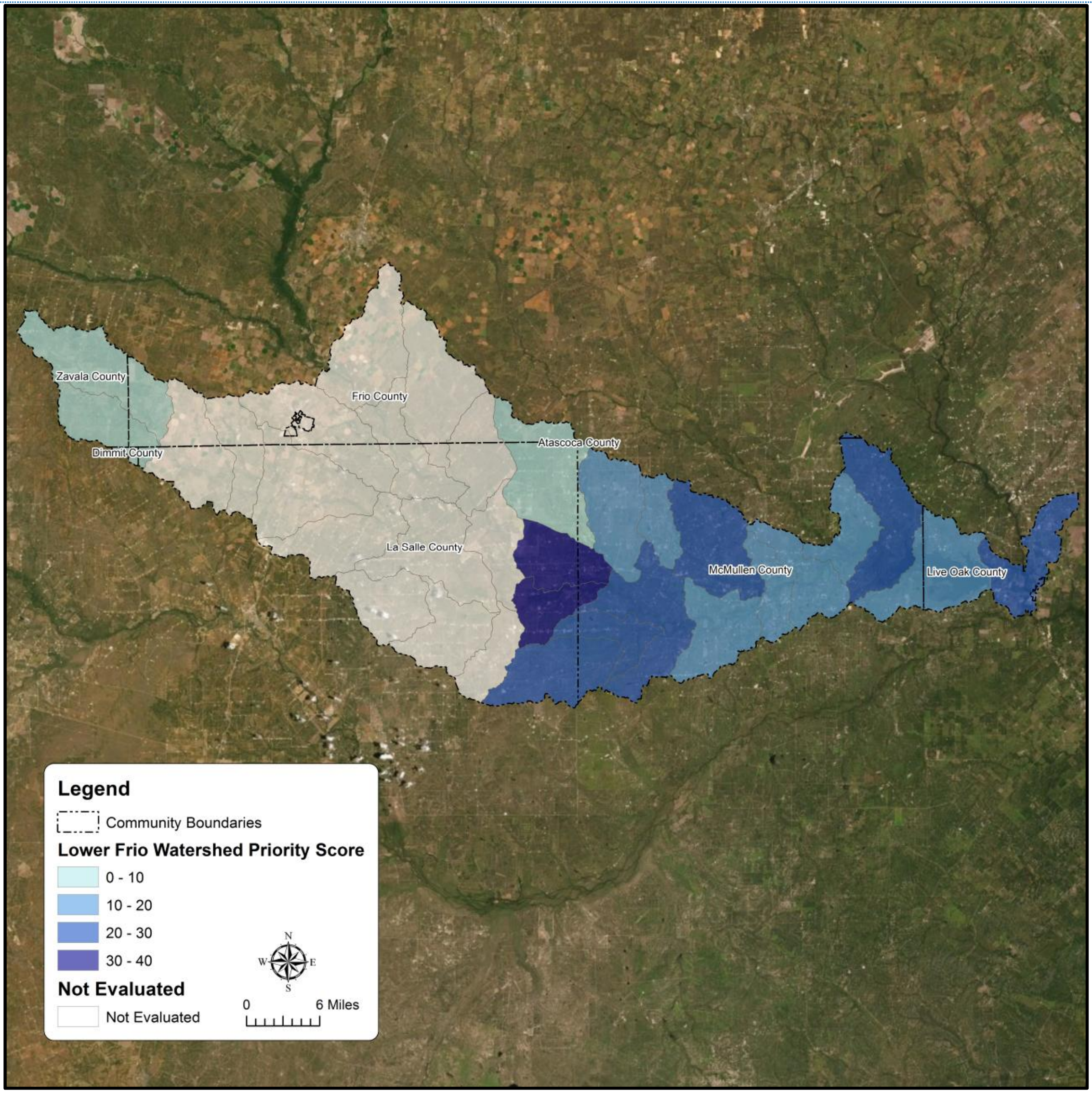

Figure 8: Ranking of Lower Frio Watershed HUC-12s

3.2 Flood Risk Analysis

An advanced flood risk analysis was performed using the updated 1-percent-annual-chance grid (known as ‘refined base level engineering grid”) created for this project. The loss analysis uses 2010 census data and the subsequent results are stored in the L_RA_Results table.

Hazus version 4.2 was used for the loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 4.0 uses dasymetric census blocks. Dasymetric mapping removes undeveloped areas (such as areas covered by other bodies of water, wetlands, or forests) from the Census blocks, changing their shape and reducing their size in these areas. For more information on dasymetric data visit FEMA’s Media Library for the Hazus-MH Data Inventories: Dasymetric vs. Homogenous, or Hazus 3.0 Dasymetric Data Overview.

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Appendix A BLE Map