Compass
Identify, Interpret, Integrate

Yegua Watershed, TX
Base Level Engineering (BLE) Results

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Executive Summary

FEMA Region VI contracted Compass to complete a Base Level Engineering (BLE) analysis for the Yegua 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	Yegua Stream Miles
CNMS	1,064.0

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	564.7
UNVERIFIED	BEING STUDIED	499.3

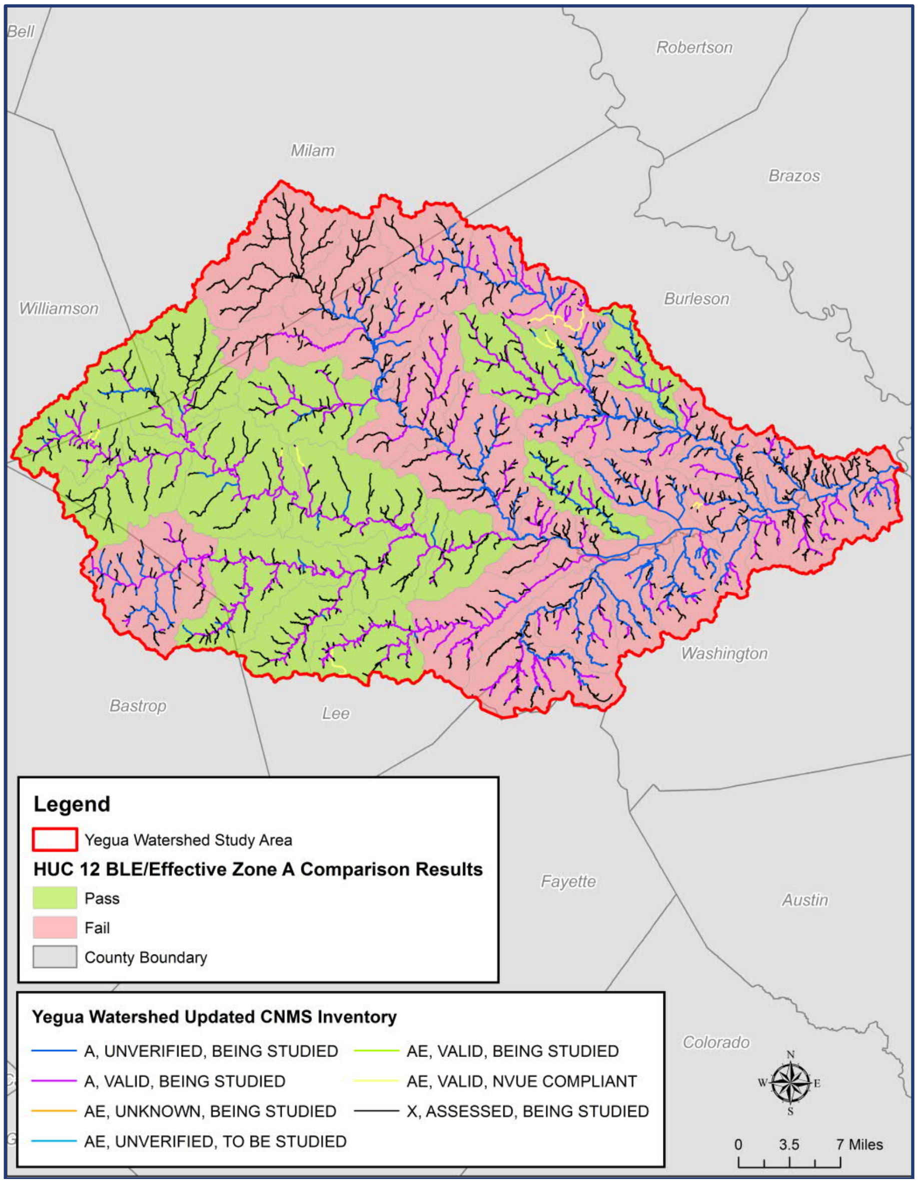

Figure ES-1: Yegua Watershed CNMS Validation Results

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 Yegua HUC-8 priority scores which can be used to initiate discussions during the Discovery phase.

Independence Creek-Yegua Creek River HUC-12 was determined to have the highest priority score and the most need while Upper Nail Creek HUC-12 had the lowest score.

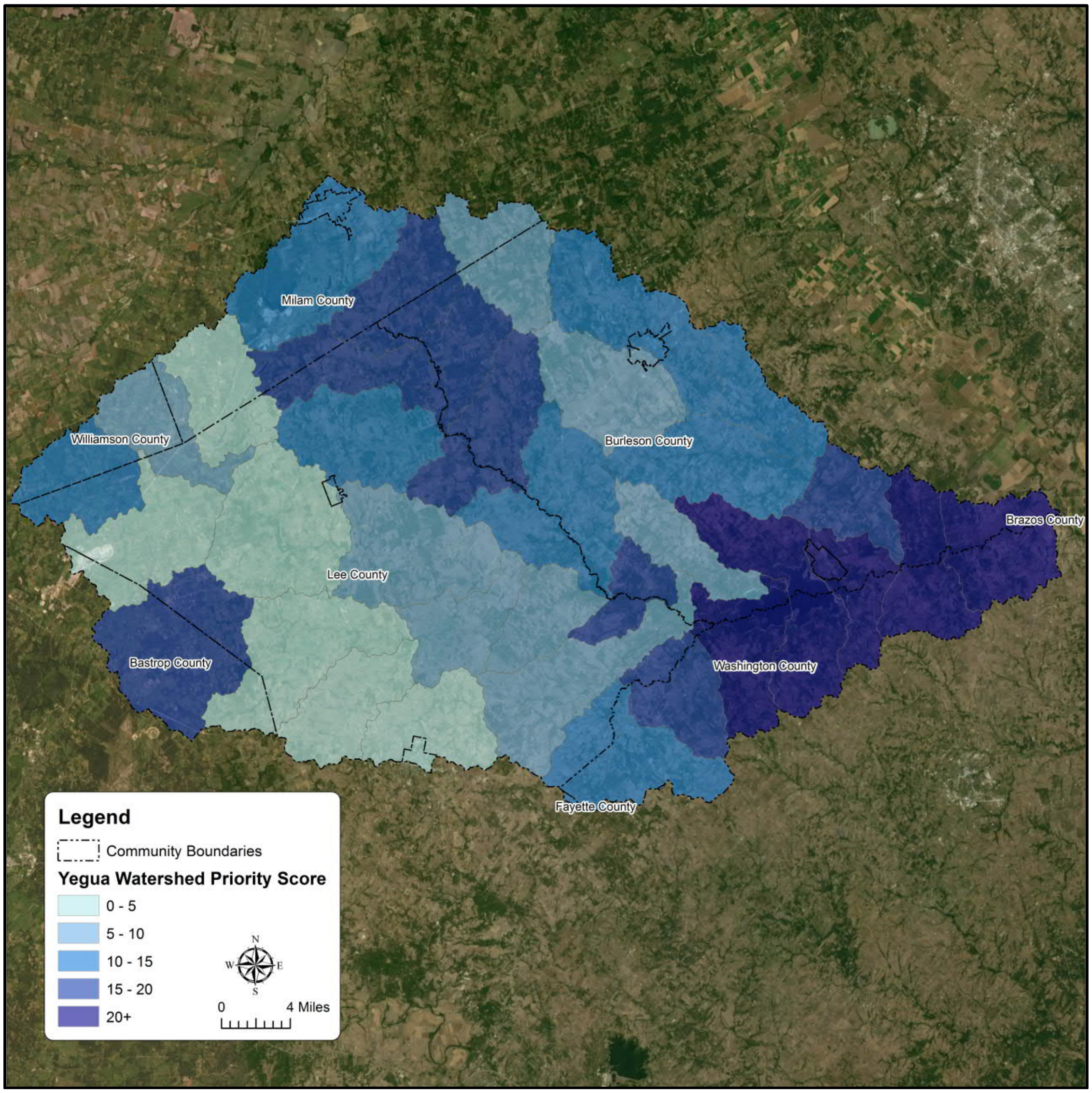

Figure ES-2: Ranking of Yegua Watershed HUC-12s

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 VI contracted Compass to complete a BLE analysis for the Yegua 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 Bastrop, Burleson, Fayette, Lee, Milam, Washington, and Williamson Counties, and include the following communities: the Cities of Caldwell, Carmine, Giddings and Somerville, and Town of Lexington. The study area consists of five HUC-10 basins: Davidson Creek, East Yegua Creek, Middle Yegua Creek, Nails Creek-Yegua

Creek, and Yegua Creek. Figure 1 shows the orientation of the Yegua HUC-10 basins with respect to the counties.

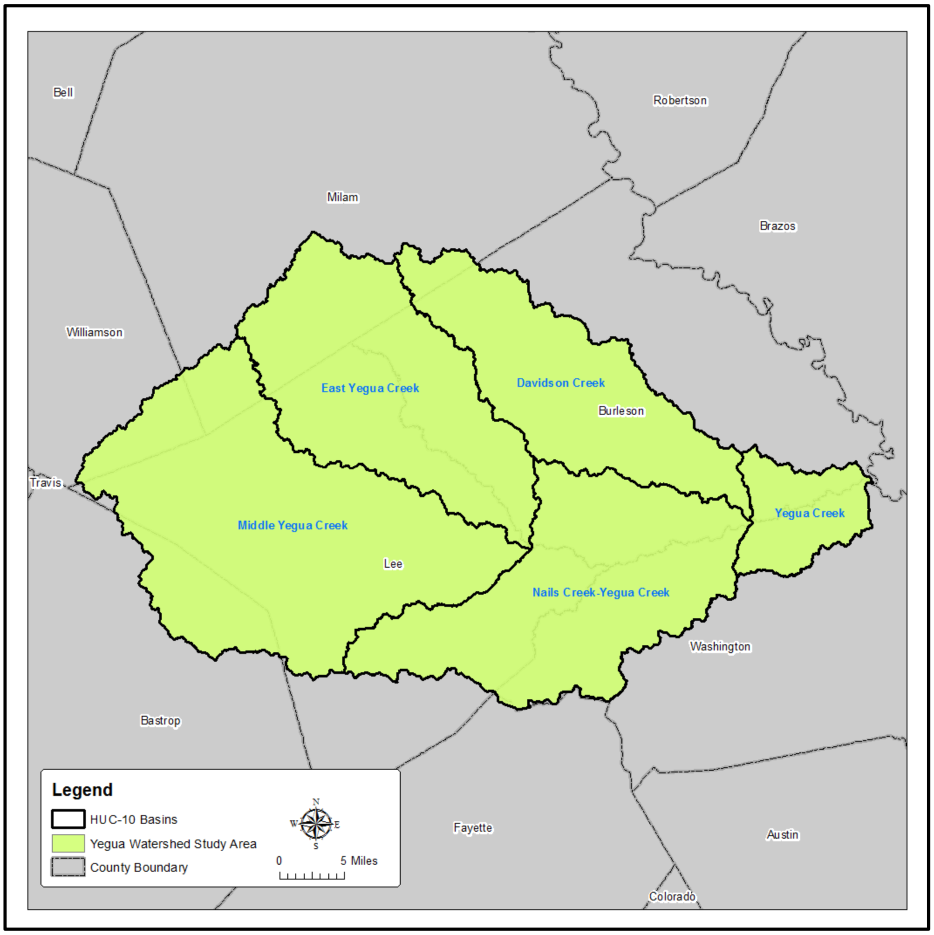

Figure 1: Yegua Watershed HUC-10 Basins

AECOM studied approximately 1,930 miles of stream reaches within the Yegua 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 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 Yegua Watershed.

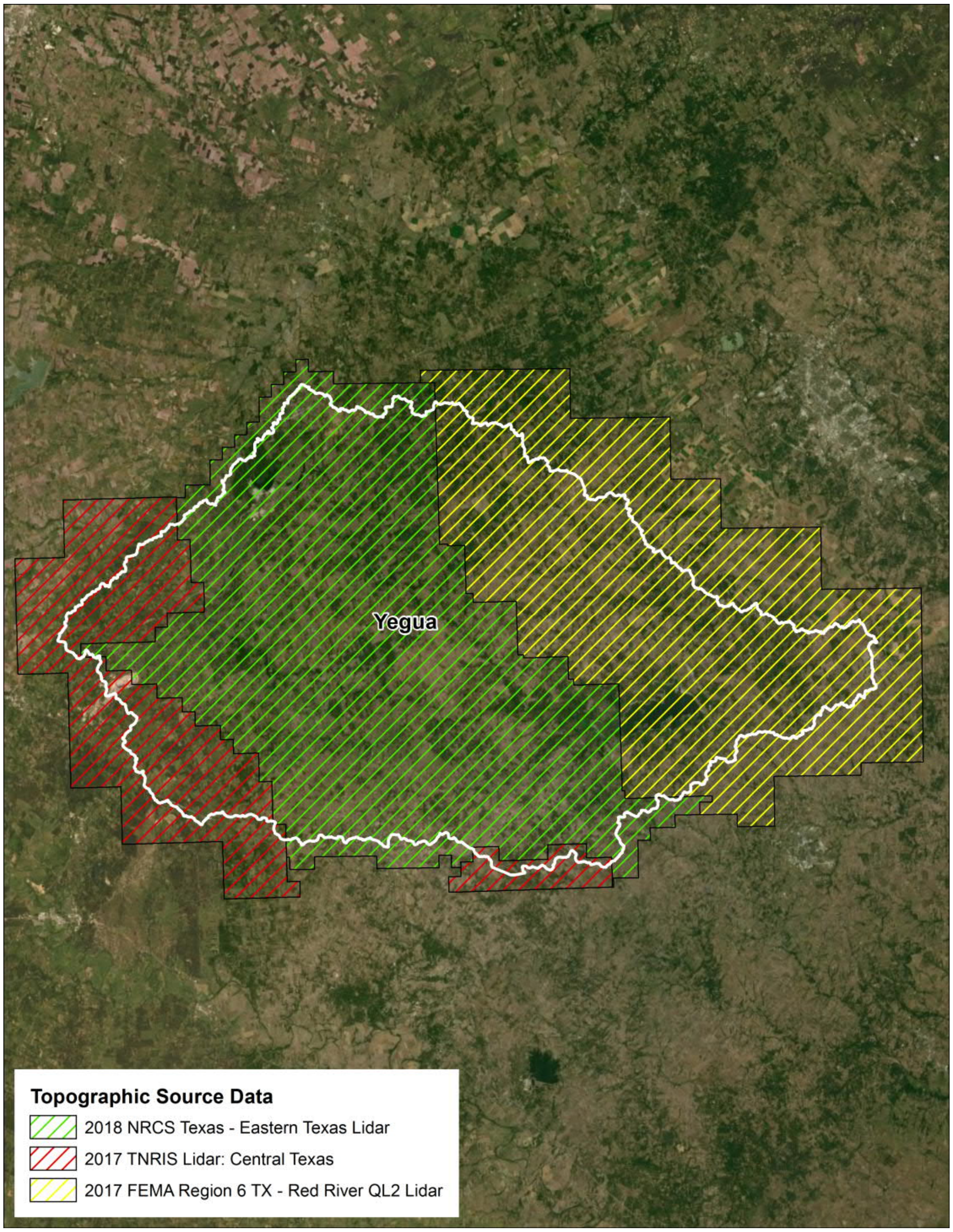

Figure 2: Extent of LiDAR Data for Yegua Watershed

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 NRCS Texas – Eastern Texas LiDAR

The 2018 NRCS Texas – Eastern Texas LiDAR was acquired from the United States Geological Survey (USGS). Data was collected and processed by Digital Aerial Solutions (DAS), LLC. The LiDAR data was collected from March 6th to March 21st of 2018. This task order requires LiDAR data to be acquired over approximately 5,577 square miles of LiDAR affecting Leon, Washington, Sabine, San Jacinto, Shelby, Grimes, Lee, Madison, Milam, Trinity and Newton Counties in Texas. The LiDAR was collected at a nominal pulse spacing (NPS) of 0.7 meters. The LiDAR data was acquired and processed in compliance with USGS National Geospatial Program LiDAR Base Specification version 1.2. The Root Mean Square Error (RMSE)z reported for the dataset was 5.1 cm at the 95% confidence level which meets project accuracy specifications of the National Standard for Spatial Data Accuracy (NSSDA).

1.1.1.2 2017 TNRIS LiDAR: Central Texas

Texas Water Development Board (TWDB) in cooperation with their project partners tasked Fugro Geospatial, Inc. (Fugro) under the Department of Information Resources (DIR) Geographic Information Systems (GIS) Hardware, Software and Services contract also known as the StratMap contract to acquire high resolution elevation data and associated products from airborne LiDAR systems during the 2016-2017 leaf-off season. The collection took place from January 28th through March 22nd, 2017. The StratMap Program promotes inter-governmental collaboration and partnerships to purchase geospatial data products that provide cost savings and project efficiencies. Both the StratMap Program and the StratMap Contract are administered by Texas Natural Resources Information System (TNRIS), a division of TWDB. Project partners include: Williamson County (Wilco), City of San Marcos (COSM), City of Round Rock (CORR), United States Fish and Wildlife Service (USFWS), USGS, NRCS, and the River Authority. This Central Texas project consists of approximately 6,570 square miles and is located in Central Texas around the I-35 corridor from Williamson County to Bexar County. The project includes large metropolitan areas as well as various vegetation classifications spanning farmland to dense forest. The San Antonio Area of Interest (AOI) consists of approximately 887 square miles and was acquired utilizing a Riegl LMS-Q680i sensor; collecting multiple return x, y, and z as well as intensity data. Specialized in-house and commercial software processes the native LiDAR data into 3-dimensional positions that can be imported into GIS software for visualization and further analysis. The horizontal datum for the data is the NAD83, 2011 in meters and the vertical datum is the NAVD88 in meters realized with GEOID12B.

1.1.1.3 2017 FEMA Region 6 TX – Red River QL2 LiDAR

DAS collected 5,445 square miles in the Texas counties of Brazos, McLennan, Freestone, Washington, Falls, Grimes, Navarro, Milam, Limestone, Hill, Robertson, and Burleson. The purpose of this LiDAR data was to produce high accuracy 3D elevation products, including tiled LiDAR in LAS 1.4 format, 3D breaklines, and 1 meter cell size hydro flattened Digital Elevation Models (DEMs). All products follow and comply with USGS LiDAR Base Specification Version 1.2. The nominal pulse spacing for this project was 1 point every 0.7 meters. Dewberry used proprietary procedures to classify the LAS according to project specifications: 1-Unclassified, 2-Ground, 7-Low Noise, 9-Water, 10-Ignored Ground due to breakline proximity, 17- Bridges, 18-High Noise. Dewberry produced 3D breaklines and combined these with the final LiDAR data to produce seamless hydro flattened DEMs for the project area. The data was formatted according to the

United States National Grid (USNG) tile naming convention with each tile covering an area of 1,500 meters by 1,500 meters.

1.1.2 Terrain Data Processing

The LiDAR data were processed in Environmental System Research Institute (ESRI) ArcGIS software to create a composite 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 Yegua 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 NRCS Texas - Eastern Texas LiDAR dataset was prioritized as the best data source for the Yegua Watershed followed by the 2017 TNRIS LiDAR: Central Texas, and 2017 FEMA Region 6 TX - Red River QL2 LiDAR.

The 10-foot DEMs created from the LiDAR datasets described in Section 2.2 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 50,000-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 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. USGS Peak FQ Version 7.3 was used to perform the Flood Frequency Analysis (FFA) for the four gages within the Yegua Watershed (see below for further discussion).

1.2.1 Regression Analysis

The 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, all inputs for the USGS regression equations.

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
$Q_{10\%}$	$P^{1.203} \times S^{0.403} \times 10^{[0.918\Omega + 13.62 – 11.97A\wedge(-0.0289)]}$
$Q_{4\%}$	$P^{1.140} \times S^{0.446} \times 10^{[0.945\Omega + 11.79 – 9.819A\wedge(-0.0374)]}$
$Q_{2\%}$	$P^{1.105} \times S^{0.476} \times 10^{[0.961\Omega + 11.17 – 8.997A\wedge(-0.0424)]}$
$Q_{1\%}$	$P^{1.071} \times S^{0.507} \times 10^{[0.969\Omega + 10.82 – 8.448A\wedge(-0.0467)]}$
$Q_{0.2\%}$	$P^{0.988} \times S^{0.569} \times 10^{[0.976\Omega + 10.40 – 7.605A\wedge(-0.0554)]}$

Variables:
- Q_i, peak flow for i recurrence interval (a.c.e.), in cubic feet per second;
- P, mean annual precipitation, in inches;
- S, Main-channel slope (dimensionless);
- Ω, OmegaEM parameter;
- A, cumulative 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 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 OmegaEM 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 Yegua 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 regression discharges, and those discharges were incorporated into the Hydrologic Engineering Center's River Analysis System (HEC-RAS) 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.

1.2.2 Stream Gage Analysis

Figure 3 shows the location of the four active USGS stream gages on the Yegua Creek HUC8 watershed used to develop weighted discharges for the study (Table 2). FFA were performed for these gages, according to USGS Bulletin 17C guidelines.

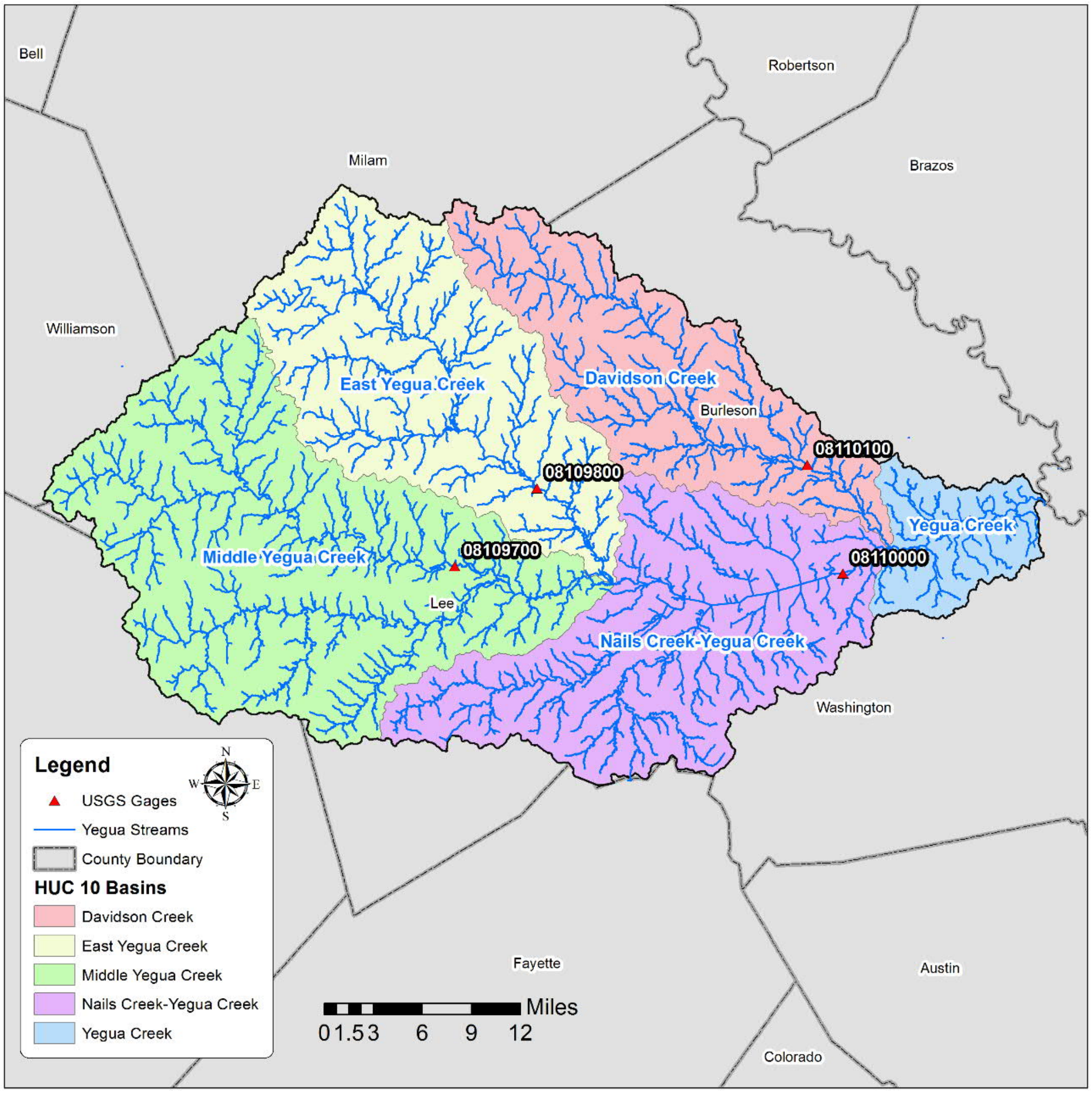

Figure 3: Locations of USGS Gages Utilized in Flood Frequency Analyses

Table 2: USGS Stream Gages in Yegua Watershed

Gage ID	Flooding Source and Location	Computed Drainage Area (mi.^{2})	Published Drainage Area (mi.^{2})	Period of Record
08109700	Middle Yegua Creek near Dime Box, TX	237	236	1914-2019
08109800	East Yegua Creek near Dime Box, TX	238	244	1940-2019
08110000	Yegua Creek near Somerville, TX	1010	1,009	1968-2019
08110100	Davidson Creek near Lyons, TX	195	195	1947-2019

The flood flow frequency data from these gages were weighted with the regression developed discharges using the procedure described in SIR 2009-5087. Adjusted discharges were held constant if the adjustment resulted in flows decreasing in the downstream direction. The formula used to determine the weighted peak discharges (WRI 98-4015 page 10, equation 6, WRI 98-4178, Page 12 equation 4):

$$Q_{TW} = \frac{SE_{TR}^2 Q_{TS} + SE_{TS}^2 Q_{TR}}{SE_{TR}^2 + SE_{TS}^2}$$

Where:

SE_{TS}, standard error of the log-Pearson Type III distribution at recurrence interval T, in log-cubic feet per second;

SE_{TR}, standard error of prediction of the regression at recurrence interval T, in log-cubic feet per second;

Q_{TW}, weighted peak discharge at recurrence interval T, in cubic feet per second;

Q_{TS}, log-Pearson Type III peak discharge at recurrence interval T, in cubic feet per second

Q_{TR}, regression peak discharge at recurrence interval T, in cubic feet per second;

The weighted factor for the regression is the square of the standard error of estimation of the regression, which can be found at WRI 96-4307, Page 64 (Table 2, Region 6, Weighted standards error of estimate in $\log_{10}$ units). The standard error of estimation for 500 year was estimated from the relationship between 10 year and 50 year standard error of estimate, as 0.34 in Table 4.

The weighted factor for the Log-Pearson Type III distribution is the square of the standard error, or the variance error of estimate. It is computed using the 67-percent prediction interval in a USGS computer program PEAKFQ (to estimate peak-discharge frequency on the basis of the Log-Pearson Type III distribution). The 67-percent prediction interval of the regression equation is equivalent to the {100-(100-67)/2} = 83.5-percent interval in PEAKFQ. Thus, the standard error and the variance error of estimate can be determined from the program PEAKFQ by setting the confidence limits at 83.5 percent.

Gage variances for each storm event were used to develop weighted discharges. These variances are provided in Table 3.

Table 3: Summary of Gage Variances Used

Gage ID	Variance				
	10PCT	4PCT	2PCT	1PCT	0.2PCT
08109700	0.0078	0.0117	0.0151	0.0188	0.0288
08109800	0.0059	0.0081	0.0100	0.0123	0.0191
08110000	0.0029	0.0038	0.0053	0.0074	0.0144
08110100	0.0047	0.0062	0.0076	0.0093	0.0146

Weighted discharges were adjusted using a gage adjustment factor developed from a comparison between the rural and gage discharges and rounded to determine final discharges. Final discharges for the Yegua Creek Watershed estimated by gage analysis adjustment, and used in the final BLE hydraulic models, are presented in Table 4.

For gage 08110000 (Yegua Creek near Somerville, just downstream of the Lake Somerville), the flood frequency analysis flows at this gage are not adjusted, and only based on gage FFA discharge only, without weighting with regression flows. The flows upstream of this gage are completely regulated by the Somerville Lake Dam, thus it was determined to only use gage flows. Downstream of the gage, the flows were computed as gage flows weighted with the regression flows based on the drainage area.

The FFA at this gage (08110000) is based on the regulated period only; as such it reflects only the flow out of Lake Somerville. Because the regressions are based on and are applicable to unregulated gage sites, the regression flows don't apply at this location. The purpose of the weighted estimate is to improve the frequency flow estimate at a site by averaging 2 independent estimates of the frequency flow; because the regressions don't apply to this gage location, therefore, average the gage and regression estimate is not applied.

Table 4: Final Discharges at USGS Stream Gages in Yegua Watershed

Gage ID	10PCT (cfs)	4PCT (cfs)	2PCT (cfs)	1PCT (cfs)	0.2PCT (cfs)
08109700	8,070	13,420	18,340	24,030	40,280
08109800	7,483	12,260	16,130	20,430	32,060
08110000	3,470	4,400	5,050	5,660	6,940
08110100	13,680	20,630	26,520	32,930	49,710

1.3 Hydraulics

The hydraulic approach for this BLE analysis of the Yegua 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. 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 ArcGIS 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 5. These default values for dimensions and spacing were subject to change based on engineering judgment.

Table 5: 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 6. 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 6: 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
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 downstream 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 4. 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 5 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.

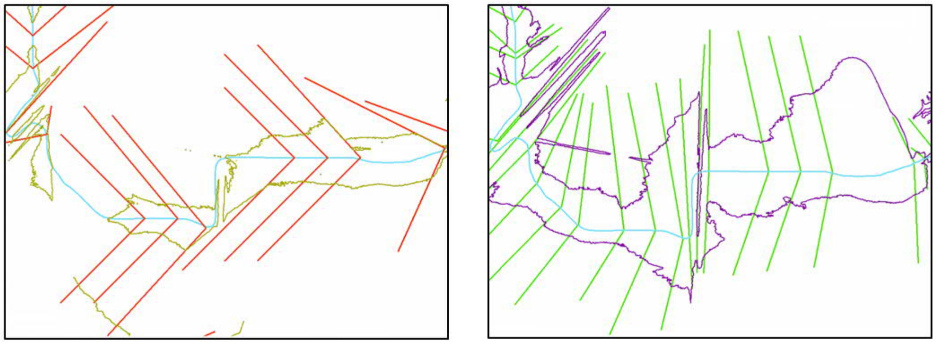

Figure 4: Default "V" angle cross-sections automated by WISE (left). Manually edited cross-sections to more accurately capture terrain (right). Resulting flood boundaries shown in gold (left) or purple (right) for clarity.

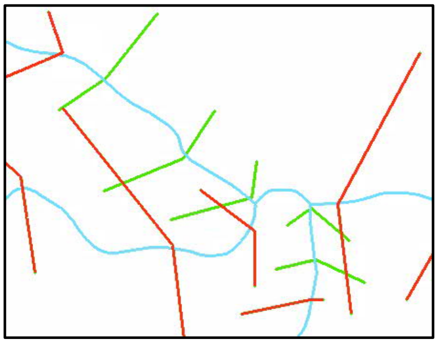

Figure 5: Manually added cross-sections (green) to improve accuracy of tie-ins at confluences.

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 line are 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

Several streams in the Davidson Creek South watershed required iterative n-value manipulation in order to achieve proper tie-ins. In general, stream centerlines in the watershed need further study. There were several instances in which sizeable portions of stream centerline were altered to be within mapping. In particular, UNT 077, UNT 070, UNT 006, Davidson Creek Tributary 2, and East Pin Oak Creek stream centerlines should be reviewed more in-depth.

In Davidson Creek North watershed, Berry Creek needs further study as cross sections are overtopped. Further study is required on UNT 109 in DavidsonCrN. Mapping does not match with the effective flood hazard area for UNT109.

In Middle Yegua Watershed (MYC), UNT028 and UNT119 in MYC need further study. The UNT119 is mainly quarry area, and the channel elevations are much lower than adjacent areas. The related basin (Basin 316) boundaries are not well defined because of the lower elevations related to the quarry.

The Middle Yegua Creek downstream tie-in applied a coincident cross section which is the exactly the same as the Yegua Creek mainstem model's most upstream cross section. To match the water surface elevations, the known water surface boundary conditions were employed.

In the Nails Creek – Yegua Creek watershed, there were some instances of spilled flows between sub-watersheds including Cedar Creek to UNT262, Hockel Branch to Nails Creek, UNT085 to Little Cedar Creek, McCain Creek to Fourmile Creek, Little Hickory Creek to UNT265, Nails Creek to UNT264, and Tracy Creek to Black Creek. The shared floodplains between Alligator Creek and UNT078 as well as UNT356 and UNT251 is not well-described by 1D analysis and may be better suited for 2D analysis. Split flows were observed for Sweetwater Creek and UNT288. More in-depth analysis for the aforementioned areas in the Nails Creek – Yegua Creek watershed is recommended.

In the Yegua Creek watershed, there were some instances of spilled flow between sub-watersheds including UNT78 to Yegua Creek and UNT8 to Bridge Creek. Split flows were observed for UNT11 and UNT14 and may warrant further study using 2D methods.

Coordination efforts were made with the Lower Brazos-Little Brazos BLE study 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.

Results and Recommendations

The BLE results for this study produced an SFHA that conforms to the existing topography and compares favorably with the effective SFHA. These boundaries provide an approximate 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 (1,064.0 miles) in the Yegua Watershed were classified in CNMS with validation status of "UNVERIFIED" (499.3 miles) or "VALID" (564.7 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 Yegua Watershed, LiDAR was not available for the effective studies except for those within Lee County. Lee County studies utilized 2010 TNRIS LiDAR and, therefore, passes this check. The LiDAR sources discussed in section 1.1 are a significant improvement from the effective Zone A topographic sources for all other studies and they failed this check for the effective SFHA.

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.

The most current regression equations (SIR 2009-5087) were used for the effective studies in Lee County, so these studies pass this check. Regression was not used for the remainder of the effective studies in the Yegua HUC-8 Watershed, so they also pass this 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.

There are six reaches near the City of Rockdale that are in a HUC-12 watershed that meets the urban threshold. The change is impervious area since the effective analysis is minor. All other HUC-12 watersheds within the Yegua HUC-8 Watershed are classified as rural still. For these reasons, the entire study area passes this check.

All of the initial assessment results are shown in Table 7.

Table 7: Zone A Initial Assessment Results

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

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. The only model-backed studies within the Yegua HUC-8 Watershed are those in Lee County. Those reaches pass this check while all other 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 Yegua Watershed 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 8 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 they are marked as "Fail".

Table 8: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Yegua Watershed	All Streams	82,660	16,038	66,622	81%	FAIL	
Allen Creek-East Yegua Creek	120701020203	3,582	764	2,818	79%	FAIL	16.4
Berry Creek	120701020404	1,467	193	1,274	87%	PASS	10.2
Big Creek-Yegua Creek	120701020308	4,449	1,467	2,982	67%	FAIL	21.1
Birch Creek-Frontal Somerville	120701020306	2,389	291	2,098	88%	PASS	6.0
Briar Branch-East Yegua Creek	120701020202	1,227	281	946	77%	FAIL	16.0
Bridge Creek-Yegua Creek	120701020501	2,857	815	2,042	71%	FAIL	22.8
Brushy Creek	120701020204	3,218	465	2,753	86%	PASS	11.6
Brushy Creek-Davidson Creek	120701020405	3,466	548	2,918	84%	FAIL	12.0
Burn Creek-Somerville Lake	120701020307	3,021	1,213	1,808	60%	FAIL	20.6
Cedar Creek-Frontal Somerville	120701020305	2,248	429	1,819	81%	FAIL	15.4
Cross Creek	120701020104	1,505	135	1,370	91%	PASS	8.2
Dry Creek-Davidson Creek	120701020401	1,419	267	1,152	81%	FAIL	9.4
Dry Creek-East Yegua Creek	120701020206	4,121	1,161	2,960	72%	FAIL	14.5
Edwards Lake	120701020301	1,463	488	975	67%	FAIL	16.7
Elm Creek	120701020109	1,734	69	1,665	96%	PASS	3.2
Hooker Creek-East Yegua Creek	120701020205	2,877	613	2,264	79%	FAIL	15.3
Houghton Branch-Middle	120701020101	2,278	255	2,023	89%	PASS	10.0
Independence Creek-Yegua	120701020502	3,099	1,302	1,797	58%	FAIL	33.6
Indian Camp Branch-Middle	120701020106	2,365	267	2,098	89%	PASS	6.7
Lower Nails Creek	120701020303	4,108	651	3,457	84%	FAIL	9.3
Lower West Yegua Creek	120701020110	1,196	88	1,108	93%	PASS	5.9
Middle West Yegua Creek	120701020108	3,753	301	3,452	92%	PASS	3.5
Mine Creek-Middle Yegua	120701020102	1,215	26	1,189	98%	PASS	1.7
Reece Creek-East Yegua Creek	120701020201	273	55	218	80%	FAIL	10.7
Rocky Creek-Middle Yegua	120701020111	1,440	161	1,279	89%	PASS	6.5
Rough Bayou-Davidson Creek	120701020406	1,777	341	1,436	81%	FAIL	15.4
Second Davidson Creek	120701020403	2,587	350	2,237	86%	PASS	9.3
Shaw Branch-Middle Yegua	120701020105	2,386	137	2,249	94%	PASS	3.9
Thompson Branch-Davidson	120701020402	3,517	765	2,752	78%	FAIL	13.9
Turkey Creek-Cedar Creek	120701020304	2,871	473	2,398	84%	FAIL	12.9
Upper Nails Creek	120701020302	2,493	25	2,468	99%	PASS	0.8
Upper West Yegua Creek	120701020107	3,243	845	2,398	74%	FAIL	17.3
Walleye Creek	120701020103	640	36	604	94%	PASS	4.5
Wolf Creek-Yegua Creek	120701020309	2,376	761	1,615	66%	FAIL	24.8

VALIDATION RESULTS

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Yegua Watershed has been updated as summarized in Table 9 and illustrated in Figure 6 below.

Table 9: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	564.7
UNVERIFIED	BEING STUDIED	499.3

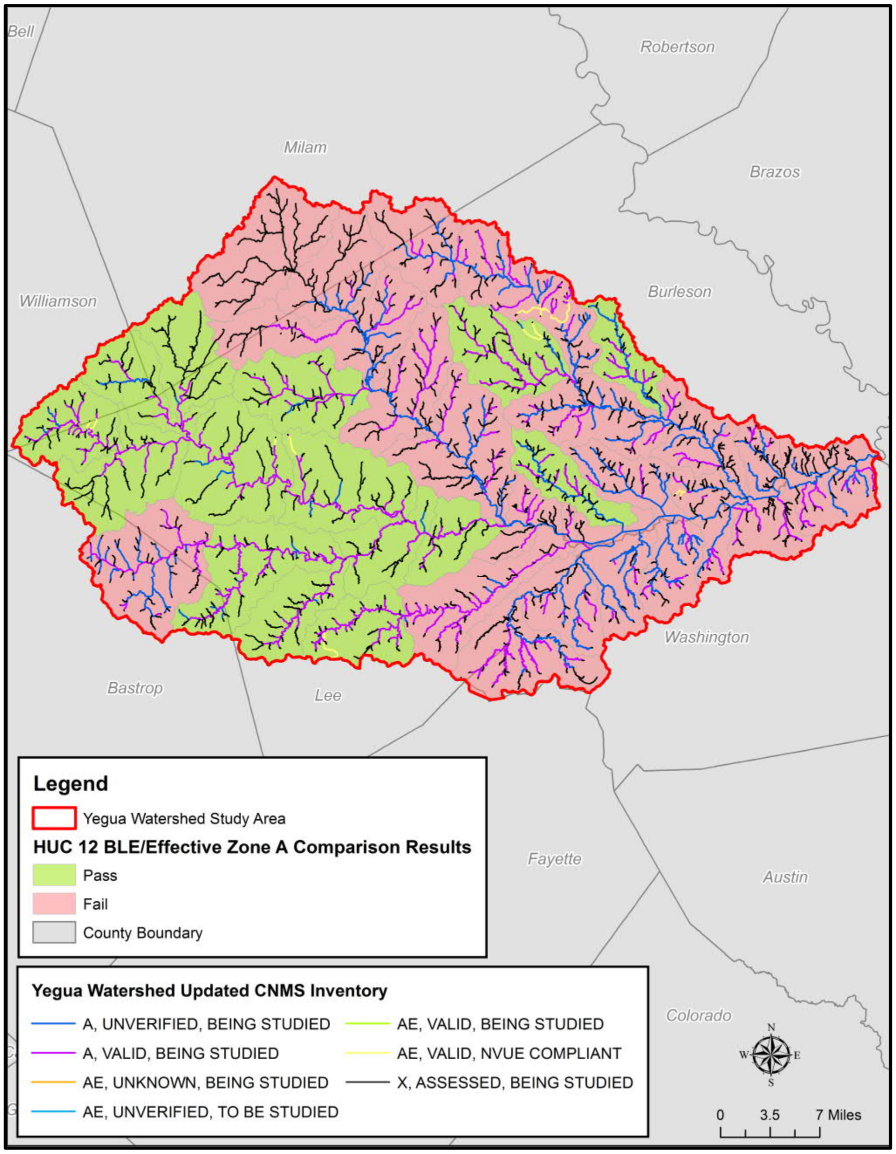

Figure 6: Yegua Watershed CNMS Validation Results

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 7 below shows the range of the HUC-12 priority scores which can be used to initiate discussions during the Discovery phase.

Independence Creek-Yegua Creek River HUC-12 was determined to have the highest priority score and the most need while Upper Nail Creek HUC-12 had the lowest score.

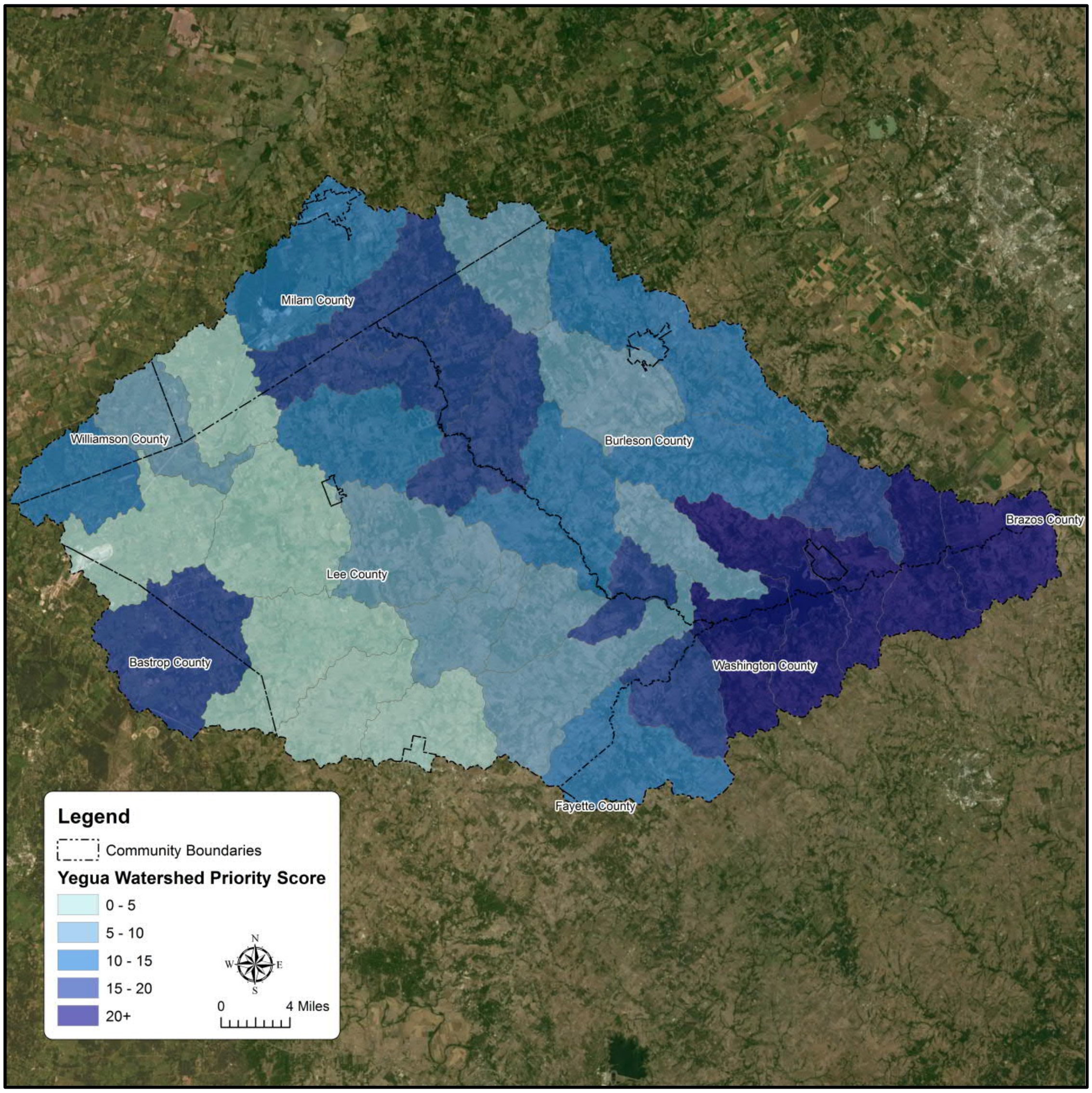

Figure 7: Ranking of Yegua Watershed HUC-12s

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") and 0.2-percent-annual-chance grid created for this project. The loss analysis uses 2010 census data and the subsequent results are stored in the S_FRAC_AR feature class.

Hazus version 4.2 with SP1, SP2 and SP3 was used for the loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 4.2 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.

References

1. Asquith, William H. and Roussel, Meghan C., "Regression Equations for Estimation of Annual Peak-Streamflow Frequency for Undeveloped Watersheds in Texas Using an L-moment-Based, PRESS-Minimized, Residual-Adjusted Approach," United States Geological Survey Scientific Investigations Report 2009-5087, 2009.
2. Chow, Ven T. "Development of Uniform Flow and It Formulas." Open Channel Hydraulics. Caldwell, NJ: Blackburn, 1959. 109-113. Print.
3. FEMA, "Guidance for Flood Risk Analysis and Mapping – Automated Engineering", May 2016. (https://www.fema.gov/media-library-data/1469144112748-f3c4ecd90cb927cd200b6a3e9da80d8a/Automated_Engineering_Guidance_May_2016.pdf).
4. Texas Precipitation – Average monthly and annual precipitation for the climatological period 1981-2010. Data from NRCS. Retrieved July 2019. (https://www.twdb.texas.gov/mapping/gisdata.asp/).
5. United States Army Corps of Engineers, Hydrologic Engineering Center. (June 2018). HEC-RAS River Analysis System, Version 5.0.5. Davis, California.
6. United States Geological Survey, "Estimating Magnitude and Frequency of Floods Using PeakFQ Program: USGS Fact Sheet", 2006.
7. United States Geological Survey. Multi-Resolution Land Characteristics Consortium. National Land Cover Database 2016. (http://www.mrlc.gov/nlcd2011.php).
8. United States Geological Survey, Interagency Advisory Committee on Water Data. "Guidelines for determining Flood Flow Frequency", Bulletin #17B of the Hydrology Subcommittee, Revised September 1981, Editorial Corrections March 1982. Reston, VA.
9. Watershed Concepts, a Division of Hayes, Seay, Mattern & Mattern. Watershed Information System (WISE,) Version 4.1.0. 2008.

Appendix A BLE Map