Identify, Interpret, Integrate

Middle Sabine Watershed, TX
Base Level Engineering (BLE) Results

Contract #HSFE60-15-D0003, Task Order # 70FBR620F00000047
February 2022

Prepared for:

DHS/FEMA (Federal Emergency Management Agency)
Attn: Sable Bell, Compass Contracting Officer Representative (COR)
FEMA Region VI
400 C Street Southwest
Washington, DC

Submitted by:

Compass PTS JV
3101 Wilson Boulevard
Suite 900
Arlington, VA 22201

Compass PTS JV
3101 Wilson Boulevard, Suite 900
Arlington, VA 22201
T: 703.682.9100; F: 703.682.4901

DOCUMENT HISTORY

DOCUMENT LOCATION

K:/FY2020/20-06-0094S/Hydraulics – Middle Sabine (Panola County, TX)|BLE (FY20) 09/Hydraulic Data Capture - Hydraulic Data Capture|Middle Sabine (Panola County, TX) - 01

REVISION HISTORY

Version Number	Version Date	Summary Changes	Team/Author
1	February 4, 2022	Initial Draft	AECOM

APPROVALS

This document requires the approval of the following persons:

Role	Name	Review Date	Approved Date
Project Manager	Sean Sutton	February 04, 2022	February 8, 2022

CLIENT DISTRIBUTION

Name	Title/Organization	Location
FEMA's MIP	Region VI	See path above
Diane Howe	FEMA Region VI	Denton, Texas
Larry Voice	FEMA Region VI	Denton, Texas

Table of Contents

Executive Summary

FEMA Region 6 contracted Compass to complete a Base Level Engineering (BLE) analysis for Area E – Sabine River in southeastern Texas, to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHAs). Area E includes the Upper Sabine, Lake Fork, Middle Sabine, Lower Sabine, and Sabine Lake HUC-8 watersheds. This report focuses on the Middle Sabine HUC-8 watershed. 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 5.0.7 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	Middle Sabine Stream Miles
CNMS	1740.7

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	674.5
UNVERIFIED	BEING STUDIED	1066.2

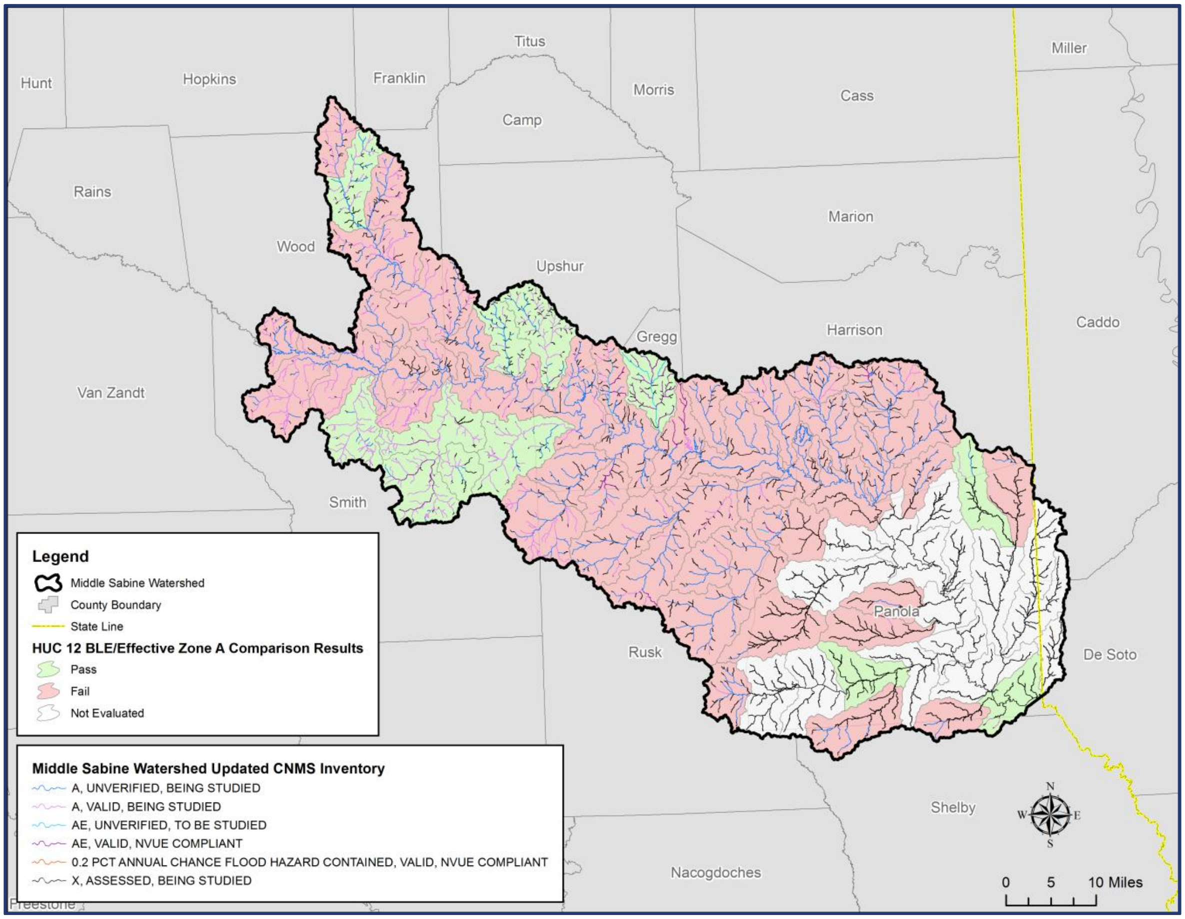


Figure ES-1: Middle Sabine Watershed CNMS Validation Results

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

Town of Hawkins-Sabine River HUC-12 was determined to have the highest priority score and the most need while West Fork Socagee Creek HUC-12 had the lowest scores.

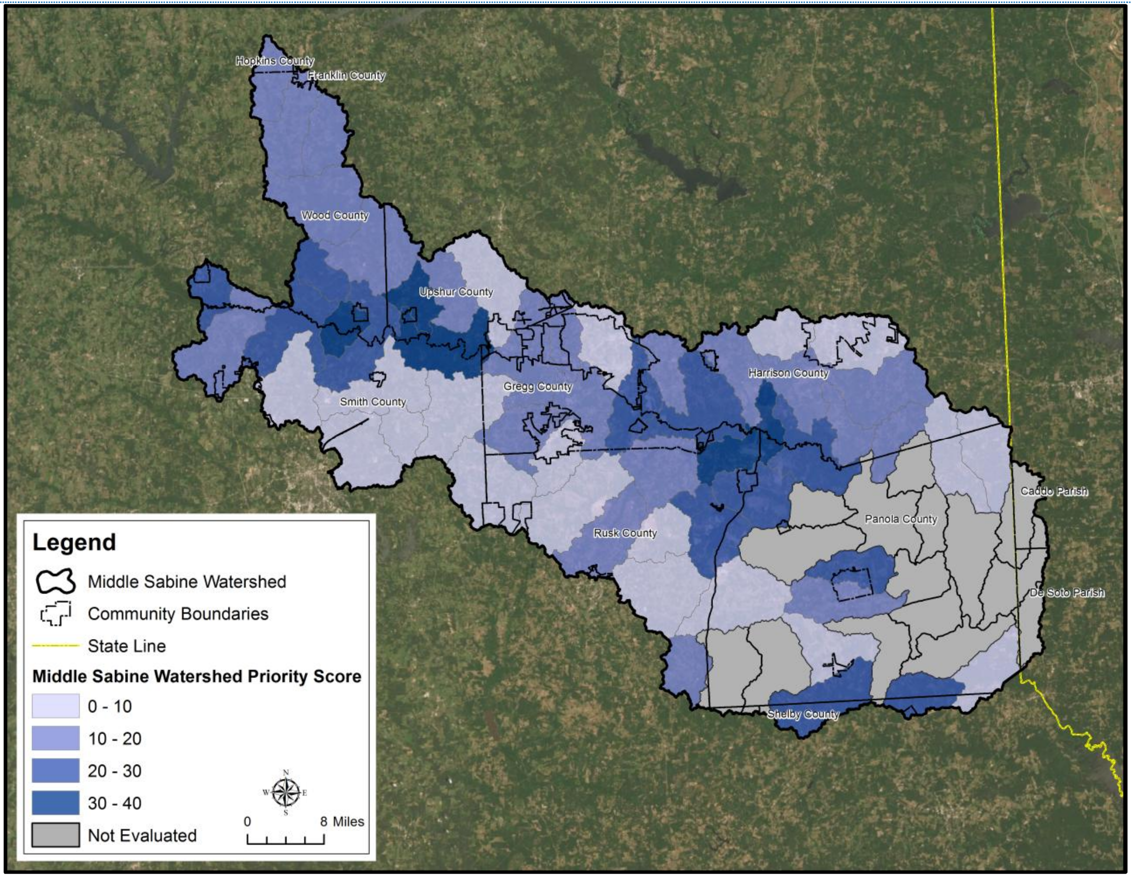


Figure ES-2: Ranking of Middle Sabine HUC-12s

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 Middle Sabine Watershed in East Texas to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHA). The study extents include portions of Franklin, Gregg, Harrison, Hopkins, Panola, Rusk, Shelby, Smith, Upshur, and Wood Counties, Parishes of Caddo and Desoto, and includes the following communities: the Cities of Beckville, Carthage, Clarksville City, East Mountain, Easton, Gladewater, Hallsville, Hawkins, Henderson, Hideaway, Kilgore, Lakeport, Lindale, Longview, Marshall, Mineola, New London, Overton, Tatum, Tenaha, Tyler, Union Grove, Warren City, White Oak, Winnsboro, Towns of Big Sandy, Gary, Scottsville, and Village of Easton. The study area consists of eleven HUC-10 basins: Cherokee Bayou – Sabine River, Eightmile Creek

– Sabine River, Harris Creek, Irons Bayou, Lake Winnsboro – Big Sandy Creek, Martin Creek, Murvaul Creek – Sabine River, Old Sabine River Channel – Sabine River, Prairie Creek – Sabine River, Rabbit Creek – Sabine River, and Socagee Creek – Sabine River. Figure 1 shows the orientation of the Middle Sabine HUC-10 basins with respect to the counties.

Figure 1: Middle Sabine Watershed HUC-10 Basins

AECOM studied approximately 3,645 miles of stream reaches within the Middle Sabine 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 Middle Sabine Watershed.

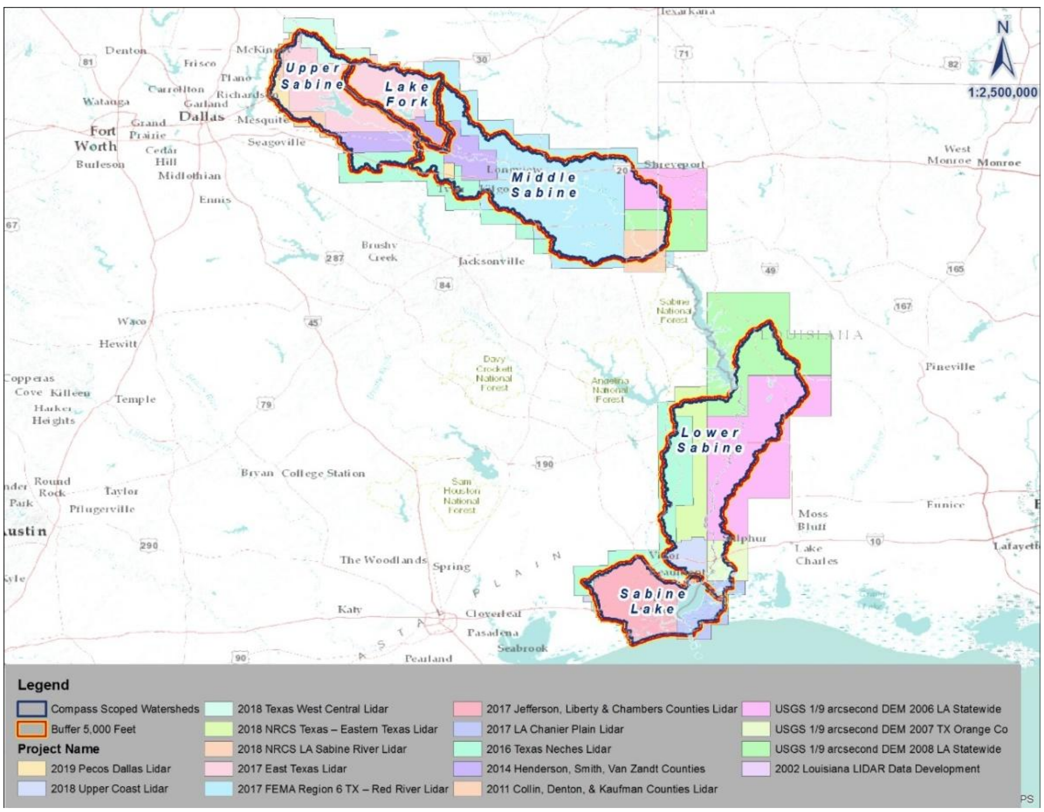


Figure 2: Extent of LiDAR Data for Area E

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 2019 Pecos Dallas LiDAR 1 Meter DEM

The source data was downloaded from the USGS National Map on December 23, 2020. These data cover Culberson, Reeves, Crane, Ward, Loving, Winkler, Palo Pinto, Stephens, Erath, Eastland, Wise, Denton, Collin, Rockwall, Dallas, Tarrant, Ellis, Johnson, Kaufman, Smith, and Parker counties in Texas. LiDAR data was acquired between February 26, 2019 and July 12, 2019.

The 2019 Pecos Dallas LiDAR project called for the Planning, Acquisition, processing, and derivative products of LiDAR data to be collected at a nominal pulse spacing of 0.7 meter. Project specifications are based on the USGS National Geospatial Program (NGP) LiDAR Base Specification (LBS), Version 1.2. The data was developed based on a horizontal projection of North American Datum of 1983 (NAD83) (2011), Universal Transverse Mercator (UTM) Zones 13, 14, and 15, meters and vertical of North American Vertical Datum of 1988 (NAVD88) (GEOID12B), meters. LiDAR data was delivered as processed Classified LAS 1.4 files, formatted to 11,461 individual 1,500 m x 1,500 m tiles, as tiled Intensity Imagery, and as tiled bare earth DEMs; all tiled to the same 1,500 m x 1,500 m schema. The measured accuracy was 0.035 meters for Non-Vegetated Accuracy (NVA).

1.1.1.2 2017 East Texas LiDAR 1 Meter DEM

Fugro was tasked to collect and process a LiDAR-derived elevation dataset for the Texas counties of Collin, Delta, Fannin, Hopkins, Hunt, Lamar, Liberty, Montgomery, Polk, Rains, San Jacinto, Van Zandt, Walker, and Wood with QL 2 Specification.

The 2017 East Texas LiDAR data was available as 1 meter rasters from TNRIS (https://data.tnris.org/collection/f09f36b9-12b1-4c88-bccb-017afa9bc3d8). The data was downloaded on September 9, 2020. The data was in NAD83 UTM Zone 15 projection with elevations in NAVD88 with units in meters. The data was collected from December 29, 2016 through April 14, 2017.

Data Specification:

Modern era LiDAR data collection is typically expected to meet specifications of the NGP - LBS. The national LBS have been modified through a series of revisions throughout time and can be accessed at 'LiDAR Base Specification Online' for reference (https://www.usgs.gov/core-science-systems/ngp/ss/LiDAR-base-specification-online). This LiDAR survey and derivative products produced in compliance with the task order are based on:

- USGS LiDAR Base Specifications v1.2
- ASPRS Positional Accuracy Standards for Digital Geospatial Data

The measured accuracy was 0.066 meters for NVA at 95% confidence level and the VVA measured as 0.096 meters.

1.1.1.3 2014 Henderson, Smith, Van Zandt Counties & Trinity River LiDAR 1 Meter DEM

Atkins, McKim & Creed, and Williams Aerial and Mapping, Inc. were tasked to collect and process a LiDAR-derived elevation dataset for the Texas counties of Anderson, Cherokee, Dallas, Ellis, Freestone, Gregg, Henderson, Kaufman, Navarro, Rains, Smith, Upshur, Van Zandt, and Wood.

The 2014 Henderson, Smith, Van Zandt Counties & Trinity River LiDAR data was available as 1 meter rasters from TNRIS (https://data.tnris.org/collection/18c52542-dc6f-4a12-88b3-59ecc8e6d53d). The data was downloaded on September 9, 2020. The data was in NAD83 UTM Zone 15 projection with elevations in NAVD88 with units in meters. The data was collected from February 25, 2014 to February 18, 2014.

The measured accuracy was 0.067 meters for Fundamental Vertical Accuracy (FVA) at 95% confidence level in open terrain.

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 Middle Sabine 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 2019 Pecos Dallas LiDAR 1 Meter LiDAR dataset was prioritized as the best data source for the Middle Sabine Watershed followed by the 2017 East Texas LiDAR 1 meter LiDAR dataset, and the 2014 Henderson, Smith, Van Zandt Counties & Trinity River LiDAR 1 meter LiDAR dataset.

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 generated from ArcHydro processes and manually edited to match the 10-foot DEMs as a source for horizontal alignment and vertical elevation. These stream centerlines are created for use in the hydraulic analysis.

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 that no unusual or non-terrestrial features were observed in the composite DEM assuring the surface files are sufficient for hydraulics analyses and floodplain mapping activities.

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. Break points were also set immediately upstream of stream confluences and at stream gages. 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 5.0.7 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 five (5) USGS stream gages on the Sabine River and five (5) USGS stream gages on tributaries within the watershed used to develop discharges for the gaged streams (Table 2).

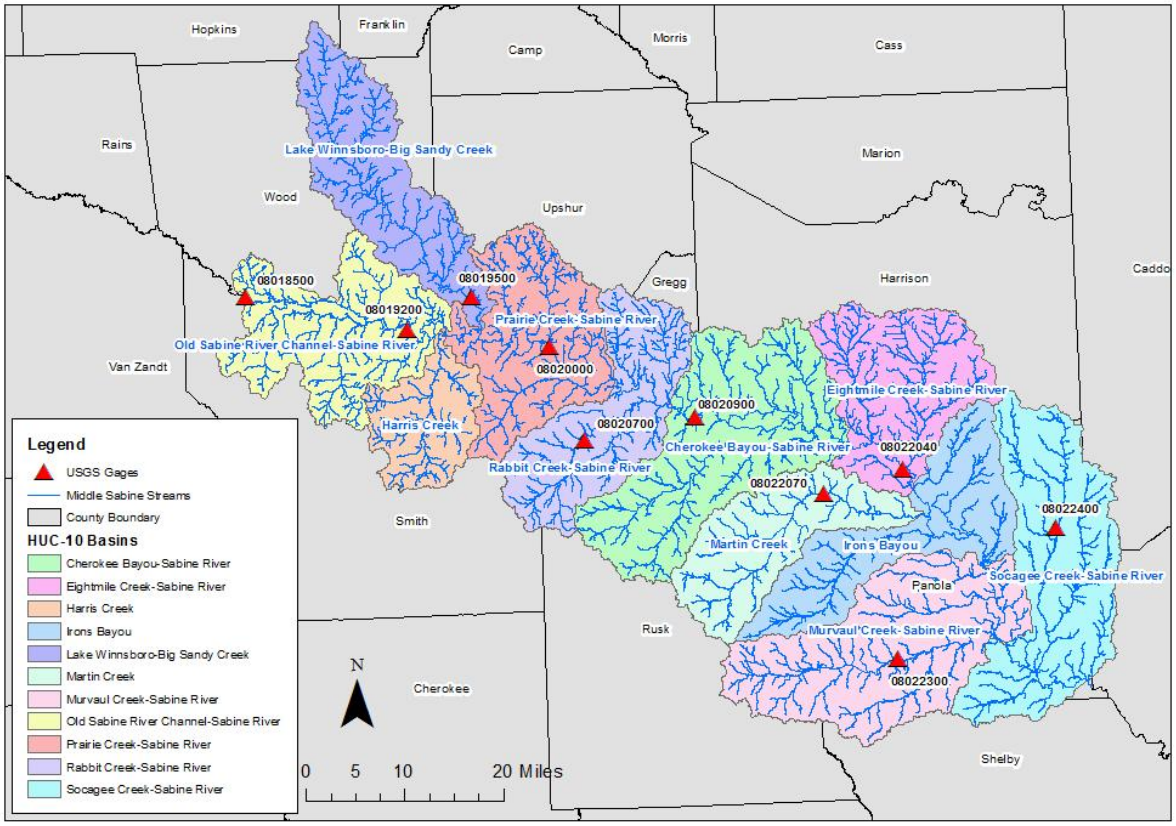


Figure 3: Locations of USGS Gages Utilized in Flood Frequency Analyses

Table 2: USGS Stream Gages in Middle Sabine River Watersheds

Gage ID	Flooding Source and Location	Computed Drainage Area (mi.^{2})	Published Drainage Area (mi.^{2})	Period of Record
08019500	Big Sandy Creek near Big Sandy, TX	232	231	1940-2020
08022070	Martin Creek near Tatum, TX	149	148	1975-1995
08022300	Murvaul Bayou near Gary, TX	133	134	1958-1983
08020700	Rabbit Creek at Kilgore, TX	75.6	75.8	1964-2020
08022040	Sabine River near Beckville, TX	3,589	3,589	1939-2020
08020000	Sabine River near Gladewater, TX	2,791	2,791	1914-2020
08019200	Sabine River near Hawkins, TX	2,259	2,259	1998-2020
08020900	Sabine River below Longview, TX	3,155	3,155	1996-2020
08018500	Sabine River near Mineola, TX	1,357	1,357	1938-2020
08022500	Sabine River at Logansport, LA	4,842	4,842	1884-2020
08022400	Socagee Creek near Carthage, TX	82.4	82.6	1962-1973

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

First, the frequency discharges were determined at the Sabine River gages (from upstream to downstream) using flood frequency analysis (FFA), according to Bulletin 17C (EMA) guidelines.

Second, the discharges for the reaches between gages were calculated using the following equation:

$$Q_{ungaged} = Q_{USgage} \text{ x}10\text{^}(((\log(DA_{ungage})-\log(DA_{USgage}))*(\log(Q_{DSgage})-\log(Q_{USgage}))/(\log(DA_{DSgage})-\log(DA_{USgaged}))).$$

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. The most upstream discharges were taken from the Upper Sabine BLE study to ensure consistency between the BLE studies. Table 3 lists the final Sabine River discharges used for this study.

Table 3: Final Discharges for Sabine River

RAS Station	Cum DA (mi^2)	10PCT (cfs)	4PCT (cfs)	2PCT (cfs)	1PCT (cfs)	0.2PCT (cfs)
996,437 (USGS Gage 08018500)	1,357	23,600	32,100	39,000	46,500	65,700
995,676 (USGS Gage 08019200)	2,259	29,900	38,500	44,500	50,100	61,900
825,813	2,304	30,300	39,015	45,096	50,771	62,729
777,651	2,435	31,460	40,509	46,822	52,715	65,130
739,281 (USGS Gage 08020000)	2,791	34,500	45,400	53,200	60,500	75,600
665,740	2,946	31,313	41,206	48,286	54,912	68,617
526,639 (USGS Gage 08020900)	3,155	27,700	35,600	41,200	46,300	57,000
475,584	3,258	28,160	36,191	41,884	47,069	57,946
375,217 (USGS Gage 08022040)	3,589	29,600	38,800	46,400	54,500	75,700
289,714	3,771	31,004	40,640	48,600	57,084	79,290
235,678	4,128	33,751	44,241	52,907	62,143	86,316
189,383	4,265	34,801	45,618	54,553	64,076	89,001
99,305	4,537	36,879	48,341	57,810	67,902	94,315
49,505 (USGS Gage 08022500)	4,842	39,200	53,000	64,200	76,000	106,000

For the five tributary gages, FFA was performed according to the Bulletin 17C (EMA) guidelines and used for gage weighted regression adjustments. The flood flow frequency data from the tributary gages were weighted with the regression developed discharges using the procedures described in SIR 2009-5087.

1.3 Hydraulics

The hydraulic approach for this BLE analysis of the Middle Sabine 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 5.0.7 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	6	5	0.8
2	300	7	6	0.8
4	300	10	8	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

Drainage area (upper limit)	XS Spacing	Channel Top Width	Channel Bottom Width	Channel Depth
30	500	21	16	0.8
40	500	22	17	0.8
50	600	23	18	0.8
75	600	24	19	1
100	750	25	20	1
150	750	26	21	1
250	1000	30	22	2
500	1500	35	23	2
1000	2500	41	24	2
2000	2500	42	25	2
5000	2500	43	26	2

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
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.

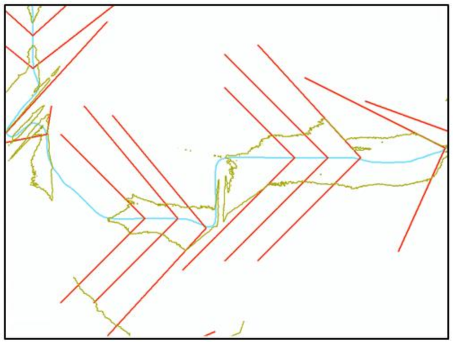
1.4 Quality Control

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 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.



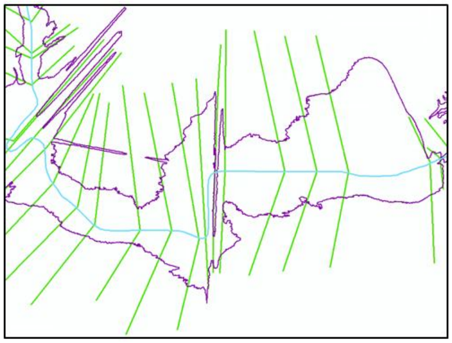


Figure 4: Default "V" angle cross-sections automated by WISE (left). Manually edited cross-sections to more accurately capture terrain (right). Resulting flood boundaries shown in gold (left) or purple (right) for clarity.

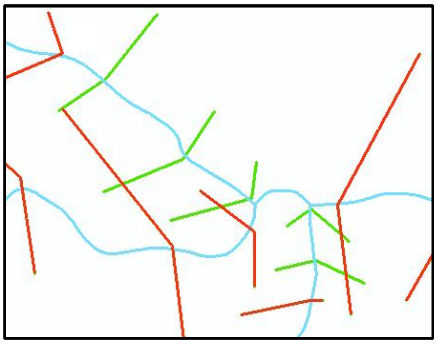


Figure 5: Manually added cross-sections (green) to improve accuracy of tie-ins at confluences.

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 datasets 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

Area E – Sabine River (TX) is located in southeastern 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.

Coordination efforts were made with the Toledo Bend, Lake Fork, and Upper Sabine BLE studies to ensure a water surface elevation tie-in. A known water surface elevation was applied at the downstream boundary condition of the Sabine River model using the results from the Toledo Bend BLE.

In the Cherokee Bayou watershed, there were multiple instances where the land use and/or terrain had changed since the effective data was modeled. This resulted in extensive cross-section adjustment due to overtopping issues, as observed at the upstream portion of UNT 334 in CBW. In addition, the change in land use/terrain at the upstream portion of Hardin Creek resulted in a different flow path from the effective mapping. Ultimately, UNT 342 in CBW was created to model the effective mapping boundaries. Additionally, there were areas within the watershed in which the storm events were not able to be contained. These spill areas may require additional detailed study. Examples of these areas include Black Slough Trib 1 and UNT 180 in CBW.

In the Martin Branch watershed, Taylor Branch has a split flow into Martin Creek that may require additional detailed study.

In the Rabbit Cr watershed, UNT 002 in Rabbit Cr was unable to contain mapping due to a low lying area in the left overbank. Mapping was limited to the extent of the cross-section. Wade Creek was also unable to contain mapping due to a low lying area in the right overbank as it flows into Grace Creek. This split flow area may require further detailed study.

In the Old Sabine River Channel watershed, there were some areas within the watershed that have an observed change in land use/terrain since the effective data was modeled. An example of this can be observed near the downstream portion of UNT 028 in ORSC Watershed where the streamline deviates from the effective mapping. In addition, UNT 028 in ORSC Watershed also shows a spill area at the location in which the streamline deviates from the effective mapping. Additional detailed study may be required at this location.

In the Irons Bayou watershed, there are a few areas that may need additional study. Caddo Creek has a split flow area in the right overbank that spills into UNT 042 in Irons Bayou Wtrshd. Anderson Branch, Buckner Branch, and Davis Branch have spotty mapping along their streamlines due to low lying overbank areas adjacent to the channel. UNT 060 in Irons Bayou Wtrshd is overtopped by the 100YR event. Mapping was clipped to the basin extents. Jackson Creek has a split flow area that spills into UNT 011 in Irons Bayou Wtrshd.

In the Murvaul Creek watershed, multiple streams may require further study. Respass Creek, Sixmile Creek, UNT 14, UNT 16, and UNT 20 were unable to fully contain the 0.2%-acf flows. In addition, Cooper Creek, Hoggs Bayou, Murvaul Creek, Respass Creek, Roberts Creek, Sixmile Creek, UNT 3, and UNT 6 have split flow areas that may require further detailed study.

In the Socagee Cr watershed, UNT025 in SCW runs parallel with Mill Creek which made it difficult to tie-in due to the lack of relief in the overbanks. This tie-in may require additional investigation. The upstream end of UNT 039 in SCW has very little relief in the overbanks. Mapping was constrained to the extents of the cross-sections in this area.

In the Harris Cr watershed, Wiggins Creek may require additional detailed study due to the split flow area. This split flow area appears to rejoin Wiggins Creek. Mapping was clipped to the cross-section extent.

In the Eightmile Creek watershed there are streams that may require further study. UNT 184 is covered by the UNT 151 backwater and covered beyond the watershed extents.

In the Lake Winnsboro watershed, there are multiple areas that may need additional study. Glade Creek, Ballard Branch, Board Branch, Mansell Creek, Mill Creek, Rogers Branch, UNT 034, UNT 065, UNT 076 UNT 082, UNT 084, UNT 085, UNT 123, and UNT 171 were unable to contain the 0.2%-acf flows within the basin boundaries. Cross-sections were clipped to the extent of the basin. Additional detailed modeling is suggested for these areas.

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 (1740.7 miles) in the Middle Sabine Watershed were classified in CNMS with validation status of “UNVERIFIED” (1066.2 miles) or “VALID” (674.5 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. The 2005 Louisiana LiDAR Project was utilized in Caddo Parish, therefore, this check passes in that study area. For the rest of the watershed, LiDAR was not utilized. The LiDAR sources used in this BLE study are considered significant improvements from the effective zone A topographic sources. For that reason, those Zone A reaches in the watershed fail 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.

Effective studies in Gregg County, Harrison County (except for the City of Marshall), and Smith County used regression equations in the effective analyses. New regression equations were published in 2009 that would create a significant impact to the BFE and, therefore, these studies fail this check. In addition, effective studies in Caddo Parish used regression equations; however, no new equations have been published, causing this check to pass for these reaches. All other effective Zone A studies in the watershed are not known to have used regression methods and automatically 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.

All Zone A studies within the watershed are in HUC-10 watersheds that do not meet the minimum percent impervious area to be classified as urban except for a single reach in Gregg County. Despite being classified as urban, this urbanized reach did not experience a significant increase urbanization. Therefore, all effective Zone A studies in this watershed 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.

Effective studies in Gregg County, Harrison County (except for the City of Marshall), Smith County, and Caddo Parish are model-backed and, therefore, pass this assessment check. All other Zone A studies within the watershed are not model-backed and fail this assessment 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						
Middle Sabine Watershed	All Streams	94,194	22,69	71,502	76%	FAIL	
Bearden Branch-Murvaul Creek	120100021004	1,123	306	817	73%	Fail	12.5
Bighead Creek	120100020503	664	120	544	82%	Fail	7.1
Brumley Lake-Sabine River	120100020105	2,855	712	2,143	75%	Fail	21.4
Caddo Creek	120100020903	790	220	570	72%	Fail	13.9
Clarks Creek-Sabine River	120100020603	2,560	1,247	1,313	51%	Fail	25.0
Colliers Creek-Sabine River	120100020705	1,141	313	828	73%	Fail	13.7
Dorsett Creek-Martin Creek	120100020801	2,127	523	1,604	75%	Fail	6.6
Dry Creek-Martin Lake	120100020802	1,009	219	790	78%	Fail	8.4
Duck Creek-Old Sabine River	120100020102	3,571	749	2,822	79%	Fail	17.6
East Fork Socagee Creek	120100021101	204	41	163	80%	Fail	5.0
Gandia Branch-Sabine River	120100020706	1,059	631	428	40%	Fail	29.8
Glade Branch-Sabine River	120100020403	3,248	1,363	1,885	58%	Fail	34.7
Grace Creek	120100020505	31	3	28	90%	Pass	8.7
Gunstream Lake-Big Sandy Creek	120100020204	3,129	628	2,501	80%	Fail	16.7
Hatley Creek	120100020607	1,867	417	1,450	78%	Fail	11.0
Hawkins Creek	120100020504	896	237	659	74%	Fail	18.1
Henderson Creek-Brushy Creek	120100021007	526	231	295	56%	Fail	20.8
Hoggs Bayou	120100021001	180	73	107	59%	Fail	28.6
Indian Creek-Murvaul Creek	120100021008	64	5	59	92%	Pass	6.3
Lake Cherokee	120100020606	1,932	538	1,394	72%	Fail	14.7
Lake Gladewater-Glade Creek	120100020402	3,723	480	3,243	87%	Pass	9.2
Lake Greenbriar-Big Sandy Creek	120100020205	3,248	615	2,633	81%	Fail	16.6
Lake Hawkins	120100020103	1,119	303	816	73%	Fail	21.7
Little White Oak Creek	120100020401	1,982	250	1,732	87%	Pass	10.7
Lower Harris Creek	120100020303	2,633	181	2,452	93%	Pass	3.9
Lower Lake Winnsboro-Big Sandy Creek	120100020202	2,649	367	2,282	86%	Pass	11.4
Lower Potters Creek	120100020702	1,658	541	1,117	67%	Fail	17.3
Martin Lake	120100020803	1,461	600	861	59%	Fail	20.5
Mason Creek	120100020602	1,207	432	775	64%	Fail	16.4
McFaddin Creek	120100021107	259	78	181	70%	Fail	24.1
Mill Creek-Lake Cherokee	120100020605	1,865	549	1,316	71%	Fail	14.7
Moody Creek-Sabine River	120100020405	2,619	650	1,969	75%	Fail	17.2

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Moorman Creek-Sabine River	120100021109	146	14	132	90%	Pass	7.7
Parker Creek-Eightmile Creek	120100020703	1,962	405	1,557	79%	Fail	9.6
Peavine Creek-Rabbit Creek	120100020502	1,731	425	1,306	75%	Fail	17.7
Prairie Creek	120100020404	2,693	271	2,422	90%	Pass	7.1
Quapaw Creek-Eightmile Creek	120100020704	2,106	691	1,415	67%	Fail	14.1
Rogers Creek-Sabine River	120100020107	3,122	825	2,297	74%	Fail	20.0
Rogers Lake-Sabine River	120100020608	2,205	1,119	1,086	49%	Fail	32.7
Saline Creek-Sabine River	120100020104	3,284	258	3,026	92%	Pass	5.4
Sixmile Creek	120100021002	72	14	58	81%	Fail	15.6
Stout Creek	120100020203	2,032	341	1,691	83%	Fail	14.0
Sunstroke Creek	120100020302	910	85	825	91%	Pass	7.2
Tatum Creek-Martin Creek	120100020804	752	306	446	59%	Fail	20.6
Tiawichi Creek	120100020604	2,748	525	2,223	81%	Fail	9.0
Town of Big Sandy-Big Sandy Creek	120100020206	1,167	443	724	62%	Fail	33.6
Town of Hawkins-Sabine River	120100020106	1,199	541	658	55%	Fail	36.8
Town of Mineola-Sabine River	120100020101	1,905	563	1,342	70%	Fail	28.6
Upper Harris Creek	120100020301	2,865	170	2,695	94%	Pass	4.3
Upper Irons Bayou	120100020901	171	42	129	75%	Fail	6.1
Upper Lake Winnsboro	120100020201	1,587	303	1,284	81%	Fail	14.1
Upper Potters Creek	120100020701	1,737	332	1,405	81%	Fail	9.4
West Fork Socagee Creek	120100021102	300	44	256	85%	Pass	3.7
Wilds Creek-Rabbit Creek	120100020501	3,330	559	2,771	83%	Fail	6.5
Wood Creek-Sabine River	120100020601	1,052	374	678	64%	Fail	22.5
Wynns Bayou-Sabine River	120100020506	1,719	420	1,299	76%	Fail	19.5

VALIDATION RESULTS

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Middle Sabine Watershed has been updated as summarized in Table 8 and illustrated in Figure 6 below.

Table 8: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	674.5
UNVERIFIED	BEING STUDIED	1066.2

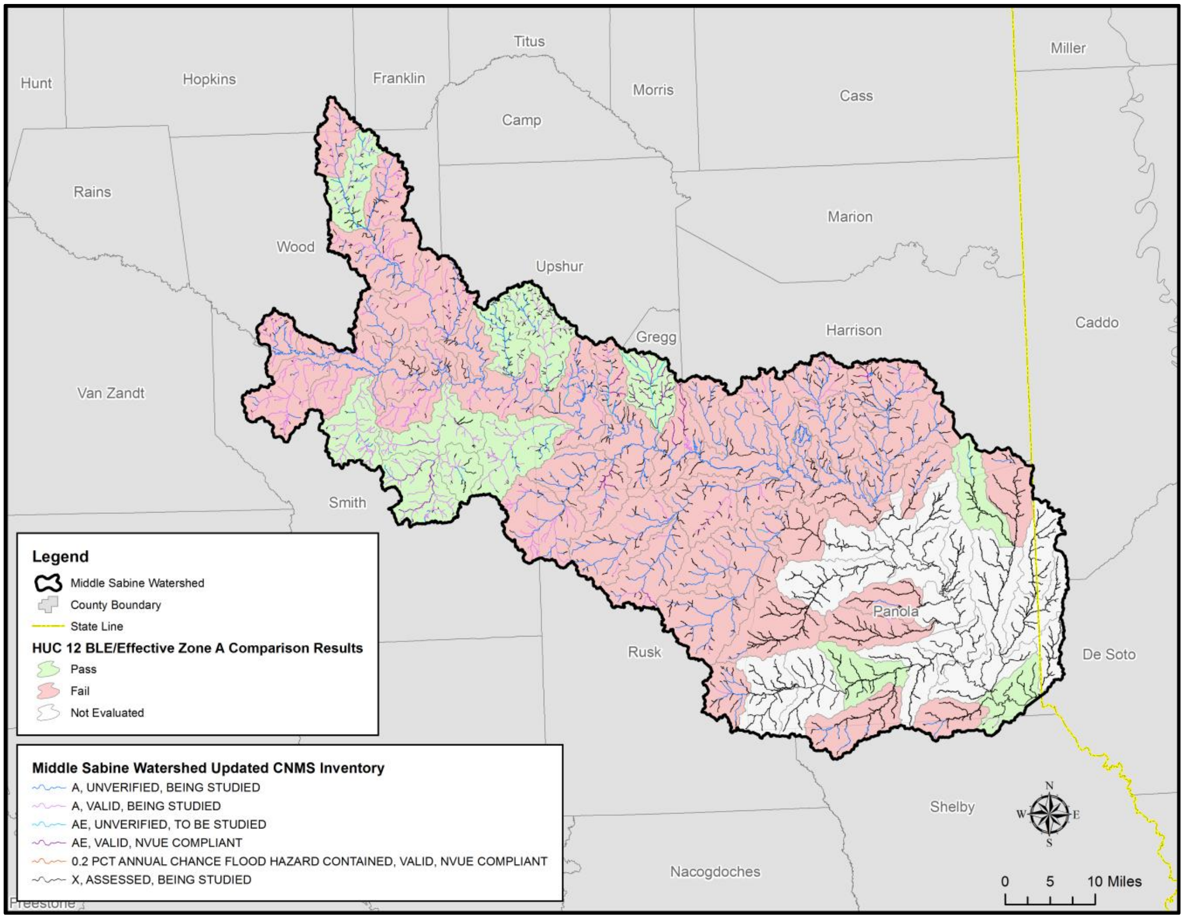


Figure 6: Area E Watershed CNMS Validation Results

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.

Town of Hawkins-Sabine River HUC-12 was determined to have the highest priority score and the most need while West Fork Socagee Creek HUC-12 had the lowest scores.

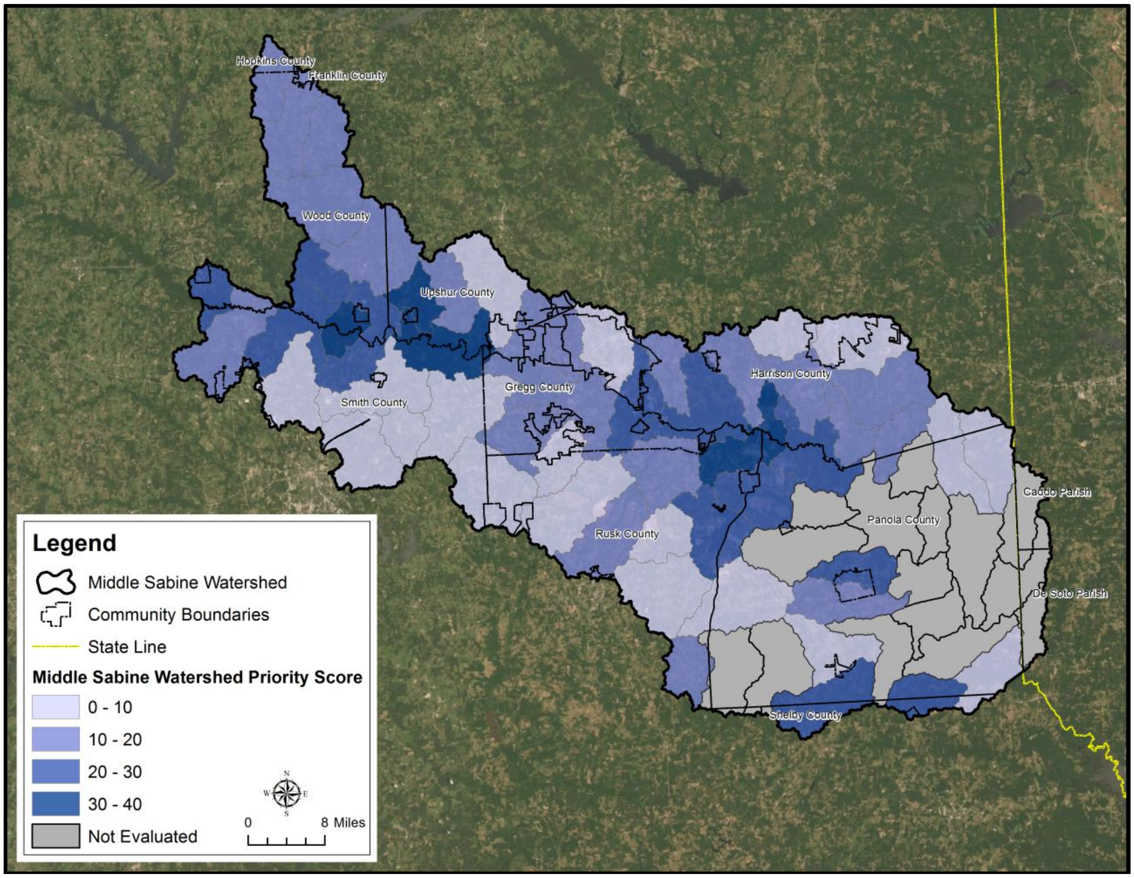


Figure 7: Ranking of Area E Watershed HUC-12s

3.2 Flood Risk Analysis

A flood risk analysis was performed for this project. The updated 1% annual chance and 0.2% annual chance depth grids were used to calculate the potential flood losses. The loss results are stored in the S_FRAC_AR spatial file within the FRD geodatabase. All results are reported in whole dollar values.

Hazus version 4.2 (SP03) was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 4.2 (SP03) 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.

Hazus analysis was performed by county within the project watershed extents for each return period to ensure proper model processing. A summary of results for the 1-percent a.c.e. scenarios are shown in Table9.

Table 9: Hazus 4.2 (SP03) Results for 1-percent-annual-chance (100 year) scenario

County	Full Replacement - Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Caddo	$229,000	$134,427,000	$77,776,000
DeSoto	$97,000	$49,785,000	$30,047,000
Franklin	$678,000	$58,018,000	$36,584,000
Gregg	$257,409,000	$12,156,966,000	$8,312,791,000
Harrison	$76,453,000	$4,454,605,000	$2,964,527,000
Hopkins	$236,000	$44,769,000	$33,615,000
Panola	$47,627,000	$2,273,978,000	$1,404,136,000
Rusk	$21,707,000	$2,244,024,000	$1,280,953,000
Shelby	$286,000	$104,620,000	$57,385,000
Smith	$48,037,000	$3,452,952,000	$2,223,004,000
Upshur	$26,060,000	$1,143,471,000	$648,670,000
Wood	$38,903,000	$2,106,423,000	$1,301,817,000
Total	$517,722,000.00	$28,224,038,000.00	$18,371,305,000.00

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 5.0.7. 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