Identify, Interpret, Integrate

Pecan-Waterhole Watershed, TX
Base Level Engineering (BLE) Results

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APPROVALS

This document requires the approval of the following persons:

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Table of Contents

Executive Summary

FEMA Region VI contracted Compass to complete a Base Level Engineering (BLE) analysis for the HUC-08 watershed Pecan-Waterhole (PEW) on the Texas-Oklahoma-Arkansas border, to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHAs). 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 the United States Geological Survey (USGS) regression equations. 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 4.1.0 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 stream miles associated with this validation analysis.

Table ES-1: Summary of Stream Miles

Source	Red River Stream Miles
CNMS	648.3

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: Aggregated Zone A Validation Results

Validation Status	Status Type	Total Miles
Valid	Being Studied	32.9
Unverified	Being Studied	615.4

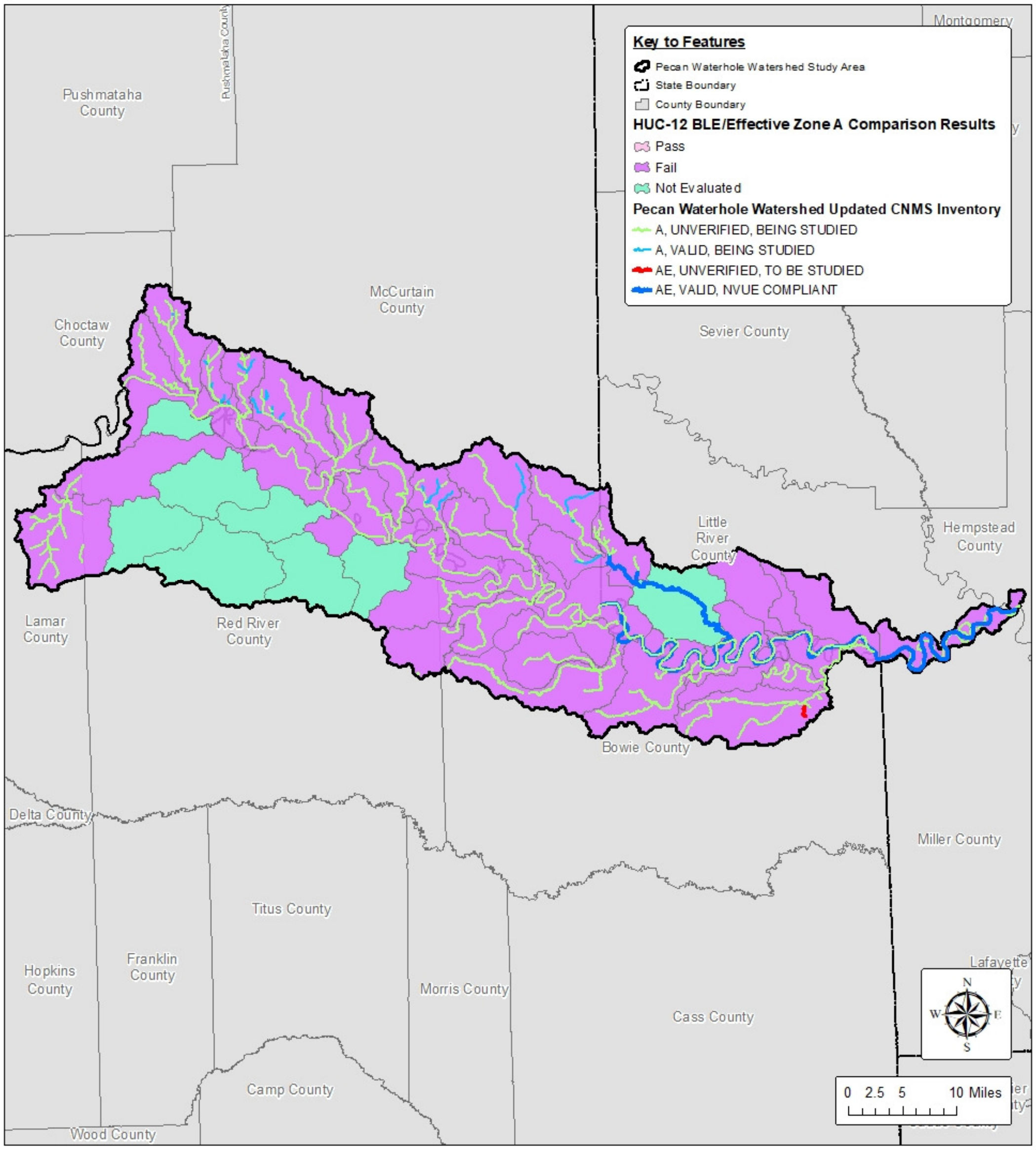

Figure ES-1: Pecan-Waterhole Watershed CNMS Validation Results

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 Pecan-Waterhole Watershed HUC-08 priority scores which can be used to initiate discussions during the Discovery phase.

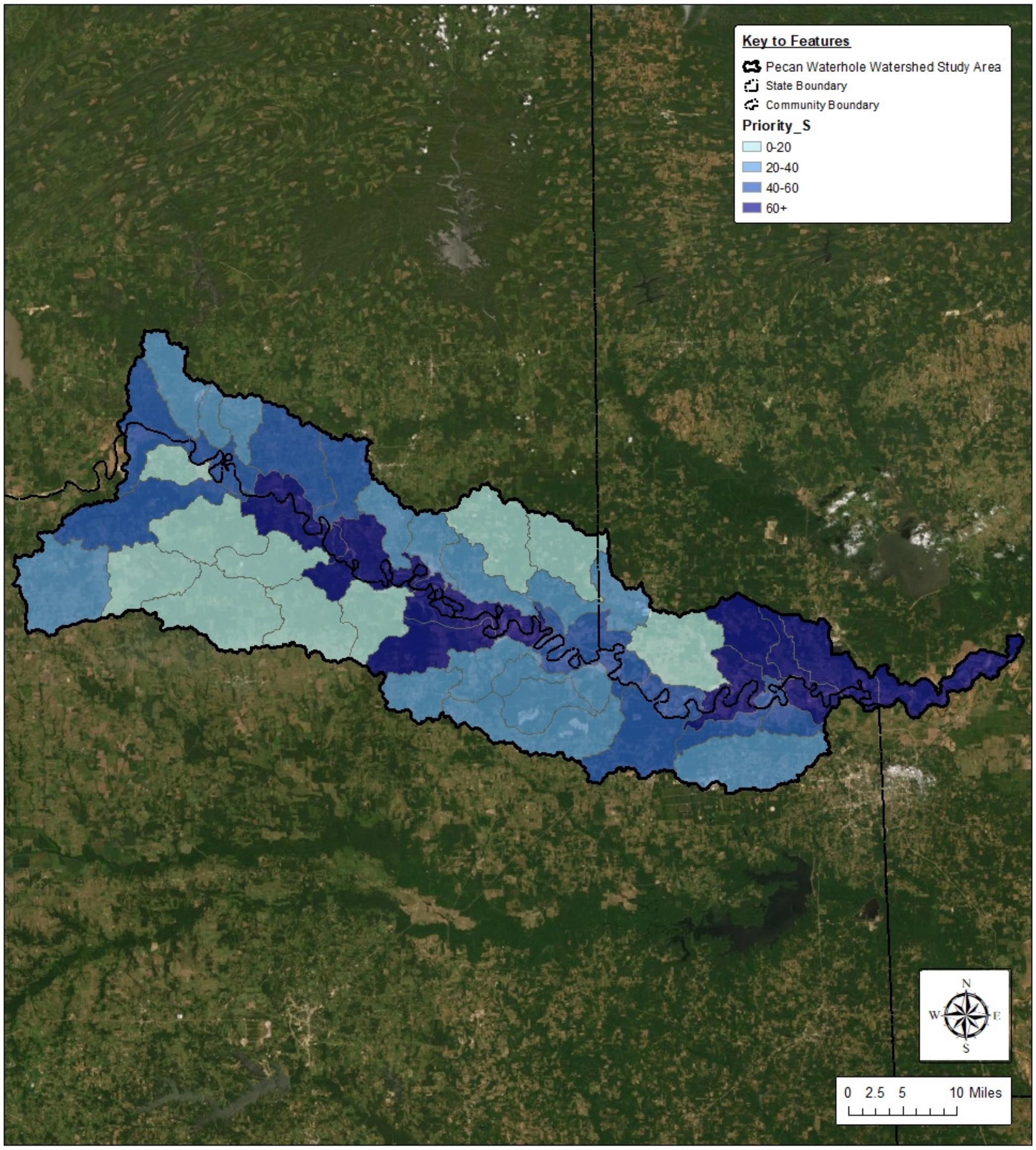

Figure ES-2: Ranking of Pecan-Waterhole Watershed HUC-12

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 Pecan-Waterhole Watershed on the Texas-Oklahoma-Arkansas Border to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHA). The study extents include portions of Bowie, Choctaw, Hempstead, Lamar, Little River, McCurtain, Miller, and Red River Counties, and include the following communities: The Cities of Ashdown, Avery, Hooks, Idabel, Leary, and Ogden. As well as the towns of De Kalb, Garvin, and Valliant. The study area consists of 6 HUC-10 basins: Pine Creek-Red River, Town of Dimple-Pecan Bayou, Whitegrass Creek-Red River, Mill Creek-Red River, Walnut Bayou-Red River, and Bull Creek-Red River. Figure 1 shows the orientation of the Pecan-Waterhole HUC-10 basins with respect to the counties.

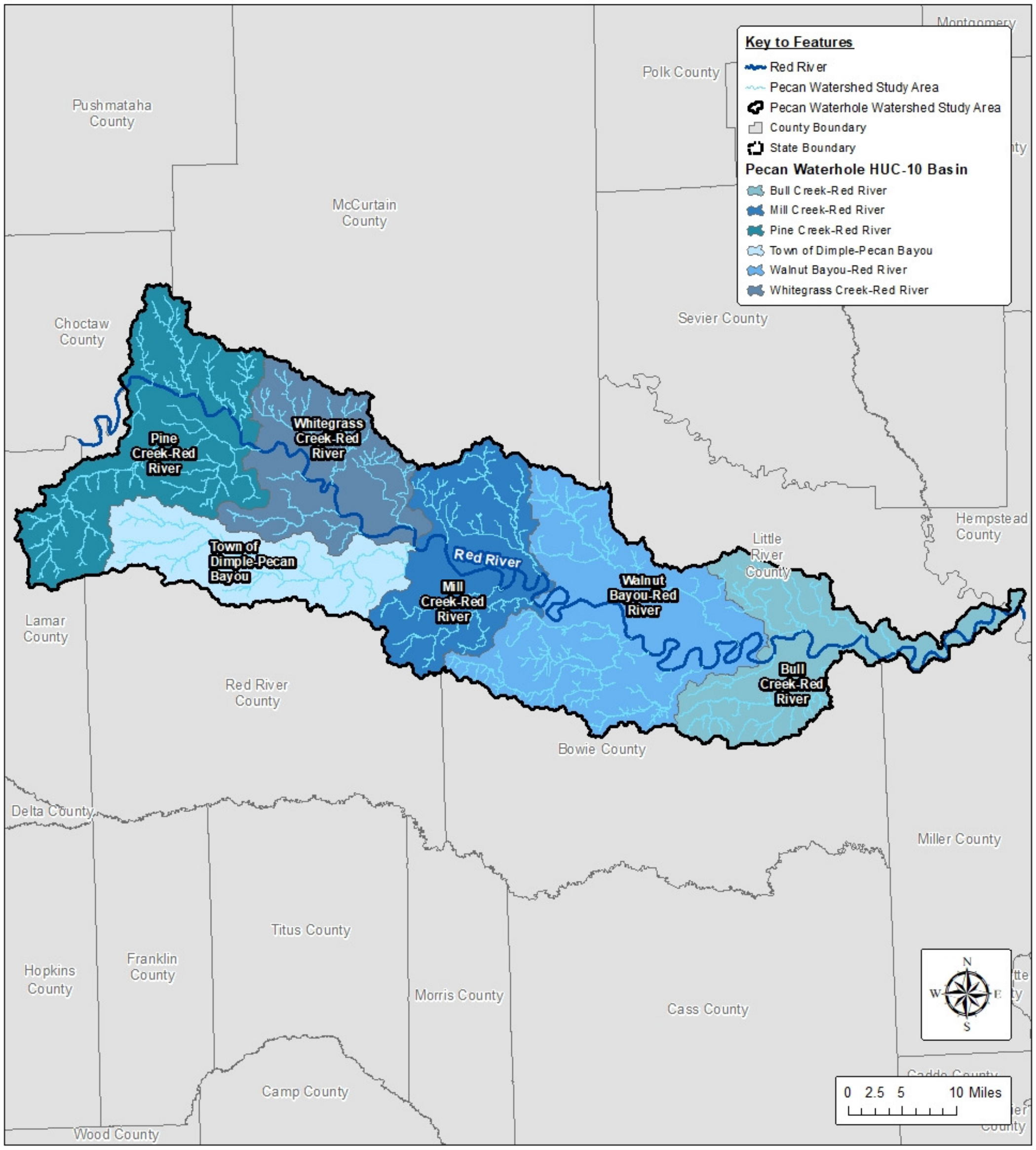

Figure 1: Pecan-Waterhole Watershed HUC-10 Basins

Compass studied approximately 1,600 miles of stream reaches within the Pecan-Waterhole Watershed with a minimum drainage area tolerance of one square mile. 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

An inventory of existing topographic data was conducted for the Pecan-Waterhole BLE project footprint. Figure 2 depicts the datasets identified and leveraged across the project area. FEMA, TNRIS, and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

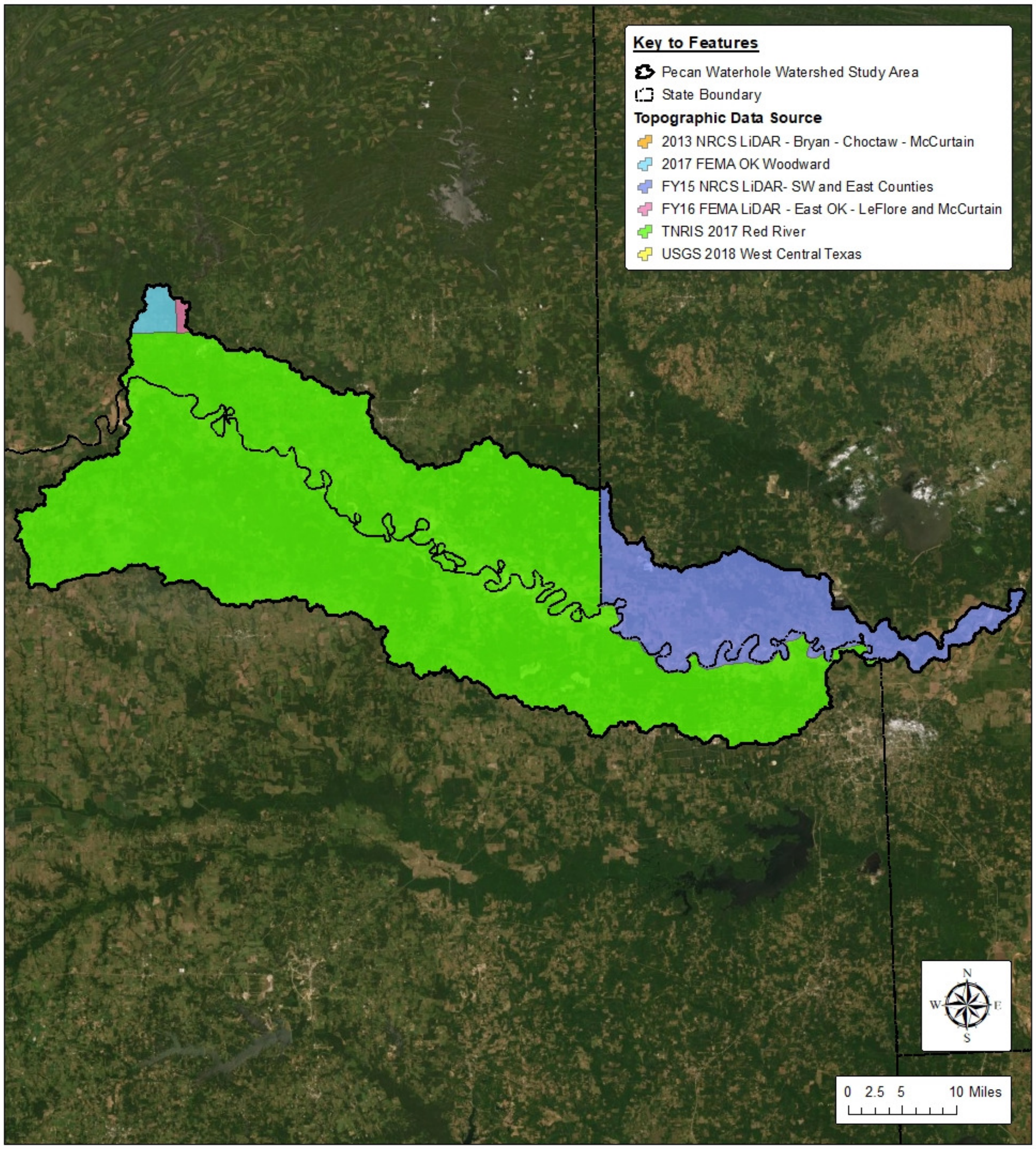

Figure 2: Extent of LiDAR Data for Pecan-Waterhole Watershed

1.1.1 Evaluation

A data coverage assessment was conducted to check for data gaps, extent, accuracy, and completeness. A review of related documentation, reports, indexes, and metadata associated with the leverage datasets ensured each dataset meets FEMA accuracy requirements for topographic data. Decisions to leverage or exclude a dataset (or portion of it), were based generally on the following criteria coupled with engineering judgment:

- Data meet FEMA vertical accuracy standards (Table 1)
- Date of origination
- Data density and coverage

Table 1 depicts the Risk Map SID 43 vertical accuracy requirements based on flood risk and terrain slope within the floodplain being mapped.

Table 1: FEMA Vertical Accuracy Requirements for Leveraged Data

Level of Flood Risk	Typical Slopes	Specification Level	Vertical Accuracy*	LiDAR Nominal Pulse Spacing (NPS)
High (Deciles 1,2,3)	Flattest	Highest	24.5 cm / 36.3 cm	≤ 2 meters
High (Deciles 1,2,3)	Rolling or Hilly	High	49.0 cm / 72.6 cm	≤ 2 meters
High (Deciles 2,3,4,5)	Hilly	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Flattest	High	49.0 cm / 72.6 cm	≤ 2 meters
Medium (Deciles 3,4,5,6,7)	Rolling	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Hilly	Low	147 cm / 218 cm	≤ 5 meters
Low (Deciles 7,8,9,10)	All	Low	147 cm / 218 cm	≤ 5 meters

***Vertical Accuracy at 95% Confidence Level (FVA or NVA)/(CVA or VVA)**

Table 2 depicts the complete list of source elevation data and attributes leveraged for the Pecan-Waterhole Watershed BLE project. All the Terrain datasets used for hydrology, hydraulic analyses, and mapping meet the highest specification level defined in Table 1. Further explanation of the Table 2 datasets can be referenced in section 1.1.1.1.

Table 2: Source Topographic Data Available for the Pecan-Waterhole Watershed

Year	Description	Data Type	RMSE	Source/Owner
2016	2016 FEMA East OK LiDAR	Airborne LiDAR	8.9 cm	FEMA
2016	2016 NRCS Arkansas LiDAR	Airborne LiDAR	7.8-8.8 cm	NRCS
2017	2017 TNRIS LiDAR Red River	Airborne LiDAR	5.6 cm	TNRIS
2017	2017 USGS Woodward Oklahoma LiDAR	Airborne LiDAR	10-15 CM	USGS

1.1.1.1 Pecan-Waterhole Watershed Source Terrain Data

The source elevation data for the Pecan-Waterhole Watershed are DEMs derived from the FEMA/USGS and NRCS LiDAR data. Only points classified as “ground” points (i.e., bare earth) were imported from the LiDAR and used for development of the project DEMs. Bare-earth LIDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the raw laser returns. Figure 2 depicts the extent of the data defined in Table 2.

2016 FEMA LiDAR East OK – Leflore and McCurtain - The 2016 FEMA East OK LiDAR was collected with a nominal pulse spacing of 0.69 meters. The RMSEz reported for the dataset was 17.4 cm at the 95% confidence level which meets the project accuracy specifications of the NSSDA.

2016 NRCS LiDAR Arkansas – SW and East Counties - The 2016 NRCS Arkansas LiDAR was collected with a nominal pulse spacing of 0.7 meters. The RMSEz reported for the dataset was between 15.3 cm to 17.2 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

2017 TNRIS LiDAR Red River - The 2017 TNRIS LiDAR Red River was collected with a nominal pulse spacing of 0.71 meters. The RMSEz reported for the dataset was 10.9 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

2017 USGS Woodward Oklahoma LiDAR - The 2017 USGS Woodward Oklahoma LiDAR was collected with a nominal pulse spacing of 1 meter. The RMSEz reported for the dataset was between 19.6 cm to 29.4 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

1.1.1.2 Terrain Data Processing

The LiDAR data were processed in Environmental System Research Institute (ESRI) ArcGIS software to create a composite Digital Elevation Model (DEM) dataset for the project area. The DEM was used to generate hydrologically correct stream centerlines and served as a source for horizontal alignment and vertical elevation during manual revisions.

The Watershed Information System (WISE) Terrain Analyst (WTA) module software platform was utilized in order to create a Hydrologically correct DEM (HDEM) for the project area. WTA is used to identify natural sinks, peaks and flat areas in the DEM surface. The WTA module uses several routines that take localized elevations from the source topographic data and apply them to the streams. This ensures that the streams in the watershed are lower in elevation than any overbank sumps and also descend in height down to an outfall. The final generated streams file is then “burned” into DEMs to force flow through structures while preventing it from jumping out of the channel banks.

During the hydro enforcement of DEM, elevations of the cells 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 HUC-08 basin. The outputs from the processing described above, which included composite DEMS and HDEMs (10-ft and 50-ft cell-size), were used during the hydrology, hydraulics, and floodplain mapping processes.

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, hydraulic analyses, and floodplain mapping activities are sufficient for BLE analysis.

1.2 Hydrology

The Pecan Waterhole watershed crosses the states of Texas and Oklahoma. Flood discharges for this study were calculated using two different United States Geological Survey (USGS) regression equations.

In both states, the drainage area for each sub-basin was determined based on automated basin delineations performed by WISE based on the 50-foot DEM. Basin break points were set by the user with a sub-basin target of one square mile (outside population centers) in size. This criterion was adjusted for streams with larger drainage areas to avoid excessive and unnecessary discharge breaks. Break points were also set just 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. WISE was also used to calculate the main-channel slope and main-channel length for each basin. The basin shapefile attribution was automated by WISE with drainage area, main-channel slope, and precipitation.

The sub-basin shapefile was attributed with the computed discharges, and those discharges were incorporated into the 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. Final discharges can be found in the Vector and raster GIS data, file geodatabase dataset (SUBBASINS) on the eBFE viewer and in the SUBBASINS.shp file on FEMA's Mapping Information Platform (MIP) in the hydraulics task.

1.2.1 Texas

For the portion of the Pecan Waterhole Watershed located in Texas, the 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 mean annual precipitation values for both Texas regression equations were determined based on gridded coverage obtained from the PRISM Climate Group and available for download from the following location: http://prism.oregonstate.edu/normals/. 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. The elevations for those endpoints were based on the 10-foot DEM developed from the LiDAR.

Table 3 presents the published equations used in this study. In these equations, Q_i represents peak streamflow for i-recurrence interval (annual chance exceedance) 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 3: Summary of Regression Equations in Texas (SIR 2009-5087)

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

Variables:

Q_i, peak flow for i recurrence interval annual chance exceedance in cubic feet per second;

P, mean annual precipitation, in inches;

S, Main-channel slope (dimensionless);

Ω, OmegaEM parameter; and

A, cumulative drainage area, in square miles.

Discharges for the 1-percent plus and 1-percent minus annual chance event were calculated as $Q_{1\%+/-} = Q_{1\%} \pm 10^{1.6*0.30}$, where 0.30 is the mean residual standard error for the $Q_{1\%}$ equation.

From USGS 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, along with a python script in ArcCatalog, 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.

1.2.2 Oklahoma

For the portion of the Pecan Waterhole Watershed located in Oklahoma, flood discharges for this study were calculated using both USGS regression equations. Regression equations obtained from the USGS Scientific Investigations Report (SIR) 2010-5137, *Methods for Estimating the Magnitude and Frequency of Peak Streamflows for Unregulated Streams in Oklahoma* (2010) contain the most recent regression equations for Oklahoma and were weighted according to area as the basis for regression calculations. Weighted discharges for streams with gages were calculated using the weighting procedure described also in SIR 2010-5137 (see Section **Error! Reference source not found.Error! Reference source not found.**).

Table 4 shows the published equations for unregulated streams. In these equations, Q_i represents peak streamflow for i-recurrence interval (annual chance exceedance) in cubic feet per second (cfs), CONTDA is the cumulative drainage area in square miles, CSL10_85*fm* represents the main-channel slope measured between two points along the channel, one at 10 percent of the channel length and the other at 85 percent of the channel length, and PRECIP represents mean annual precipitation in inches.

Main-channel slope, in feet per mile, was calculated using the WISE software. An automated routine determined the longest flowpath from upstream of a reach to the outlet of the sub-basin of interest. The slope was determined by dividing the elevation change by the distance along the longest flowpath between points at 10-percent and 85-percent of the distance from the outlet to the basin divide. The elevations for those endpoints were based on the 10-foot DEM developed from the LiDAR.

Table 4: Summary of Regression Equations in Oklahoma

Recurrence Interval	Region 2 Equation
$Q_{10\%}$	126 (CSL10_85fm)^(0.46) (CONTDA)^(0.78)
$Q_{4\%}$	174 (CSL10_85fm)^(0.47) (CONTDA)^(0.78)
$Q_{2\%}$	204 (CSL10_85fm)^(0.50) (CONTDA)^(0.79)
$Q_{1\%}$	240 (CSL10_85fm)^(0.50) (CONTDA)^(0.79)
$Q_{0.2\%}$	363 (CSL10_85fm)^(0.51) (CONTDA)^(0.80)

[1] Variables:
Q_i peak flow for i recurrence interval (a.c.e.), in cubic feet per second;
CONTDA, Contributing Drainage Area in square miles;
CSL10_85*fm*, Main-channel 10-85 slope (feet per mile);

For ungaged streams with flood control structures, equations listed in Table 5 were used. These equations, also from the SIR 2010, require the same parameters CSL10_85*fm* and PRECIP however they use the "contributing drainage area of the unregulated part of the basin or the drainage area downstream from the floodwater retarding structure". This parameter is identified as "DAUNREG" in the equations below. This method was only used for those basins where the DAUNREG is at least 14% of the cumulative drainage area and for only those flood control structures identified in the dam inventory file obtained from the Oklahoma Water Resource Board (OWRB).

Table 5: Summary of Regression Equations for Ungaged Streams with Flood Control Structures (SIR 2010-5137)

Recurrence Interval	Equation[1]
$F_{10\%(r)}$	$1.74(\mathrm{DAUNREG})^{0.66}\mathrm{PRECIP}^{1.42}(\mathrm{CSL10\_85}fm)^{0.21}$
$F_{4\%(r)}$	$4.90(\mathrm{DAUNREG})^{0.66}\mathrm{PRECIP}^{1.24}(\mathrm{CSL10\_85}fm)^{0.23}$
$F_{2\%(r)}$	$13.18(\mathrm{DAUNREG})^{0.66}\mathrm{PRECIP}^{1.05}(\mathrm{CSL10\_85}fm)^{0.21}$
$F_{1\%(r)}$	$26.9(\mathrm{DAUNREG})^{0.65}\mathrm{PRECIP}^{0.92}(\mathrm{CSL10\_85}fm)^{0.21}$
$F_{0.2\%(r)}$	$126(\mathrm{DAUNREG})^{0.64}\mathrm{PRECIP}^{0.64}(\mathrm{CSL10\_85}fm)^{0.19}$

[1] Variables:
$F_{x(r)}$ peak flow adjusted for x recurrence interval (a.c.e.), in cubic feet per second;
DAUNREG, Contributing Drainage Area in square miles;
CSL10_85*fm*, Main-channel slope (feet per mile);

Recurrence Interval	Equation[1]
	PRECIP, Mean Annual Precipitation in inches

Discharges for the 1-percent plus and 1-percent minus a.c.e. were calculated as well. These values were computed as $Q_{1\%+} = Q_{1\%}$ x (1.3572) and $Q_{1\%-} = Q_{1\%}$ x (0.6428), where 35.72% (0.3572) is the mean residual standard error of prediction for the $Q_{1\%}$ equation.

1.2.3 Flood Frequency Analyses

A flood frequency analysis was prepared for the Pecan Waterhole watershed. Gauges within the Lake Texoma, Bois D'Arc, and Farmers Mud HUC-8's were also included in the frequency analysis. Peak annual discharge from eleven USGS gages were processed to generate frequency discharges at each gage. Table 4 presents the gages included in the flood frequency analysis including the source of the data, location of the gage, period of record, and stream the gage is located on. Figure 3 shows the locations of USGS gages within Pecan Waterhole that were utilized in the flood frequency analyses.

Table 4: Flood Frequency Analysis Stream Gages

Gage Number	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
USGS 07331600	Red Rv at Denison Dam nr Denison, TX	39720	1962-2020
USGS 07335500	Red River at Arthur City, TX	40677	1936-2020
USGS 07336820	Red Rv nr De Kalb, TX	39340	1984-2020
USGS 07351500	Red Rv at Fulton, AR	46444	1950-2020
USGS 08065350	Trinity Rv nr Crockett, TX	13911	1964-2019
USGS 07315700	Mud Creek nr Courtney, OK	574	1967-2020
USGS 07332600	Bois D'Arc Ck nr Randolph, TX	72	1967-1984
USGS 07332620	Bois D'Arc Ck at FM 1396 nr Honey Grove, TX	270	2007-2020
USGS 07332622	Bois D'Arc Ck at FM 409 nr Honey Grove, TX	370	2010-2020
USGS 07336750	Little Pine Ck nr Kanawha, TX	75.4	1969-1980
USGS 07336800	Pecan Bayou nr Clarksville, TX	100	1962-1977

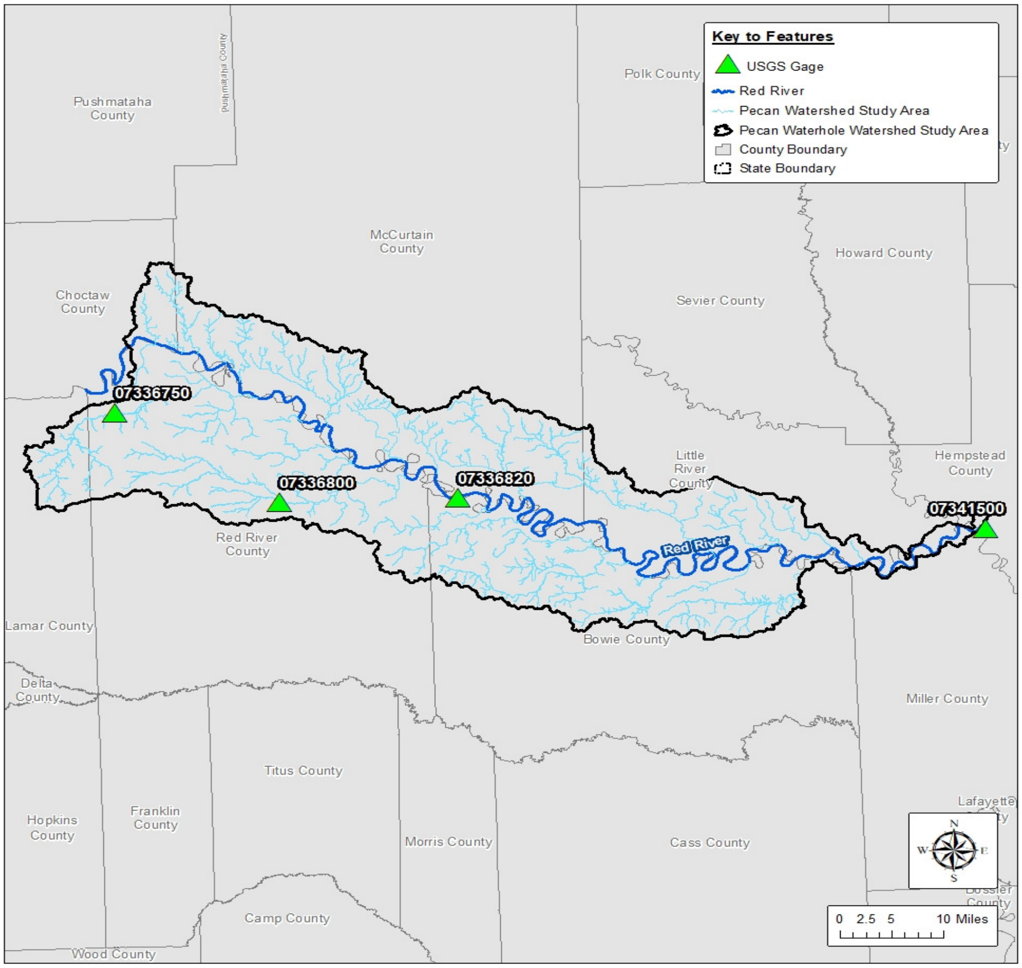

Figure 3: Locations of USGS Gages Utilized in Flood Frequency Analysis

A flood frequency analysis was computed for each USGS gage to determine the peak discharges for the Pecan Waterhole Watershed using the USGS "Guidelines for Determining Flood Flow Frequency, Bulletin 17B", revised September 1982. The USACE flood frequency analysis was leveraged along the Red River Main Stem. Flows between the gauges were interpolated based on cumulative drainage areas and no adjustment factor was necessary along the main stem. No adjustment factor was used for the rest of the Pecan Waterhole HUC-8.

A comparison of 1-percent annual chance event frequency analysis compared to the USACE frequency analysis is shown in Figure 4, below. The 1-percent annual chance event peak streamflow comparisons as calculated with the 2009 regression model and from gage data for Pecan Waterhole tributaries is shown in Figure 5. The frequency analysis results indicated that no adjustment factors would be required within the Pecan Waterhole HUC-8.

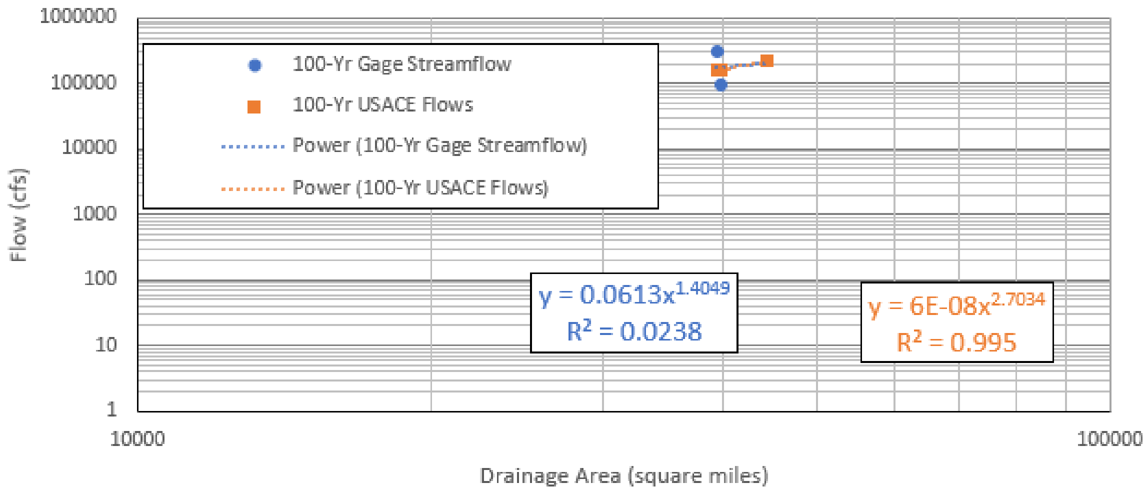

Figure 4: 1-Percent Annual Chance Event Flood Frequency Analysis for Pecan Waterhole Mainstem

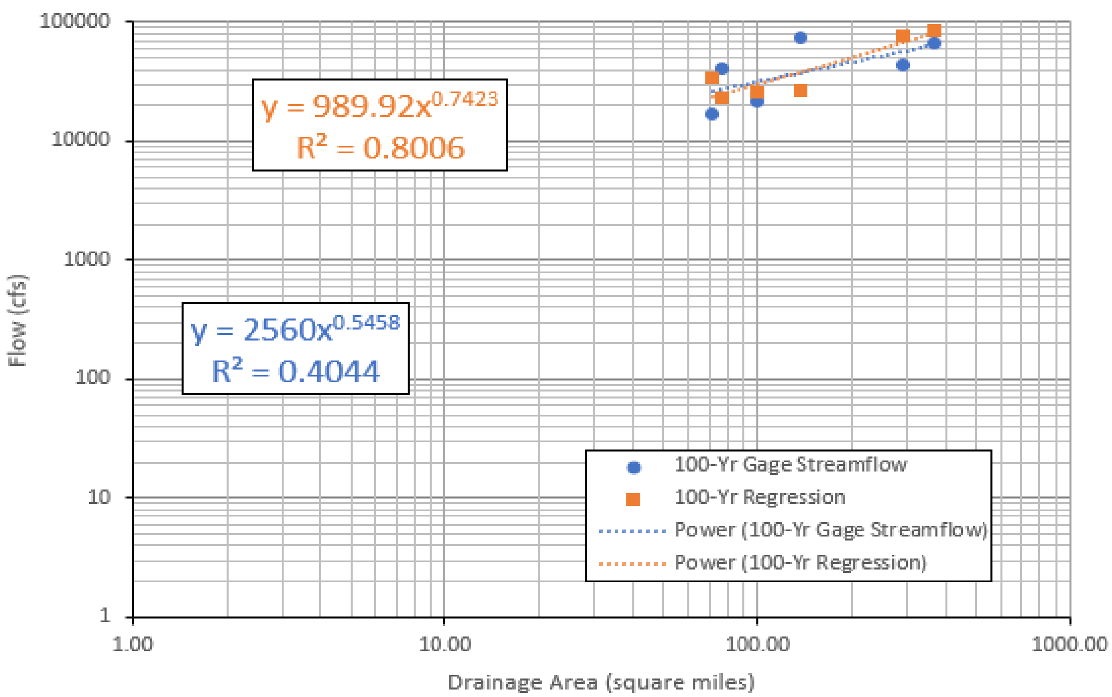

Figure 5: 1-Percent Annual Chance Event Flood Frequency Analysis for Pecan Waterhole Creek Tributaries

1.3 Hydraulics

The hydraulic approach for this BLE analysis of the Pecan-Waterhole Watershed consisted of using the terrain model described in Section 1.1 in combination with the hydrologic outputs from Section 1.1.1 to establish water surface elevations using 1-D steady state analysis. The Hydrologic Engineering Center's River Analysis System (HEC-RAS) program version 4.1.0 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 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. At this stage, a second pass inspection for cross-section placement 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 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 tops for significant dams with well-defined spillways to better represent ponded water upstream of the structures. In so doing, it was assumed that most 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) (mi^2)	XS Spacing (ft)	Channel Top Width (ft)		Channel Bottom Width (ft)		Channel Depth (ft)
		Minimum	Maximum	Minimum	Maximum	
1	500	5	12	4	11	0.1
2	500	5	14	4	13	0.1
4	500	9	14	8	13	0.3
6	500	11	16	10	15	0.3
10	500	12	17	11	16	0.5
20	500	14	22	13	21	0.5
30	500	16	24	15	23	0.5
40	500	17	26	16	25	0.5
50	600	17	27	16	26	0.5
75	600	19	30	18	29	0.5

Drainage area (upper limit) (mi^2)	XS Spacing (ft)	Channel Top Width (ft)		Channel Bottom Width (ft)		Channel Depth (ft)
		Minimum	Maximum	Minimum	Maximum	
100	750	19	32	18	31	0.5
200	750	22	36	21	35	0.5
300	1000	23	38	22	37	0.5

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). 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. Under the current BLE task order, the n-value assignments were modified in a calibration process detailed in Section 1.1.

Table 6: Manning's "n" Roughness Based on 2016 NLCD Classification (Moore, 2011)

NLCD Classification	Minimum	Normal	Maximum	Source
Open Water	0.025	0.03	0.033	Chow 1959
Developed, Open Space	0.01	0.013	0.016	Calenda et al. 2005
Developed, Low Intensity	0.038	0.05	0.063	Calenda et al. 2005
Developed, Medium Intensity	0.056	0.075	0.094	Calenda et al. 2005
Developed, High Intensity	0.075	0.1	0.125	Calenda et al. 2005
Barren Land	0.025	0.03	0.035	Chow 1959
Deciduous Forest	0.1	0.12	0.16	Chow 1959
Evergreen Forest	0.1	0.12	0.16	Chow 1959
Mixed Forest	0.1	0.12	0.16	Chow 1959
Scrub/Shrub	0.035	0.05	0.07	Chow 1959
Grassland/Herbaceous	0.025	0.03	0.035	Chow 1959
Pasture/Hay	0.03	0.04	0.05	Chow 1959
Cultivated Crops	0.025	0.035	0.045	Chow 1959
Woody Wetlands	0.08	0.1	0.12	Chow 1959
Emergent Herbaceous Wetland	0.075	0.1	0.15	Chow 1959

The boundary condition used for most 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 into 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. Simplifications of these systems may considerably affect perceived risk.

1.4 Quality Control

Following the initial BLE analysis in each watershed, the flood hazard area delineations created by the BLE process were reviewed for areas where the results were not ideal.

Quality Control (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 SFHA data.

Typical manual editing 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 6. The majority of the cross sections were adjusted. Other examples of manual editing included the addition of cross-sections at confluence areas (see Figure 7 below), modifications to improve perpendicular orientation at the channel, adjustment of discharge breaks to better represent flow addition points, revisions to dam spillways and dam tops, 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 and 0.2-percent annual chance event profiles were 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 and 0.2-percent annual chance event water surface profiles. 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.

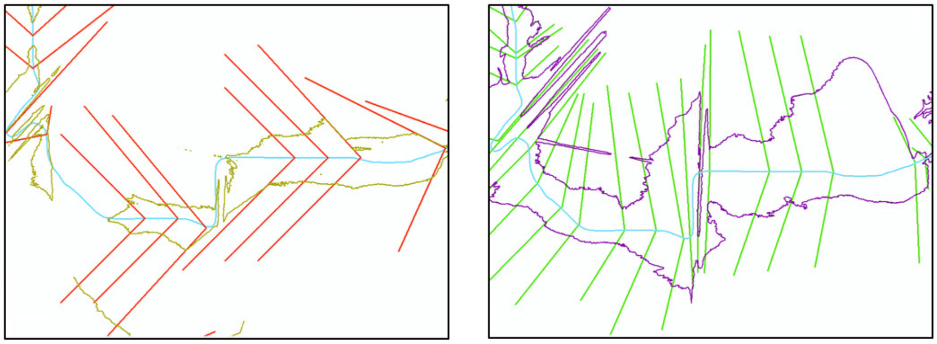

Figure 6: Default "V" angle cross-sections automated by WISE (left). Manually edited cross-sections to more accurately capture terrain (right). Resulting flood boundaries shown in gold (left) or purple (right) for clarity.

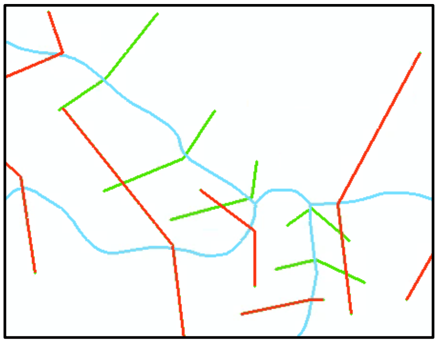

Figure 7: Manually added cross-sections (green) to improve accuracy of tie-ins at confluences.

1.5 Floodplain Delineation (10%, 1%, and 0.2% events)

The 10-percent, 1-percent and 0.2-percent annual chance event 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, areas with a size of less than 5,000 square feet were removed and all others were investigated to determine whether they should be considered as potentially part of the SFHA. 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. Islands with a size between roughly 5,000 and 30,000 square feet were inspected and, in general, islands that were less than 10,000 square feet were 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

Challenges encountered during BLE analyses vary based on available data on which to run the analysis. The Pecan Waterhole Watershed presented challenges as summarized in the following paragraphs.

A significant effort was made to improve 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 small-sized dams on the tributaries throughout the watershed. Discharges calculated with the regression equations do not take into account the impact of these structures apart for ungauged streams with flood control structures, see Section 1.2.2 There may be need for further investigation when upgrading these models for detailed studies.

A significant effort was made to maintain consistent discharges along the Trinity River mainstem between the Lake Texoma, Farmers Mud, Pecan Waterhole and Bois D'Arc Watershed BLE studies. Revisions were made to the regression equation parameters in this study to ensure consistent discharges between the two BLE studies mentioned.

As part of this study, areas where mapping was significantly different than current effective mapping or required a more detailed analysis were identified and documented. These are part of the GIS deliverables under Areas of Mitigation Interest (AOMI's).

The effective, steady-state HEC-RAS model received from the U.S. Army Corp of Engineers (USACE) on October 2020 was used as the mainstem Red River model for this study.

Revisions to the USACE Red River hydraulic cross sections and HEC-RAS model were required to provide mapping using BLE methodology. Storage areas were removed, cross sections were extended, and ineffective areas were revised due to the higher flows calculated during this study. Bank stations were also adjusted to better represent the main channel. Manning's roughness coefficients (n-values) were updated based on the increased roughness coefficients attributed to high flows in the USACE hydraulic model.

No hydrologic calculations were performed along the main stem. The USACE frequency analysis was utilized and applied to the hydraulic model. Flows between the gauges were interpolated based on cumulative drainage area.

Results and Recommendations

The BLE results for this study produced a SFHA that compares reasonably well with the effective SFHA. These boundaries provide an additional estimated SFHA in areas that 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 **Error! Reference source not found.**.

3.1 CNMS Validation of Effective Zone A SFHA

The following summarizes the results of the CNMS validation assessments for the effective Zone A studies in the Pecan-Waterhole Watershed.

3.1.1.1 Initial Assessment A1 – Significant Topography Update Check

The significant topography update check determines whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. For most of the study area the effective Zone A topographic data source is unknown, but most likely would have leveraged contours from USGS 24K map products. This caused most reaches to FAIL this element because the elevation data leveraged in the BLE study represents a significant improvement from the USGS 24K map products. The exception to this is the streams in McCurtain County, which were restudied more recently in 2008 and utilized LiDAR.

3.1.1.2 Initial Assessment A2 – Check for Significant Hydrology Changes

The significant hydrology changes check determines 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. A majority of the reaches being assessed did not use regression methods or the hydrologic methods are unknown/undocumented. Reaches within McCurtain County used regression equation methods in 2008. The most recent equations are from 2010 (SIR 2010-5137) but streams PASS this check since there is no significant change in discharges with dates being so close together. Reaches in Bowie, Choctaw, Hempstead, Lamar, Little River, Miller and Red River did not use regression methods therefore, the reaches in these counties PASS this check.

3.1.1.3 Initial Assessment A3 – Check for Significant Development

The significant development check, using the National Urban Change Indicator (NUCI) dataset, assesses increased urbanization in the watershed of the BLE. If the percentage of urban area within the HUC-12 watershed containing the effective Zone A study is 15 percent or more and has increased by 50 percent 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 the Pecan-Waterhole study area was completed by evaluating percentage of urban change at the HUC-12 level. All of the watershed is classified as rural and, therefore, all reaches PASS this assessment.

Table 7 presents the summarized results of checks A1 through A3.

Table 7: A1-A3 Validation Results

Assessment Checks	Pass / Fail	Notes
A1 - Topography	Fail/Pass	Available LiDAR sources in areas of effective studies that did not utilize LiDAR/Studies within McCurtain County utilized LiDAR for effective study
A2 - Hydrology	Fail/Pass	Regression was not used for effective studies or the most current regression equations were used; Regression was used for effective studies and new equations now exist.
A3 - Development	Pass	Watershed is classified as Non-Urban

3.1.1.4 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. Due to lack of documentation of the original engineering methods ~~in Freestone County, check A4 has been marked as FAIL for these reaches. The~~the majority of reaches within Pecan Waterhole ~~have some documentation of engineering methods, and therefore, PASS~~fail this check. Reaches in McCurtain County, OK have documentation of engineering methods, and therefore PASS this check.

3.1.1.5 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).

Of the 500 modeled BLE streams in the study area, 178 were found to correspond (within the tolerance limits) with effective Zone A flood zones. 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 marked as "Fail".

Table 8: HUC-12 Zone A Validation Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Pecan-Waterhole	**All Streams**	**49,813**	**27,990**	**21,823**	**39.57%**	**Fail**	
Clear Creek	111401060101	1,483	435	1,048	70.67%	Fail	23.2
Garland Creek	111401060102	953	406	547	57.40%	Fail	37.2
Buzzard Creek	111401060103	1,199	459	740	61.72%	Fail	34.5
Upper Little Pine Creek	111401060104	2,005	826	1,179	58.80%	Fail	30.3
Lower Pine Creek	111401060107	328	239	89	27.13%	Fail	56.5
Doaksville Creek-Red River	111401060108	2,389	1537	852	35.66%	Fail	51.9
Upper Whitegrass Creek	111401060301	3,643	1,763	1,880	51.61%	Fail	43.6
Lower Whitegrass Creek	111401060302	1789	843	946	52.88%	Fail	42.3
Greenwood Branch-Red River	111401060304	772	721	51	6.61%	Fail	79.8
Waterfall Creek	111401060305	1,313	683	630	47.98%	Fail	26.0
Bass Creek-Red River	111401060306	1052	916	136	12.93%	Fail	77.1
Holly Branch	111401060401	1,470	813	657	44.69%	Fail	23.0
Little Mill Creek	111401060402	571	416	155	27.15%	Fail	75.9
Norwood Creek	111401060403	1724	719	1005	58.29%	Fail	16.3
Push Creek	111401060404	1,348	672	676	50.15%	Fail	23.8
West Fork Mill Creek-Mill Creek	111401060405	223	84	139	62.33%	Fail	30.1
Tanyard Creek-Mill Creek	111401060406	1856	829	1027	55.33%	Fail	35.9
Whitaker Bend Cut off-Red River	111401060407	2,535	2442	93	3.67%	Fail	65.6
Hooks Bayou	111401060501	1,441	653	788	54.68%	Fail	34.9

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Holly Creek	111401060502	1363	554	809	59.35%	Fail	36.6
Mud Creek	111401060503	3,100	1229	1871	60.35%	Fail	32.8
Hokes Creek-Red River	111401060504	2,708	2,160	548	20.24%	Fail	57.4
Red Bayou-Red River	111401060505	2617	1255	1362	52.04%	Fail	41.4
McKinney Creek	111401060506	1,828	1008	820	44.86%	Fail	16.2
Upper Walnut Bayou	111401060507	3,151	2,072	1,079	34.24%	Fail	30.5
Lower Walnut Bayou-Red River	111401060509	569	461	108	18.98%	Fail	72.9
McKinney Bayou-Red River	111401060601	1,082	569	513	47.41%	Fail	47.3
Bull Creek	111401060602	28	24	4	14.29%	Fail	77.1
McKinney Bayou	111401060603	313	160	153	48.88%	Fail	46.0
Barkman Creek	111401060604	3,169	1273	1896	59.83%	Fail	25.4
Allen Creek-Red River	111401060605	388	371	17	4.38%	Fail	86.1
Haney Creek-Red River	111401060606	333	329	4	1.20%	Fail	88.9
Mill Branch-Red River	111401060607	1,070	1069	1	0.09%	Fail	83.1

VALIDATION RESULTS

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Pecan-Waterhole Watershed has been updated as summarized in Table 9 and illustrated in Figure 8 below. The priority scores are illustrated in Figure 9.

Table 9: Aggregated Zone A Validation Results

Validation Status	Status Type	Total Miles
Valid	Being Studied	32.9
Unverified	Being Studied	615.4

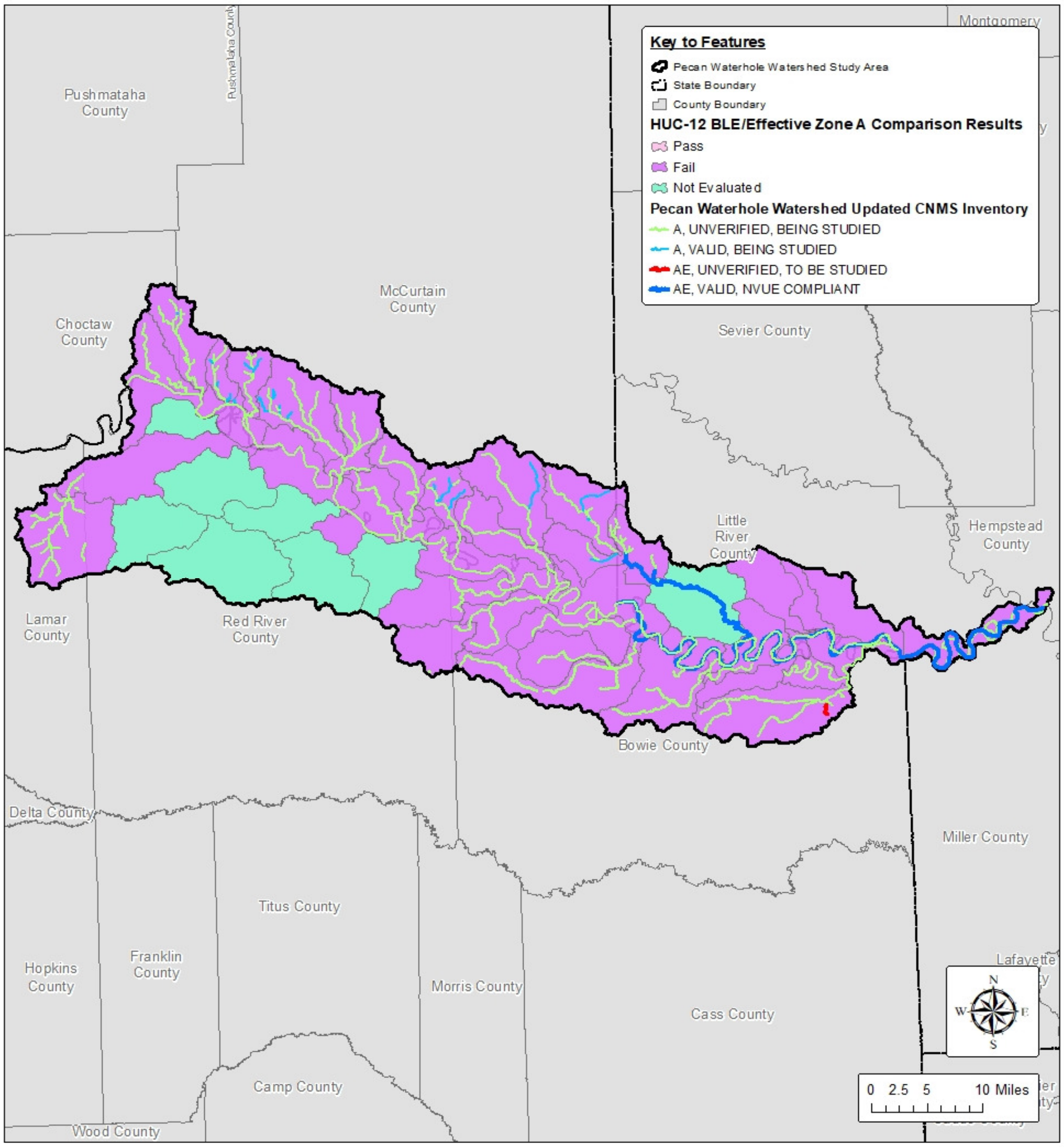

Figure 8: Pecan-Waterhole Watershed CNMS Validation Results

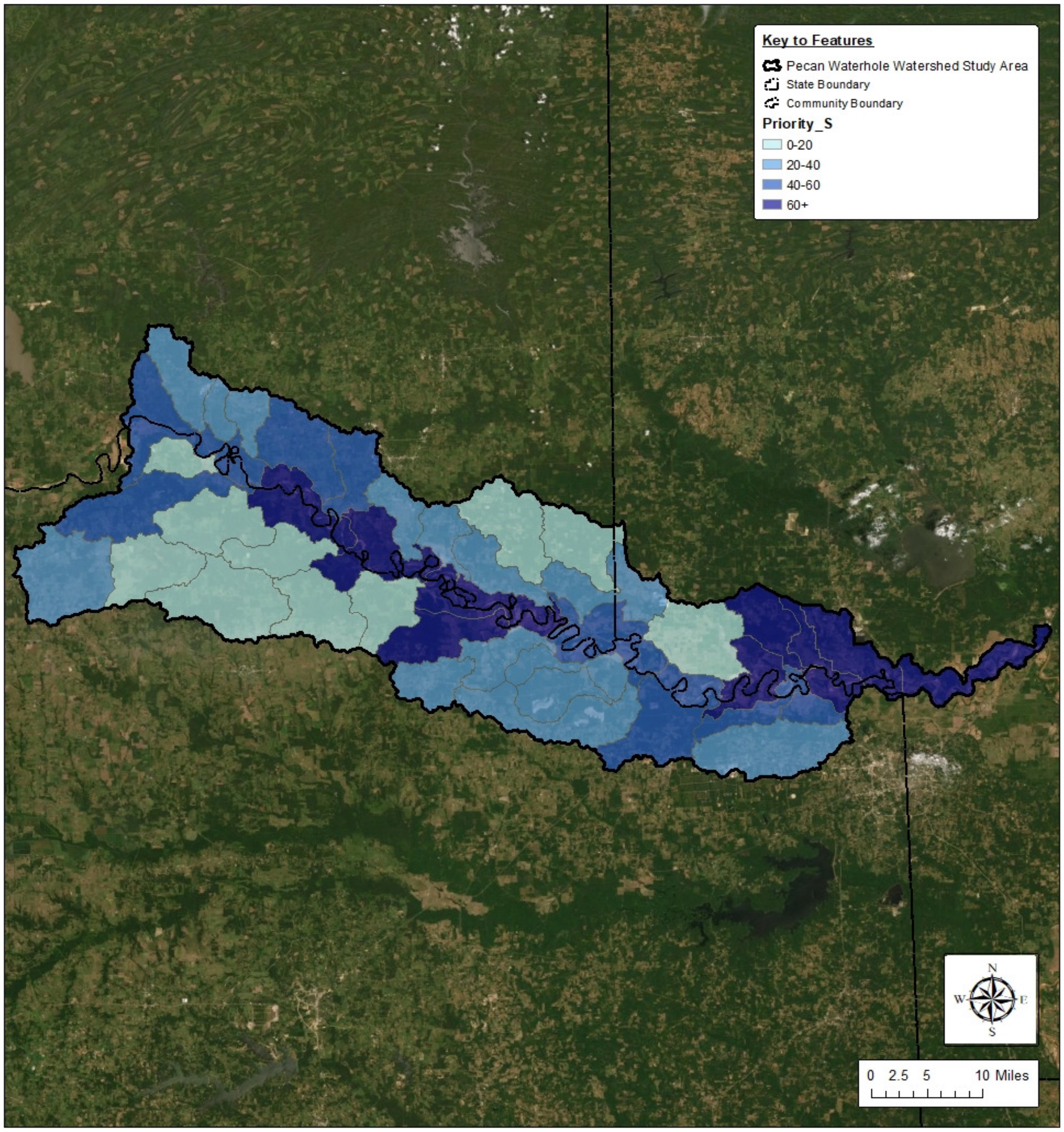

Figure 9: Ranking of Pecan-Waterhole Watershed HUC-12s

3.2 Flood Risk Analysis

A flood risk analysis was performed for this project. The updated 1-percent annual chance grid (known as the 'refined' grid) was used to perform the flood risk analysis to produce the flood losses. The refined grid loss results are stored in the S_FRAC_Ar feature class.

Hazus version 4.2 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 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 on a watershed level for the study area extents to ensure proper model processing. A summary of results per county for the 1-percent annual chance event scenarios are shown in Table 10.

Table 10: Hazus 4.2 Results for 1-Percent Annual Chance Scenario for Pecan-Waterhole

County	Full Replacement - Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Anderson	$89,823,000	$2,390,199,000	$1,432,729,000
Freestone	$39,179,000	$1,569,922,000	$937,910,000
Henderson	$14,349,000	$930,728,000	$602,141,000
Houston	$19,778,000	$1,057,484,000	$663,051,000
Leon	$40,718,000	$544,966,000	$340,692,000
Limestone	$1,991,000	$362,133,000	$239,512,000
Navarro	$14,000	$37,052,000	$19,335,000
Total	$205,852,000	$6,892,484,000	$4,235,370,000

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Appendix A BLE Map