Upper Clear Fork Brazos Watershed, TX
Base Level Engineering (BLE) Results

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Executive Summary

The Federal Emergency Management Agency (FEMA) Region VI contracted Compass to complete a Base Level Engineering (BLE) analysis for the Upper Clear Fork Brazos Watershed in Northwest Central Texas, to support FEMA's validation of effective Zone A Special Flood Hazard Area (SFHA). 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 (H&H) analysis as well as mapping activities were leveraged from FEMA and supplemented with USGS National Elevation Dataset (NED) as appropriate. The FEMA acquired terrain dataset was 2014 0.7-meter Light Detection and Ranging (LiDAR) survey data, while the USGS NED 1/3 Arc Second DEM was approximately 10-meter equivalent.

Flood discharges for this study were calculated using both USGS regression equations and gage analysis, where stream gages with sufficient records exist. Regression Equations obtained from the 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) were used while PeakFQ version 7.1 was used to perform Flood Frequency Analysis (FFA) for the seven gages in the Upper Clear Fork Brazos watershed however only two of those gages were used to adjust stream discharges.

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) program version 4.1 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 Upper Clear Fork Brazos Watershed was compiled using FEMA's CNMS inventory. Table ES-1 lists the stream miles identified for this BLE validation analysis.

Table ES-1. Summary of Stream Miles

Source	Upper Clear Fork Brazos Stream Miles
CNMS	1,020
Total	**1,020**

The full inventory of Zone A studies (724.3 miles) in the Upper Clear Fork Brazos Watershed study were classified in CNMS. These miles are summarized in Table ES-2 and illustrated in Figure ES-1 below. This figure also presents the pass/fail HUC-12 results as determined by the CNMS validation.

Table ES-2: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	NVUE COMPLIANT	96.7
UNVERIFIED	TO BE STUDIED	923.3

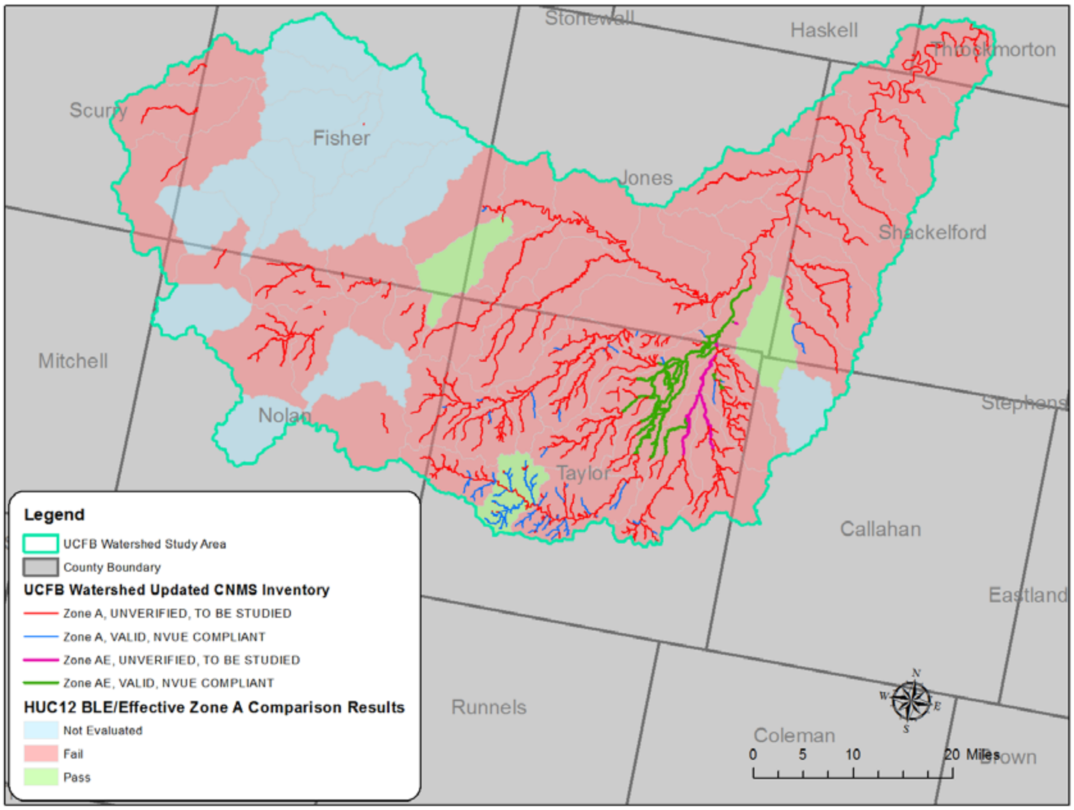

Figure ES-1. Upper Clear Fork Brazos Watershed CNMS Validation Results

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. The range of the Upper Clear Fork Brazos HUC-8 priority scores can be used to initiate discussions with communities. Walnut Creek - Clear Fork Brazos HUC-12 was determined to have the highest priority score and the most need while 14 of the HUC-12 basins were not able to be evaluated since there is no effective digital or CNMS data available.

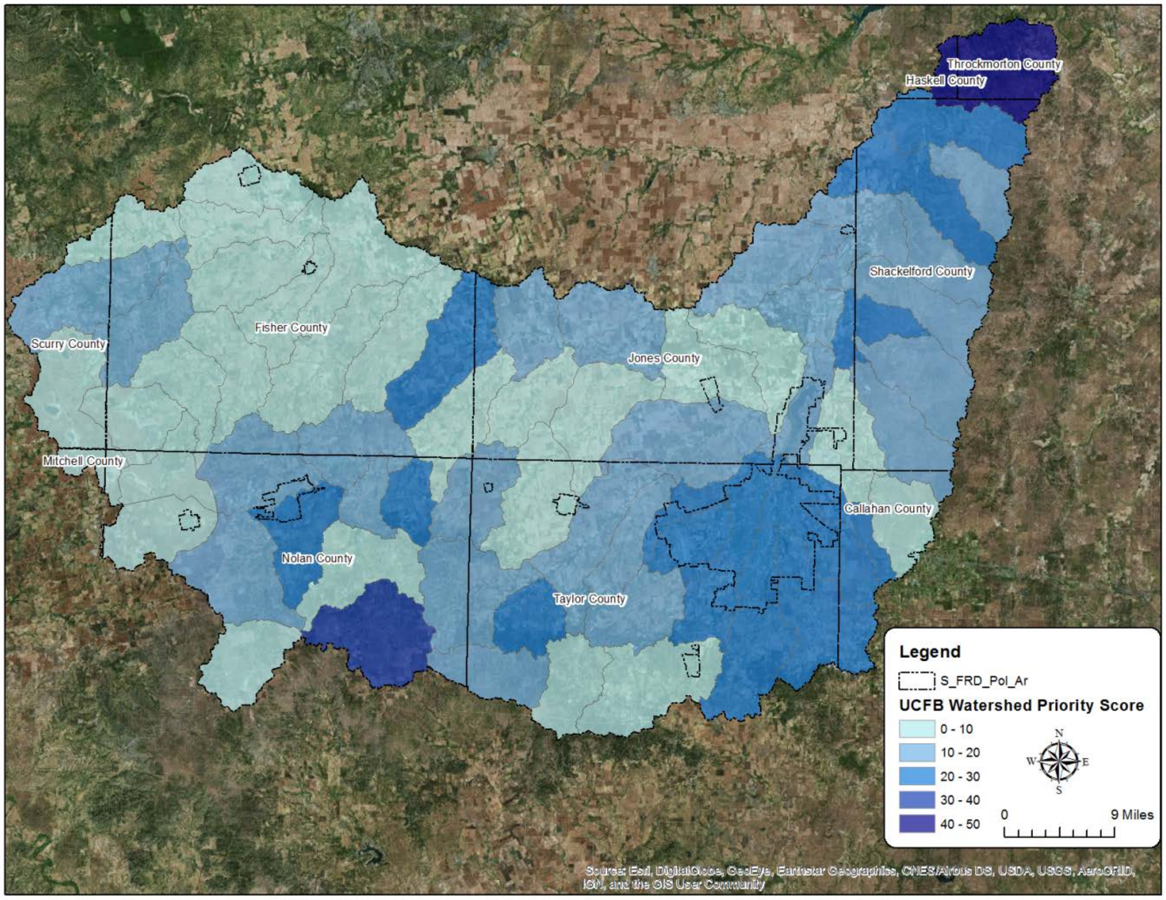

Figure ES-2. Ranking of Upper Clear Fork Brazos Watershed HUC-12s

Base Level Engineering (BLE) Methodology

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

As described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e), once every five years, FEMA must evaluate whether the information on Flood Insurance Rate Maps (FIRMs) reflects the current risks in floodprone 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 Region 6 is producing this study in parallel to a current Phase II study in the same area. The products produced for this study will be shared and results 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 Upper Clear Fork Brazos Watershed in Northwest Central Texas, to support FEMA's validation of effective Zone A Special Flood Hazard Area (SFHA). The study extents include portions of Callahan, Throckmorton, Haskell, Fisher, Jones, Scurry, Shackelford, Taylor, and Nolan counties and include the following communities: Cities of Abilene, Clyde, Hawley, Lueders, Merkel, Trent, Tuscola, Tye, Roby, Roscoe, Rotan, and Sweetwater and the Towns of Buffalo Gap and Impact. The study area consisted of nine HUC-10 basins: Bitter Creek – Sweetwater Creek, Chimney Creek – Clear Fork Brazos River, Deadman Creek – Clear Fork Brazos River, Elm Creek, Headwaters Clear Fork Brazos River, Linn Creek – Cottonwood Creek, Mulberry Creek, Noodle Clear – Clear Fork Brazos River, and Plum Creek – Clear Fork Brazos River. Figure 1 shows the orientation of the Upper Clear Fork Brazos Creek HUC-10 basins with respect to the counties.

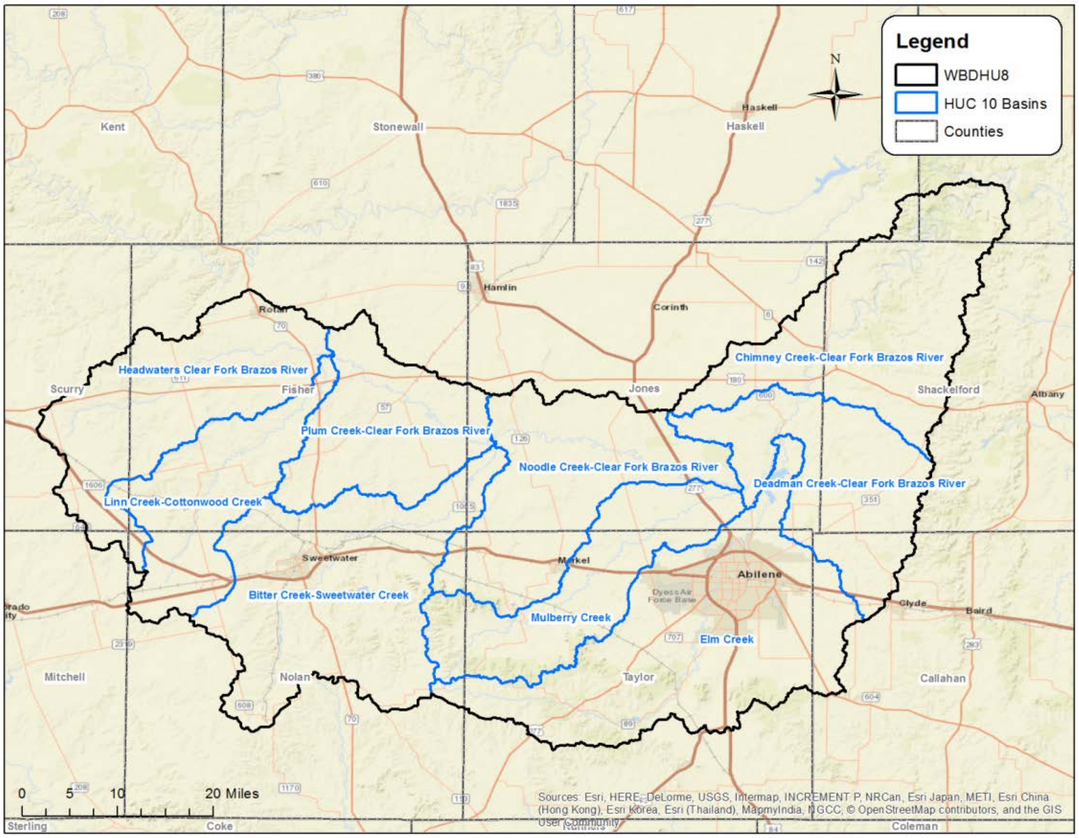

Figure 1: Upper Clear Fork Brazos Watershed HUC-10 Basins

Compass studied approximately 3,340 miles of stream reaches within the Upper Clear Fork Brazos Watershed with a minimum drainage area tolerance of one square mile. The selection and extent of stream reaches studied was based upon the number of stream miles with minimum drainage area of one square mile and not the number of effective Zone A stream miles. Study reaches were extended above this one square mile threshold as appropriate to ensure all effective Zone A floodplain received an updated analysis. Topographic data available from the United States Geologic Survey (USGS) was used to determine the hydrologic and hydraulic characteristics of the watershed. The following sections will summarize the BLE process and will discuss the results along with their recommended use.

1.1 Topographic Data

Documentation regarding leverage data and process including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables and text within this section. All vertical accuracy specifications were obtained from the metadata or survey reports provided with the leverage datasets. All available metadata, survey reports, and other leverage documentation are included in the FEMA Data Capture Technical Reference compliant submittal content for their respective watershed. Figure 2 shows the extents of the source Digital Terrain Model (DTM) data used for the Upper Clear Fork Brazos watershed studied.

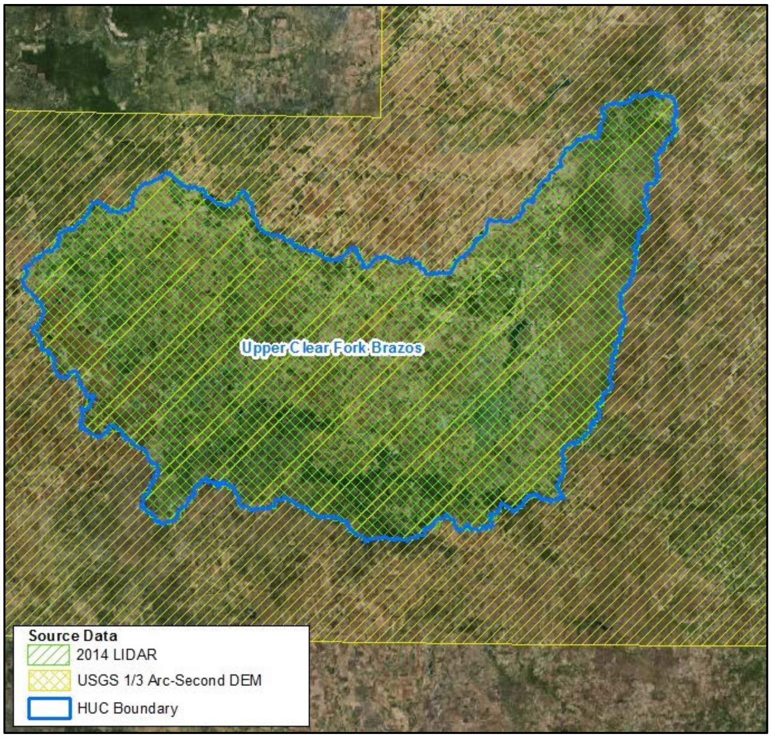

Figure 2: Extent of LiDAR Data

1.1.1 Source Terrain Data

1.1.1.1 2014 LiDAR Upper Clear Fork Brazos TX

The Light Detection and Ranging (LiDAR) dataset is a survey of the Upper Clear Fork Brazos_G14PD01081 0.7 meter LiDAR Survey in Northwest Central Texas and encompasses 2,983 square miles. The LiDAR point cloud was flown at a nominal post spacing of 0.7 meters for unobscured areas. The LiDAR data and derivative products produced are in compliance with the USGS National Geospatial Program Guidelines and Base Specifications, Version 1.0. The flight lines were acquired by Digital Aerial Solutions, LLC between December 12, 2014 and December 24, 2014. Derivative products from the aerial acquisition include: raw point cloud data in LAS v1.2, classified point cloud data in LAS v1.2, bare earth surface tiles (32-bit Floating point raster DEM ERDAS Imagine format), LiDAR Intensity Image, breaklines, control points, project report acquisition report, and FGDC compliant XML metadata. A manual QA review of the tiles was completed in Global Mapper to ensure full coverage with no gaps or slivers within the project area. All data is seamless from one tile to the next, no gaps or no data areas. The vertical unit of the data file is in decimal feet with 2-decimal point precision.

1.1.1.2 USGS

National Elevation Dataset (NED) is available in 1/3 arc-second resolutions and was used wherever better topographic data was not available in the project area. The NED is an elevation dataset that consists of seamless layers and a high resolution layer. Each of these layers is composed of the best available raster elevation data of the conterminous United States, Alaska, Hawaii, territorial islands, Mexico and Canada. The NED is updated continually as new data become available. All NED data are in the public domain. The NED are derived from diverse source data that are processed to a common coordinate system and unit of vertical measure. These data are distributed in geographic coordinates in units of decimal degrees, and in conformance with the North American Datum of 1983 (NAD 83). All elevation values are in meters and, over the continental United States, are referenced to the North American Vertical Datum of 1988 (NAVD 88). The vertical reference will vary in other areas. NED data are available nationally (except for Alaska) at resolutions of 1 arc-second (approximately 30 meters) and 1/3 arc-second (approximately 10 meters), and in limited areas at 1/9 arc-second (approximately 3 meters). The NED serves as the elevation layer of The National Map, and provides basic elevation information for earth science studies and mapping applications in the United States. The data are utilized by the scientific and resource management communities for global change research, hydrologic modeling, resource monitoring, mapping and visualization applications.

Additional information for the NED may be found on http://ned.usgs.gov/. Data may be downloaded through The National Map Viewer: http://nationalmap.gov/viewer.html. Direct links for direct access by automated services are provided in the Distribution section of this metadata.

1.1.2 Terrain Data Processing

The Watershed Information System (WISE) software platform was utilized in order to create a digital surface model for the Upper Clear Fork Brazos, TX 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. For the Upper Clear Fork Brazos HUC, TX LiDAR project, 2014 LiDAR Upper Clear Fork Brazos TX and USGS NED data were used as the data sources for creating the 10-foot and 50-foot DEMs.

The DEMs created from the LIDAR datasets mentioned above were compiled in order of vertical accuracy into a mosaic dataset using ArcMap. From this mosaic, a tile index was created for the project area and the mosaic was clipped into 50,000 foot tiles, converted to asciis and imported into Wise Terrain Analyst (WTA). Visual inspection of the 10-foot DEMs was performed to ensure no voids and/or artifacts were present in the DEM. The DEM surface model was affirmed to be suitable for hydraulic takeoffs and supporting other hydraulic analyses.

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

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

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

1.2 Hydrology

Flood discharges for this study were calculated using USGS regression equations and gage analysis, where stream gages with sufficient records exist. 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) contains the most recent regression equations for Texas and was used as the basis for regression discharge calculations.

Table 1 shows the published equations used for 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, P represents mean annual precipitation in inches, S represents dimensionless main-channel slope, Ω represents the OmegaEM parameter, and A is cumulative drainage area in square miles.

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

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

[1] Variables:
Q_i peak flow for i recurrence interval (a.c.e.), in cubic feet per second;
P, Mean Annual Precipitation in Inches;
S, Main-channel slope (dimensionless);
Ω, OmegaEM parameter;
A, Cumulative Drainage Area in square miles

Discharges for the 1-percent plus and 1-percent minus a.c.e. were calculated as well. These values were computed by multiplying the $Q_{1\%}$ discharges by 0.30*log10, which is the mean residual standard error for the $Q_{1\%}$ equation.

The WISE computer program was used to delineate drainage basins in shapefile format using the 50-foot resolution DEM. Basin break points were set by the user with a sub-basin target area of one square mile in size. This criterion was adjusted for streams with larger drainage areas in order 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 used to calculate the main-channel slope for each basin. An automated routine was used to determine the longest flowpath from the headwaters of a watershed to the outlet of the point of interest based on flowpaths developed from the 50-foot DEM. Using the longest flowpath, elevations for the endpoints were determined based on the 50-foot DEM. The slope was calculated by dividing the difference in elevation with the flowpath length. The result was expressed in unit less form.

In order determine mean annual precipitation and OmegaEM values for each sub-basin, a Python script was created and run in ESRI's ArcCatalog. The script batch processed the geoprocessing needed to assign mean annual precipitation values in inches and OmegaEM values to each sub-basin.

The mean annual precipitation values were determined based on a shapefile coverage obtained from the Texas Water Development Board and available for download from the following location: http://www.twdb.texas.gov/mapping/gisdata/doc/Precipitation_Shapefile.zip

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

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 to determine OmegaEM values on a sub-basin basis. For streams that crossed multiple OmegaEM values, a weighted OmegaEM parameter was calculated and then applied on a sub-basin basis.

Additionally, the Python script used all inputs from each sub-basin and calculated the appropriate discharge values using the regression equations. The resulting discharge values were appended to the sub-basin shapefile attribute table.

Flood Frequency Analyses (FFA) were performed following Bulletin 17B guidelines, using PeakFQ version 7.1, for two gages on Clear Fork Brazos River, and one gage each on Cat Claw, Cedar, Elm, Little Elm, and Mulberry Creeks. After evaluation, only the gages along Clear Fork Brazos River were used to determine the a.c.e. flows. All gages evaluated are listed in Table 2. For gage on

Clear Fork Brazos River, the record for the period since the beginning of regulation in 1962 was examined in order to determine the a.c.e. flows under the existing regulated conditions.

Table 2: USGS Stream Gages Used in Analysis

Gage ID	Flooding Source and Location	Computed Drainage Area (mi^2)	Published Drainage Area (mi^2)	Period of Record
08083245*	Mulberry Creek near Hawley, TX	204	205	1967 - 1989
08083100	Clear Fork Brazos River near Roby, TX	239	228	1962 - 2016
08083300*	Elm Creek near Abilene, Texas	142	133	1964 - 1979
08083400*	Little Elm Creek near Abilene, Texas	39.5	39.1	1964 - 1979
08083420*	Cat Claw Creek at Abilene, Texas	13.6	13.0	1971 - 2016
08083480*	Cedar Creek at IH20, Abilene, Texas	125	136	1971 - 2016
08084000	Clear Fork Brazos River at Nugent, TX	2,273	2,199	1941 - 2016

*Gages were evaluated but were not used to adjust flows.

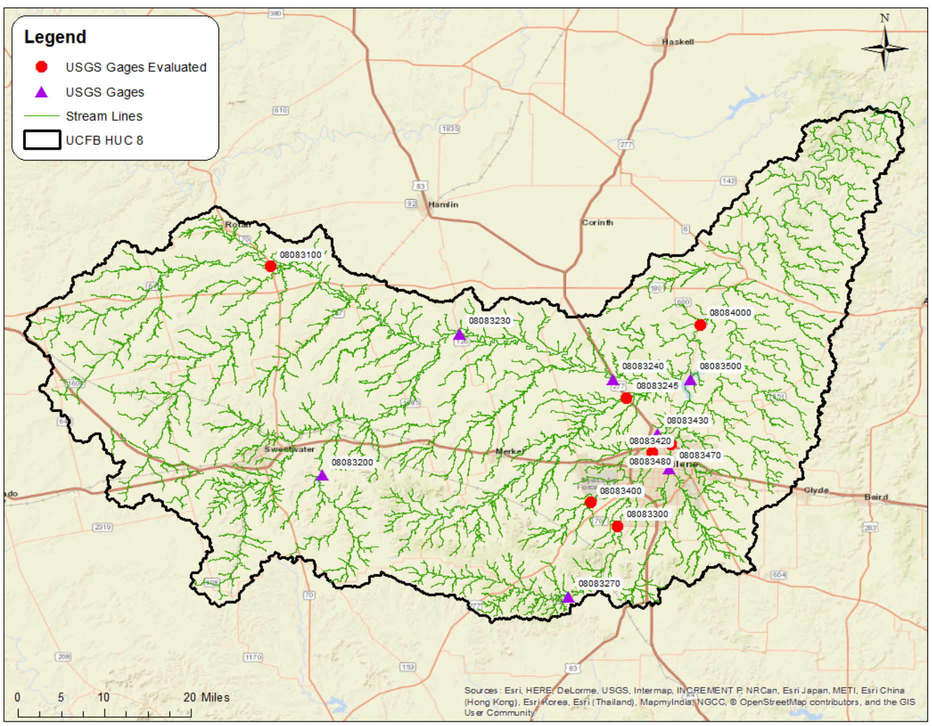

Figure 3: USGS Gage Stations within Upper Clear Fork Brazos Watershed

The BLE analysis compared hydrologic results in areas where effective discharge data was available. At these locations, the general trend showed that the effective discharges were significantly higher than the discharges computed using regression equations and gage analysis.

The peak discharges on Upper Clear Fork Brazos Watershed are attenuated by the combined effect of several flood control reservoirs in the headwaters of the sub-basin. These reservoirs are on the main stem as well as several tributary streams. As a result of the peak attenuation, the

USGS regression equations likely over predict the a.c.e. flows for Clear Fork Brazos River as well as study segments on tributaries to Clear Fork Brazos River that are downstream of flood control impoundments.

It should be noted that there was no hydrologic routing used to adjust peak discharges to account for any attenuation due to the flood control dams on streams in the Upper Clear Fork Brazos Watershed. As such, no explicit method was used to account for any reduction in peak discharges due to dams. Gage-based adjustments to the peak discharges, however, provided implicit adjustment to the impact of these structures on any of the regulated gaged streams.

1.3 Hydraulics

The hydraulic approach for BLE analysis for the Upper Clear Fork Brazos watershed consisted of using the terrain model described in section 1.1 in combination with hydrology input computed as described in 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 4.1 was chosen as the computer model to compute water surface elevations on a stream by stream basis. The WISE computer program was used to establish model stream orientation, initial hydraulic cross section layout and stationing, assign n-values to cross sections, and to 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 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 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. Cross sections were placed at the upstream and downstream face of major roads and railroads. Major roads are those designated in the Texas DOT road coverage as On System Highways. The road coverage can be acquired in shapefile format from the TNRIS website at the following link: https://tnris.org/data-catalog/entry/txdot-roadways/. Ineffective flow stations were placed in the hydraulic models as appropriate to account for flow constrictions at crossings as well as at 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 in order to better represent ponded water upstream of the structures. It was assumed in doing this 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.

Significant effort was made to start all tributaries below the receiving water surface elevations but this was not always achieved, particularly in wide, flat floodplains where small tributaries ran parallel to large streams or where road crossings or dams interfered with cross section alignments.

The relationship between drainage area and assigned channel geometry is shown in Table 3. These default values for dimensions and spacing are subject to change based on the details noted above as well as the judgment of the responsible engineer.

Table 3: Cross Section Default Parameters

Drainage area (upper limit)	XS Spacing	Channel Top Width	Channel Bottom Width	Channel Depth
1.0	500	4	3.5	0.5
2.0	500	6	5	0.5
4.0	500	11	10	0.5
8.0	500	18	17	0.5
10.0	500	20	19	0.5
15.0	600	26	25	0.5
20.0	600	32	31	0.5
25.0	600	38	36	0.5
30.0	600	43	41	0.5
40.0	600	52	50	0.5
50.0	600	60	57	1
75.0	750	68	65	1
100.0	750	76	73	1
150.0	1000	91	88	1
250.0	1000	122	119	2
500.0	1500	198	195	2
1000.0	2500	351	346	3
2000.0	4000	657	652	3
5000.0	4000	1575	1565	3
>5000.0	4000	2000	1990	4

Manning's roughness coefficients (n-values) were determined using the 2011 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 4. Manning's n-value takeoffs were performed by WISE and the n-values were adjusted in some locations based on engineering judgment. N-values within channel banks were limited by the automated routine to a range of 0.030 to 0.070.

Table 4: Manning's "n" Roughness Based on 2001 NLCD Classification (Moore, 2011)

NLCD Classification	Minimum	Normal	Maximum	Source
Open Water	.025	.03	.033	Chow 1959
Developed, Open Space	.01	.013	.016	Calenda, et al. 2005
Developed, Low Intensity	.038	.05	.063	Calenda, et al. 2005
Developed, Medium Intensity	.056	.075	.094	Calenda, et al. 2005
Developed, High Intensity	.075	.1	.125	Calenda, et al. 2005
Barren Land	.025	.03	.035	Chow 1959
Deciduous Forest	.1	.12	.16	Chow 1959
Evergreen Forest	.1	.12	.16	Chow 1959
Mixed Forest	.1	.12	.16	Chow 1959
Scrub/Shrub	.035	.05	.07	Chow 1959
Grassland/Herbaceous	.025	.03	.035	Chow 1959
Pasture/Hay	.03	.04	.05	Chow 1959
Cultivated Crops	.025	.035	.045	Chow 1959
Woody Wetlands	.08	.1	.12	Chow 1959
Emergent Herbaceous Wetland	.075	.1	.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 names in the National Flood Hazard Layer (NFHL) and streams with large drainage areas (generally greater than 8 square miles), the normal depth slope was calculated based on the HEC-RAS profile invert.

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.

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. It is estimated that 50 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 adding cross-sections at confluence areas, modification to improve perpendicular orientation at the channel, adjustment of discharge breaks to better represent flow addition points, revisions to dam spillways and dam tops, 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 another frequency or by the 1-percent plus or 1-percent minus 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 feet 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 reasonable resolve these drawdown situations.

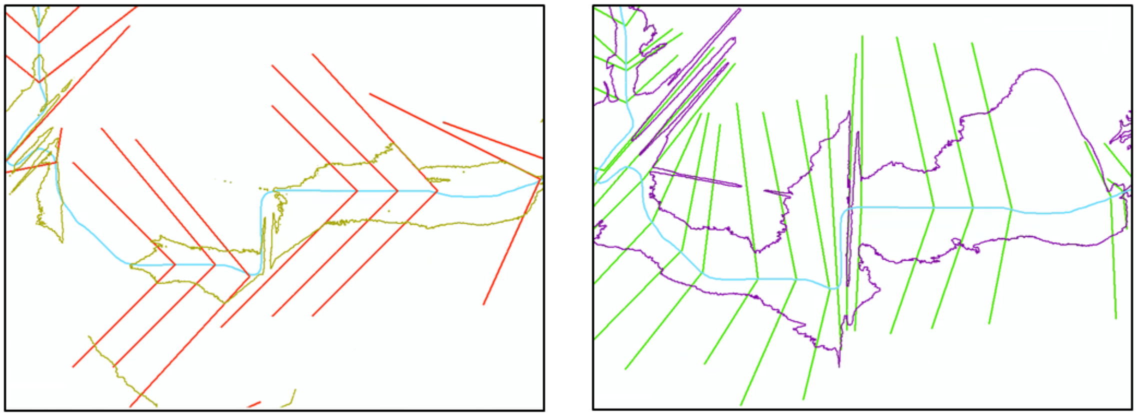

Figure 4: Default "V" angle cross-sections automated by WISE (left). Manually edited cross-sections to more accurately capture terrain (right). Resulting flood boundaries shown in gold (left) or purple (right) for clarity.

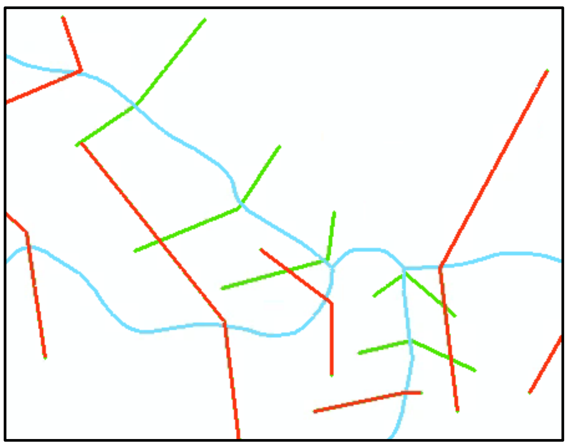

Figure 5: Manually added cross-sections (green) to improve accuracy of tie-ins at confluences.

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 FEMA acquired LiDAR. 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 flood plain 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 will vary based on available data on which to run the analysis. The Upper Clear Fork Brazos Watershed analysis presented challenges as summarized in the following paragraphs.

As noted above, there are a significant number of flood control dams throughout this watershed. Hydrologic results from regression calculations were not adjusted to take into account the impact of these structures. Further investigation should be conducted when upgrading these models.

Significant effort was made to start all tributaries below the receiving water surface elevations but this was not always achieved, particularly in wide, flat floodplains where small tributaries ran parallel to large streams or where road crossings or dams interfered with cross section alignments.

As noted in Section 1.4 above, multiple streamlines did not extend far enough to fully capture effective flood hazard data. The streamlines generated in the development of the one square mile basins were extended in order to more closely match the effective areas and CNMS streams.

Due to the flat topography in areas throughout the watershed, it was often difficult to obtain relief without overflows and spillover into adjacent floodplains. Cross sections were extended and re-oriented in a manner to most reasonably model and map these areas.

This watershed is mainly characterized with very flat landscape in general, that coupled with the internal storm drainage systems around the various communities made the BLE study challenging to generate a defined streams and hence very difficult to calculate the water surface elevation using a 1D hydraulic model accurately. However, a significant effort was made to achieve a reasonable water surface elevation by using very long cross sections in an attempt of modeling small streams as backwater areas of larger streams.

Results and Recommendations

The BLE results for the Upper Clear Fork Brazos Watershed produced a SFHA that compares reasonably well with the effective SFHA in most cases, and provides an additional estimated SFHA in areas that do not currently have a SFHA mapped. Some of these areas where SFHA was added include the smaller cities and towns throughout this watershed (Cities of Abilene, Rotan, Hawley, Merkel, Roby, Roscoe and Sweetwater). These results provide context for flood risk communication, and should be verified through community work map meetings before being applied to a regulatory product.

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

3.1 Validation of Effective Zone A SFHA

The full inventory of Zone A studies in the Upper Clear Fork Brazos contains 1,020 miles. The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A3 were evaluated for the CNMS inventory of Zone A studies.

INITIAL ASSESSMENT A1 – SIGNIFICANT TOPOGRAPHY UPDATE CHECK

This check involves determining whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. For the study area in Jones, Nolan, Shackelford and Throckmorton TX, the effective Zone A topographic data leveraged a variety of sources, but primarily based upon USGS 24K map products. The topography listed in Section 1.1 above represents a significant improvement from the assumed effective Zone A topographic source.

INITIAL ASSESSMENT A2 – CHECK FOR SIGNIFICANT HYDROLOGY CHANGES

This check involves first determining 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 a.c.e. 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) contains the most recent regression equations for Texas. The Regression Equations used for the effective Zone A studies for Jones and Taylor Counties were developed using the most current regression equation and therefore have passed A2. However, the equations used for the effective Zone A studies in Johnson County are unknown. Scurry, Nolan, Fisher, Shackelford and Throckmorton County models are unknown and therefore A2 was passed.

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 the Texas study area was completed by evaluating percentage of urban change at the HUC-12 level. Of the 65 HUC-12 polygons within the study area none meet the threshold of 15% or more urban cover. There is no increase in urbanization of 50% or more since the effective study.

Table 5: Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Fail	FEMA acquired 2014 LiDAR significantly better than effective USGS topographic source.
A2 – Hydrology	Pass	Latest regression equations for Texas are dated 2009. Jones and Taylor used the 2009 equations. All others are unknown.
A3- Development	Pass	No increase of 50% or more since effective study.

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 complete documentation of the original engineering methods in Scurry, Nolan, Taylor, and Shackelford Counties, check A4 for streams within them have failed the A4 check in CNMS. Streams within Jones and Haskell Counties have been marked as Pass in FEMA's CNMS database since they were supported by sound engineering judgment.

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 963 modeled BLE streams in the study area, 105 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 7 below 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".

VALIDATION RESULTS

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Upper Clear Fork Brazos Watershed study area has been updated, with 923.3 miles categorized as UNVERIFIED – TO BE STUDIED, and 96.7 miles categorized as VALID – NVUE COMPLIANT. Total miles in each of these categories are summarized in Table 6 and illustrated in Figure 6 below. It should be noted that due to the lack of effective digital data in this watershed approximately 20% of the HUC-12s have no data to evaluate.

Table 6: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	NVUE COMPLIANT	96.7
UNVERIFIED	TO BE STUDIED	923.3

Table 7: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Upper Clear Fork Brazos	All Streams	56,396	19,120	37,276	66.1%	Fail	
Headwaters Cottonwood Creek	120601020101	Not Evaluated					
Linn Creek	120601020102	Not Evaluated					
Upper Cottonwood Creek	120601020103	291	71	220	75.6%	Fail	6.1
Middle Cottonwood Creek	120601020104	Not Evaluated					
Lower Cottonwood Creek	120601020105	Not Evaluated					
Outlet Cottonwood Creek	120601020106	Not Evaluated					
Upper Buffalo Creek	120601020201	247	74	173	70.0%	Fail	8.5
Lower Buffalo Creek	120601020202	21	9	12	57.1%	Fail	11.5
Coon Hollow-Spring Creek	120601020203	197	54	143	72.6%	Fail	9.0
Headwaters Clear Fork Brazos River	120601020204	1,031	420	611	59.3%	Fail	11.6
Town of Rotan-Hackberry Creek	120601020205	Not Evaluated					

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Alkali Creek	120601020206	Not Evaluated					
120601020207	120601020207	Not Evaluated					
Spring Creek-Sweetwater Creek	120601020301	Not Evaluated					
Finn Creek-Sweetwater Creek	120601020302	1,331	808	523	39.3%	Fail	16.4
Kildoogan Creek	120601020303	1,881	853	1,028	54.7%	Fail	19.1
Salt Branch-Sweetwater Creek	120601020304	1,506	773	733	48.7%	Fail	24.8
Upper Bitter Creek	120601020305	287	205	82	28.6%	Fail	34.6
Middle Bitter Creek	120601020306	Not Evaluated					
Lower Bitter Creek	120601020307	179	51	128	71.5%	Fail	14.2
Little Stink Creek	120601020308	555	265	290	52.3%	Fail	23.9
Rock Creek-Sweetwater Creek	120601020309	597	190	407	68.2%	Fail	15.6
120601020310	120601020310	344	4	340	98.8%	Pass	0.5
Plum Creek	120601020401	Not Evaluated					
Sandy Creek-Clear Fork Brazos River	120601020402	Not Evaluated					
China Creek-Clear Fork Brazos River	120601020403	Not Evaluated					
Raven Creek-Clear Fork Brazos River	120601020404	77	39	38	49.4%	Fail	22.8
Nubia Creek	120601020501	1,442	438	1,004	69.6%	Fail	15.2
Upper Mulberry Creek	120601020502	2,656	1,092	1,564	58.9%	Fail	19.9
Bull Wagon Creek	120601020503	1,674	485	1,189	71.0%	Fail	14.5
Middle Mulberry Creek	120601020504	2,664	908	1,756	65.9%	Fail	15.7
Lower Mulberry Creek	120601020505	1,368	446	922	67.4%	Fail	16.1
Upper Noodle Creek	120601020601	921	349	572	62.1%	Fail	13.4
Lower Noodle Creek	120601020602	755	164	591	78.3%	Fail	5.4
120601020603	120601020603	582	233	349	60.0%	Fail	14.0
Headwaters Bitter Creek	120601020604	1,702	604	1,098	64.5%	Fail	9.0
Outlet Bitter Creek	120601020605	1,055	379	676	64.1%	Fail	9.6
Dark Hollow Branch-Clear Fork Brazos River	120601020606	829	242	587	70.8%	Fail	12.8

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
City of Hawley	120601020607	581	131	450	77.5%	Fail	6.4
Horse Hollow-Elm Creek	120601020701	1,442	361	1,081	75.0%	Fail	12.5
Little Elm Creek-Elm Creek	120601020702	2,419	213	2,206	91.2%	Pass	4.4
Coon Hollow-Elm Creek	120601020703	5,381	884	4,497	83.6%	Fail	8.2
Upper Little Elm Creek	120601020704	1,758	632	1,126	64.1%	Fail	18.0
Lower Little Elm Creek	120601020705	696	320	376	54.0%	Fail	26.0
Indian Creek	120601020706	955	458	497	52.0%	Fail	24.5
Lytle Creek	120601020707	1,440	577	863	59.9%	Fail	25.1
Upper Cedar Creek	120601020708	1,926	810	1,116	57.9%	Fail	26.7
Box Oil Field-Buck Creek	120601020709	643	215	428	66.6%	Fail	21.3
Lower Cedar Creek	120601020710	1,803	670	1,133	62.8%	Fail	26.7
Cat Claw Creek-Elm Creek	120601020711	1,220	399	821	67.3%	Fail	23.2
Lake Fort Phantom Hill	120601020712	469	106	363	77.4%	Fail	18.1
Upper Deadman Creek	120601020801	Not Evaluated					
West Fork Spring Creek-Spring Creek	120601020802	939	210	729	77.6%	Fail	11.3
Middle Deadman Creek	120601020803	18	2	16	88.9%	Pass	7.2
120601020804	120601020804	633	124	509	80.4%	Fail	7.7
Long Creek	120601020805	1,233	363	870	70.6%	Fail	14.7
Lower Deadman Creek	120601020806	138	56	82	59.4%	Fail	22.8
City of Nugent	120601020807	546	200	346	63.4%	Fail	18.5
Chimney Creek	120601020901	703	199	504	71.7%	Fail	14.2
Mesquite Creek-Cottonwood Creek	120601020902	979	307	672	68.6%	Fail	15.7
Bluff Creek	120601020903	732	155	577	78.8%	Fail	10.6
Hog Creek-Clear Fork Brazos River	120601020904	855	341	514	60.1%	Fail	19.9
Fish Creek	120601020905	501	131	370	73.9%	Fail	13.1
Swager Creek-Clear Fork Brazos River	120601020906	1,237	536	701	56.7%	Fail	21.7

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Antelope Creek-Clear Fork Brazos River	120601020907	998	431	567	56.8%	Fail	22.1
Walnut Creek-Clear Fork Brazos River	120601020908	1,959	1,133	826	42.2%	Fail	44.2

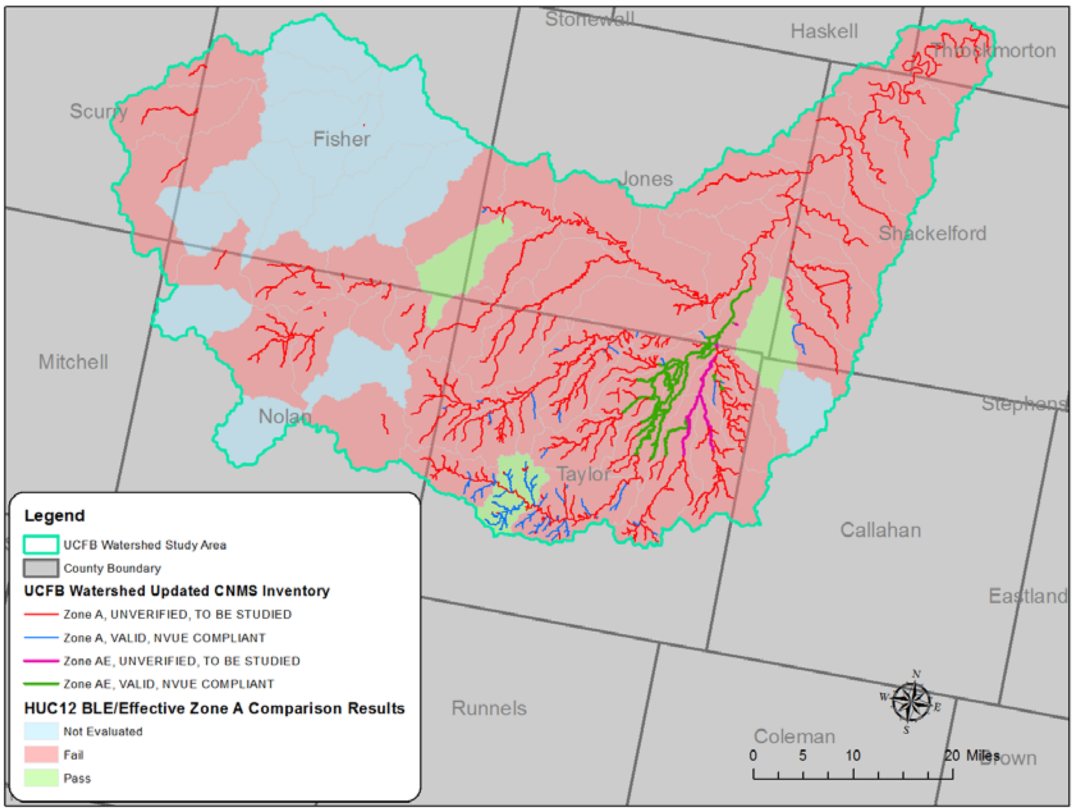

Figure 6: Upper Clear Fork Brazos Watershed CNMS Validation Results

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. The range of the Upper Clear Fork Brazos HUC-8 priority scores can be used to initiate discussions with communities. Walnut Creek - Clear Fork Brazos HUC-12 was determined to have the highest priority score and the most need while 14 of the HUC-12 basins were not able to be evaluated since there is no effective digital or CNMS data available.

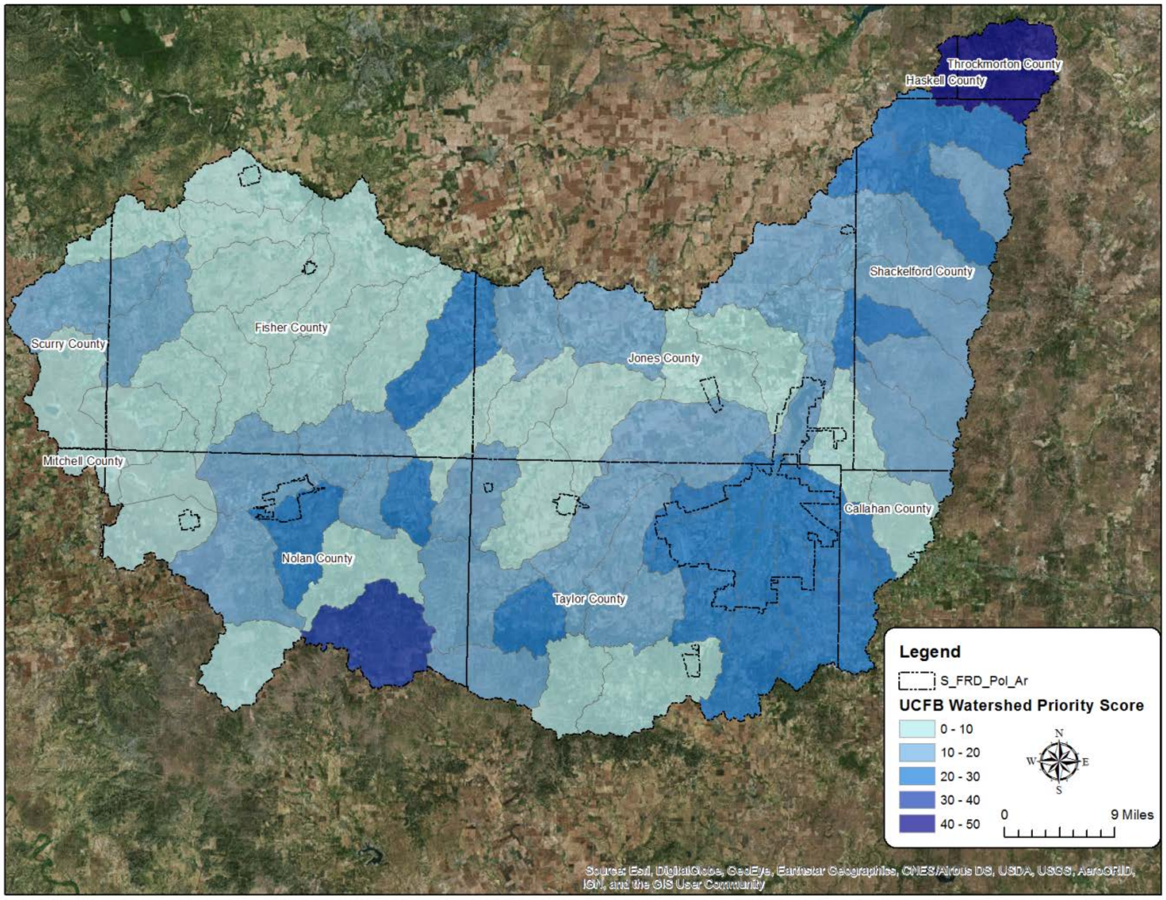

Figure 7: Ranking of Upper Clear Fork Brazos Watershed HUC-12s

3.2 Flood Risk Analysis

A flood risk analysis was performed for this project. The initial 2010 AAL study was based upon 2000 census data, for this project a new Basic Hazus analysis was performed to establish a base level of flood losses. Those results are stored in the L_RA_AAL table. The updated 1-percent annual chance grid (known as 'refined' grid) was used to update the flood losses. The refined grid loss results are stored in the L_RA_Refined table. Both tables are combined to populate the L_RA_Composite table.

Hazus version 3.2 was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 3.2 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.

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Appendix A BLE Maps