

Llano County, TX

Base Level Engineering (BLE) Results

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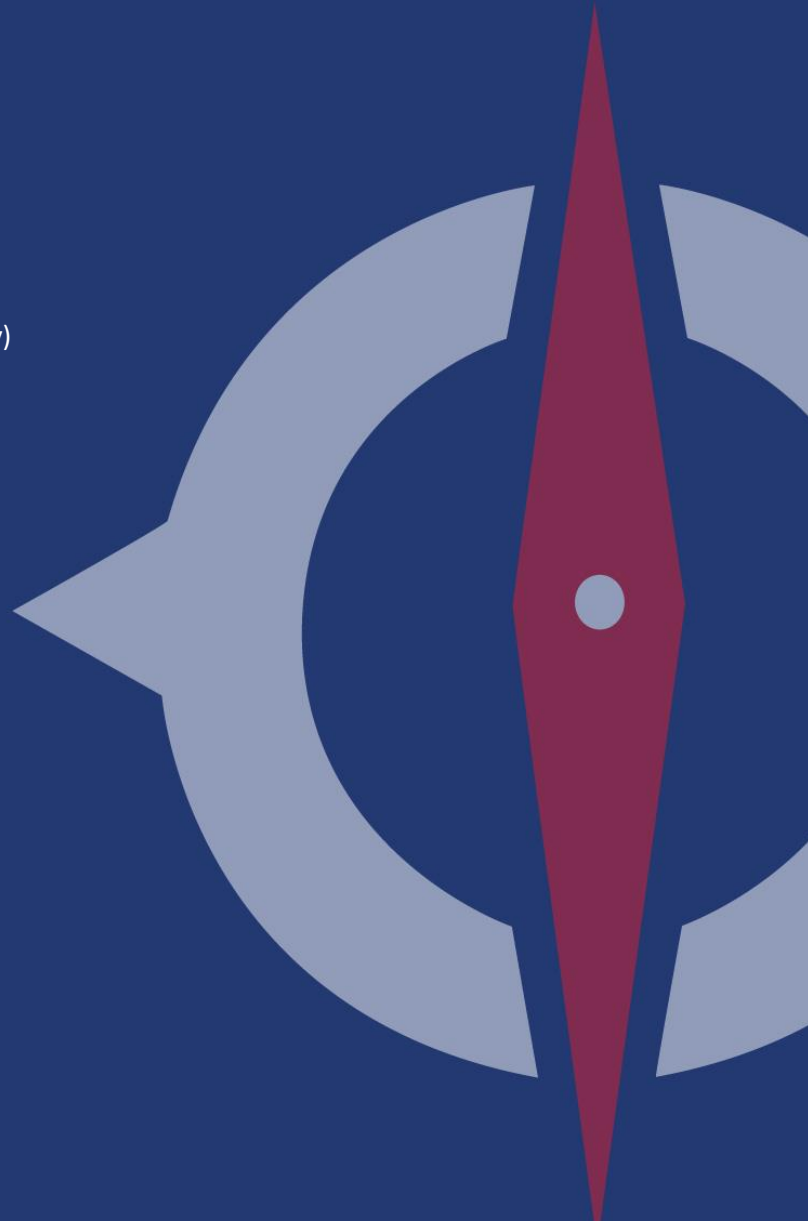
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Executive Summary

The Federal Emergency Management Agency (FEMA) Region VI contracted Compass to complete a Base Level Engineering (BLE) analysis for Llano County in 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 Texas Natural Resources Information System (TNRIS), Lower Colorado River Authority (LCRA) and supplemented with USGS National Elevation Dataset (NED) as appropriate. The TNRIS terrain dataset was 2014 1-meter gridded DEM data, the LCRA 2007 (70 cm and 140 cm) were both derived from Light Detection and Ranging (LiDAR) data, while the USGS NED 1/3 Arc Second DEM was approximately 10-meter equivalent.

Flood discharges for this study were calculated using only USGS regression equations since the gages in the area had insufficient length of historical streamflow records. Regression Equations used were obtained from the USGS Scientific Investigations Report (SIR 96-4307), *Regional Equations For Estimation of Peak-Streamflow Frequency For Natural Basins in Texas*.

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 Llano County 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	Llano County Stream Miles
CNMS	780.8
Total	780.8

The full inventory of Zone A studies (724.3 miles) in the Llano County 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	648.1
UNVERIFIED	TO BE STUDIED	53.4
UNKNOWN	BEGIN STUDIED	22.8

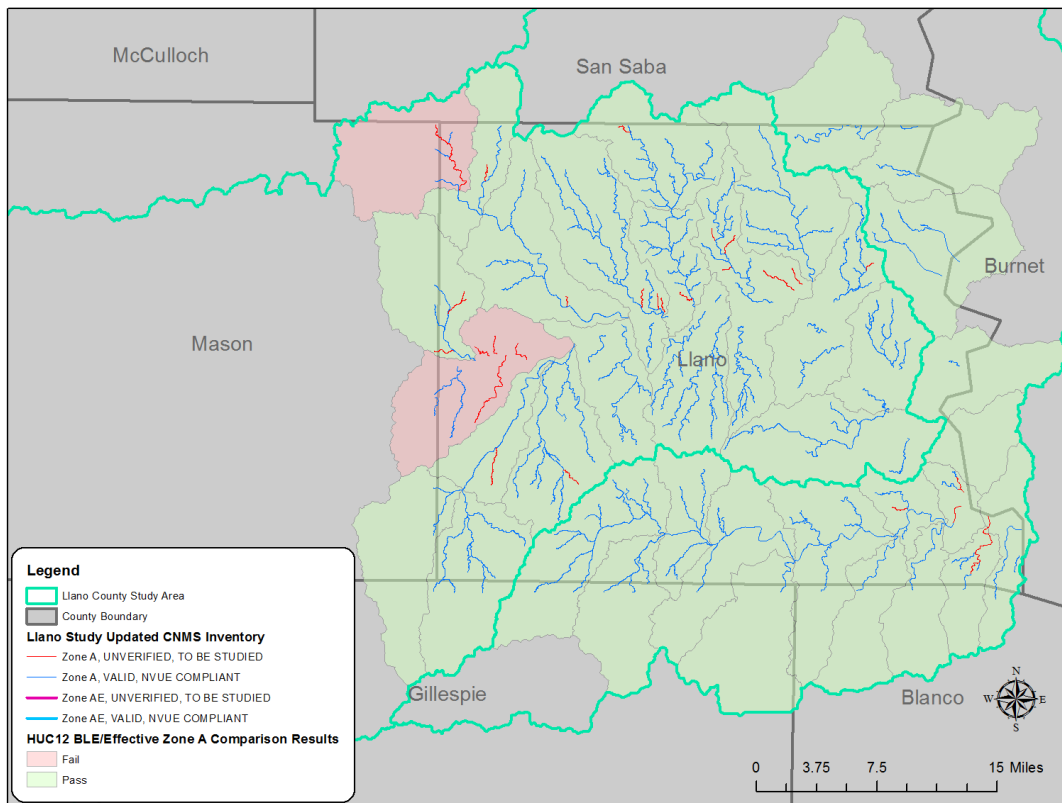


Figure ES-1. Llano County CNMS Validation Results

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 Llano County priority scores can be used to initiate discussions with communities. Upper San Fernando Creek HUC-12 was determined to have the highest priority score and the most need while Mill Creek – Lake Lyndon B Johnson, Peters Creek – Lake Lyndon B Johnson and White Creek HUC-12s had the lowest priority score.

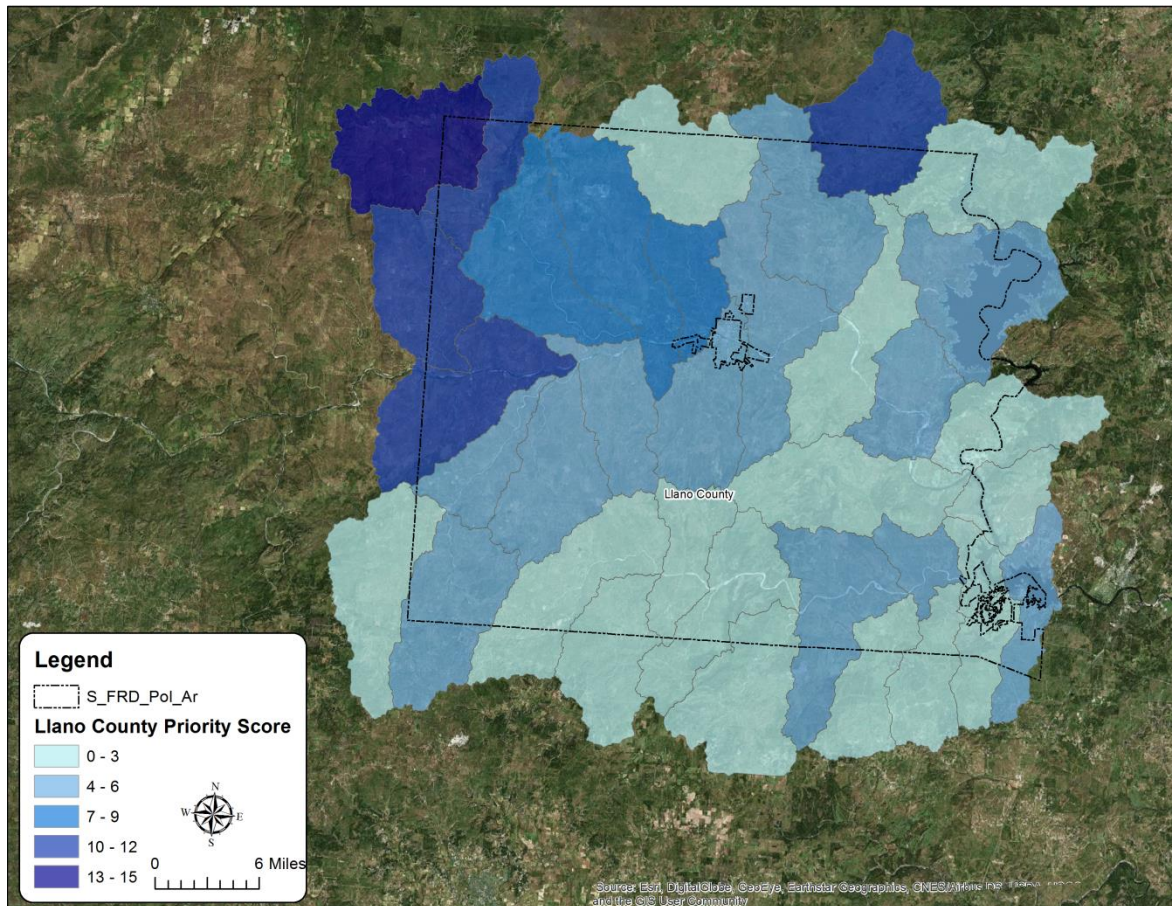


Figure ES-2. Ranking of Llano County HUC-12s



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 III 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 Llano County in Central Texas, to support FEMA's validation of effective Zone A Special Flood Hazard Area (SFHA). The study extents include the majority of Llano County and Cities of Sunrise Beach Village, Llano and Horseshoe Bay. The study area, Llano County, consists of portions of two HUC-8 basins: Llano and Buchanan-Lyndon B. Johnson Lakes. Only portions of the six HUC-10 basins within Llano County were studied including Colorado River-Lake Buchanan, Sandy Creek, Inks Lake-Lake Lyndon B. Johnson, Hickory Creek-Llano River, San Fernando Creek-Llano River and Little Llano River-Llano River. Figure 1 shows the orientation of the Llano County HUC-10 basins with respect to the counties.

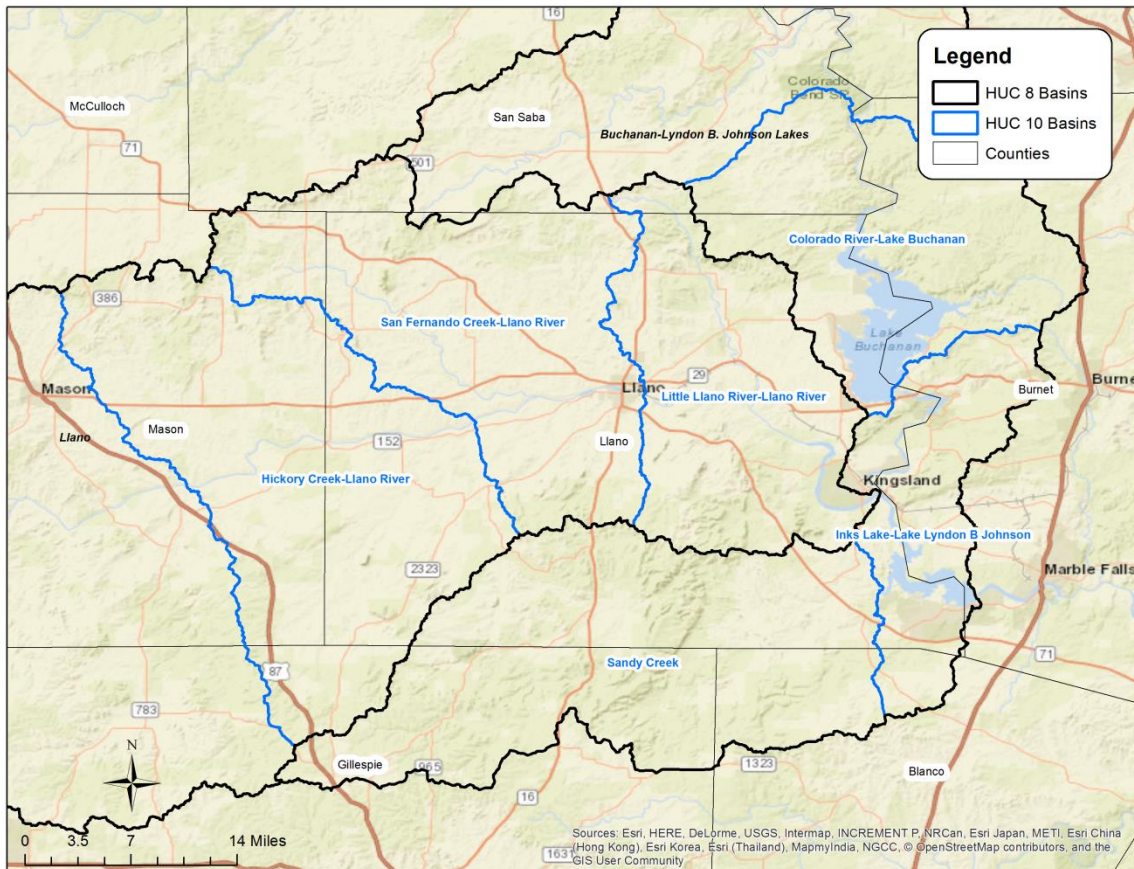


Figure 1: Llano County HUC-10 Basins

Compass studied approximately 1,015.84 miles of stream reaches within the Llano County study limits 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 Llano County area studied.

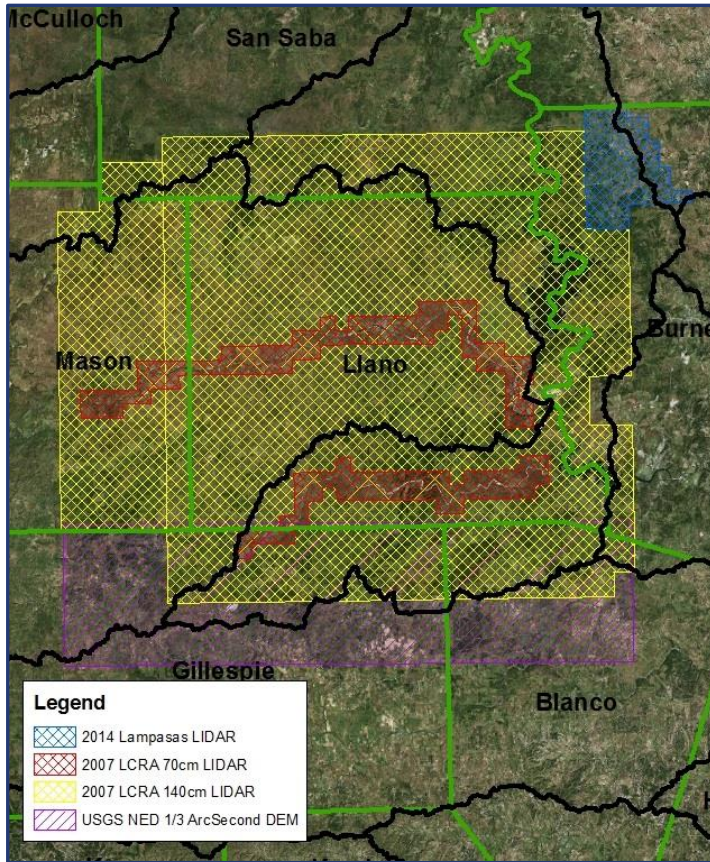


Figure 2: Extent of LiDAR Data

1.1.1 Source Terrain Data

1.1.1.1 2014 Lampasas County LIDAR TX

2014 Lampasas LIDAR was acquired and developed by the Texas Natural Resources Information System (TNRIS) for collection and delivery of topographic elevation point data derived from multiple return light detection and ranging (LiDAR) measurements for the 2,256 sq. mile project area encompassing Bandera and Lampasas Counties, Texas. Fugro EarthData, Inc. acquired 305 flight lines in 36 lifts from December 18, 2013 to January 25, 2014. LiDAR data collection was performed with a Cessna 310 twin engine aircraft, utilizing a Riegl LMS-Q680i LiDAR sensor; collecting multiple return x, y, and z as well as intensity data. The classified LiDAR point cloud data are delivered in LAS 1.2 format: 1, unclassified, 2, bare-earth ground, 3, low vegetation, 4, medium vegetation, 5, high vegetation, 6, buildings, 7, low points(noise), 9, water, 13, bridges, and 14, culverts. 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.

1.1.1.2 2007 LCRA 70cm LIDAR

2007 LCRA 70cm LIDAR was acquired by the Lower Colorado River Authority (LCRA) and developed by the TNRIS for collection and delivery of topographic elevation point data derived



from multiple return LiDAR measurements for the areas of Blanco, Gillespie, Burnet, Llano, Mason, Kimble, Menard, San Saba, McCulloch, Mills, Brown, Coleman, Concho counties in Texas. Sanborn acquired the data from October 2006 to November 2006 collecting multiple return x, y, and z as well as intensity data. The classified LiDAR point cloud data are delivered in LAS 1.2 format: 1, unclassified, 2, bare-earth ground, 3, low vegetation, 4, medium vegetation, 5, high vegetation, 6, buildings, 7, low points(noise), 9, water, 13, bridges, and 14, culverts. 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.

1.1.1.3 2007 LCRA 140cm LIDAR

2007 LCRA 140cm LIDAR was acquired by the LCRA and developed by the TNRIS for collection and delivery of topographic elevation point data derived from multiple return LiDAR measurements for the areas of Blanco, Gillespie, Burnet, Llano, Mason, Kimble, Menard, San Saba, McCulloch, Mills, Brown, Coleman, Concho counties in Texas. Sanborn acquired the data from October 2006 to November 2006 collecting multiple return x, y, and z as well as intensity data. The classified LiDAR point cloud data are delivered in LAS 1.2 format: 1, unclassified, 2, bare-earth ground, 3, low vegetation, 4, medium vegetation, 5, high vegetation, 6, buildings, 7, low points(noise), 9, water, 13, bridges, and 14, culverts. 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.

1.1.1.4 USGS NED DEM

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 Llano County, 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 Llano County, TX LiDAR project, 2014 Lampasas County TX LiDAR, 2007 LCRA 70cm LiDAR, 2007 LCRA 140cm LiDAR 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 generated using USGS regional regression equations. Gage analysis was not conducted given the insufficient length of historical streamflow record. Results of two USGS regional regression equations (SIR 96-4307 and SIR 2009-5087) were compared in order to identify the most appropriate flows for Llano County. After careful evaluation, streamflow values generated from USGS Scientific Investigations Report (SIR 96-4307), *Regional Equations For Estimation of Peak-Streamflow Frequency For Natural Basins in Texas* were selected for use. These regional equations are not the most recent regression equations for Texas however were selected for the following reasons:

- 1) TXDOT does not recommend the use of the most recent USGS regression equations (SIR 2009-5087) for basins under 10 square miles (69 percent of the basins within this study are smaller than 10 square miles)
- 2) Detailed studies of similar watersheds (Onion Creek, Guadalupe River) in the region produce Q100 values/square mile in between the regression equations with the 1996 regression equations generally producing more conservative values
- 3) Streamflow generated from SIR 2009-5087 are likely producing underestimating flood risk given the low Omega EM value within Llano County, the value is not representative of the Llano Watershed as a whole
- 4) Streamflow values generated from SIR 96-4307 were more similar to detailed studies within Llano County (Buttery Creek, BATTERY Creek Tributary 1, BATTERY Creek Tributary 2 and Flag Creek) than SIR 2009-5087. Streamflow estimates were obtained for the 2-, 5-, 10-, 25-, 50- and 100-yr return periods using regional regression.

The 500-year return period was calculated using an equation interpolated from the USGS regional regression equations given that the 1996 regression equations do not have a 500-year regression equation. 1-percent plus and minus values were assumed to be the 67 percent confidence limits of the 100-year streamflow.

Table 1 shows the published equations for Texas that were 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, A is the cumulative drainage area in square miles, SL represents the mean channel slope defined as the ratio of headwater elevation of longest channel minus main channel elevation at site to main channel length (ft./mi.), and SH represents the basin-shape factor defined as the ratio of main channel length squared to contributing drainage area (mi^2/mi^2).

Table 1: Summary of Regression Equations for Texas Region 4 (USGS SIR 96-4307)

Recurrence Interval	Equation ¹
	Equations for contributing areas less than 32 mi^2
$Q_{10\%}$	$293(A)^{0.697}SH^{0.281}$



Recurrence Interval	Equation ¹
Q _{4%}	$455(A)^{0.741} SH^{0.311}$
Q _{2%}	$53(A)^{0.927} SL^{0.558} SH^{0.333}$
Q _{1%}	$51(A)^{0.968} SL^{0.627} SH^{0.353}$
Q _{0.2%}	$50(A)^{0.980} SL^{0.700} SH^{0.370}$ (Interpolated equation)
	Equations for contributing areas greater than 32 mi ²
Q _{10%}	$0.00467(A)^{1.20} SL^{2.18}$
Q _{4%}	$0.102(A)^{1.16} SL^{2.18}$
Q _{2%}	$0.166 (A)^{1.13} SL^{2.19}$
Q _{1%}	$0.252(A)^{1.11} SL^{2.19}$
Q _{0.2%}	$0.350(A)^{1.09} SL^{2.19}$ (Interpolated equation)
¹ Variables: Q _i peak flow for i recurrence interval (a.c.e.), in cubic feet per second; A, Contributing Drainage Area in square miles; SL, Main-channel slope (feet per mile); SH, Shape factor (square mile/square mile)	

Following the TxDOT Hydraulic Design Manual, for drainage areas between 10 and 100 sq. mi., a weighted discharge (Q_w) was calculated using equation 5-39:

$$\text{Equation 5-39: } Q_w = (2 - \log(A/z))Q_1 + (\log(A/z) - 1)Q_2$$

where:

Q_w = weighted discharge (cfs)

A = contributing drainage area (sq. mi.)

z = 1.0 for English measurements units, or 2.56 for metric

Q₁ = discharge based on regression coefficients for A < 32 sq. mi. (cfs)

Q₂ = discharge based on regression coefficients for A ≥ 32 sq. mi. (cfs)

Drainage areas for each sub-basin were determined based on automated basin delineations performed in WISE. 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 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 and main-channel length for each basin. The basin shapefile attribution was automated by WISE with drainage area, main-channel slope, and shape factor.

The sub-basin shapefile was attributed with the computed discharges as part of the automated script. From the sub-watershed basin shapefile the 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.

1.2.1 Special Considerations

The Llano River main stem is not included as part of this project. A detailed study currently exists for the Llano River and was submitted to Llano County as a LOMR in 2011.

1.3 Hydraulics

The hydraulic approach for BLE analysis for Llano County 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. 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. The elevations used in the modeling were checked against known elevations from past flooding events and effective Zone A boundaries and the results were determined reasonable.

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 2. 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 2: 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 3. 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 3: 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. For studies that have a known downstream water surface elevation from an effective study, those known water elevations were used as the starting condition.

1.3.1 Special Considerations

The Llano River main stem is not included as part of this project. A detailed study already exists for the Llano River and was submitted to Llano County as a LOMR in 2011.

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.

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 3. 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 (see Figure 4 below), 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 reasonably resolve these drawdown situations.

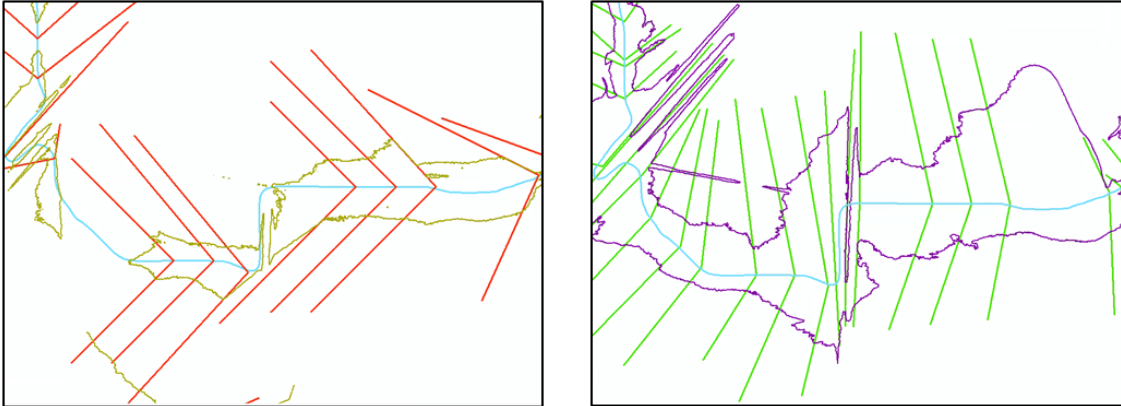


Figure 3: Default “V” angle cross-sections automated by WISE (left). Manually edited cross-sections to more accurately capture terrain (right). Resulting flood boundaries shown in gold (left) or purple (right) for clarity.

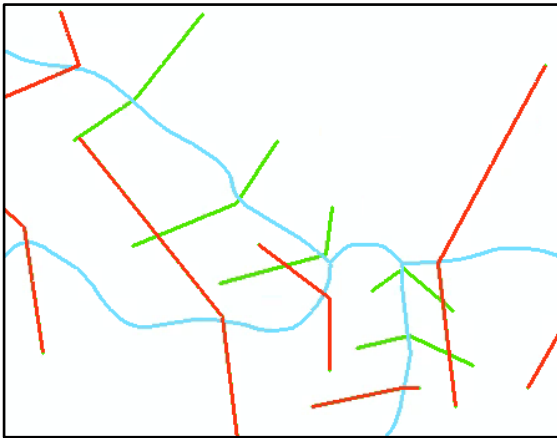


Figure 4: Manually added cross-sections (green) to improve accuracy of tie-ins at confluences.

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 Llano County watershed analysis presented challenges as summarized in the following paragraphs.

As noted in Section 1.2 above, considerable effort was made to determine the most appropriate hydrology methods.

As noted in Section 1.3 above, 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.



Results and Recommendations

The BLE results for Llano County 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. 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 (780 miles) in the Llano County were classified in CNMS with a validation status of “UNKNOWN” and status type of “TO BE ASSESSED.” 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 Llano TX, the effective Zone A topographic data leveraged a variety of sources, but primarily based upon 2-foot LCRA contour map products. Topography mentioned in Section 1 of this report is considered to be significantly better.

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-annual-chance flow. The equations used for the effective Zone A studies in Llano County are unknown. It is unknown if the newer Regression Equations will significantly impact the 1-percent annual chance flow and therefore A-2 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 Llano County study area was completed by evaluating percentage of urban change at the HUC-12 level. Of the 36 HUC-12 polygons within the study area none met the threshold of 15% or more urban cover.



Table 4: Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Fail	TNRIS 2014 LiDAR and LCRA 2007 LiDAR is significantly better than effective USGS topo source.
A2 – Hydrology	Pass	Methods 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 Llano County, check A4 for streams within these counties have been marked as Unverified in CNMS.

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 308 modeled BLE streams in the study area, 263 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 6 below. 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 Llano County study area has been updated, with 53.4 miles categorized as UNVERIFIED – TO BE STUDIED, 22.8 miles categorized as UNKNOWN – BEING STUDIED and 648.1 miles categorized as VALID – NVUE COMPLIANT. Total miles in each of these categories are summarized in Table 5 and illustrated in Figure 5 below.

Table 5: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	NVUE COMPLIANT	648.1
UNVERIFIED	TO BE STUDIED	53.4
UNKNOWN	BEGIN STUDIED	22.8

Table 6: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Llano County	All Streams	41,044	2,638	38,406	94%	Pass	
Coal Creek	120902010306	245	5	240	98%	Pass	1.1
Comanche Creek-Sandy Creek	120902010307	1,506	80	1,426	95%	Pass	3.8
Elm Creek	120902040605	652	95	557	85%	Pass	11.7
Fall Creek-Lake Buchanan	120902010204	239	3	236	99%	Pass	0.8
Headwaters Fall Creek	120902010203	553	81	472	85%	Pass	11.7
Headwaters Pecan Creek	120902040706	1,657	47	1,610	97%	Pass	2.3
Headwaters Sandy Creek	120902010303	2,114	31	2,083	99%	Pass	1.1
Hondo Creek-Sandy Creek	120902010304	983	28	955	97%	Pass	2.3
Honey Creek-Lake Lyndon B Johnson	120902040805	1,472	37	1,435	97%	Pass	2.0
Johnson Creek-Llano River	120902040705	3,317	298	3,019	91%	Pass	7.2
Keyser Creek-Llano River	120902040606	1,386	210	1,176	85%	Fail	12.1
Lake Buchanan	120902010206	583	25	558	96%	Pass	3.0
Legion Creek-Sandy Creek	120902010305	954	29	925	97%	Pass	2.2
Little Llano River	120902040801	1,896	138	1,758	93%	Pass	5.8
Lower Crabapple Creek	120902010302	671	10	661	99%	Pass	0.9

HUC-12 Watershed		Total	Fail	Pass	%Pass	BLE	Priority
Lower Hickory Creek	120902040610	2,460	105	2,355	96%	Pass	3.4
Lower San Fernando Creek	120902040704	1,907	181	1,726	91%	Pass	7.6
Marschall Creek	120902040607	314	6	308	98%	Pass	1.4
Middle Hickory Creek	120902040609	1,031	59	972	94%	Pass	4.6
Middle San Fernando Creek	120902040703	653	81	572	88%	Pass	9.9
Mill Creek-Lake Lyndon B Johnson	120902010403	62	-	62	100%	Pass	0.0
Miller Creek-Llano River	120902040803	1,472	43	1,429	97%	Pass	2.3
Oatman Creek-Llano River	120902040708	2,949	219	2,730	93%	Pass	5.9
Pecan Creek-Lake Lyndon B Johnson	120902010405	86	3	83	97%	Pass	2.4
Pecan Creek-Llano River	120902040707	1,823	185	1,638	90%	Pass	8.0
Pennington Creek-Llano River	120902040804	1,197	74	1,123	94%	Pass	4.8
Peters Creek-Lake Lyndon B Johnson	120902010402	18	-	18	100%	Pass	0.0
Sixmile Creek-Llano River	120902040701	1,259	52	1,207	96%	Pass	3.3
Slickrock Creek-Lake Lyndon B Johnson	120902010406	274	9	265	97%	Pass	2.6
Spring Branch-Lake Lyndon B Johnson	120902010404	101	1	100	99%	Pass	0.9
Upper Hickory Creek	120902040608	1,512	129	1,383	91%	Pass	5.8
Upper San Fernando Creek	120902040702	588	99	489	83%	Fail	13.5
Upshaw Creek-Sandy Creek	120902010309	892	43	849	95%	Pass	4.0
West Walnut Creek-Walnut Creek	120902010310	549	3	546	99%	Pass	0.3
White Creek	120902010308	411	-	411	100%	Pass	0.0
Wrights Creek-Llano Creek	120902040802	3,258	229	3,029	93%	Pass	5.6

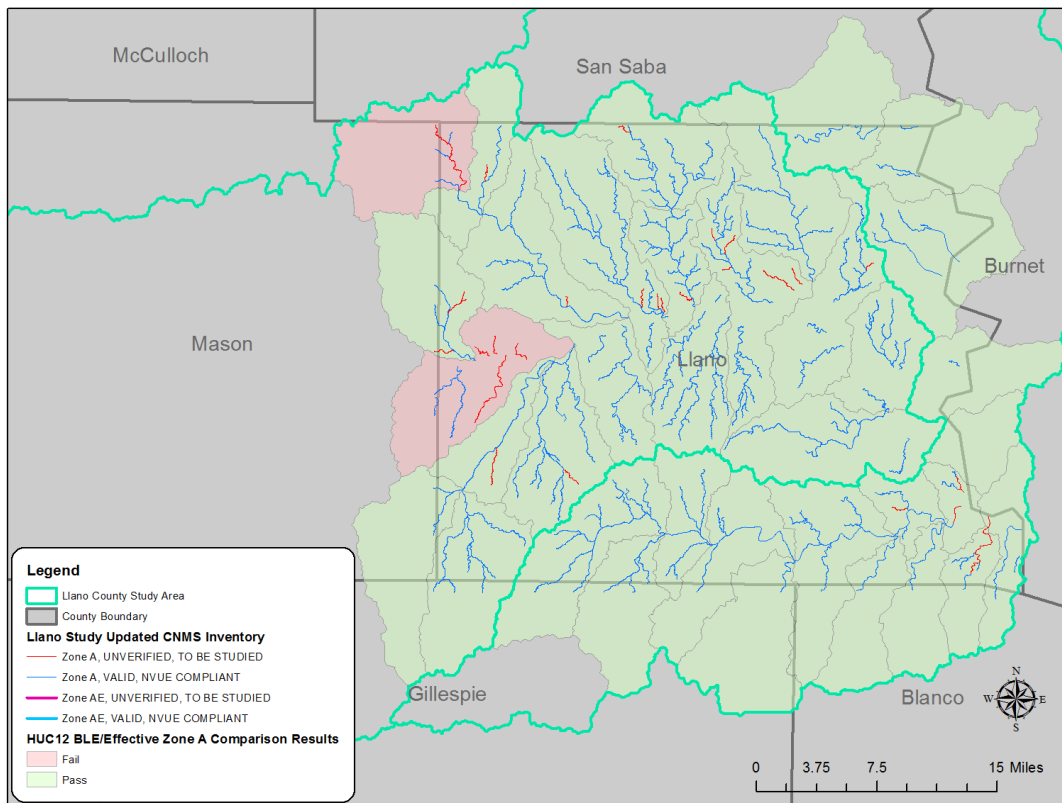


Figure 5: Llano County CNMS Validation Results



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 effectively determine the priority score. The range of the Llano County priority scores can be used to initiate discussions with communities. Upper San Fernando Creek HUC-12 was determined to have the highest priority score and the most need while Mill Creek – Lake Lyndon B Johnson, Peters Creek – Lake Lyndon B Johnson and White Creek HUC-12s had the lowest priority score.

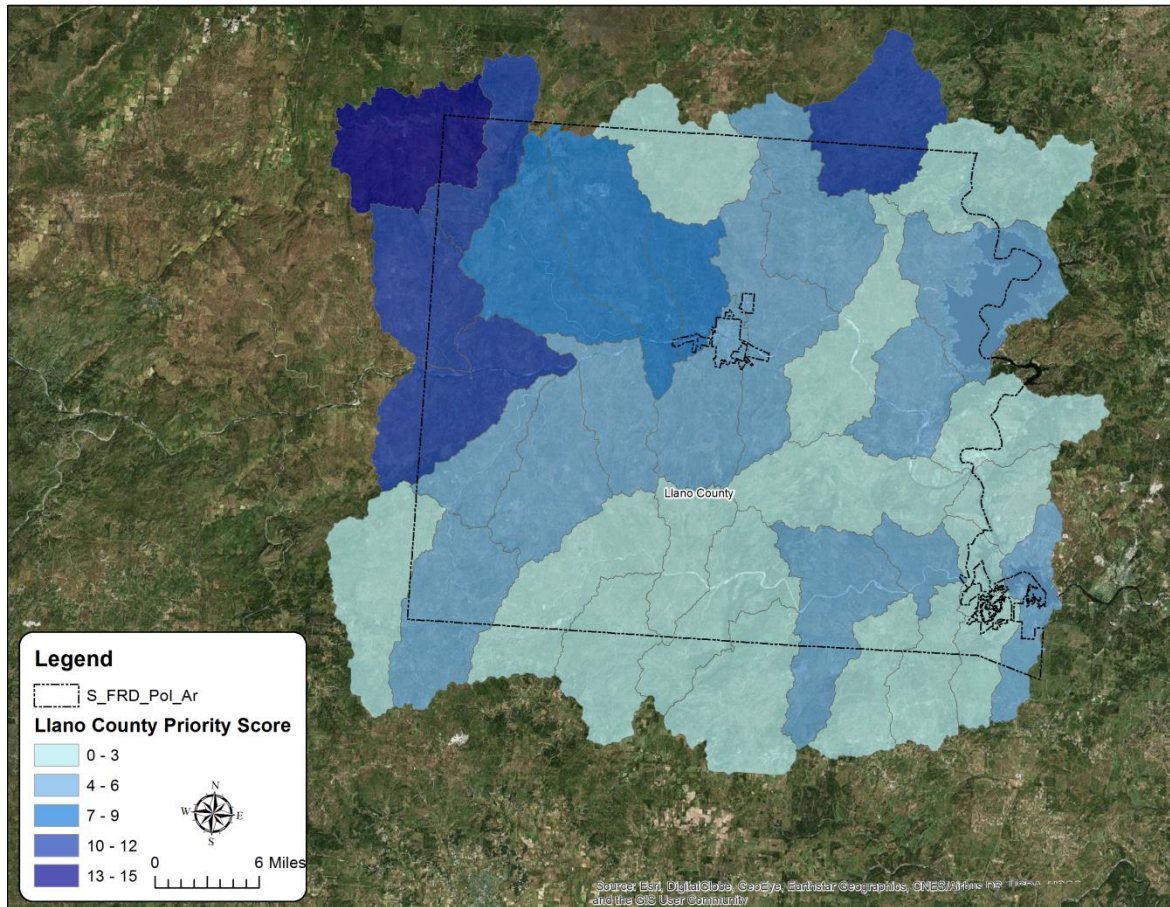


Figure 6: Ranking of Llano County HUC-12s



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

