compass
Identify, Interpret, Integrate

Richland Watershed, TX
Base Level Engineering (BLE) Results

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1.0	December 2015	Initial First Order Approximation Draft	AECOM
1.1	February 2016	Revised to reflect Base Level Engineering effort	AECOM
1.2	March 2017	Revised to add Base Level Engineering in detailed studied areas	AECOM

APPROVALS

This document requires the approval of the following persons:

Role	Name	Phone Extension	Title (CLIN/RMC)	Review Date	Approved Date
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Name	Title/Organization	Location
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Executive Summary

The U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) Region VI contracted Compass to complete a Base Level Engineering (BLE) analysis for the Richland Watershed in North Eastern Texas, to support FEMA's Discovery process and 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) and supplemented with USGS National Elevation Dataset (NED) as appropriate. The TNRIS terrain dataset was 2013 1-meter gridded DEM data 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 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 three gages in the Richland Watershed.

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 for Richland Watershed was compiled using FEMA's Coordinated Needs Management Strategy (CNMS) inventory in conjunction with the National Hydrography Dataset (NHD) 24K High Resolution. Table ES- 1 lists the stream miles identified by each source for this BLE validation analysis.

Table ES- 1. Summary of Stream Miles

Source	Richland Stream Miles
CNMS	1,033
NHD High	10
Total	**1,043**

Of the 1,043 stream miles in the study area, only 1,033 were evaluated. The 10 stream miles added to the inventory from NHD were not compared as no effective floodplain exists. Based on the validation assessment, CNMS has been updated to reflect 820.7 miles of UNVERIFIED – TO BE STUDIED and 212.3 miles of VALID – NVUE COMPLIANT.

Total miles in each of these categories are summarized in Table ES- 2 and illustrated in Figure ES-1 below.

Table ES- 2. Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	NVUE COMPLIANT	212.3
UNVERIFIED	TO BE STUDIED	820.7

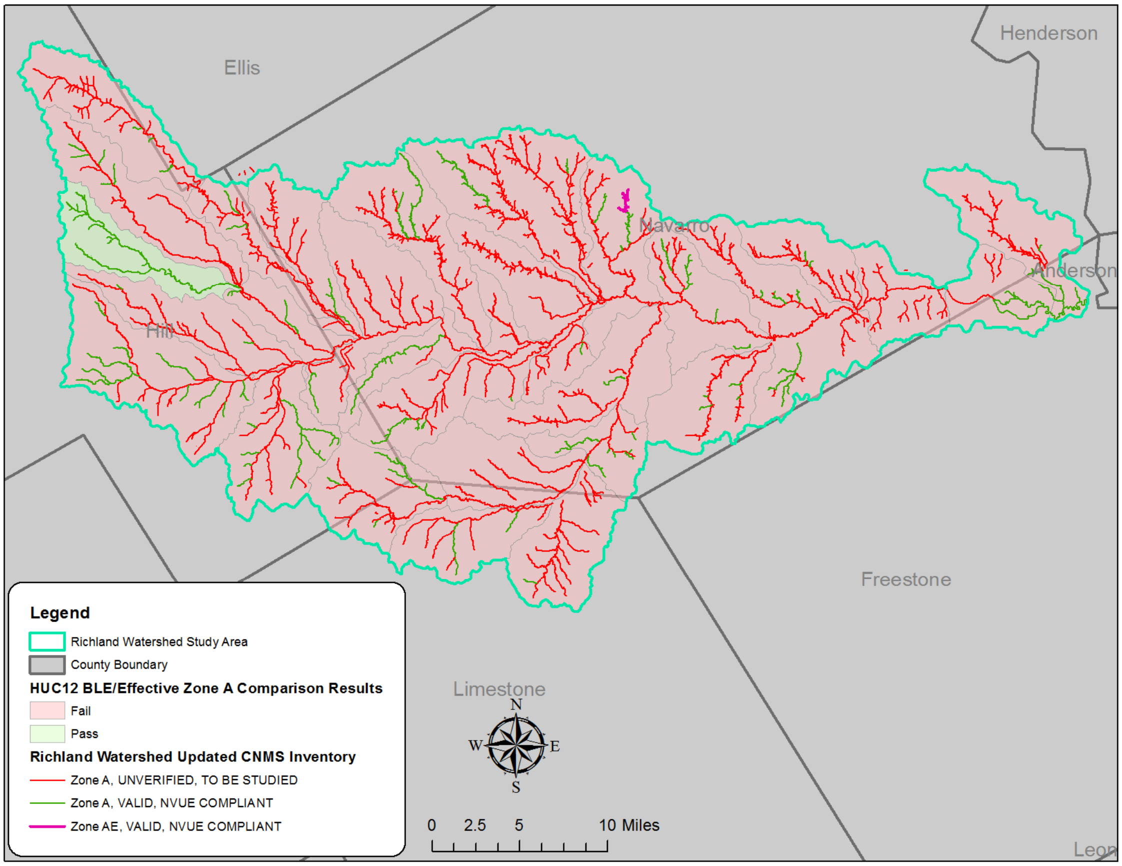

Figure ES- 1. Richland Watershed CNMS Validation Results

An overall risk for each HUC-12 watershed was calculated using the National Flood Risk Percentages Dataset and its proportional area. The weighted risk was multiplied by the percentage of points in the watershed that failed the CNMS comparison to effective to determine the priority score. Figure ES- 2 below shows the range of the Richland HUC-8 priority scores which can be used to initiate discussions during the Discovery phase. Alligator Creek – Pin Oak Creek HUC-12 was determined to have the highest priority score and the most need while Grove Creek – Pecan Creek HUC-12 has the lowest score.

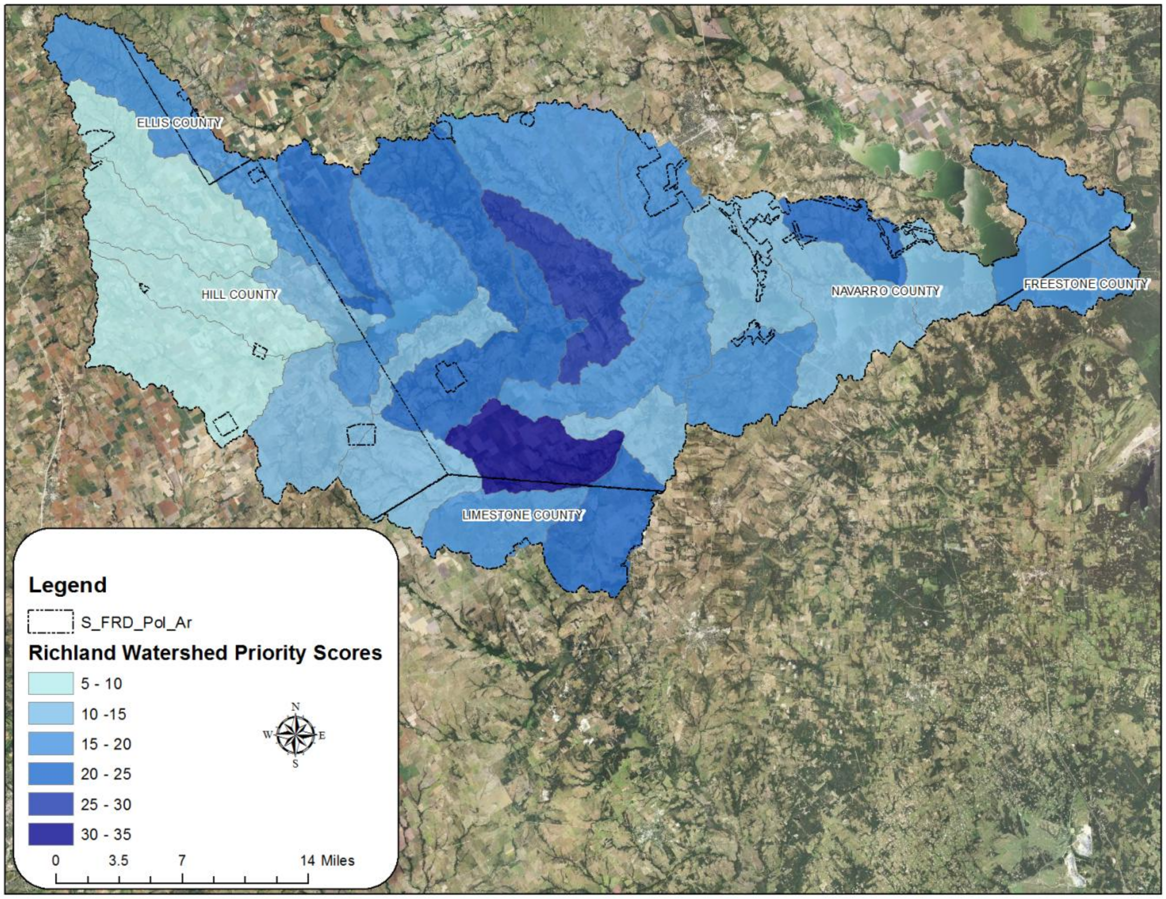

Figure ES- 2. Ranking of Richland Watershed HUC-12s

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 standards require flood risk data to be provided in the early stages of a Flood Risk Project. FEMA Program Standard SID #29 requires that during Discovery, data must be identified that illustrates potential changes in flood elevation and mapping that may result from the proposed project scope. If available data does not clearly illustrate the likely changes, an analysis is required that estimates the likely changes. This data and any associated analyses should be shared and results should be discussed with stakeholders.

An important goal of the BLE process is the scalability of the results. Scalability means that the results of a BLE analysis can not only be used for CNMS evaluations of Zone A studies, but can also be leveraged throughout the Risk MAP program. The data resulting from a BLE analysis can be updated as needed and used for the eventual production of regulatory and non-regulatory products, outreach and risk communication, and MT-1 processing. Leveraging this data outside the Risk MAP program may also be valuable to external stakeholders.

FEMA Region VI contracted Compass to complete a BLE analysis for the Richland Watershed in North Eastern Texas, to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Area (SFHA). The study extents include portions of Ellis, Hill, Navarro, Limestone, and Freestone Counties and include the following communities: Cities of Angus, Blooming Grove, Bynum, Carl's Corner, Coolidge, Corsicana, Dawson, Eureka, Hubbard, Malone, Milford, Retreat, Richland and the Towns of Barry, Mertens, Mildred, Mustang, Navarro, Oak Valley, Penelope, and Tehuacana. The study area consisted of four HUC-10 basins: Alligator Creek, Navarro Mills Lake, Pin Oak Creek, and Post Oak Creek. Figure 1 shows the orientation of the Richland Creek HUC-10 basins with respect to the counties.

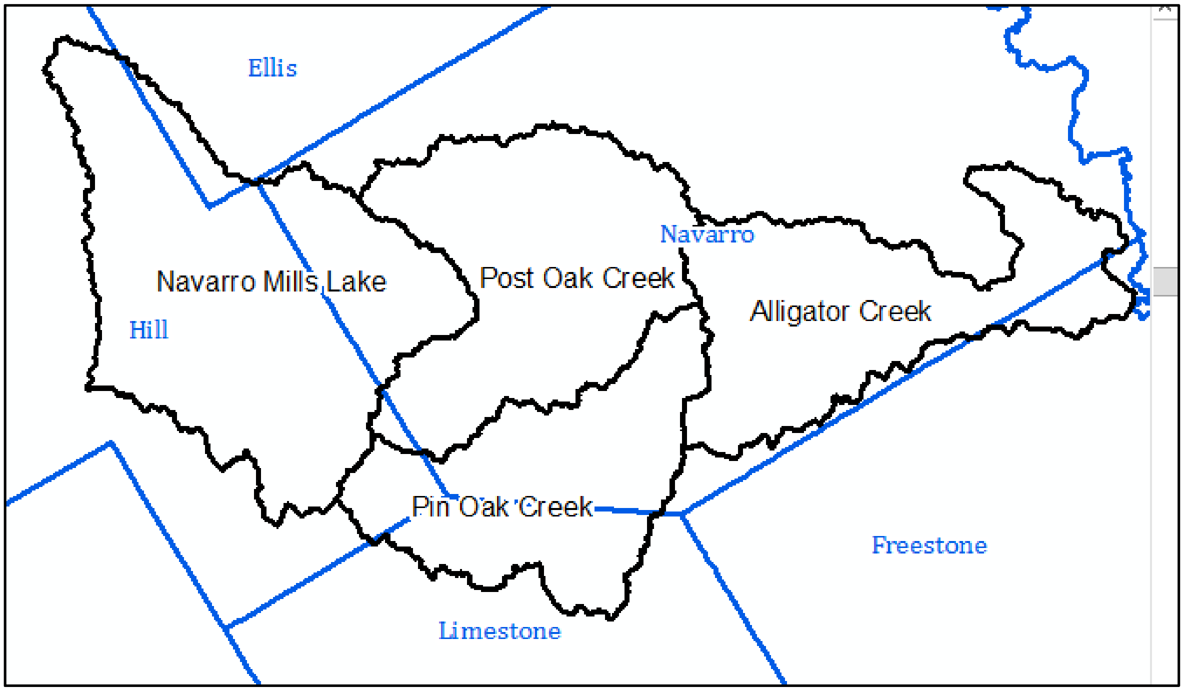

Figure 1. Richland Creek HUC-10 Basins

Compass studied approximately 1,036 miles of stream reaches within the Richland 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

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) and supplemented with USGS National Elevation Dataset (NED) as appropriate. The leveraged TNRIS DEM data consisted of 2013 1-meter gridded DEM data derived from Light Detection and Ranging (LiDAR) data. The USGS NED 1/3 Arc Second DEM (approximately 10-meter equivalent) was used to provide a buffer along the northeastern ridge line and around the southern extent of the Richland-Chambers Reservoir as a buffer to the HUC-10 watersheds. Figure 2 shows the extent of the TNRIS LiDAR data.

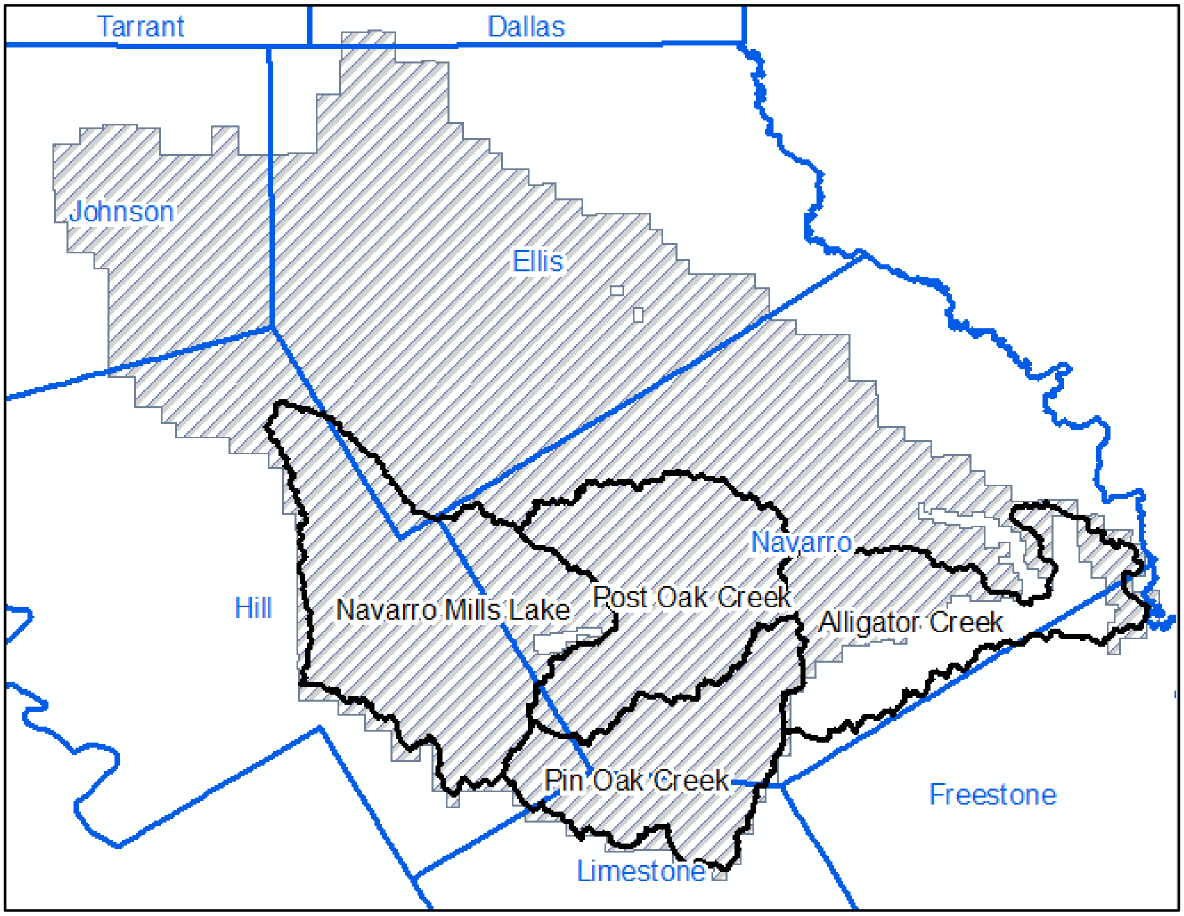

Figure 2. Extent of LiDAR Data

A new composite surface of the combined source topographic datasets, a seamless Triangular Irregular Network (TIN), was constructed using the WISE (Watershed Information System) Terrain Analyst tools. The TNRIS DEM data were used as the primary data source for the TIN while the 10-meter DEM was the secondary data source where TNRIS data did not exist for adequate buffer of the project area. A 10-foot DEM was sampled from the composite TIN and was used as the primary source for cross section takeoffs supporting hydraulic analyses. This 10-foot DEM was also used for visual QC and to support floodplain mapping tasks. A 50-foot DEM was sampled from the TIN for hydro enforcement to support hydrology tasks including flow vector and basin delineation.

Root Mean Square Error (RMSE) was calculated on the leveraged LiDAR-derivative DEM data used in this BLE analysis. The vertical accuracy of the source DEMs was calculated using QC checkpoints for the entire Richland/Chambers project area from original LiDAR QC reports acquired with the TNRIS data. The entire project area tested at 3.77 centimeters (cm) RMSEz, well within the 12.5 cm FEMA requirement for leveraged topographic data.

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 H&H and floodplain mapping activities are sufficient for BLE analysis.

1.2 Hydrology

Flood discharges for this study were calculated using both 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 calculations.

The WISE computer program was used to delineate drainage basins in shapefile format using the 50-foot resolution DEM. WISE was used to calculate the main-channel slope for each basin. The basin shapefile attribution was automated by WISE with drainage area and main-channel slope.

In order to perform the regression analysis and attribute each basin with appropriate discharge values, a script was written in Python and run in ESRI's ArcCatalog. This script required input of drainage area and main-channel slope (from WISE), as well as mean annual precipitation and OmegaEM.

PeakFQ version 7.1 was used to perform Flood Frequency Analysis (FFA) for three gages in the Richland Watershed.

Table 1 shows the published equations that were used for this study. In these equations, Qi 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]
$Q_{10\%}$	$P^{1.203}S^{0.403}$ x $10^{[0.918\ \Omega\ +13.62-11.97A\text{^}(-0.0289)]}$
$Q_{4\%}$	$P^{1.140}S^{0.446}$ x $10^{[0.945\ \Omega\ +11.79-9.819A\text{^}(-0.0374)]}$
$Q_{2\%}$	$P^{1.105}S^{0.476}$ x $10^{[0.961\ \Omega\ +11.17-8.997A\text{^}(-0.0424)]}$
$Q_{1\%}$	$P^{1.071}S^{0.507}$ x $10^{[0.969\ \Omega\ +10.82-8.448A\text{^}(-0.0467)]}$
$Q_{0.2\%}$	$P^{0.988}S^{0.569}$ x $10^{[0.976\ \Omega\ +10.40-7.605A\text{^}(-0.0554)]}$

[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 0.30log10, which is the mean residual standard error for the $Q_{1\%}$ equation.

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).

Main channel slope was calculated in WISE. An automated routine was used to determine the longest flowpath from the upstream of a reach to the outlet of the sub-basin of interest based on flowpaths developed from the 50-foot DEM. Once the length of the flowpath was delineated, elevations for the endpoints were determined based on the TIN developed from the LiDAR. The slope was calculated by dividing the fall by the reach distance and the result was reported in foot/foot.

From USGS SIR 2009-5087, the OmegaEM parameter is a generalized terrain and climate index that expresses relative differences in peak-streamflow potential. A shapefile was developed and populated with OmegaEM values based on Figure 2 in SIR 2009-5087. This shapefile was used, along with a python script in ArcCatalog, to determine OmegaEM values on a sub-basin basis. For sub-basins that are split, the dominant OmegaEM value for the sub-basin was used.

Drainage area for each sub-basin was 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 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.

As discussed in previously, a Python script in ArcCatalog was used to compute discharges for each sub-basin. 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.

The peak discharges on Richland Creek 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 Richland Creek as well as study segments on tributaries to Richland Creek that are downstream of flood control impoundments.

Three USGS stream gages in the Richland and Chambers HUC-8 watersheds listed in Table 2 were used to determine the a.c.e. flows for Richland Creek. 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
08063500	Richland Creek near Richland, TX	731	734	1962-1989
08064100	Chambers Creek near Rice, TX	803	807	1984 - 2014
08064500	Chambers Creek near Corsicana, TX	959	963	1913, 1939-1984

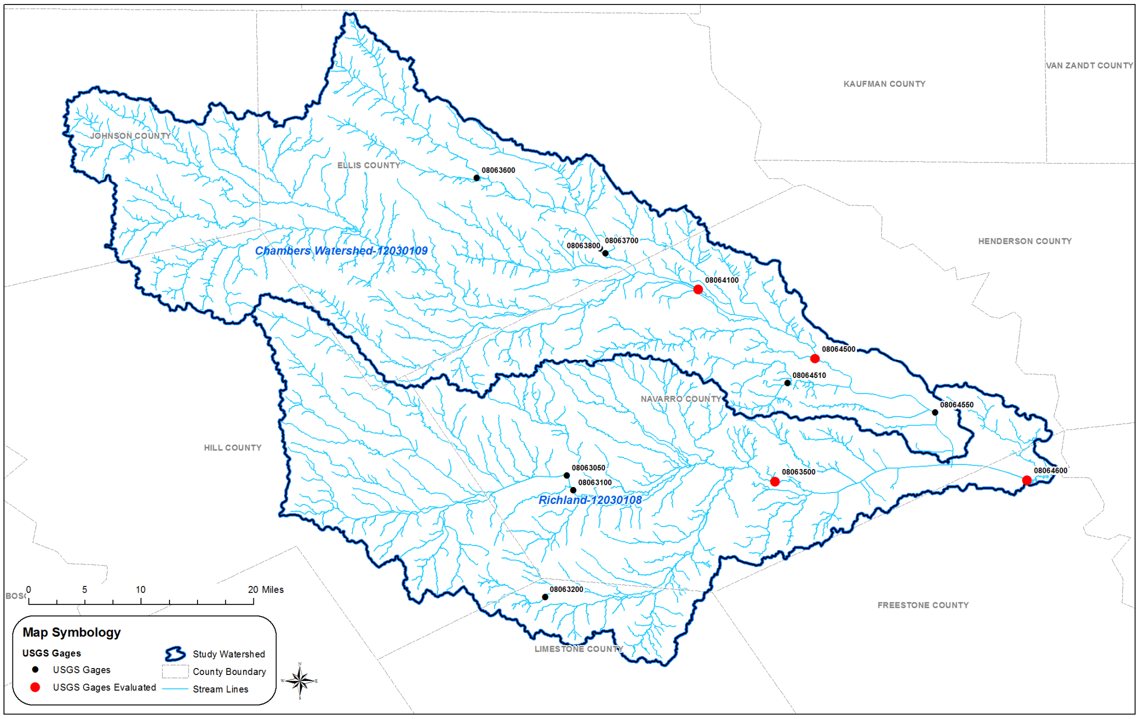

Figure 3. USGS Gage Stations within Chambers and Richland Watersheds

The gage on Richland Creek near Richland (08063500) has a post-regulation period of record of 28 years (1962-1989). The two stream gages on Chambers Creek, near Rice (08064100) and near Corsicana (08064500) are at similar drainage areas and have a combined period of record of 54 years (1961-2014) that spans the entire regulated period.

Flood Frequency Analyses (FFA) were performed following Bulletin 17B guidelines for the Richland Creek near Richland gage (08063500) and for the 2 gages on Chambers Creek (08064100, 08064500). The FFAs for each of the Chambers Creek gages used combined period of record, which was developed using drainage area transposition. The peak discharges resulting from the FFA of the Chambers Creek gage near Rice (08064100) were transposed to the Richland Creek near Richland gage (08063500) location; the transposed peak discharges were used instead of the at-site (08063500) FFA results because the combined period of record at the Chambers Creek near Rice gage (08064100) is nearly twice the period at the 08063500 gage.

The study reach on Richland Creek includes Richland Reservoir, which impounds 1,950 square miles and results in additional peak attenuation. The a.c.e. flows for Richland Creek just above the reservoir were determined by averaging the results of the flows transposed by drainage area from each of the two Chambers Creek gages (08064100, 08064500). The flows downstream of Richlands Reservoir were determined by using a plot of the observed inflows and outflows for the Reservoir. The inflows were determined by summing the concurrent observed annual peak flows from Richland Creek near Richland (08063500) and Chambers Creek near Corsicana (08064500). The summed flows represent the total inflow from Chambers Creek and Richland Creek above the confluence of Chambers Creek with Richland Creek. The summed flows were adjusted by drainage area transposition to the drainage area at the gage on Richland Creek below Richlands Reservoir (08064600). The outflows used were observed flows at the gage below Richland Reservoir (08064600). A least-squares best fit line was developed in order to approximate the relation between inflow and outflow of the Richlands reservoir. This linear relation was used to convert the a.c.e. flows out of Richland Reservoir, based on the previously estimated inflows to the Reservoir.

Stage only gages and gages with insufficient periods of record were not used for hydrologic computations.

Similar to the regression analysis results, the discharges used on these streams are associated with the hydraulic cross sections in the GIS shapefiles. In addition to the gages listed above, there are several stage only gages which were used for reference only as a reasonability check on lake elevations.

Again, it should be noted that throughout the watershed there are a significant number of flood control dams on tributaries to Richland Creek. Hydrologic results from regression calculations were not adjusted to take into account the impact of these structures.

1.3 Hydraulics

The hydraulic approach for BLE analysis for the Richland 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.

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. This was the method used for the Richland/Chambers Reservoir as flood elevations at the desired frequencies were not available. The elevations used in the modeling were checked against known elevations from past flooding events and effective Zone A boundaries and the result was determined reasonable.

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.

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.

There are no certified levees within the study area, therefore the levees that do exist were disregarded for this effort. For a flooding source with levees on both sides, this approach may result in under prediction of flooding elevations. Similarly, flooding elevations and extents may be under predicted on the overbank opposite of a levee when the flooding source has a levee on one side. Other scenarios are possible as well depending on locations and extents of levee failures.

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

Drainage area (upper limit)	XS Spacing	Channel Top Width	Channel Bottom Width	Channel Depth
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.

Stage data was available for the Navarro-Mills Dam from USGS Gage 0863050. A statistical analysis using a Log-Pearson III (LP3) distribution was performed to determine reasonable stage elevations for each of the modeled return periods.

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 model 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. 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.

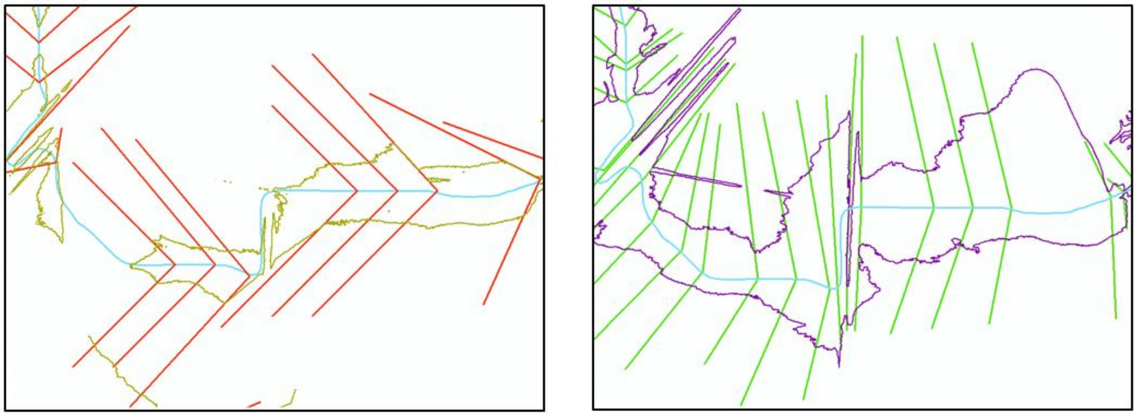

Figure 4. Default "V" angle cross-sections automated by WISE (left). Manually edited cross-sections to more accurately capture terrain (right). Resulting flood boundaries shown in gold (left) or purple (right) for clarity.

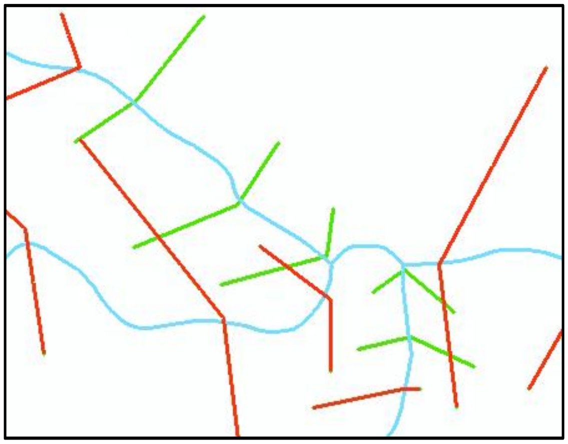

Figure 5. Manually added cross-sections (green) to improve accuracy of tie-ins at confluences.

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 TNRIS 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 special flood hazard area (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 Richland Watershed analysis presented challenges as summarized in the following paragraphs.

As noted in Section 1.2 above, there are a significant number of flood control dams on tributaries to Richland Creek. 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.

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 the Richland Watershed produced an 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 an SFHA mapped. These results provide context for flood risk communication as part of the Discovery process, and should be verified through community work map meetings before being applied to a regulatory product.

Maps 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 Richland Watershed contains 1,035.5 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 Richland Watershed Texas, the effective Zone A topographic data leveraged a variety of sources, but primarily based upon USGS map products. The topography listed in Section1.1 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 annual chance flow. Scientific Investigations Report 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 Ellis, Navarro and Hill Counties were developed using the USGS Water Resources Investigations Report 96-4307, "Regional Equations for Estimation of Peak-Streamflow Frequency for Natural Basins in Texas". However, the equations used for the effective Zone A studies in Limestone and Freestone Counties are unknown. The newer Regression Equations will not 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 the Texas study area was completed by evaluating percentage of urban change at the HUC-12 level. Of the 28 HUC-12 polygons within the study area, none currently meet the threshold of 15% or more urban cover, and therefore all effective Zone A's pass this check.

Table 5. Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Fail	2013 LiDAR significantly better than effective USGS topo source.
A2 – Hydrology	Pass	Latest regression equations for TX are dated 2009. Ellis, Navarro and Hill Counties used regression equations from 1997 while Limestone and Freestone Counties source are unknown.
A3- Development	Pass	Less than 15% urbanization in all subwatersheds within the study area.

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 Hill, Ellis, Freestone and Navarro Counties, check A4 for streams within these counties have been marked as fail in CNMS. Streams Limestone 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 the *First Order Approximation—Methodology, Validation, and Scalability Guidance Procedures (Version 1.5).* 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 290 modeled BLE streams in the study area, 104 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 9 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 Richland Watershed study area has been updated, with 820.7 miles categorized as UNVERIFIED – TO BE STUDIED, and 212.3 miles categorized as VALID – NVUE COMPLIANT. Total miles in each of these categories are summarized in Table 6 and illustrated in Figure 6 below.

Table 6. Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	NVUE COMPLIANT	212.3
UNVERIFIED	TO BE STUDIED	820.7

Table 7. BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Richland	All Streams	62,467	19,870	42,597	68.2%	Fail	
Headwaters Richland Creek	120301080101	2,774	815	1,959	70.6%	Fail	18.4
Town of Mertens-Richland Creek	120301080102	2,241	825	1,416	63.2%	Fail	19.1
Hackberry Creek-Navarro Mills Lake	120301080103	1,385	561	824	59.5%	Fail	20.2
Cottonwood Creek-White Rock Creek	120301080104	3,792	592	3,200	84.4%	Fail	7.6
Grove Creek-Pecan Creek	120301080105	2,756	228	2,528	91.7%	Pass	4.9
Headwaters Ash Creek	120301080106	5,764	986	4,778	82.9%	Fail	9.9
Cottonwood Creek-Ash Creek	120301080107	4,984	1,146	3,838	77.0%	Fail	11.4
Bynum Creek	120301080108	3,670	674	2,996	81.6%	Fail	8.4
Ash Creek-Navarro Mills Lake	120301080109	1,855	563	1,292	69.6%	Fail	13.7
Tom Harris Branch-Navarro Mills Lake	120301080110	2,345	943	1,402	59.8%	Fail	17
Treadwell Branch-Richland Creek	120301080201	891	692	199	77.7%	Fail	13.1
Post Oak Creek	120301080202	1,674	1,310	364	78.3%	Fail	21.8
Battle Creek-Richland Creek	120301080203	1,851	1,361	490	73.5%	Fail	20.5
Melton Branch-Richland Creek	120301080204	1,355	948	407	70.0%	Fail	25.2
Rush Creek	120301080205	2,633	1,896	737	72.0%	Fail	15.1
Cedar Creek-Richland Creek	120301080206	1,600	1,245	355	77.8%	Fail	15.4

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
North Fork Pin Oak Creek	120301080301	3,504	596	2,908	83.0%	Fail	12.6
Munger Branch	120301080302	2,934	638	2,296	78.3%	Fail	18.3
Elm Creek-Pin Oak Creek	120301080303	3,507	1,137	2,370	67.6%	Fail	22.9
Alligator Creek-Pin Oak Creek	120301080304	2,139	817	1,322	61.8%	Fail	32.1
Town of Union High-Pin Oak Creek	120301080305	688	150	538	78.2%	Fail	14.7
Board Creek-Pin Oak Creek	120301080306	1,224	292	932	76.1%	Fail	16.9
Little Pin Oak Creek-Richland Creek	120301080401	1,362	225	1,137	83.5%	Fail	11.8
Mesquite Creek-Little Pin Oak Creek	120301080402	900	150	750	83.3%	Fail	15.1
Grape Creek-Richland Creek	120301080403	1,954	333	1,621	83.0%	Fail	14.9
Crab Creek	120301080404	735	206	529	72.0%	Fail	22.9
Jones Branch-Richland Creek	120301080405	534	97	437	81.8%	Fail	13.7
Hog Pen Slough-Richland Creek	120301080406	523	180	343	65.6%	Fail	15.9
Yonker Pin Slough-Richland Creek	120301080407	893	304	589	66.0%	Fail	15.9

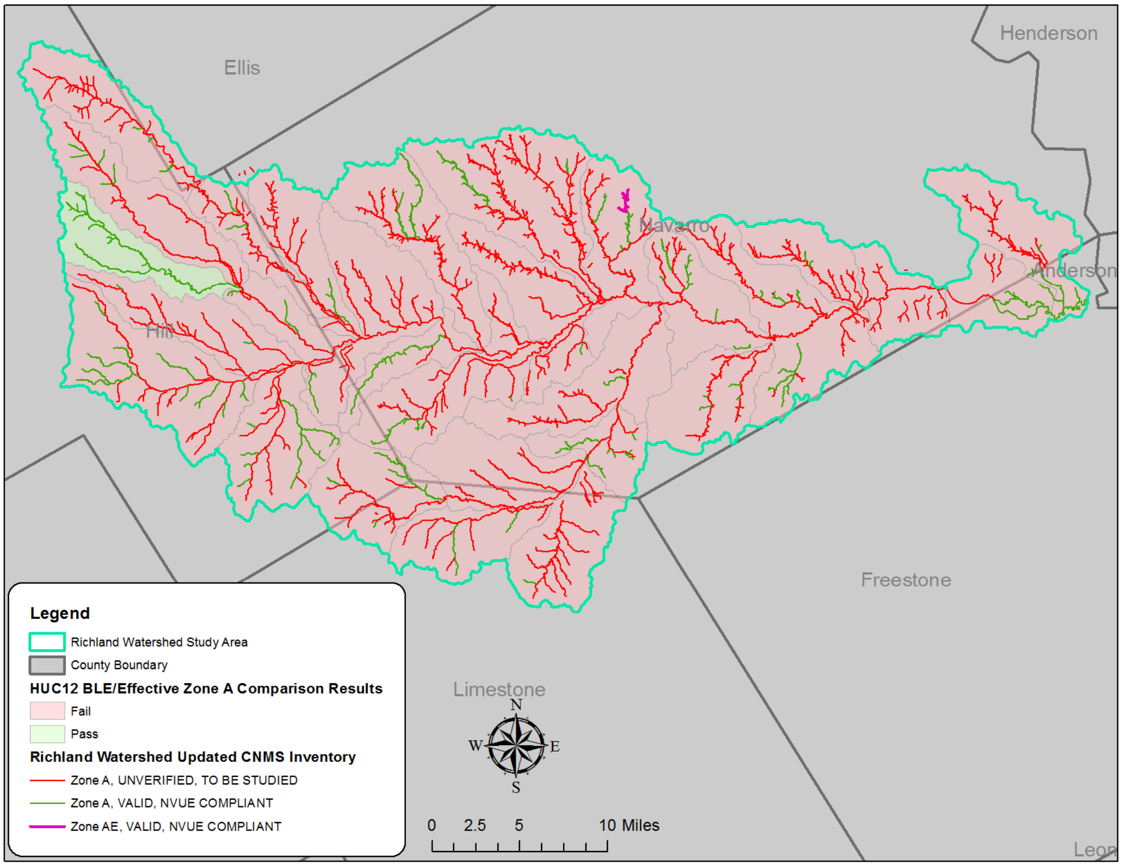

Figure 6. Richland Watershed CNMS Validation Results

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 Richland HUC-8 priority scores can be used to initiate discussions during the Discovery phase. Alligator Creek – Pin Oak Creek HUC-12 was determined to have the highest priority score and the most need while Grove Creek – Pecan Creek HUC-12 has the lowest score. Priority scores are identified above in Table 7.

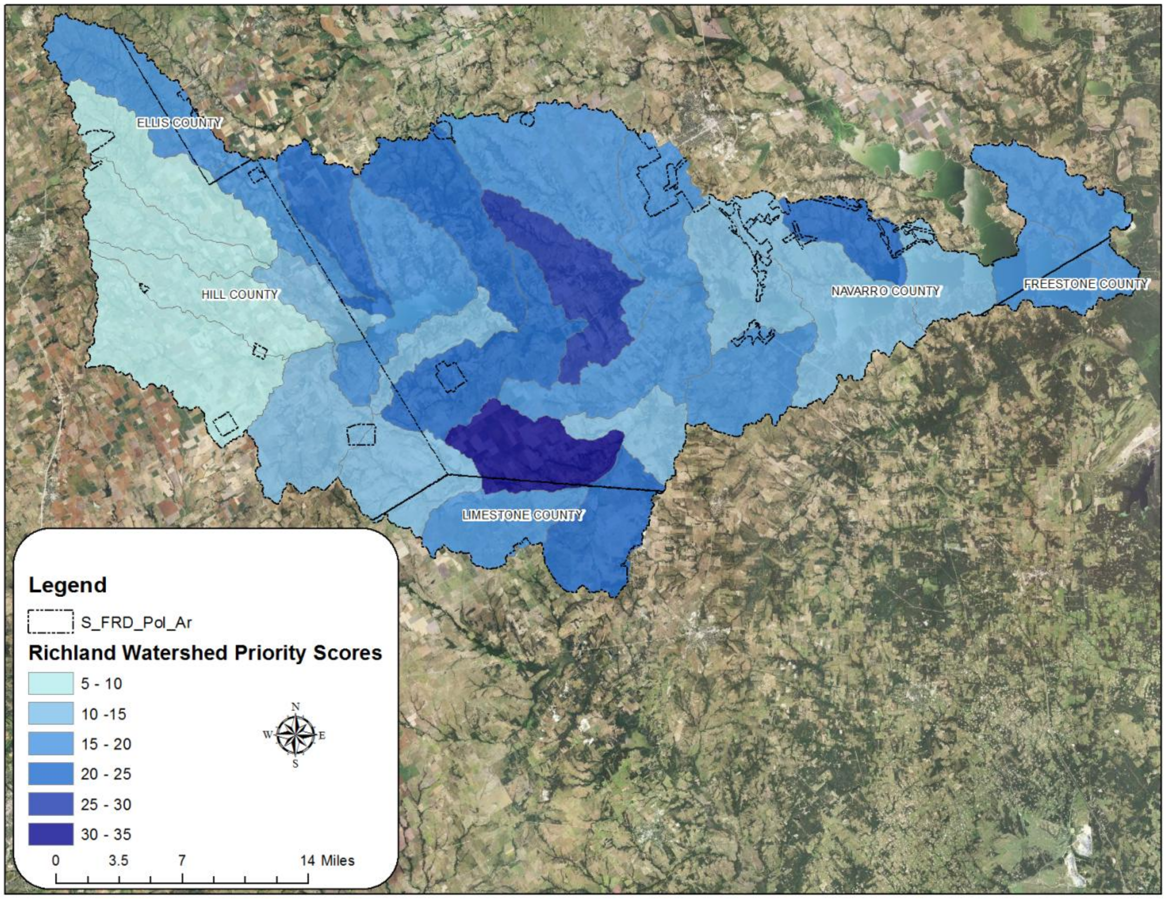

Figure 7. Ranking of Richland Watershed HUC-12s

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) were 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