Leon Watershed, Texas
2D Base Level Engineering and Mapping Methods and Results

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This document requires the approval of the following persons:

Role	Name	Phone	Title (CLIN/RMC)	Review Date	Approved Date
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1. Introduction

Base Level Engineering (BLE) provides technically credible flood data for various geographies - community, county, watershed and/or state level. BLE data can be shared with Federal, State, local and tribal governments, this data sharing provides stakeholders at all levels the necessary data to make informed decisions to reduce future flood losses. Without the mapping of flood prone areas, there can be a lack of information to effectively communicate flood risk to community officials, citizens, and businesses.

BLE is a riverine hydrologic and hydraulic modeling approach that builds on lessons learned to produce a baseline understanding of flood risk to communities, produced to support the assessment and maintenance of the national flood hazard inventory. Engineering models are created during a BLE assessment, producing information that meets the mapping Standards for Flood Risk Projects (FEMA Policy Memo FP 204-078-1) to produce Zone A (1-percent-annual-chance flood) information. BLE data is intended to represent the base level of investment needed for all flood study efforts FEMA will undertake. The Leon watershed BLE documented here was designed to use two-dimensional (2D) modeling techniques with enhancements and calibration to develop products that can be communicated and shared with stakeholders, and transitioned into FEMA regulatory data development workflows.

The intent of BLE is to provide communities technically credible flood hazard information in a cost efficient and timely manner. Additionally, BLE provides communities a chance to review draft modeling information, reflecting the potential changes in risk within their community. Providing additional flood risk datasets, like water surface elevation (WSEL) grids and flood depth grids, delivers alternative information that reinforces the variability of flood risk within a designated floodplain and supports historic community requests for a source to determine a Base Flood Elevation in Zone A areas.

For floodplain management purposes, BLE data may be used as best available information in areas that are designated as Zone A floodplain. It may also be used to regulate development in areas where no Special Flood Hazard Area (SFHA) has been mapped before. Communities may adopt BLE data to support local regulations, which facilitates use of the data in local floodplain management activities, including in the post disaster environment where a need for updated and/or enhanced flood hazard information may be necessary.

BLE provides information to communities who are currently unmapped and provides a digital entry to communities that are currently un-modernized. BLE acts as a measuring tool to allow FEMA to assess the current Zone A inventory identified as unknown or unverified in FEMA's Coordinated Needs Management Strategy (CNMS), which FEMA is required to evaluate once every five years, as described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e). 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. Another important goal of the BLE process is scalability of the results, meaning that the model produced during the BLE assessment may be refined to produce a more enhanced model with additional manual correction and on the ground survey. If BLE modeling exists, FEMA will recommend that it be used as the base model for any detailed studies performed in those areas.

BLE practices leverage high-resolution topography that meets or exceeds the United States Geological Survey (USGS) 3-D Elevation Program (3DEP) standards and often applies flood engineering at a large scale as opposed to targeting stream reaches within a watershed. BLE can be conducted at any scale, commonly for larger areas (Hydrologic Unit Code (HUC)-8 watershed) but may be produced at the county or local level too. It is encouraged to do BLE for wider areas in order to build on efficiencies in modeling and ensure cost efficiency. Using current technologies, multiple watersheds or watersheds with large land areas can be analyzed at a more efficient rate to produce water-surface elevations and site-specific hazard data replacing outdated flood studies shown in existing Flood Insurance Rate Maps (FIRMs). All flood prone areas within a watershed will have an engineering model calculating multiple flood recurrence intervals and defining floodplains with elevation grids using high-resolution topography.

Per standard identification SID #84 and #133, BLE will include all recurrence intervals (0.2-percent, 1-percent, 1-percent plus, 1-percent minus, 2-percent, 4-percent, and 10-percent-annual-chance floods). As such, hydrologic and hydraulic analysis should be performed to determine the expected WSELs for each of the seven recurrence intervals previously identified.

The Leon HUC-8 2D BLE project was scoped as described in the Texas Water Development Board (TWDB) Task Order 10. In an effort to increase and enhance the flood risk products in Texas, the study was contracted through the TWDB's Cooperative Technical Partner (CTP) program to AECOM Technical Services, Inc. This report documents the BLE process, products, and results for this watershed. Figure 1 depicts the Leon watershed footprint.

Figure 1: Leon Watershed

2. 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2D hydraulic engineering analysis for the Leon watershed. Inputs such as elevation data, hydrology from rain-on-grid and inflow hydrographs, and hydraulic analyses and variables are defined herein. HEC-RAS 6.1 rain-on-grid utility was applied in the production of the 2D BLE products produced for this watershed.

2.1 Topographic Data

A high resolution Digital Elevation Model (DEM) is a fundamental component for 2D engineering analyses by providing a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the Leon BLE project by leveraging available high resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the State of Texas. The 1 meter DEM developed to support the 2D BLE modeling and analysis, within the Leon watershed, was executed using the following steps:

1. Available elevation data for the project area were inventoried and collected.
2. Leveraged elevation data were evaluated and prioritized based on source vertical accuracy, year of collection, and resolution.
3. Seamless DEMs were processed using Geographic Information Systems (GIS).
4. Quality was assured using quantitative and qualitative assessment.

Documentation regarding leveraged data including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables and text within Section 2.1.2. 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 the Leon watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Leon BLE watershed footprint. Figure 2 depicts the datasets identified and leveraged across the project area. FEMA, National Oceanic and Atmospheric Administration (NOAA), USGS, Texas Natural Resources Information System (TNRIS) and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

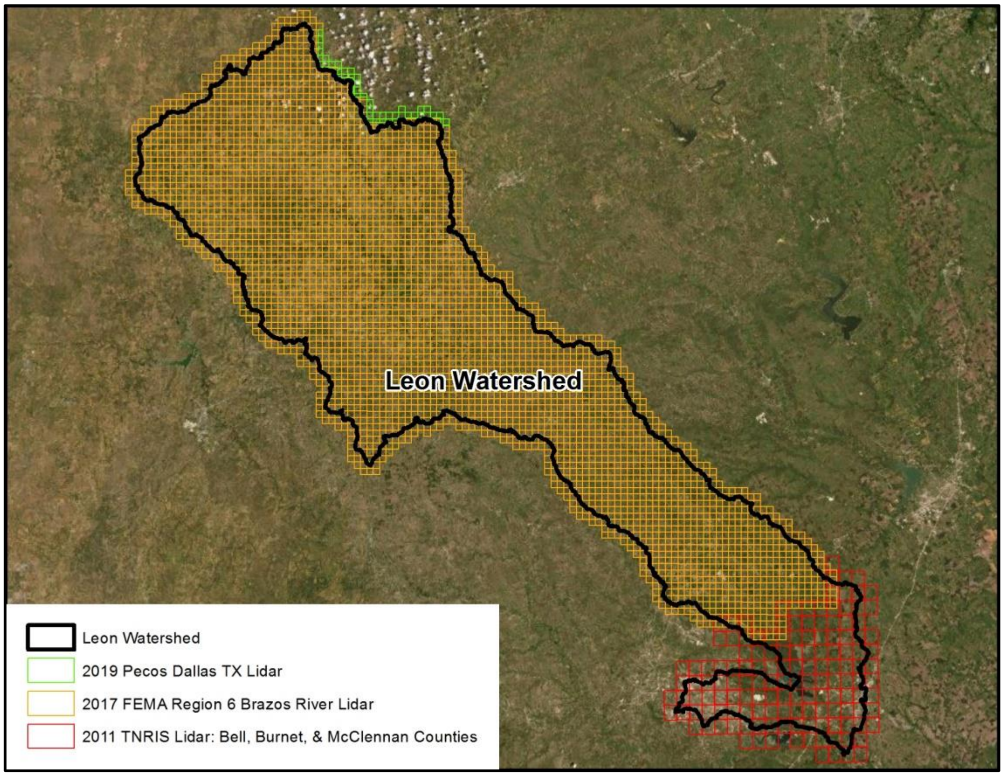


Figure 2: Leon Watershed BLE Source Terrain Data

2.1.2 Evaluation

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

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

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

Table 1: FEMA Vertical Accuracy Requirements for Leveraged Data

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

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

Table 2 depicts the complete list of source elevation data and attributes leveraged for the Leon watershed. All datasets used for hydraulic analyses and mapping meet the highest specification level defined in Table 1. The following datasets were evaluated and prioritized as best available:

Table 2: LiDAR Topographic Data Available for the Leon Watershed

Year	Description	Source/Owner	Accuracy[1]	Approximate Footprint (mi^2)[2]
2019	2019 Pecos Dallas TX LiDAR	TNRIS/TWDB	7.3 cm	33
2017	2017 FEMA Region 6 TX – Brazos River QL2 LiDAR	FEMA	7.9 cm	3,184
2011	2011 TNRIS LiDAR: Bell, Burnet, and McLennan Counties	TNRIS	9.445 cm	576

[1]RMSEz reported at the 95% confidence level

[2]Size of LiDAR DEM footprint utilized for BLE study

2.1.2.1 Leon Watershed Source Terrain Data

The source elevation data for the Leon watershed are DEMs derived from the 2019 Pecos Dallas TX LiDAR; the 2017 FEMA Region 6 TX – Brazos River QL2 LiDAR; and the 2011 TNRIS LiDAR: Bell, Burnet, and McLennan Counties. Only points classified as “ground” points (i.e., bare earth) were imported from the LiDAR and used for development of the project DEMs. Bare-earth LiDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the raw laser returns. Figure 2 depicts the extent of the data defined in Table 2.

2019 Pecos Dallas TX LiDAR

Digital Aerial Solutions LLC was tasked to collect and process lidar for three areas of interest (AOIs) covering approximately 9,557 square miles in the following Texas counties: Collin, Crane, Culberson, Dallas, Denton, Eastland, Ellis, Erath, Johnson, Kaufman, Loving, Palo Pinto, Parker, Reeves, Rockwall, Smith, Stephens, Tarrant, Ward, Winkler, and Wise. The lidar aerial acquisition was conducted between January 26, 2019 and July 12, 2019. The horizontal datum for the data was North American Datum of 1983 (NAD83 2011) Universal Transverse Mercator (UTM) Zone 14N with units in meters and the vertical datum is North American Vertical Datum of 1988 (NAVD88) with the elevation units in meters realized with GEOID12B.

For the 2019 Pecos Dallas TX Lidar, the tested Root Mean Square Error (RMSEz) of the classified lidar data is 7.3cm.

2017 FEMA Region 6 TX – Brazos River QL2 LiDAR

The area covered by the Brazos portion of the Texas Red River FEMA Region 6 Lidar project includes the counties of Archer, Baylor, Bell, Bosque, Brown, Callahan, Coleman, Comanche, Coryell, Dickens, Eastland, Erath, Fisher, Hamilton, Jack, Jones, King, Knox, Lampasas, McLennan, Mills, Palo Pinto, Runnels, Shackelford, Stephens, Stonewall, Taylor, Throckmorton, and Young. The lidar aerial acquisition was conducted between January 1, 2017 and May 28, 2018. The horizontal datum for the data was NAD83 (CORS 2011) UTM Zone 14N with units in meters and the vertical datum is NAVD88 with the elevation units in meters realized with GEOID12B.

For the Brazos Basin Texas FEMA R6 Lidar Project, the tested RMSEz of the classified lidar data is 7.9cm.

2011 TNRIS LiDAR: Bell, Burnet, and McLennan Counties

The area covered by the 2011 TNRIS Lidar: Bell, Burnet, and McLennan Counties project is approximately 2,349 square miles and includes portions of Bell, Burnet, Coryell, Falls, Lampasas, and McLennan counties. The lidar aerial acquisition was conducted between March 11, 2011 and July 1, 2011. The horizontal datum of the data was NAD83 UTM Zone 14N with units in meters and the vertical datum of the data was NAVD88 with elevation units in meters realized with GEOID03. The lidar data tested at 9.445cm RMSEz.

2.1.3 Data Processing

ArcGIS software was utilized in order to create a digital surface model for the Leon HUC-8 watershed project area. The LiDAR datasets were added to a mosaic dataset and prioritized by date with the most recent dataset taking the first priority. If two datasets are from the same year or flown at similar dates, the accuracy was reviewed to determine the priority. The mosaic dataset was exported to make a seamless bare earth 1-meter DEM for mapping and modeling according to the model area extents, including a 1,000 foot buffer.

The exported DEM was reviewed through automated quality control (QC) to check for anomalies and outlier locations based on slope and cells that exceed z value differences from surrounding cells. Visual review was also performed to check for ground differences at the extents of the datasets for differences in ground values.

2.1.4 DEM QA/QC

DEMs developed for use in the Leon watershed BLE analysis were developed and independently assured to meet quality standards of the project. The data were developed using a controlled process, were evaluated and assured by a topographic data development team, and were evaluated and assured by the engineering team. Quality assurance (QA) during the data development process includes, but is not limited to the following QC checks:

- Horizontal Projection Check
- Vertical Datum Check
- Resolution Check
- Format Check
- Seamless Data Check to ensure the DEM files are consistent and seamless along source data edges

The QC after the development process by the DEM development team included visual observations using hillshade, contouring, color rendering, and/or other visual aids to review and identify potential impactful anomalies within the DEM surface. This QC step included, but was not limited to the following QC checks:

- Seamless Data Check to ensure no voids along the edges and between the prioritized datasets
- NoData Value Check to ensure no null values
- Manual Elevation Check using hillshade rasters to find erroneous elevation issues
- Unit Consistency Check
- Legacy Cell Value Anomalies

QA conducted after the seamless DEM development conducted by the engineering team included visual or automated assessments to identify potentially impactful anomalies or slope changes that may adversely impact hydraulic analysis.

The final DEM data developed for the Leon watershed is assured to meet FEMA standards and present a representative surface developed from leveraged elevation data for the purposes of this BLE project.

2.2 2D BLE Methods

HEC-RAS 6.1 (RAS6) rain-on-grid utility was applied in the Texas 2D BLE products workflow. The following sections describe the engineering methods and model inputs used.

2.2.1 2D Computational Mesh and Settings

Due to the size of the Leon watershed (approximately 3,021 sqmi) and presence of highly populated and urbanized areas, and to account for computational and modling limitits, the HUC-8 was split into five separate HEC-RAS geometries as shown in Figure 3. The HUC-8 was split into modeling areas as Leon 1, 2, 3, 4, and 5. Minor adjustments have been made to HUC-10 boundaries to improve modeling efficiency. The most downstream portion of the Cowhouse HUC-8 watershed, that contains a portion of Belton Lake, was removed from the Cowhouse 2D BLE model area, and instead is modeled as part of the Leon HUC-8 2D BLE project (added to model area Leon 5). This was done to allow Belton Lake to be modeled within one 2D mesh, and assist in the tie-in between the two BLE watersheds. Therefore, users should note that while the mapped floodplains and other datasets will be consistent with the original HUC-8 watershed boundaries, the modeling footprints will represent the edits to the boundaries described above near Belton Lake.

The RAS6 watershed boundaries were created for the Leon model areas using ArcGIS toolsets, which reduce the need for manual edits to mesh cells within RAS6 that result in error generation. The Leon 1, 2, 3, 4, and 5 2D meshes contain 697,343, 606,502, 617,634, 826,072, and 1,510,988 cells, respectively, consisting of 200 foot cells, with the exception of 100 foot along the 1 square mile streams, and 50 foot cells within community boundaries using refinement regions. Within community boundaries the streamlines were also extended to the 0.5 square mile extent and assigned 50 foot cell spacing in order to be more detailed. Internal connections were used to extract flow readings for gage locations throughout the model, while profile lines were used for all other flow extractions. An adaptive 30 second time step was used to allow the model to lower the time step, as necessary, to keep the maximum courant number under 3 for the duration of the simulation. For Leon models 1, 2, 3, and 5, the time step was allowed to reach 120 seconds for a maximum and 3.75 seconds for the minimum. For Leon 4, the time step was allowed to reach 120 seconds for a maximum and 7.5 seconds for a minimum. The RAS6 model was run with Diffusion Wave (simplified Full Momentum) equations.

2.2.2 Model and Boundary Condition Setup

Using RAS6 rain-on-grid modeling requires a 2D computational mesh boundary and often requires defining inflow boundary conditions and application of excess precipitation. Excess precipitation was applied to the 2D mesh as a precipitation boundary condition. The process to determine the excess precipitation to be applied is outlined in the hydrology section. Figure 3 depicts the Leon 1, 2, 3, 4, and 5 model boundaries, flow transition points between models, and USGS stream gages used in the study.

Because the Leon HUC-8 was split into five work areas, the outflows from the upstream models along the Leon River were extracted and used for the downstream work areas. The hydrographs were extracted from the upstream model using a 2D connection, and then placed as a stage hydrograph external boundary condition for the downstream model.

Outflow boundary conditions (from the computational 2D mesh) were used along model boundaries. Outflow boundaries were established as normal depth using approximate energy grade-line slope estimated from the LiDAR data. This allowed the boundary conditions defined as continuous boundaries to allow drainage to leave the model area freely to adjacent basins.

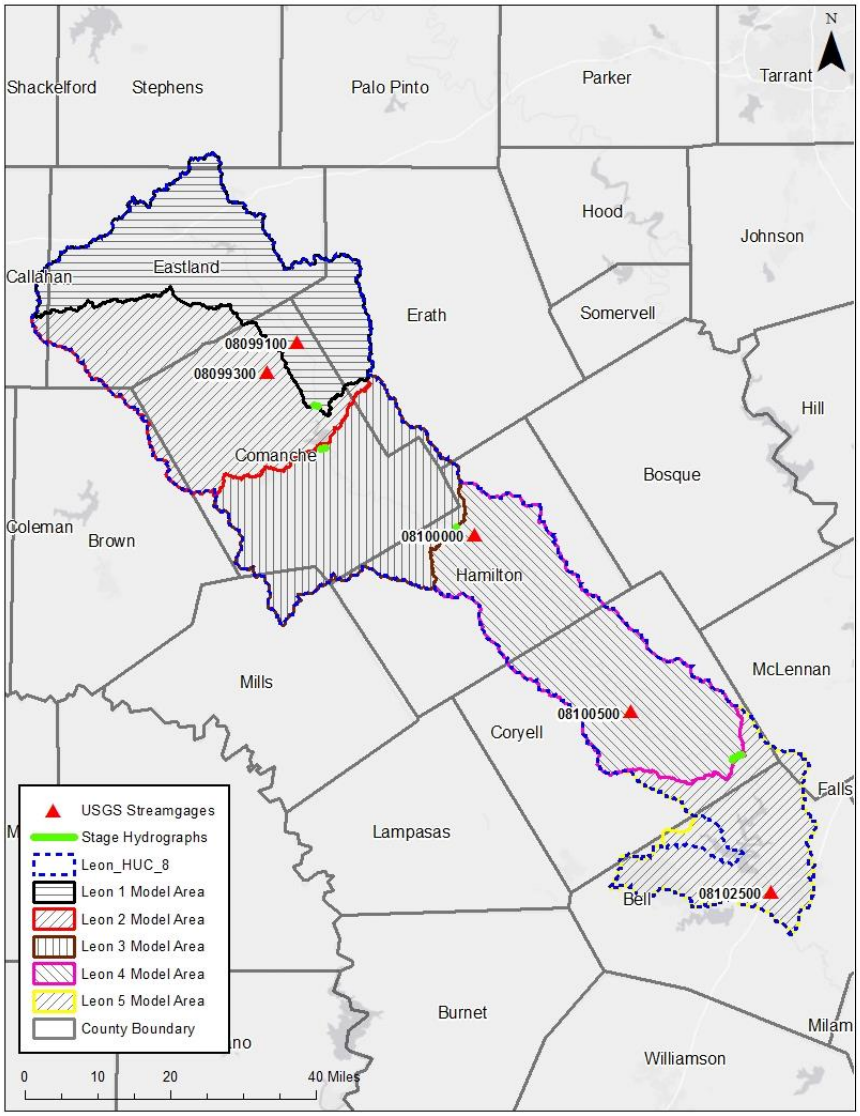


Figure 3: RAS6 2D Computational Mesh and Boundary Conditions and USGS Peak Streamflow Gages

2.2.3 Hydrology

Precipitation frequency data (NOAA, 2018) was used for this study. This data was obtained from NOAA's Precipitation Frequency Data Server (PFDS) (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html), and appropriate values for all sub-basin elements were determined considering spatial variation and a representative total for all model areas. Excess precipitation for the 2D meshes were developed as described in Section 2.2.3.1 USGS streamflow gage data was leveraged to estimate peak flows for downstream gages within each work area for calibration purposes, as discussed in Section 3.1. The 10-, 4-, 2-, 1-, and 0.2-percent annual chance 24-hour precipitation depths for all sub-basin elements were determined by area-weighted intersection of gridded PFDS data with sub-basins.

The models were compared to known USGS peak flows to validate model results. USGS stream gages with less than 10 years of record, or no daily stream discharge data were not considered for this study. Twelve USGS stream gages existed within our study area. Gages 08098470, 08099382, 08100630, 08102590, 08102595, and 08102600 were not utilized because the gages do not provide daily discharge data with more than 10 years of record, or are no longer active sites and have data that is out-of-date. Gages 08099500 and 08102500 were discarded due to their close proximity to Proctor Dam and Lake Belton Dam. The flow values for gages 08099500 and 08102500 are controlled by the release rates of their respective dams, and due to the scope of this study the extensive efforts required to calibrate to these gages is not feasible. Other USGS gages classified as 'lake' gages were present in the model but were not used in calibration so they are not listed here. USGS gages 08099100, 08099300, 08100000, and 08100500, the gages used for analysis in this study, are listed in Table 3.

Table 3: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
08099100	Leon Rv nr De Leon, TX	479	1961-2021
08099300	Sabana Rv nr De Leon, TX	264	1961-2021
08100000	Leon Rv nr Hamilton, TX	1,891	1908-2021
08100500	Leon Rv at Gatesville, TX	2,342	1908-2021

2.2.3.1 Excess Precipitation for 2D Computational Mesh

HEC-HMS version 4.8 was used to apply the Soil Conservation Service (SCS) Curve Number (CN) method to calculate losses and define excess precipitation for this watershed. Temporal distributions of point rainfall totals were defined using 24-hour, frequency-based storm distributions. The plus and minus standard error for the 1-percent annual chance precipitation depths were determined as the upper and lower 84% confidence limits on the nominal 1-percent depth, assuming a normal distribution of the logarithms for the precipitation depths. An areal reduction as per Technical Paper 40 (TP-40) was used in HEC-HMS on all recurrence interval total precipitation depths in order to determine the effective precipitation for the sub-basin representing 2D mesh.

In addition to recurrence interval precipitation estimates, NOAA Atlas 14 provides 90% confidence intervals of reported precipitation values. On a normal distribution curve, 90% confidence intervals (i.e. the upper and lower 95% confidence limits) correspond to +/- 1.645 standard deviations. The 1-percent plus and minus events are defined to be one standard deviation above and below the 1-percent event. It should be noted that the standard errors for the 1-percent rainfall depth were based on the depth used post-areal reduction. The estimated 1-percent plus and minus rainfall depths are shown, alongside the other events, in Table 6 later in this section.

Curve numbers were computed by intersecting the National Land Cover Dataset (NLCD) 2019 coverage and NRCS soils data based on the matrix presented in Table 4.

Table 4: Land Use(LU)-Soils-CN Matrix for Defining Initial Curve Number

LU_GridCode	NLCD LU Description	Hydrologic Soil Group			
		A	B	C	D
11	Open Water	99	99	99	99
21	Developed Open Space	49	69	79	84
22	Developed Low Intensity	61	75	83	87
23	Developed Medium Intensity	81	88	91	93
24	Developed High Intensity	89	92	94	95
31	Barren Land	39	61	74	80
41	Deciduous Forest	30	55	70	77
42	Evergreen Forest	30	55	70	77
43	Mixed Forest	30	55	70	77
52	Shrub Scrub	30	48	65	73
71	Herbaceous	49	62	74	85
81	Hay Pasture	39	61	74	84
82	Cultivated Crops	51	67	76	80
90	Woody Wetlands	72	80	87	93
95	Emergent Herbaceous Wetlands	72	80	87	93

In addition to rainfall, the 1-percent plus and minus event estimates were further refined by adjustment of their respective CNs. A CN can be considered a parameter, exhibiting variability that follows some frequency distribution. While Antecedent Runoff Condition (ARC) II CNs were used for a 1-percent event, the range between ARC I and ARC III for the ARC II CN was assumed to correspond to an 80% confidence interval of the ARC II CN. The CN loss method assumes a maximum potential retention parameter, S, is inversely related to a CN by S = 1000 / CN – 10; this relationship is based on a median value of S determined from plotting a large number of observations.

Chapter 5 of the NRCS National Engineering Handbook (NEH) Part 630 provides an example of computing a CN for a watershed based on annual peak gage observations. The example involves computing a CN and corresponding S value for each event, then taking the logarithms of the S values. Further, the logarithm of S is assumed to vary normally, and the mean of the logarithms corresponds to the arithmetic median. Therefore, 10% (S10) and 90% (S90) extremes of lognormally distributed S values can be assumed to correspond to ARC III and ARC I condition CN values, respectively. This range represents an 80% confidence interval, corresponding to +/- 1.282 standard deviations from the mean. The following procedure was used to estimate one standard deviation of a given CN (in fact, one standard deviation of the logarithm of S) for the purposes of modeling 1-percent plus and minus events. First, ARC III (corresponding to S10) and ARC I (corresponding to S90) CN values can be estimated from a 1-percent CN (ARC II) by:

$$\mathrm{CNI} = 4.2 * \mathrm{CNII} / (10 - 0.058 * \mathrm{CNII})$$

$$\mathrm{CNIII} = 23 * \mathrm{CNII} / (10 + 0.13 * \mathrm{CNII})$$

Next, S90 and S10 can be computed by:

$$\mathrm{S10} = 1000 / \mathrm{CNIII} - 10$$

$$\mathrm{S90} = 1000 / \mathrm{CNI} - 10$$

The following relationship can then be used to compute one standard deviation of the logarithm of S:

$$\log(S10) = \text{mean}(\log(S)) + 1.282\ \text{std. dev.}(\log(S))$$

$$\log(S90) = \text{mean}(\log(S)) - 1.282\ \text{std. dev.}(\log(S))$$

$$1\ \text{std. dev.}(\log S) = (\log S10 - \log S90)\ /\ 1.282$$

Therefore, 1-percent plus and minus S values can be estimated by:

$$\log \text{SPlus} = \log S + [1\ \text{std. dev.}(\log S)]$$

$$\log \text{SMinus} = \log S - [1\ \text{std. dev.}(\log S)]$$

Finally, 1-percent plus and minus CNs can be computed by:

$$\text{CNPlus} = 1000\ /\ (\text{SPlus} + 10)$$

$$\text{CNMinus} = 1000\ /\ (\text{SMinus} + 10)$$

Since the 1-percent plus and minus events represent plus and minus one standard deviation of a 1-percent event, CNs used in a rainfall-runoff simulation for modeling 1-percent plus and minus events were developed, as described above. A single basin was used in HEC-HMS for simulation to estimate excess precipitation.

The table below shows the curve numbers initially computed and the verfied values. The Leon 4 model was the only model that needed to have its CNs revised in order to calibrate properly. Those values are shown in the table as well.

Table 5: Rainfall-Runoff Curve Numbers

Sub-basin Description	CN (initial)	CN (verified)	CN 1-percent Minus	CN 1-percent Plus
Leon – 1	66.95	66.95	52.45	78.86
Leon – 2	64.89	64.89	50.47	77.09
Leon – 3	69.51	69.51	55.05	81.00
Leon – 4	74.45	82	89.8	70.1
Leon – 5	80.76	80.76	69.16	88.83

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including CNs for defining rainfall losses. No routing was considered in the rainfall-runoff modeling. Frequency-based storm with 50% storm centering were used for-defining temporal distributions of point rainfall totals. Table 6 provides the precipitation totals applied to the model including areal reduction.

Table 6: Precipitation Totals estimated in HEC-HMS (post ARF)

Percent Annual Chance Precipitation Depths (in.)							
Sub-Basin Description	1-percent	0.2-percent	2-percent	4-percent	10-percent	1-percent Plus	1-percent Minus
Leon – 1	8.17	11.19	7.08	6.09	4.9	9.79	6.55
Leon – 2	8.32	11.28	7.19	6.17	4.95	9.92	6.72
Leon – 3	8.24	11.10	7.17	6.20	5.01	9.83	6.66
Leon – 4	8.44	11.38	7.41	6.45	5.23	10.11	6.78
Leon – 5	9.28	12.92	8.00	6.85	5.48	11.17	7.40

Table 7 shows the excess precipitation totals determined from the HMS model. These values are a factor of the average CN and precipitation depths for each model area. Note that the CNs for Leon 4 were modified during the calibration process, and the excess precipitation depths were recalculated to install confidence in the final model results.

Table 7: Total Excess Precipitation Applied to 2D Mesh

Sub-Basin Description	Percent Annual Chance Precipitation Depths (in.)						
	1-percent	0.2-percent	2-percent	4-percent	10-percent	1-percent Plus	1-percent Minus
Leon – 1	4.26	6.88	3.37	2.59	1.73	7.18	1.63
Leon – 2	4.14	6.67	3.24	2.47	1.61	7.07	1.55
Leon – 3	4.62	7.16	3.71	2.92	2.00	7.48	1.92
Leon – 4	6.28	9.11	5.30	4.40	3.29	8.86	3.45
Leon – 5	6.93	10.45	5.71	4.64	3.39	9.79	3.86

Figures 4 -Figure 8 show the excess precipitation hyetographs used for the Leon models. CN and precipitation depth are the two factors used by the HMS model to determine the magnitude of the excess precipitation event. The excess precipitation hyetograph is calculated in 6-minute increments. All models in this study have excess hyetograph shapes that closely resemble this one, but with varying maximum excess precipitation values.

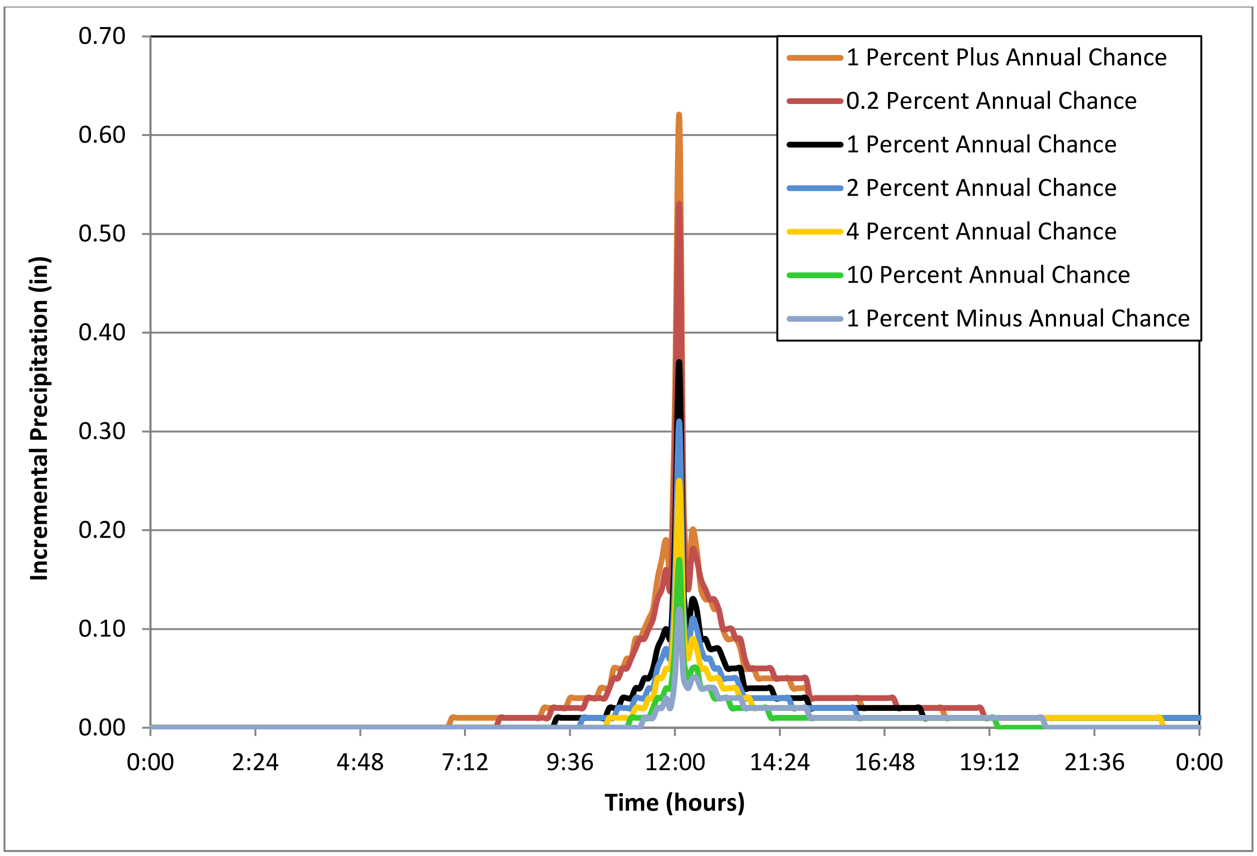


Figure 4: Excess Precipitation Hyetograph Applied to 2D Mesh – Leon 1

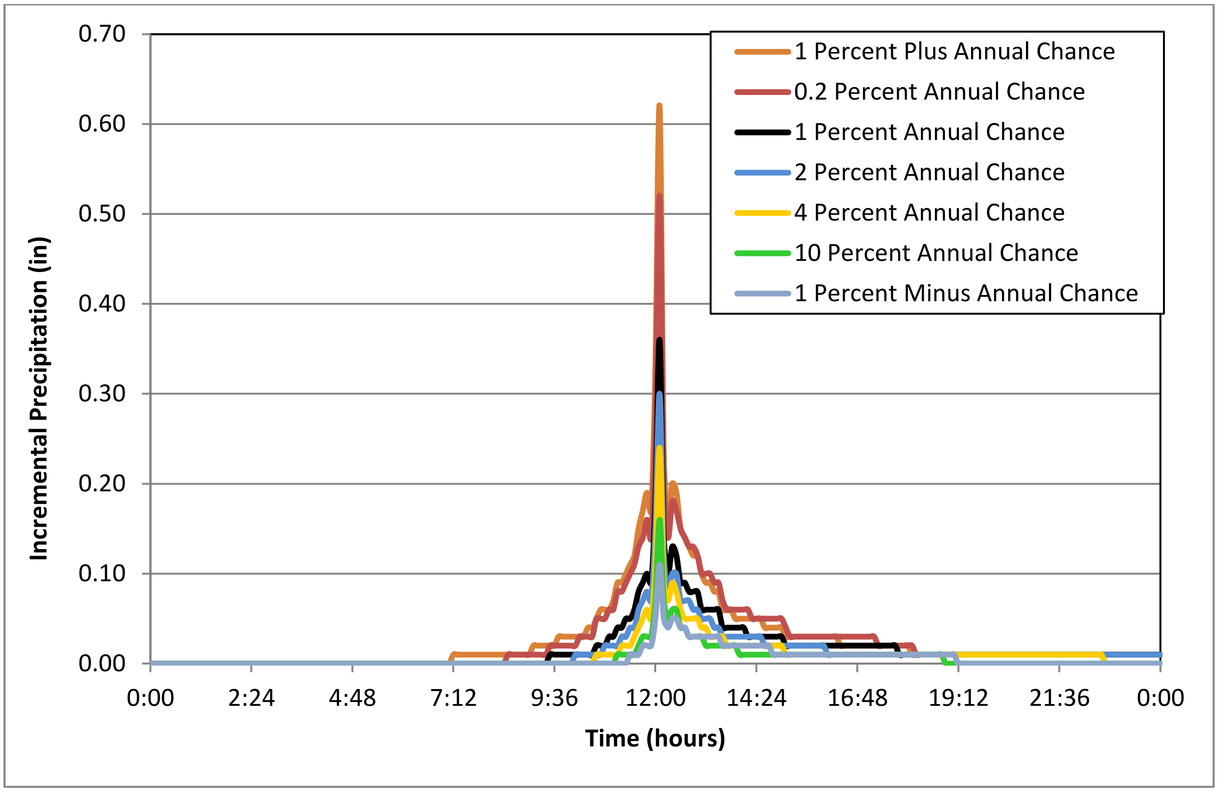


Figure 5: Excess Precipitation Hyetograph Applied to 2D Mesh – Leon 2

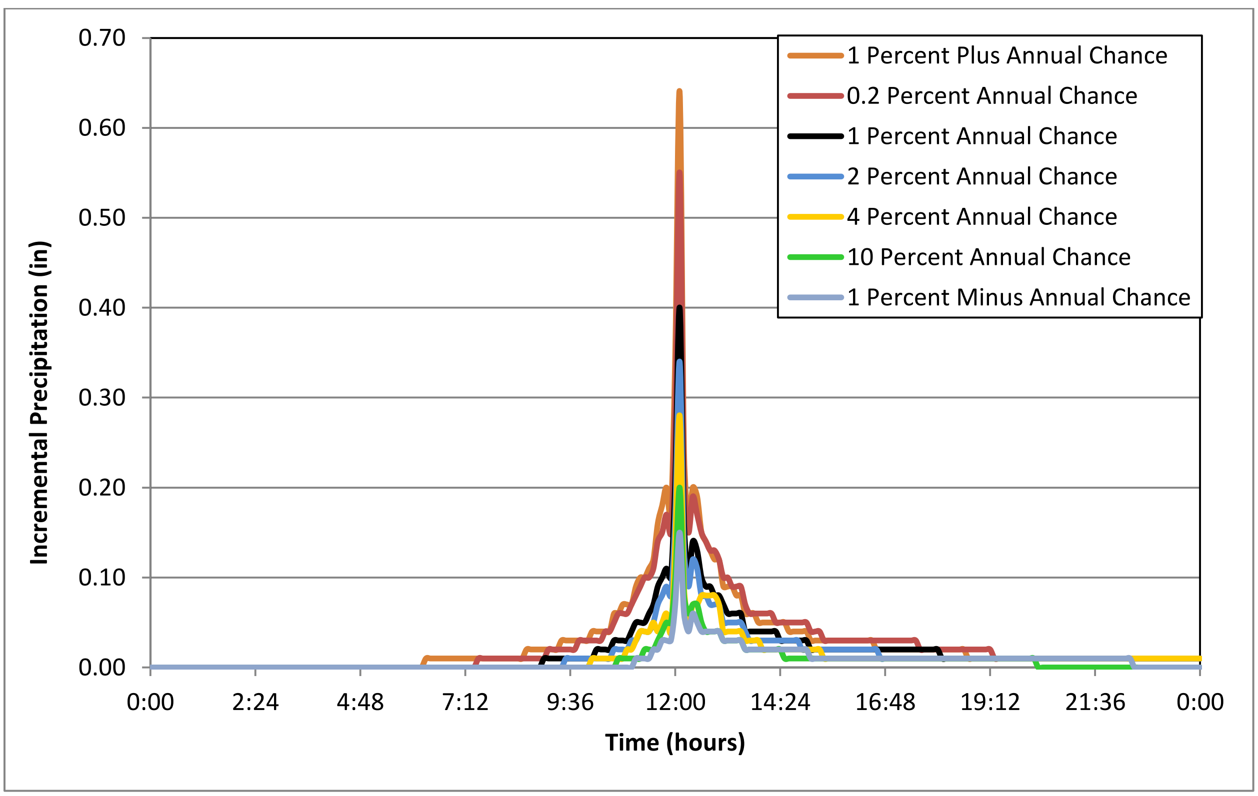


Figure 6: Excess Precipitation Hyetograph Applied to 2D Mesh – Leon 3

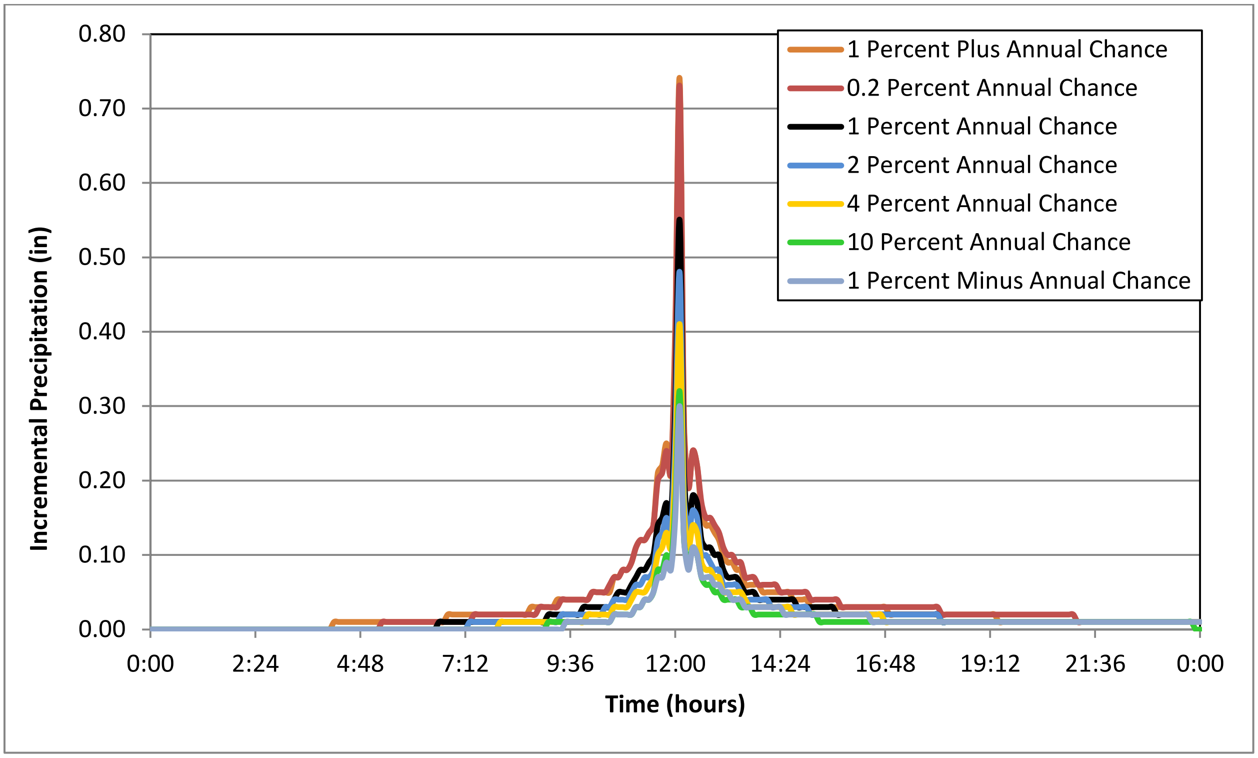


Figure 7: Excess Precipitation Hyetograph Applied to 2D Mesh – Leon 4

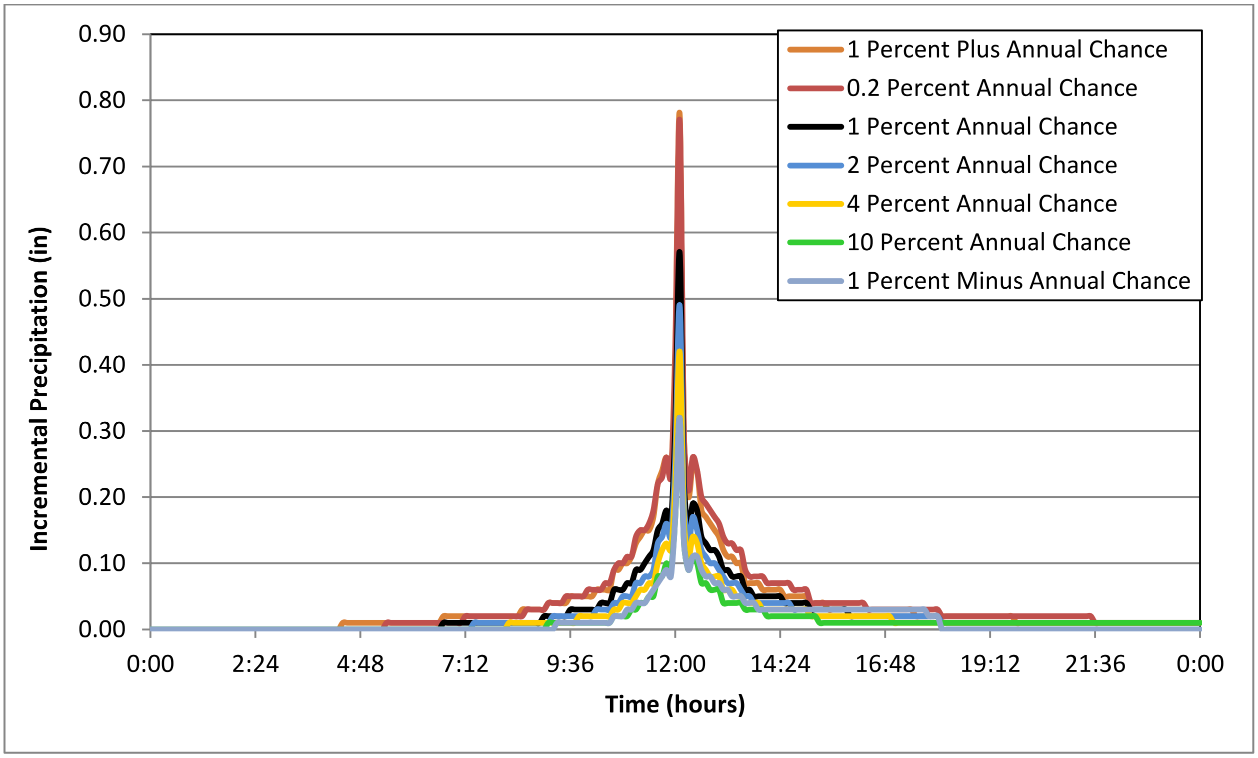


Figure 8: Excess Precipitation Hyetograph Applied to 2D Mesh – Leon 5

2.2.3.2 Stage Hydrograph Boundary Conditions

Flows from the upstream models in the Leon HUC-8 watershed were used as inflows into the models immediately downstream. The stage hydrograph was derived by utilizing the results of the HEC-RAS model for the Leon modeling area directly upstream. By using upstream model results as stage hydrographs to the downstream model, it allows the two separate HEC-RAS models to act as one continuous model of the larger Leon watershed area. The stage hydrograph was extracted from the upstream Leon model using a 2D connection. Figures 9, 10, 11, and 12 show the stage hydrographs used to transition flow between models.

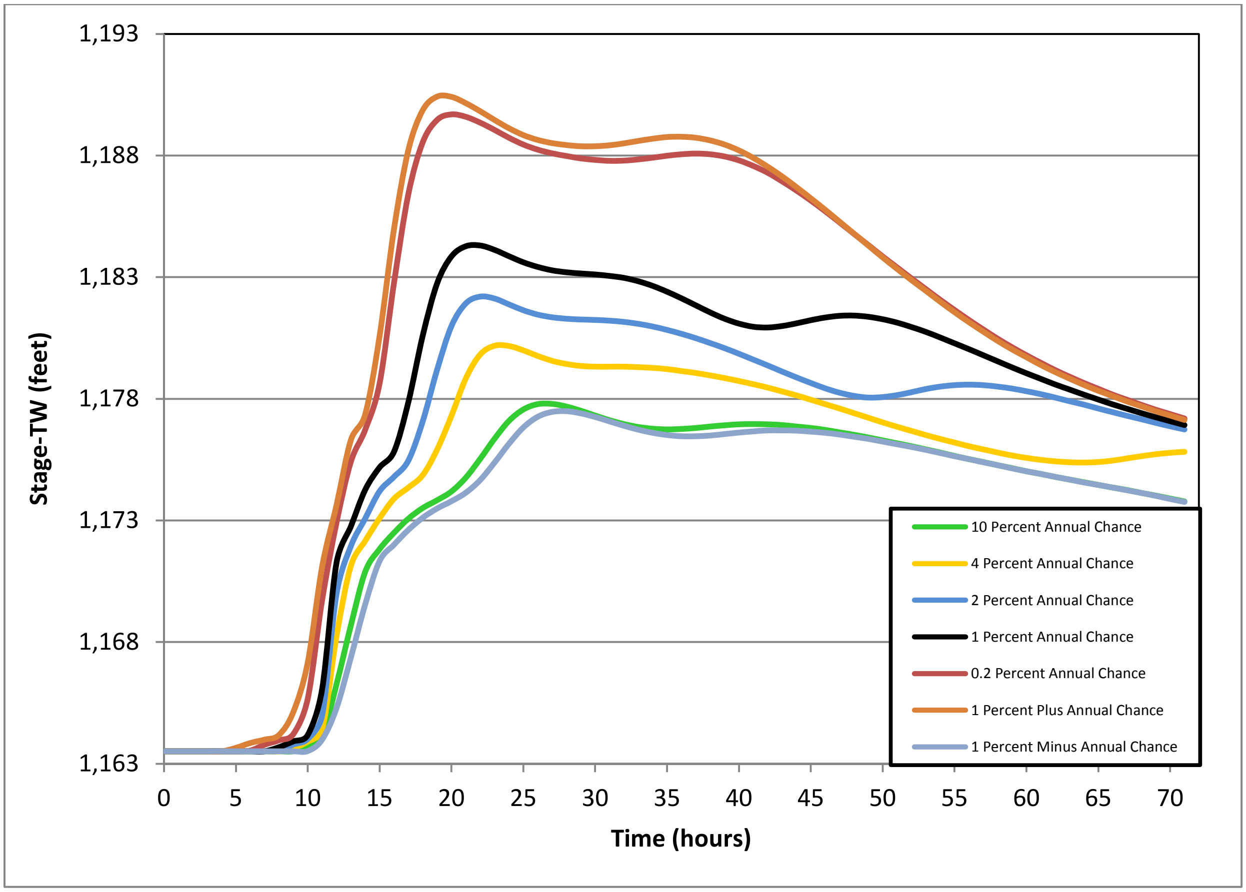


Figure 9: Stage Hydrograph from Leon 1 applied to Leon 2

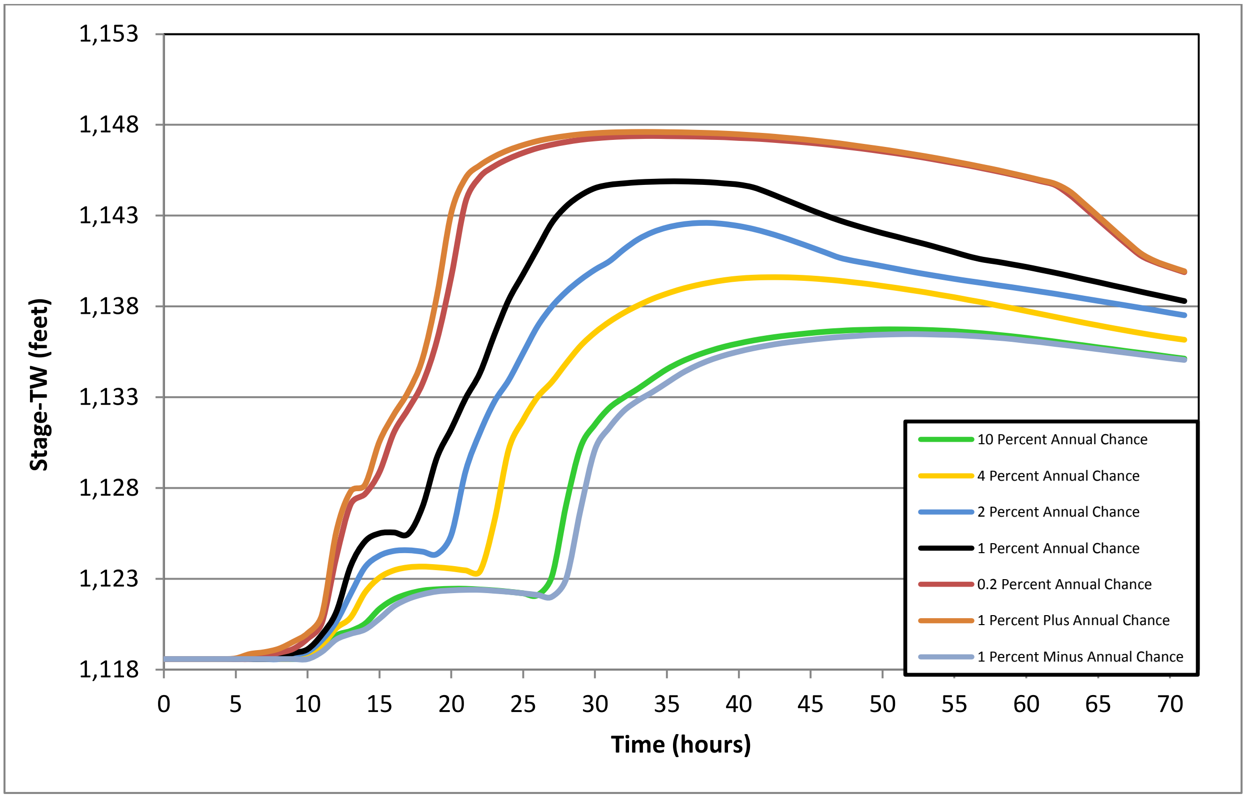


Figure 10: Stage Hydrograph from Leon 2 applied to Leon 3

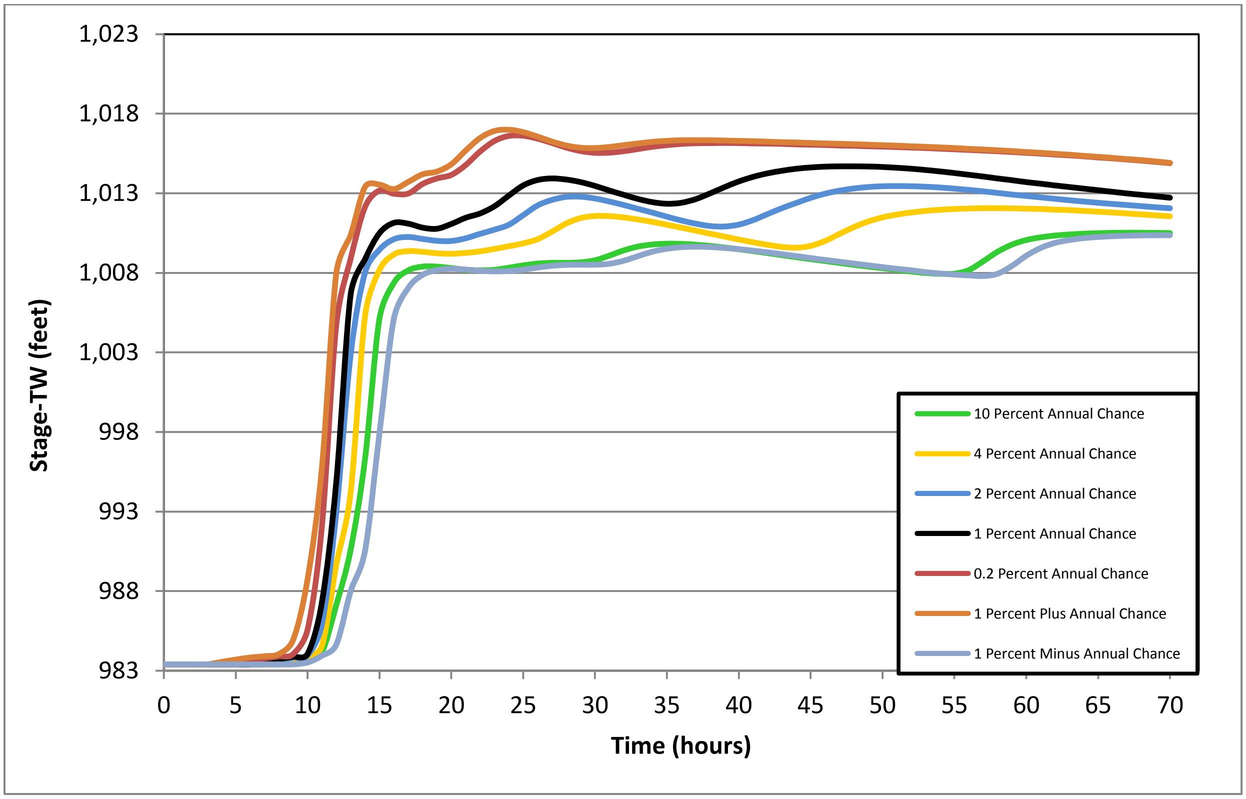


Figure 11: Stage Hydrograph from Leon 3 applied to Leon 4

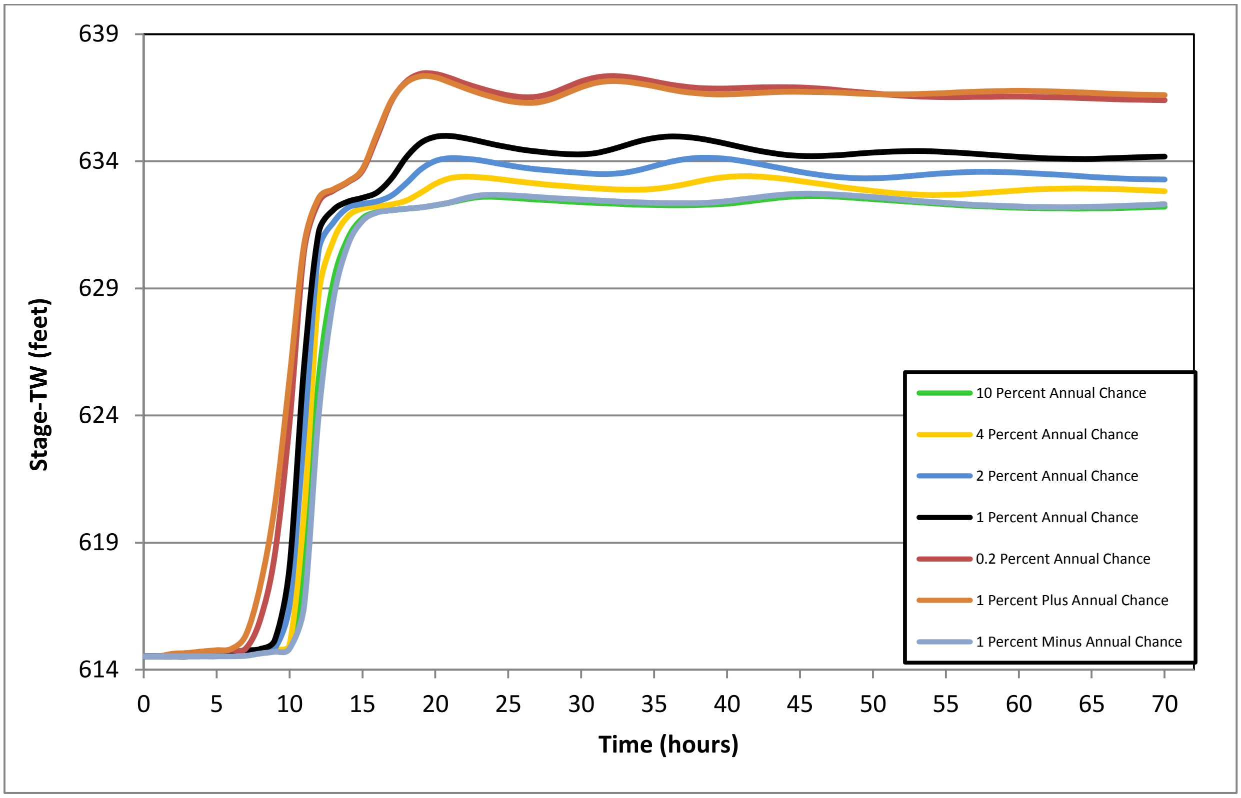


Figure 12: Stage Hydrograph from Leon 4 applied to Leon 5

In order to achieve a seamless flood hazard result at a transition location (locations where flow is exchanged between 2D model areas), the water surface elevation (WSE) and inundation tie-ins between models must be made as close as possible. A 1,000 feet buffer was applied to each model work area for the mesh boundary. This is done so that the inflow boundary condition of the downstream model and the normal depth outlet boundary condition of the upstream model are far enough away from the work area transition location that they do not impact the WSE tie-ins between models in an undesired way. To make this overlap work without double accounting for rainfall, an internal 2D connection is placed in the upstream model at the exact same location as the inflow boundary condition for the downstream model. Approximately halfway between the model overlap is the actual model area boundaries where the mapped floodplain products switch from the upstream model results to the downstream model results. This transition location is the targeted area to have the water surface elevation and inundation tie-in as closely as possible.

2.2.4 Hydraulics

This section describes the remaining hydraulic modeling considerations, including implementation of Manning's roughness, breaklines, refinement regions, and hydraulic structures within the 2D computational mesh.

2.2.4.1 Roughness Coefficients

Manning's n roughness coverage was developed for the 2D computational mesh using typical roughness values for given NLCD land classifications. Two different sets of Manning's n values were used for areas within the channel and all other areas outside of the channels of the stream network. The channel layers were created using a 100 foot buffer. This allows for the model to accurately represent deep, swift flow within the channel and shallow overland flow outside of the channel areas. The table below shows a typical landuse-roughness matrix used in defining the roughness coverage for the study area for areas both inside and outside of the channel. In the HEC-RAS model channel n values are listed as land classification – Channel, and overbank n values are listed as land classification – Base.

Table 8: NLCD 2016 Manning's n Roughness Matrix

NLCD Classification	Channel		Overbank	
	N Value	Source	N Value	Source
Open Water	0.03	Chow, 1959	0.03	Chow 1959
Developed, Open Space	0.035	Chow, 1959	0.04	NRCS KS Dam Breach, 2016
Developed, Low Intensity	0.035	Chow, 1959	0.08	NRCS KS Dam Breach, 2016
Developed, Medium Intensity	0.035	Chow, 1959	0.1	NRCS KS Dam Breach, 2016
Developed, High Intensity	0.035	Chow, 1959	0.15	NRCS KS Dam Breach, 2016
Barren Land	0.03	Chow, 1959	0.03	NRCS KS Dam Breach, 2016
Deciduous Forest	0.05	Chow, 1959	0.16	NRCS KS Dam Breach, 2016
Evergreen Forest	0.05	Chow, 1959	0.16	NRCS KS Dam Breach, 2016
Mixed Forest	0.05	Chow, 1959	0.15	NRCS KS Dam Breach, 2016
Scrub/Shrub	0.04	Chow, 1959	0.1	NRCS KS Dam Breach, 2016
Grassland/Herbaceous	0.04	Chow, 1959	0.15	HCFCD modeling Guidelines, 2018
Pasture/Hay	0.04	Chow, 1959	0.15	HCFCD modeling Guidelines, 2018
Cultivated Crops	0.04	Chow, 1959	0.1	HCFCD modeling Guidelines, 2018
Woody Wetlands	0.04	Chow, 1959	0.12	NRCS KS Dam Breach, 2016
Emergent Herbaceous Wetland	0.04	Chow, 1959	0.07	NRCS KS Dam Breach, 2016

2.2.4.2 Breaklines

Breaklines align grid cell faces and were used within the 2D mesh area to define prominent features including road embankments and hydraulic structures. Road embankment features were delineated in GIS and imported into RAS6 as breaklines to contain water where appropriate. Similarly, significant bridge/culvert crossings that were not processed out of the terrain data were modeled by v-notch breaklines adjacent to the road embankment to align grid cells around the embankment and allow water to be routed through the embankment without creating artificial backwater. An example of the v-notch breakline approach is shown in Figure 13.

County, interstate, common name, state recognized, and U.S. roads were incorporated for road breaklines from the U.S. Census Bureau TIGER/Line road layer.

There are 5 public dams within the Leon HUC-8. Lake Comanche Dam, and NE Trib Leon River WS SCS Site 19 dam were registered as being “low hazard” and were modeled with breaklines to show that they hold back water based on the terrain. Lake Leon Dam, and Proctor Lake Dam, are considered “high hazard” and were modeled with a 2D connection using an outlet rating curve to control the rate of flow released from the dams. Lake Belton Dam, another large "high hazard" dam existed in the model, but not enough available information was found in order to model this dam with an outlet rating curve. Instead, considering this was an approximate study, Lake Belton Dam was modeled using a 2D connection with a culvert. Then another 2D connection, modeled as a weir, across the main spillway to control flow release rates for the higher storm events. Data on the dams was gathered from TWDB and incorporated in the 2D connections, either by producing a rating curve, assigning the proper weir type, or determining the culvert geometry. Private dams were not modeled as showing protection. This is to lessen the burden on private dam owners to maintain their dams in order to sustain the regulatory products that could be created in the future as a result of this study. The study area does not include any FEMA accredited levees.

Breaklines were also used along all the stream centerlines of streams draining greater than one square mile of drainage area, and 0.5 square miles of drainage area within densely populated areas. Each streamline was topo-derived and the stream centerline was enforced with 100 feet cell spacing in order to align cells along the stream line and capture more detail along the one square mile stream network. Streamline alignment was also hand checked with the terrain by the modeler to ensure accuracy. Stream names were referenced from other sources such as NFHL and NHD datasets. In the HEC-RAS model, streams that passed through densely populated regions were enforced as breaklines using 50ft cell spacing.

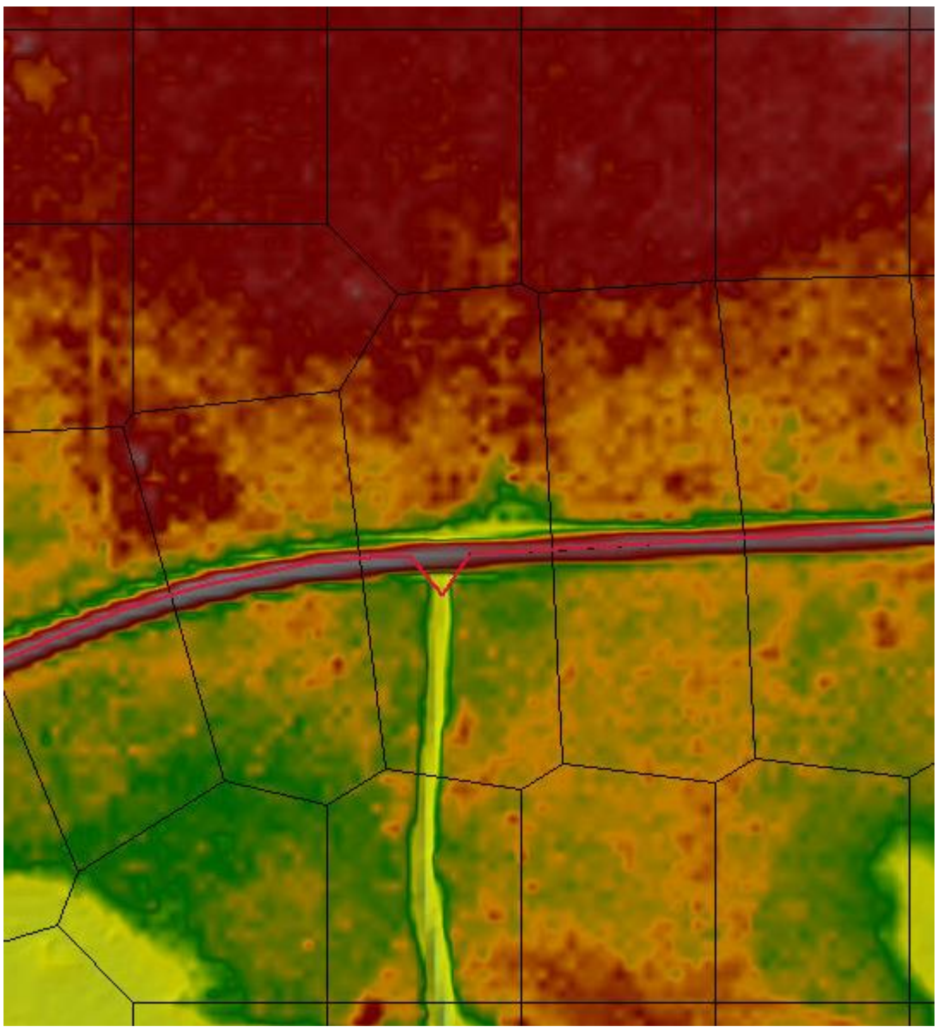


Figure 13: V-notch Breakline Approach at Bridge Crossing

2.2.4.3 Refinement Regions

Refinement regions were created for each community within the model. The political boundary was used to determine the shape of the refinement region. The regions were assigned a cell spacing of 50 feet by 50 feet. This finer cell spacing allows for more hydraulic calculations and mapping detail near areas where there are likely to be more structures. Table 9 shows the communities contained within Leon watershed that were modeled with refinement regions as well as the square mileage of the refinement region.

Table 9: Communities with 2D Mesh Refinement

Community Name	Area (mi^2)
Ranger City	0.59
Eastland City	3.55
Cisco City	3.36
Carbon Town	1.02
Gorman City	1.64
De Leon City	2.24
Rising Star Town	1.73
Dublin City	2.67
Comanche City	4.56
Gustine Town	0.92
Hamilton City	3.07
Gatesville City	8.91
South Mountain Town	1.61
Oglesby City	0.50
McGregor City	3.22
Mood City	0.48
Temple City	47.88
Nolanville City	3.48
Morgan's Point Resort City	2.47
Little River – Acedemey City	0.01
Kileen City	29.87
Harker Heights City	7.01
Belton City	11.94
Fort Hood CDP	8.14

2.2.5 Quality Control

The 2D BLE results were independently assured to meet quality standards of the project. Standard checklists complying with FEMA standards were used to review hydrology and hydraulics results, the resulting flood hazard area delineations and CNMS dataset. Quality assurance during the data development process includes, but is not limited to the following QC checks:

- Hydrological QC – included checks for curve number calculation, input precipitation, flood events, areal reduction factor and human error.
- Hydraulic QC – included checks for RAS geometry, breakline placement, v-notch placement to ensure water conveyance at crossings, refinement regions, roughness coefficients, boundary/initial conditions, timestep and mapping outputs
- Mapping – included checks for spot checking flood inundation accuracies based on floodplain mapping criteria described in section 4.1.2, ensuring flood extents from higher frequency events did not exceed lower

frequency extents due to GIS smoothing algorithms, and topological overlap and cluster tolerance errors were resolved

- CNMS - Included review of the A1-A5 analysis for all effective approximate reaches in the HUC, geometry updates to newly studied reaches added as Zone X, and removal of scoped areas which lie outside of the final BLE footprint.

3. Results

The 2D BLE results for the study produced flood hazard area that compared reasonably well with effective SFHA in most cases, and provides additional estimated flood hazard risk area where not previously mapped. The HEC-RAS peak (max) results were exported for mapping and all HEC-RAS models were run with a hydrograph output interval of 1 minute, mapping output interval of 1 hour and the detailed output interval of 1 hour.The Leon watershed is sufficient to facilitate FEMA regulatory processes while also providing the best available information for planning purposes. To further check the models accuracy additional profile lines were added and compared to Base Flood WSEs that were avaialable in the Eastland County Flood Insurance Study (FIS) dated August 5, 1997, the Hamilton County FIS dated September 4, 1991, the Coryell County FIS dated February 17, 2010, and the Bell County FIS dated September 26, 2008. The comparison is shown below in Table 10. The 2D BLE results should be verified through community work map meetings as part of the regulatory workflow.

Table 10: Effective and Model Base Flood Elevation(BFE) Comparison after calibration

Location Description	Effective BFE (feet)	Model BFE (feet)	Difference (feet)
North Fork Leon River at Missouri Pacific Railroad	1435.9	1432.6	3.3
North Fork Leon River at State Highway 112	1436.4	1434.9	1.5
Pecan Creek at East Gentry Street	1140	1141.3	1.3
Stream CG-2 Downstream of Strawmill road	741.9	749.5	7.6
Stream CG-4 at Confluence With Stillhouse Branch	783.7	787.2	3.5
Bird Creek and Loop 363	577.2	583.5	6.3
Cedar Creek and State Highway 36	625.7	624.8	0.9
Cedar Creek and State Highway 317	625.7	624.8	0.9

3.1 Calibration

Known USGS gages within the model area with more than 10-years of flow record were used as the first priority for calibration of the 1-percent annual chance event. Discharges at gages were compared to discharges in the 2D models at the exact same locations. If a published rating curve was available, WSE from the model was compared to the calculated 1-percent WSE from the gage analysis.

Effective data was the second priority for calibration. Modeled flows were compared to flows from the summary of discharges tables from the Eastland County FIS (Effective August 1997), the Hamilton County FIS (Effective September 1991), the Coryell County FIS (Effective February 2010), and the Bell County FIS (Effective September 2008). Known water surface elevations were used for validation, not calibration. Upper and lower limits for the effective flows were calculated by hand and were not taken from the FIS report. They were calculated by:

Upper Limit= 0.501 * 1%Q

Lower Limit=1.995 * 1%Q

Since no usable USGS streamgages or effective data was available for Leon 3, regression discharge estimates were utilized in different locations throughout the modeling area to validate results. The regression analysis was performed as per regional regression equations using the drainage area, dimensionless main channel slope (S), OmegaEM parameter and mean annual precipitation (P) (USGS- SIR 2009-5087). Regression comparisons were made at seven locations with varying contributing drainage area to ensure a reasonable amount of excess precipitation was being applied to the 2D mesh. Flows were taken from the model and compared with the peak flows determined by the regression equations. The results for this are shown below in Table 11.

Four USGS gages that fall within the boundary of Leon watershed were utilized for calibration purposes. Additional effective data was used for secondary calibration, but priority was given to the USGS gage analysis results. Adjustments to hydraulic features within the model were made until the flows in the model matched closely with the peak flows determined from gage and effective data. Leon modeling areas 1, 2 ,3 and 5 required no adjustments for the CN, but the Leon 4 modeling area needed CN adjustments to calibrate the model. No adjustments were needed for the n-values in any of the modeling areas for the Leon HUC-8 study. Final results following model calibration at the calibration locations are presented in Table 11. The discharge from the HEC-RAS models were calibrated with four USGS stream gages, and effective data pulled from available county FIS reports. However, due to the limitations and scope of this study, extensive efforts were not feasibile. Therefore, model flows were accepted although they are a slightly lower than the specified range at effective data location Stream CG-2 downstream of Strawmill Road.

Table 11: Calibration Results

Calibration Location	Source	Method Used in Original Study	Reference			HEC-RAS 6.1 (2D) (cfs)
			Lower Limit (cfs)	1-percent (cfs)	Upper Limit (cfs)	
Gage 08099100	Leon RV nr De Leon, TX	USGS	22,420	30,030	44,660	26,270
Gage 08099300	Sabana Rv nr De Leon, TX	USGS	24,660	33,330	49,540	32,960
Gage 08100000	Leon Rv nr Hamilton, TX	USGS	29,480	38,320	53,210	43,421
Gage 08100500	Leon Rv at Gatesville, TX	USGS	49,840	63,850	89,200	51,819
North Fork Leon River at Missouri Pacific Railroad	Eastland County FIS	USGS Report 77-110 methodologies	6,190	12,355	24,648	9,351
North Fork Leon River at State Highway 112	Eastland County FIS	USGS Report 77-110 methodologies	6,200	12,375	24,688	7,577
Pecan Creek at East Gentry Street	Hamilton County FIS	USGS Report 77-110 methodologies	2,877	5,742	11,455	7,261

Table 11, continued: Calibration Results

Calibration Location	Source	Method Used in Original Study	Reference			HEC-RAS 6.1 (2D) (cfs)
			Lower Limit (cfs)	1-percent (cfs)	Upper Limit (cfs)	
Stream CG-2 Downstream of Strawmill Road	Coryell County FIS	USGS Report 77-110 methodologies	5,075	10,130	20,209	4,715
Stream CG-4 at Confluence with Stillhouse Branch	Coryell County FIS	USGS Report 77-110 methodologies	3,853	7,690	15,342	5,307
Bird Creek and Loop 363	Bell County FIS	USGS Report 77-110 methodologies	1.911	3,815	7,611	4,887
Cedar Creek and State Highway 36	Bell County FIS	USGS Report 77-110 methodologies	6,814	13,600	27,132	18,898
Cedar Creek and State Highway 317	Bell County FIS	USGS Report 77-110 methodologies	5,980	11,936	23,812	16,697
Mercer Cr	Regression Analysis	USGS-SIR 2009-5087	4,836	9,649	19,253	10,452
Walnut Cr	Regression Analysis	USGS-SIR 2009-5087	4,043	8,066	16,094	11,426
Warren Cr	Regression Analysis	USGS-SIR 2009-5087	7,544	15,051	30,031	29,266
Mountain Cr	Regression Analysis	USGS-SIR 2009-5087	6,770	13,508	26,951	25,916
Resley Cr	Regression Analysis	USGS-SIR 2009-5087	5,944	11,860	23,665	16,188
Indian Cr	Regression Analysis	USGS-SIR 2009-5087	5,799	11,570	23,086	18,898
Resley Cr	Regression Analysis	USGS-SIR 2009-5087	8,747	17,453	34,824	23,447

Figure 14 shows the final results of the calibration locations compared to modeled flows throughout the Leon watershed along with error bars created using the difference between 1-percent and 1-percent plus discharges and 1-percent and 1-percent minus discharge as minimum and maximum values. Nineteen comparisons were made with varying drainage areas to ensure the calibration of excess precipitation for different points over the entire watershed area. This large collection of calibration points provides confidence in results throughout the entire watershed.

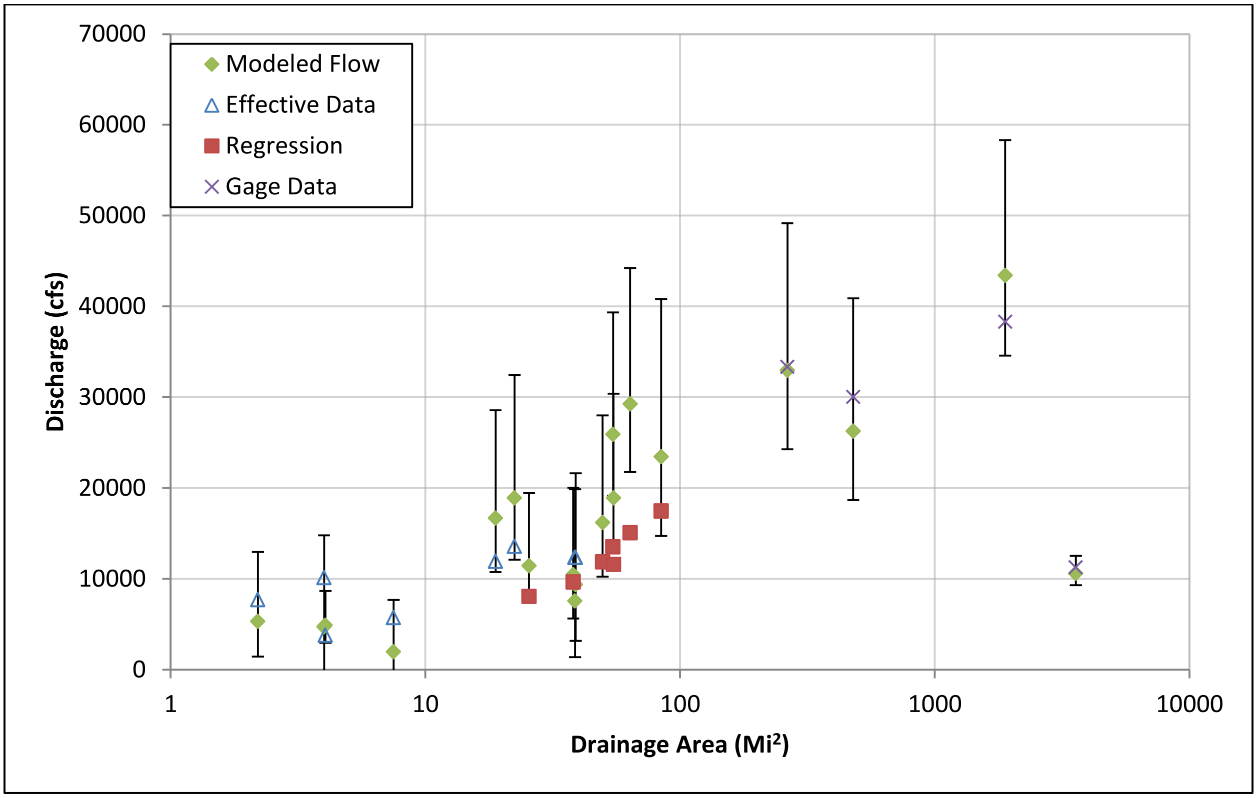


Figure 14: Calibration Comparison

The WSEL from the HEC-RAS models were validated using four USGS stream gages, gages 08099100, 08099300, 08100000, and 08100500. Based on the published rating for the USGS gage, a 1-percent gage WSEL was calculated, along with upper and lower WSELs bounds, using the 1-percent flow estimated by the gage analysis. These were compared to the WSELs at the same location in the Leon 2D BLE models, as shown in Table 12. While the WSELs generated from the 2D BLE modeling were all slightly above the validation ranges for the gages, additional calibration was not pursued, primarily because validation of flows was given a higher priority. At all of the gage locations, flows calculated by the 2D BLE model and the gage analysis estimates compared favorably. Three out of the four flow comparisons indicated the model was either very near the estimated 1-percent flow estimate, or on the low side of the range; indicating that a coarse CN adjustment to address WSELs at these locations would bring the model flows lower. For future 2D BLE model upgrades, or more detailed analysis of the watershed, spatial CN or n-value adjustments could be considered for specific areas that require it in order to allow both flow and WSEL gage validation points to compare more closely.

Table 12: 1-Percent Gage WSEL and RAS WSEL Comparison

USGS Gage ID	Lower Bound (feet)	Gage WSEL 1-percent (feet)	Upper Bound (feet)	HEC-RAS 6.1 WSEL (feet)
08099100	1,228.7	1229.6	1230.9	1232.2
08099300	1232.8	1233.2	1233.7	1237.8
08100000	989.2	990.0	991.0	994.3
08100500	757.7	758.6	760.0	760.4

3.2 Challenges

A considerable challenge for the Leon watershed was the size of the HUC8 basin. In order to model the watershed without creating runtime or cell number issues, it was decided that the watershed would be split into five working models. The outflow from the upstream model containing the Leon River was then used as an inflow boundary condition to the downstream model. The Leon watershed contains the Lake Leon Dam, Proctor Dam, Lake Comanche Dam, NE Trib Leon River WS SCS Site 19 dam and the Belton Dam. Lake Comanche Dam and Site 19 Dam were both modeled using breaklines because they are registered as low hazard. Lake Leon Dam and Proctor Dam were modeled either through an outlet rating curve created based off the outlet works conditions (Lake Leon), or using the geometry of the gates present in the dam (Lake Proctor). Lake Belton Dam was modeled with a culvert with geometry taken from a TWDB report, and a separate 2D connection for the spillway, which was modeled as a weir. These methods for modeling the dams provided approximate outflow values but could be made more accurate through more detailed modeling.

The Leon 5 area included many challenges due to the size of the model and size of Lake Belton Dam. To reduce the amount of cells in the model population centers that were defined as refinement regions were compared with aerial imagery. In areas where the refinement regions covered undeveloped space or open water, the boundary was adjusted so that the cell sizing in these areas could be increased from 50X50 feet to 200X200 feet. This was done to decrease the total cell count in the model and reduce the model run time.

Due to various large dams in the models, a few velocity hotspots were observed. Due to the nature of the study, the HEC-RAS models were run using Diffusion wave equations that do not include the local acceleration (changes in velocity with respect to time) and convective accelration (changes in velocity with respect to distance) terms.

Within the watershed, there are several populated areas and agricultural fields that appear to be trapping water which prevents runoff from reaching the channel in the model. Various v-notches were applied to represent cross culverts and improve conveyance. Further detail and study of the flow patterns and likely runoff conveyance would be recommended as part of a future study if more detailed flood risk information was needed in these areas. In addition several breaklines and refinement regions representing population centers increased the total number of cells and thereby increased the model runtime. This was specifically an issue in the Leon 5 model area where a large portion of the model contained dense population centers that required a mesh with finer cell spacing to model more accurately.

The WSEL at the USGS stream gage used for calibration in this model was slightly higher than the calculated range. Additional model detail, such as adjusting the n-valus in the model in the areas US and DS of the gage with override regions, could improve the model results relative to the gage, but due to limitations for this approximate BLE study this was not done for this project. The CN in the Leon 4 modeling area was increased for calibration. No other modeling area within the Leon HUC-8 study was adjusted from their original CN estimates.. The gage database that was referenced for this study incorrectly identified the location of gage 08100500. Aerial imagery shows this gage to be located at a bridge upstream of the location marked by the database. The gage location was updated for this study. Water data for each gage was referenced from an online USGS resource and it was found that each gage was “affected by regulation or diversion”. This observation is important to note for the resulting accuracy of flow data at each studied gage within the model, and additional detailed analysis of the gage data would be recommended for use in a more detailed hydraulic and/or floodplain mapping study.

3.3 Recommendations

This study provides significant information useful for flood identification and communication among those affected. The study is highly scalable, and stakeholder input and further analysis would enhance the product and inform implementation of regulatory flood hazard areas. In addition, the validity of the 2D BLE results should be verified through community work map meetings before being applied as a regulatory product.

Point source Atlas 14 rainfall was used in the analysis, and due to the large size of the modeled area (the entire HUC-8 watershed), the point rainfall used has a tendency to vary more widely from the actual point rainfall data at any specific location within the watershed. For detailed modeling and further improvements, smaller-sized modeled areas are recommended, which will result in smaller rainfall and CN variability. In addition, future versions of HEC-RAS are anticipated to include the capability to utilize spatially varying rainfall, which may result in additional improvements in the reasonability of some of these assumptions. The hydraulic model can further be improved by using a smaller cell size than 200 foot, adding structural and survey data for each crossing, and modeling existing "high hazard" dams with more detail than what is possible in an approximate study.

Additional detailed study in the future could consider use of full momentum equation to better simulate rapidly changing flood wave.

4. Floodplain Mapping and Effective Zone A Validation

The following sections provide a synopsis of how raw modeled depths were translated into SFHA. In addition to developing a new SFHA, the BLE model data was leveraged to validate the effective Zone A studies within the project footprint.

4.1 Special Flood Hazard Area

4.1.1 Model Outputs

The HEC acknowledged RAS Mapper may not render water surface elevation values and/or delineate inundation extent appropriately for direct use in FEMA regulatory mapping products. With guidance from TWDB, AECOM created a workflow to export model water surface elevation values for each 2D mesh cell to develop regulatory-ready water surface elevation grids and subsequent flood hazard area mapping features.

4.1.2 Methodology

The sloping render mode plots water surface elevation (WSE) by interpolating the WSE between the 2D cell faces, producing a more continuous flood inundation extent. Depth rasters from the sloping render mode were exported for the 10-percent, 1-percent, and 0.2-percent flood events with a tolerance of 0.001 feet. To reduce the extent of disconnected flood areas, raster grid processing is used to filter and remove disconnected, small, or shallow areas of flooding by processing through the 'Mapping Threshold Matrix' shown in Table 13.

Table 13: Mapping Threshold Matrix

Area (acres)	Average Depth (feet)
< 0.33	-
0.33 – 0.5	< 0.5
0.5 – 1.0	< 0.33
1.0 – 2.0	<0.1

Polygon outputs from the 'Mapping Threshold Matrix' also fill in minor areas of high ground (islands) that are less than 0.33 acre. The outputs are then modified through a Simplication and Smoothing process to reduce unnecessary/erroneous vertices, remove rough edges and reduce the size and complexity of the raw floodplain polygons for the 1-percent, and 0.2-percent flood events. For the Leon watershed, the polygon outputs were simplified by retaining critical points at a 5 foot tolerance. The simplified polygon outputs were then smoothed utilizing the PAEK algorithm and the tolerance was set to 25 feet. The 10-percent flood event polygons are not modified through the simplification and smoothing process and are delivered in the rasterized polygon shape.

Due to topographic differences within a lake footprint, these areas sometimes appear partially mapped in the flood extents from the model results. Lakes and reservoirs larger than 40 acres are reviewed to ensure full inundation on the 1-percent, and 0.2-percent polygon extents. If necessary, lake boundaries were copied into the flood event polygons to make sure they are fully mapped.

Once the final polygon flood extents are complete, it is necessary to merge the 10-percent boundaries into the 1-percent and the 1-percent extents into the 0.2-percent extents. This step ensures that the extents of the 10-percent floodplain is smaller than the 1-percent floodplain, and the 1-percent is smaller than the extents of the 0.2-percent floodplain.

4.1.3 BLE Flood Hazard Layer

BLE database format FLD_HAZ_AR feature classes were developed and attributed with Zone A and Shaded Zone X features. The BLE FLD_HAZ_AR feature class was tested for topological errors described in the FIRM Database Technical Reference and all errors were fixed for data integrity and schema agreement. The 10-percent boundaries have been included in the BLE TENPCT_FP feature class.

4.1.4 Additional 1-Percent Features

The BLE results for this study produced a SFHA that compares favorably with the effective SFHA. These boundaries provide an estimated SFHA in areas that have not been previously studied and therefore do not currently have an SFHA mapped. These results provide context for flood risk communication as part of the Discovery process, and should be verified through community work map meetings before being applied to a regulatory product.

A map showing the BLE results is included as Appendix A BLE Map.

BLE 1-percent annual chance inundation not mapped as BLE SFHA is retained in an additional 1-percent feature class that can be used at Discovery to communicate other areas of flood hazard.

4.2 Validation of Effective Zone A SFHA

The inventory of Zone A studies (1050.1 miles) in the Leon Watershed were classified in CNMS with validation status of “UNVERIFIED” (450.3 miles) or “VALID” (599.8 miles), and with status type of “BEING STUDIED.” The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A4 were evaluated for the CNMS inventory of Zone A studies.

4.2.1 Intial 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 within Leon Watershed, LIDAR sources were not used for the effective study. New LiDAR sources are now available in this area and are considered significant improvements from the effective zone A topographic sources. Therefore, all reaches in this study area fail this check.

4.2.2 Initial Assessment A2 – Check for Significant Hydrology Changes

This check involves first determining if regression equations were used for the effective study. Next, it must be determined whether new regression equations have become available from the USGS since the date of the effective Zone A study. If newer regression equations exist for the area of interest, then an engineer must determine whether these regression equations would significantly affect the 1-percent annual chance flow.

The zone A streams within McLennan County and a single LOMR reach within the study area fail A2. This is because their effective studies used older regression equations and new equations that would impact the BFE are available. All other streams within the study area pass this check. Erath County reaches pass because the newest available (SIR 2009-5087) equations were used for the effective study and all other reaches pass because regression is not known to have been used for those effective studies.

4.2.3 Initial Assessment A3 – Check for Significant Development

This check involves using the National Urban Change Indicator (NUCI) dataset to assess increased urbanization in the watershed of the Zone A study. If the percentage of urban area within the HUC-12 watershed containing the effective Zone A study is 15% or more, and has increased by 50% or more since the effective analysis, the study would fail this check. Although the NUCI data provide year-to-year changes in urbanization, the NLCD also is needed to establish a baseline of urban land cover for this analysis. The check for significant development in this watershed was completed by evaluating percentage of urban change at the HUC-12 level. About half of the zone A studies in Bell County as well as two LOMR reaches in Coryell County are urbanized watersheds that have experienced a significant increase in urban area since the effective study. Therefore, these reaches fail this check. All other effective studies in the Leon HUC-8 are in rural watersheds or urban watersheds that have not experienced significant urbanization since the effective study and pass this check. All of the initial assessment results are shown in Table 14.

Table 14: : Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Fail	Effective Study did not utilize LiDAR source and LiDAR is now available
A2 – Hydrology	Pass/Fail	Regression equations not used in effective study or newest available equations used in effective study/New equations have been published since those used in effective study
A3 – Development	Pass/Fail	Watershed does not meet urban threshold or Watershed has not experienced a significant increase in urbanization/Urban watershed has experienced significant increase in urban area

4.2.4 Validation Check A4 – Check of Studies Backed by Technical Data

Zone A studies that pass all initial assessment checks described above may be categorized as "Valid" in the CNMS Inventory only if the effective Zone A study is supported by modeling or sound engineering judgment and all regulatory products are in agreement. If the effective Zone A study passes all initial assessment checks, but is not supported by modeling, or if the original engineering method used is unsupported or undocumented, a comparison of the BLE results and effective Zone A's is performed. Streams in Erath, Brown, and McLennan along with 3 LOMR reaches are model-backed studies and, therefore, pass this check. All other streams in Leon HUC-8 are not known to be model-backed and fail this check.

4.2.5 Validation Check A5 – Comparison of BLE and Effective Zone A

The BLE /effective Zone A comparison method leverages the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach uses the 1-percent plus and 1-percent minus flood profiles and horizontal and vertical tolerances described in FEMA's Automated Engineering guidance document dated May 2016. For the comparison of BLE and effective Zone A in the Texas study area, the following vertical and horizontal tolerances were used to conduct the modified FBS procedure. One point was placed every 200 feet along the floodplain boundaries for comparison.

- Vertical Tolerance: +/- 5 - 10 feet (one-half contour interval of effective topographic source).
- Horizontal Tolerance: +/- 75 feet (standard horizontal tolerance for BLE comparison testing).

Comparison results for thse streams were grouped at the HUC-12 level and are summarized in Table to better understand the general health of the HUC-12 watershed, but the validation check was performed at the stream level. Streams where the percentage of passing FBS sample points is greater than or equal to 85% are marked as "Pass", otherwise marked as "Fail".

Table 15: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Leon Watershed	All Streams	108,909	17,605	91,304	84%	Fail	
Cedar Creek	120702011004	7,085	1,299	5,786	82%	Fail	15.4
City of De Leon-Leon River	120702010208	158	11	147	93%	Pass	3.5
Cottonwood Creek-Leon River	120702010905	539	50	489	91%	Pass	3.7
Currycomb Branch-Sabana River	120702010406	2,393	383	2,010	84%	Fail	8.2
Dargan Creek-Indian Creek	120702010502	133	6	127	95%	Pass	1.0
Dead Horse Creek	120702010102	716	106	610	85%	Pass	7.4
Dodd Branch	120702010901	200	19	181	91%	Pass	5.5
Eagle Creek-Leon River	120702010802	49	6	43	88%	Pass	6.1
Elm Creek	120702010404	868	137	731	84%	Fail	7.9
Flat Creek-Leon River	120702010204	1,231	83	1,148	93%	Pass	5.4
Fryers Creek-Leon River	120702011106	1,687	646	1,041	62%	Fail	34.5
Henning Creek-Hackberry Creek	120702010205	4,303	560	3,743	87%	Pass	10.4
Henson Creek	120702010904	119	6	113	95%	Pass	1.3
Hunting Shirt Creek-Sabana River	120702010405	1,202	146	1,056	88%	Pass	6.1
Jameson Peaks-Hog Creek	120702010202	767	158	609	79%	Fail	16.5
Jimmys Creek	120702010304	88	15	73	83%	Fail	8.5
King Mountain-Leon River	120702010907	98	8	90	92%	Pass	2.0
Lake Leon-Leon River	120702010108	2,090	572	1,518	73%	Fail	21.9
Long Branch-Sabana River	120702010403	955	83	872	91%	Pass	4.3
Lower Armstrong Creek	120702010207	6,256	996	5,260	84%	Fail	12.7
Lower Colony Creek	120702010107	1,228	218	1,010	82%	Fail	13.2
Lower Coryell Creek	120702010906	217	19	198	91%	Pass	3.8
Lower Plum Creek	120702010805	60	8	52	87%	Pass	6.7
Lower Resley Creek	120702010602	295	19	276	94%	Pass	5.2
Lower South Fork Leon River	120702010104	1,667	284	1,383	83%	Fail	11.4
Lower South Nolan Creek	120702011102	17,030	3,137	13,893	82%	Fail	12.5
Metheglin Creek-Belton Lake	120702011005	1,804	206	1,598	89%	Pass	7.0
Mexican Hat Hill-Sabana River	120702010402	744	95	649	87%	Pass	6.4
Middle South Fork Leon River	120702010103	1,507	287	1,220	81%	Fail	9.5
Mustang Creek	120702010803	15	1	14	93%	Pass	3.3
Nash Creek-Leon River	120702010201	1,846	291	1,555	84%	Fail	12.6
Nolan Creek	120702011104	2,345	533	1,812	77%	Fail	15.7
North Fork Leon River	120702010105	1,977	337	1,640	83%	Fail	13.4
North Nolan Creek	120702011103	1,895	249	1,646	87%	Pass	2.1

Table 15, continued: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Owl Creek	120702011003	494	34	460	93%	Pass	2.2
Pecan Creek	120702010703	238	19	219	92%	Pass	5.4
Pepper Creek-Leon River	120702011105	2,474	306	2,168	88%	Pass	11.0
Pew Branch-Leon River	120702010908	170	10	160	94%	Pass	2.9
Salt Branch-Leon River	120702010203	2,293	460	1,833	80%	Fail	16.0
South Copperas Creek	120702010302	9	3	6	67%	Fail	16.7
Sowells Creek	120702010408	508	46	462	91%	Pass	7.2
Stampede Creek	120702011001	672	56	616	92%	Pass	4.9
Station Creek-Belton Lake	120702011002	177	35	142	80%	Fail	15.8
Stillhouse Branch-Leon River	120702010902	323	13	310	96%	Pass	2.1
Town of Ater-Leon River	120702010806	43	9	34	79%	Fail	10.5
Town of Proctor-Walnut Creek	120702010501	1,540	99	1,441	94%	Pass	5.1
Upper Armstrong Creek	120702010206	7,028	879	6,149	87%	Pass	10.0
Upper Colony Creek	120702010106	1,163	191	972	84%	Fail	13.1
Upper Coryell Creek	120702010903	135	15	120	89%	Pass	4.5
Upper Plum Creek	120702010804	32	6	26	81%	Fail	9.4
Upper Resley Creek	120702010601	10,264	1,020	9,244	90%	Pass	7.9
Upper South Fork Leon River	120702010101	728	93	635	87%	Pass	6.4
Upper South Nolan Creek	120702011101	16,215	3,296	12,919	80%	Fail	11.4
Yellow Branch	120702010401	154	15	139	90%	Pass	4.9

4.2.6 Validation Results

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Leon watershed has been updated as summarized in Table 16 and illustrated in Figure 15.

Table 16: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	450.3
UNVERIFIED	BEING STUDIED	599.8

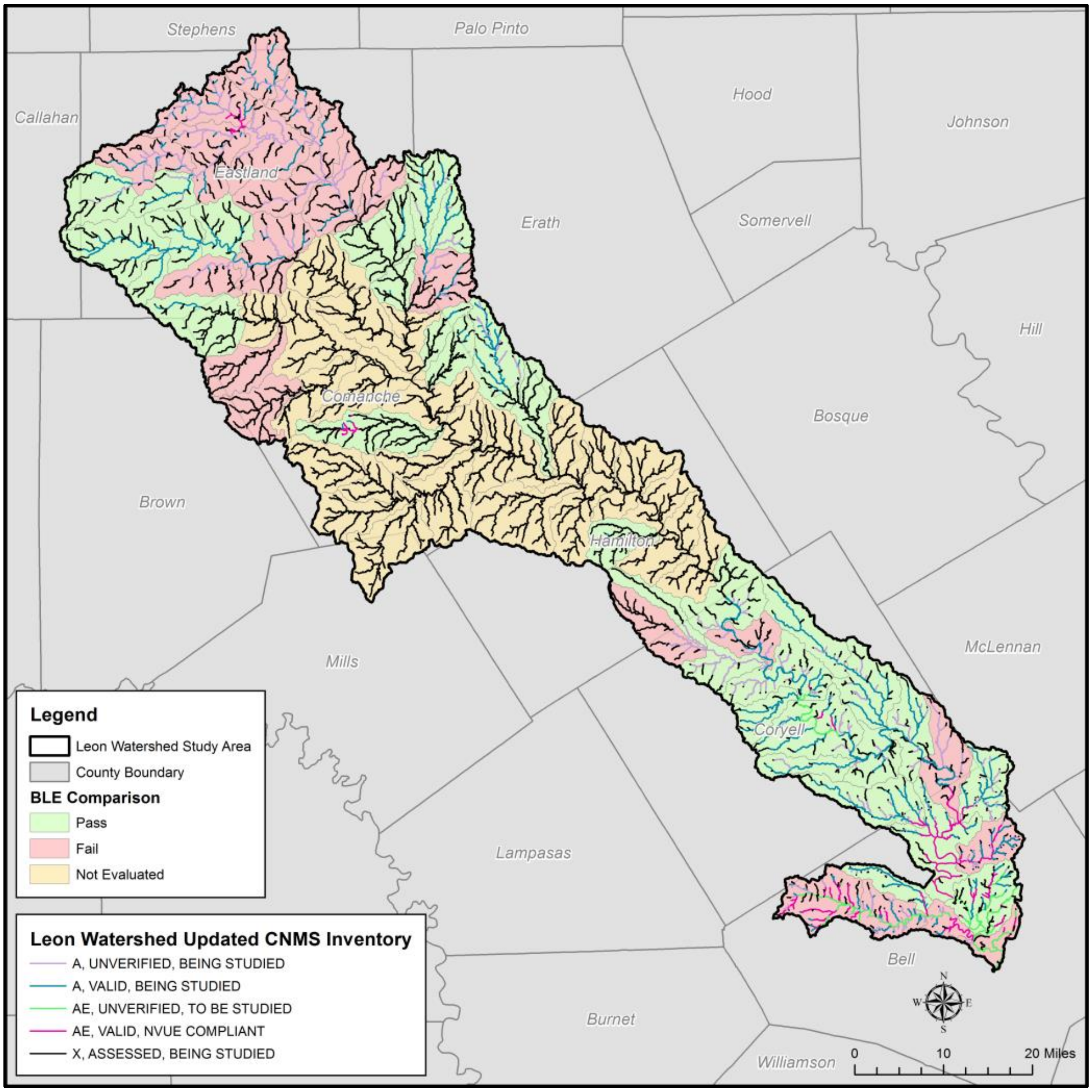


Figure 15: Leon Watershed CNMS Validation Results

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 16 below shows the range of the HUC-12 priority scores which can be used to initiate discussions during the Discovery phase.

Fryers Creek – Leon River HUC-12 was determined to have the highest priority score and the most need while Long Branch – Sabana River HUC-12 had the lowest score.

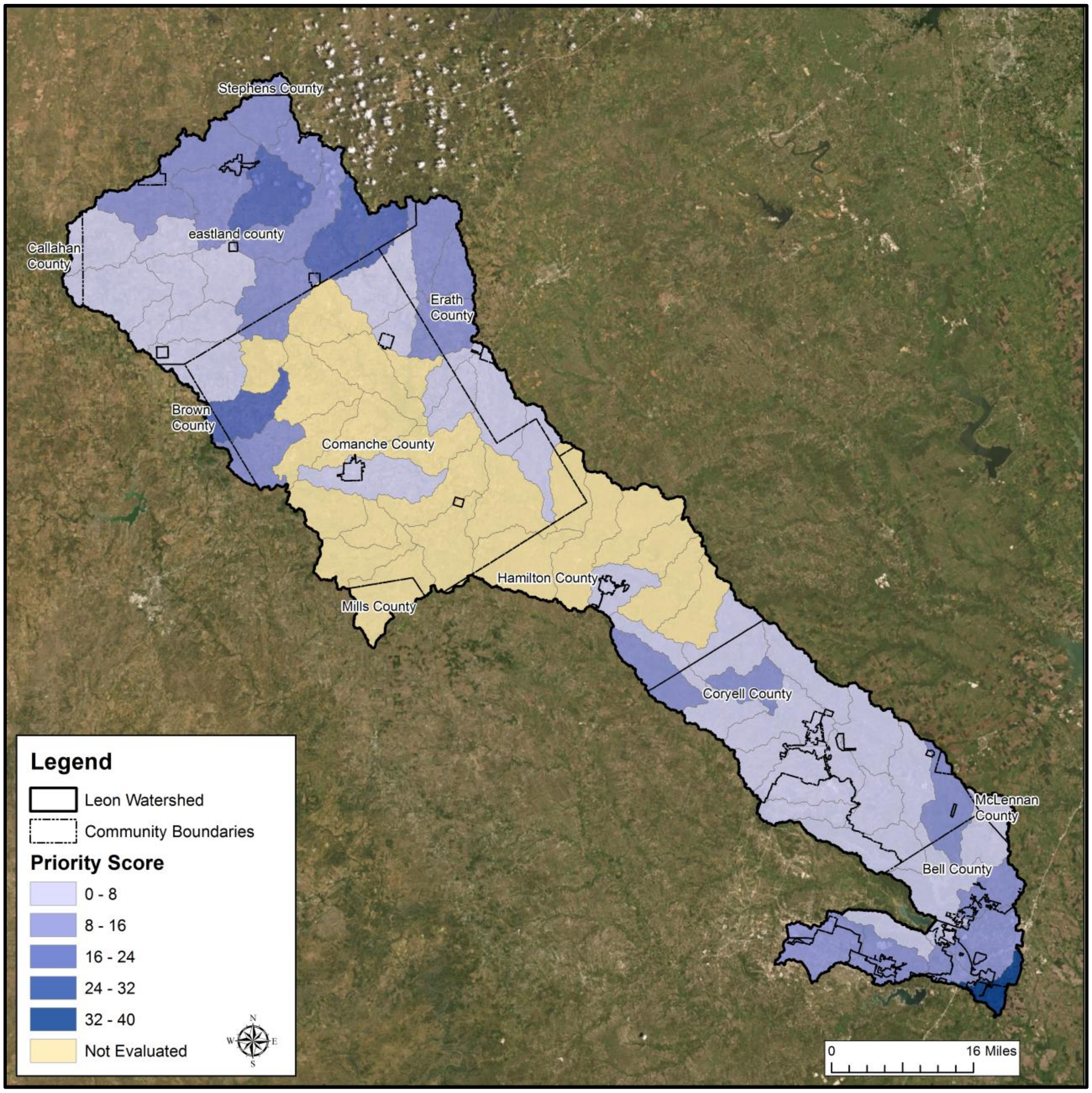


Figure 16: Ranking of Leon Watershed HUC-12s

4.3 Flood Risk Analysis

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

Hazus version 5.1 was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 5.1 uses dasymetric census blocks. Dasymetric mapping removes undeveloped areas (such as areas covered by other bodies of water, wetlands, or forests) from the census blocks, changing their shape and reducing their size in these areas. For more information on dasymetric data visit FEMA's Media Library for the Hazus-MH Data Inventories: Dasymetric vs. Homogenous, or Hazus 3.0 Dasymetric Data Overview.

Hazus analysis was performed by watershed extents for each return period to ensure proper model processing. A summary of results for counties within the watershed for the 1-percent annual chance scenarios are shown in Table 17. Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county only if all of the census blocks for that county/state were selected at the time of study region creation.

Table 17: Hazus 5.1 Results for 1-Percent-Annual-Chance (100 year) Scenario

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Bell	$1,613,151,000	$19,470,594,000	$11,419,388,000
Brown	$160,000	$18,063,000	$9,747,000
Callahan	$304,000	$19,742,000	$19,742,000
Comanche	$106,334,000	$1,258,756,000	$771,662,000
Coryell	$218,322,000	$1,933,001,000	$1,137,017,000
Eastland	$162,858,000	$1,547,046,000	$981,182,000
Erath	$29,430,000	$540,215,000	$367,646,000
Hamilton	$44,191,000	$596,047,000	$379,081,000
McLennan	$4,291,000	$104,059,000	$60,803,000
Mills	$1,218,000	$46,997,000	$25,998,000
Stephens	$248,000	$8,638,000	$4,681,000
Total	**$2,180,507,000**	**$25,543,158,000**	**$15,176,947,000**

5. References

FEMA, *Bell County Flood Insurance Study, Texas*,

FEMA, Coryell County Flood Insurance Study, Texas,

FEMA, *Eastland County Flood Insurance Study, Texas*,

FEMA, *Hamilton County Flood Insurance Study,* Texas,

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, *Completion of the 2016 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing*, v. 81, no. 5, p. 345-354

National Oceanic and Atmospheric Administration. NOAA Atlas 14, Volume 11 Version 2.0 Texas, *Precipitation-Frequency Atlas of the United States*. Silver Spring, Maryland, 2018.

Painter, C.C., Heimann, D.C., and Lanning-Rush, J.L., 2017, *Methods for estimating annual exceedance-probability streamflows for streams in Kansas based on data through water year 2015 (ver. 1.1, September 2017):* U.S. Geological Survey Scientific Investigations Report 2017–5063, 20 p., https://doi.org/10.3133/sir20175063.

USACE, *HEC-RAS 2D Modeling User's Manual*, September 2021

USACE, *HEC-RAS Hydraulic Reference Manual*, September 2021

United States Department of Agriculture, *Chapter 5 of the NRCS National Engineering Handbook Part 630. Amended* May 2012.

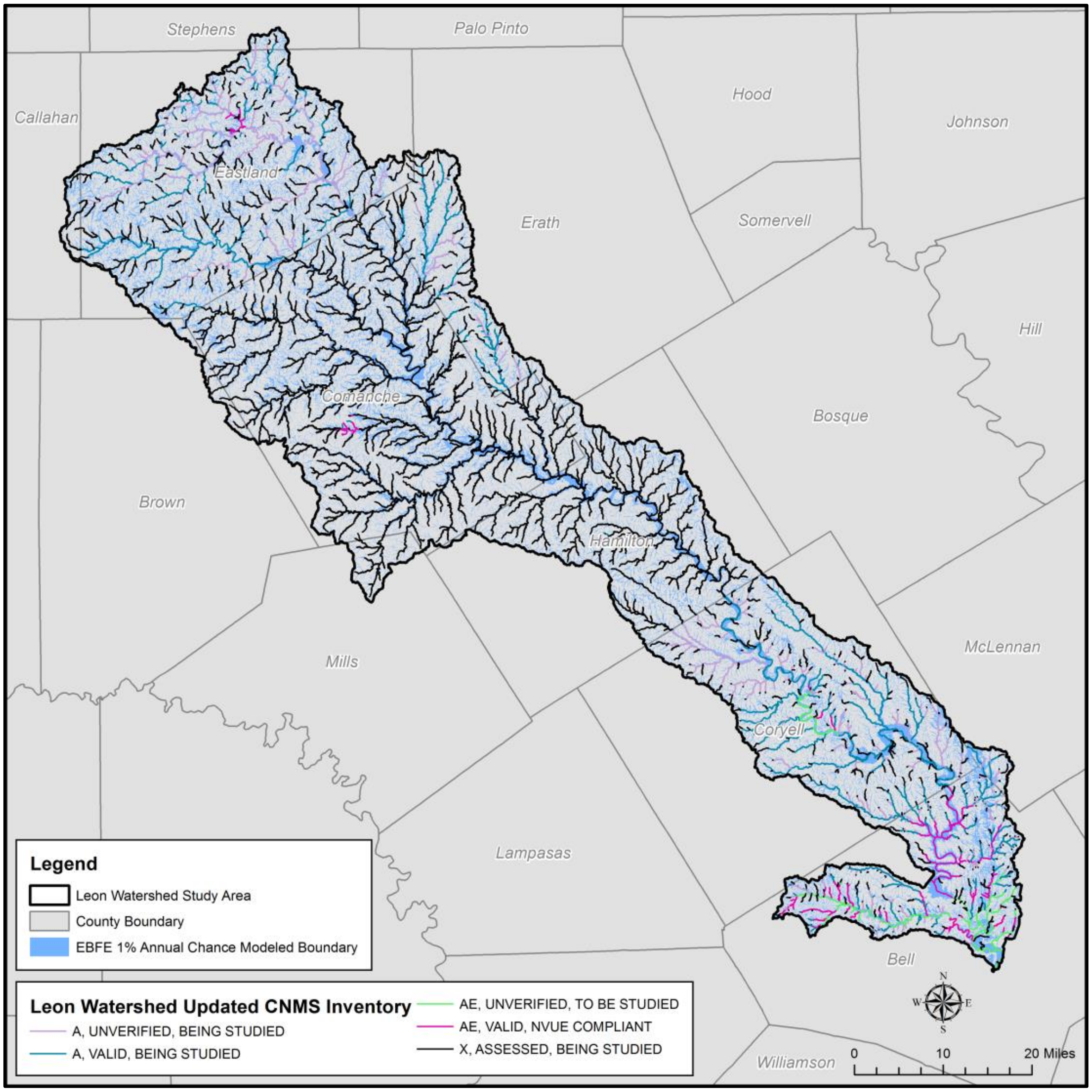
USDA, NRCS, *Manning's n Values for Various Land Covers To Use for Dam Breach Analysis in Kansas*, 2016

USDA, NRCS, *NOAA Atlas 14 rainfall for Midwest and Southeast states,* 2015.

USDA, NRCS, Part 630 National Engineering Handbook, Chapter 5 Streamflow Data, March 2020

USGS 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*, June 2009

Appendix A BLE Map



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