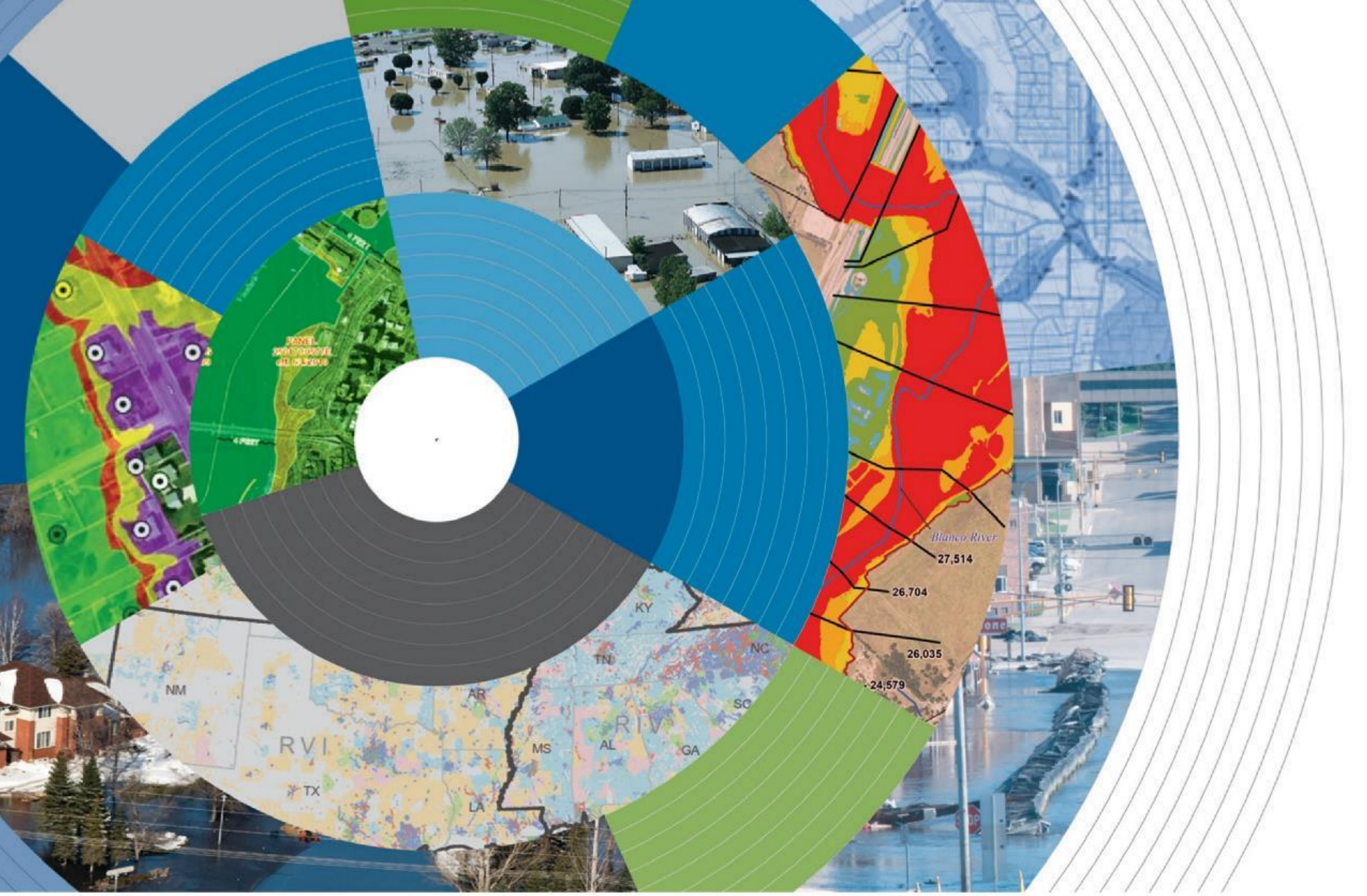

Base Level Engineering Report

San Saba (12090109)

Texas Water Development Board

January 31, 2025

Version 1.0

Report Prepared for:

Texas Water Development Board
1700 North Congress Avenue
Austin, TX 78701

Report Prepared by:

AtkinsRéalis USA, Inc.
11801 Domain Boulevard
Suite 500
Austin, TX 78758

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1.0	January 31, 2025	Initial report for the Estimated Base Flood Elevation viewer	AtkinsRéalis USA, Inc.

FINAL REPORT FOR SAN SABA (12090109)

PREPARED FOR:

Texas Water Development Board

Prepared By:

AtkinsRéalis USA, Inc.

Texas Registered
Engineering FIRM # 474

06/12/2025

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Executive Summary

The Texas Water Development Board (TWDB) contracted with AtkinsRéalis USA, Inc. (AtkinsRéalis) to complete two-dimensional (2D) Base Level Engineering (BLE) in the San Saba HUC-8 watershed (12090109). This watershed is located in Central Texas, between Eldorado, Texas and San Saba, Texas. The watershed area is 2,295 square miles (mi^2). Approximately 1,907 miles of stream centerlines were modeled. The information produced during this assessment is available on the U.S. Department of Homeland Security's Federal Emergency Management Agency's (FEMA) Mapping Information Platform (MIP) under case number 22-06-0047S.

The following guidance documents provided the methodologies for this project:

- *Base Level Engineering – Region 6 Submittal Guidance* (FEMA, January 2019)
- *Base Level Engineering – Region 6 Submittal Guidance – Appendix A: 2-D Base Level Engineering Guidance* (FEMA, January 2019)
- *Texas Two-Dimensional Base Level Engineering Guidelines, Version 1.0* (TWDB, May 2022)

Light Detection And Ranging (LiDAR) topographic data available for download from the Texas Natural Resources Information System (TNRIS) were leveraged to build a 3D terrain surface for the watershed.

The hydrologic and hydraulic modeling was completed using the U.S Army Corps of Engineers' Hydrologic Engineering Center River Analysis System (HEC-RAS), Version 6.2. In accordance with FEMA's Standard Identification Number (SID) 84, the 10%, 4%, 2%, 1%, 0.2%, 1% plus, and 1% minus annual-chance events were simulated. Precipitation data from the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 were leveraged to develop the 24-hour rainfall distribution for each event. A rain-on-grid methodology was applied to distribute the rainfall across the extents of the 2D hydraulic model area. Infiltration losses were computed using the Natural Resources Conservation Services (NRCS) Curve Number (CN) loss rate method.

The San Saba watershed was divided into nine HEC-RAS model domains—0901_A1, 0902_A2, 0903_A3, 0904_A4, 0905_A5, 0906_A6, 0907_A7, 0907_A8, and 0908_A9. Per TWDB guidance, a 200-foot by 200-foot nominal cell spacing was used for the 2D area and a finer 100-foot by 100-foot cell spacing was used along the breaklines and within the refinement regions. Breaklines were added to capture roadways, railroads, dam crests, and embankments to force the terrain surface to drain properly. Refinement regions were defined in and near urban areas, major reservoirs, and dam overflow areas to enhance the identification of the flood hazards in these higher-risk areas.

Model results were validated using stream gage data, regression flows, effective FEMA data, and outcomes from other studies in the project area.

Floodplain mapping was developed for the 10%, 1%, and 0.2% annual chance events. Raw mapping output from HEC-RAS was post-processed to delineate floodplains that aligned with the TWDB's 2D BLE mapping standards.

A summary of FEMA's Coordinated Needs Management Strategy (CNMS) data for the San Saba watershed may be found in Table 1 and Table 2 and shown on Figure 1.

Table 1: Summary of Stream Miles

Source	Stream Miles
Current Inventory -- CNMS	214.1
New Study Streams -- CNMS	1,692.6
Total (BLE) Stream Miles	**1,906.7**

Table 2: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment
VALID	TO BE STUDIED	0	0
	BEING STUDIED	0	3.6
UNVERIFIED	TO BE STUDIED	182.3	0
	BEING STUDIED	0	181.6

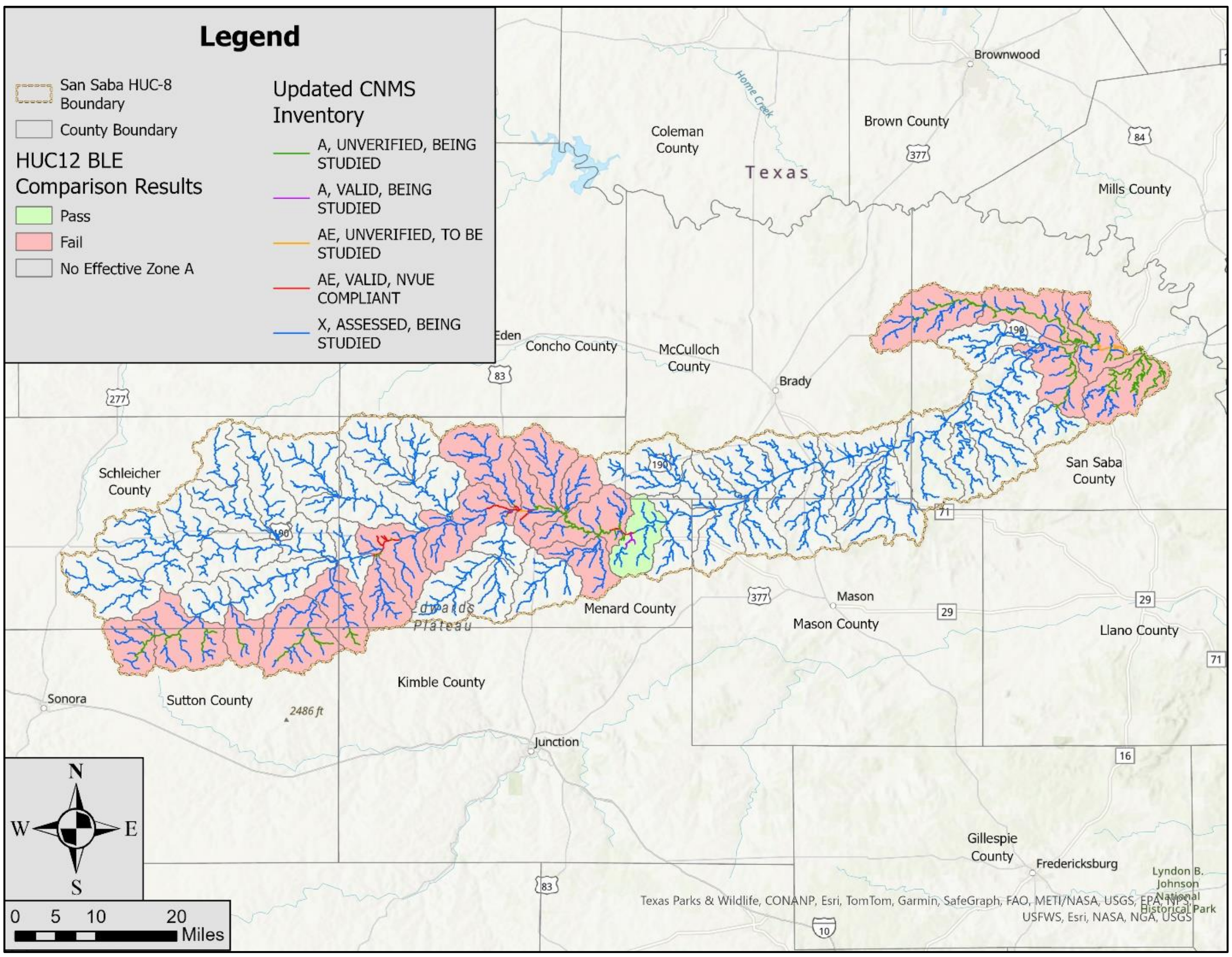


Figure 1: San Saba - 12090109 CNMS Validation Results

Base Level Engineering (BLE) Methodology

Recent innovations and increased efficiency in floodplain mapping have allowed FEMA to develop a process called 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% 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 5 years, FEMA must determine whether the information on its Flood Insurance Rate Maps (FIRMs) reflects the current risks in flood-prone areas. FEMA makes this determination of flood hazard data validity by examining flood study attributes and change characteristics, as specified in the Validation Checklist of the 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 SID 29 requires that during the Discovery process, 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, then an analysis is required that estimates the likely changes. This data and any associated analyses should be shared, and the 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 cannot 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 Mapping, Assessment, and Planning (Risk MAP) program may also be valuable to external stakeholders.

The TWDB contracted with AtkinsRéalis to complete a BLE analysis for the San Saba watershed (HUC-8 12090109). The watershed is mostly rural and the land is predominantly used for farming and ranching. Parts of Concho, Kimble, Mason, McCulloch, Menard, San Saba, Schleicher, and Sutton counties falls within the watershed. The cities of Menard, San Saba, and Richland Springs reside within the watershed. See Figure 2 for a map of the San Saba watershed.

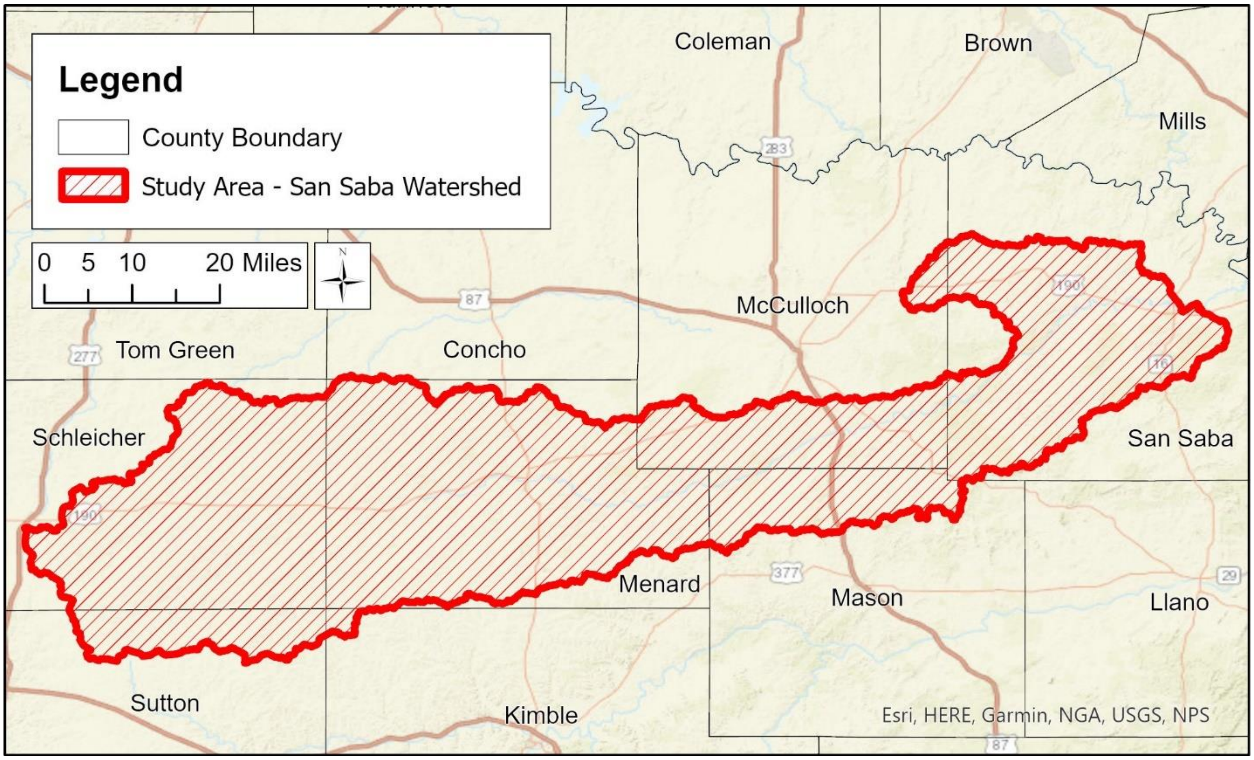


Figure 2: San Saba Watershed – HUC-8 12090109

The BLE assessment prepared a cursory engineering analysis for approximately 1,907 miles of stream reaches within the San Saba watershed with a minimum drainage area tolerance of 1 mi^2. The selection and extent of the stream reaches studied were based on the number of stream miles meeting the minimum drainage area of 1 mi^2 and not the number of effective Zone A stream miles. Study reaches were extended above this 1-mi^2 threshold as appropriate so the entire effective Zone A floodplain received an updated analysis. The following sections summarize the BLE process and discuss the results along with their recommended use.

1.1. Topographic Data

1.1.1. Development of the Seamless HUC-8 Digital Elevation Model (DEM)

The topographic data used to develop the terrain surface for the San Saba watershed included three primary data sources in the form of Digital Elevation Models (DEMs). These datasets were provided by the TWDB or downloaded directly from the TNRIS website. A description of all terrain data sources used in the study is in Table 3.

Some of the LiDAR datasets overlapped one another. Therefore, a priority hierarchy was established to determine which LiDAR dataset took precedent over the others in overlap areas. Factors used to establish the hierarchy included the age of the terrain data and its accuracy. This hierarchy is as follows:

- Lower Colorado San Bernard LiDAR
- Texas West Central LiDAR
- Hurricane LiDAR

The above-mentioned LiDAR data sets were used to create a seamless set of tiled 5-foot DEMs for the San Saba watershed and a buffered area around the watershed. Each DEM tile measured 6,000 feet by

6,000 feet. This tile size was used because tiles this size can easily be resampled by other users to 1-, 2-, 3-, 5-, 10-, 20-, or 25-foot rasters since 6,000 is evenly divisible by all of these numbers. A 1,000 meter buffer was included since the watershed divide was outside the HUC-8 watershed extents in some areas. A 5-foot cell size was used in accordance with the 10-foot cell size criterion outlined in FEMA's Region 6 BLE guidance from 2019. After projecting the terrain into the Texas State Plane Zone 3 (Central) projection (North American Datum [NAD] 1983 [2011]) with units of U.S. feet, the tiles were mosaicked into one DEM. The sources and extents of the original DEMs used to create the mosaicked DEM are shown on Figure 3.

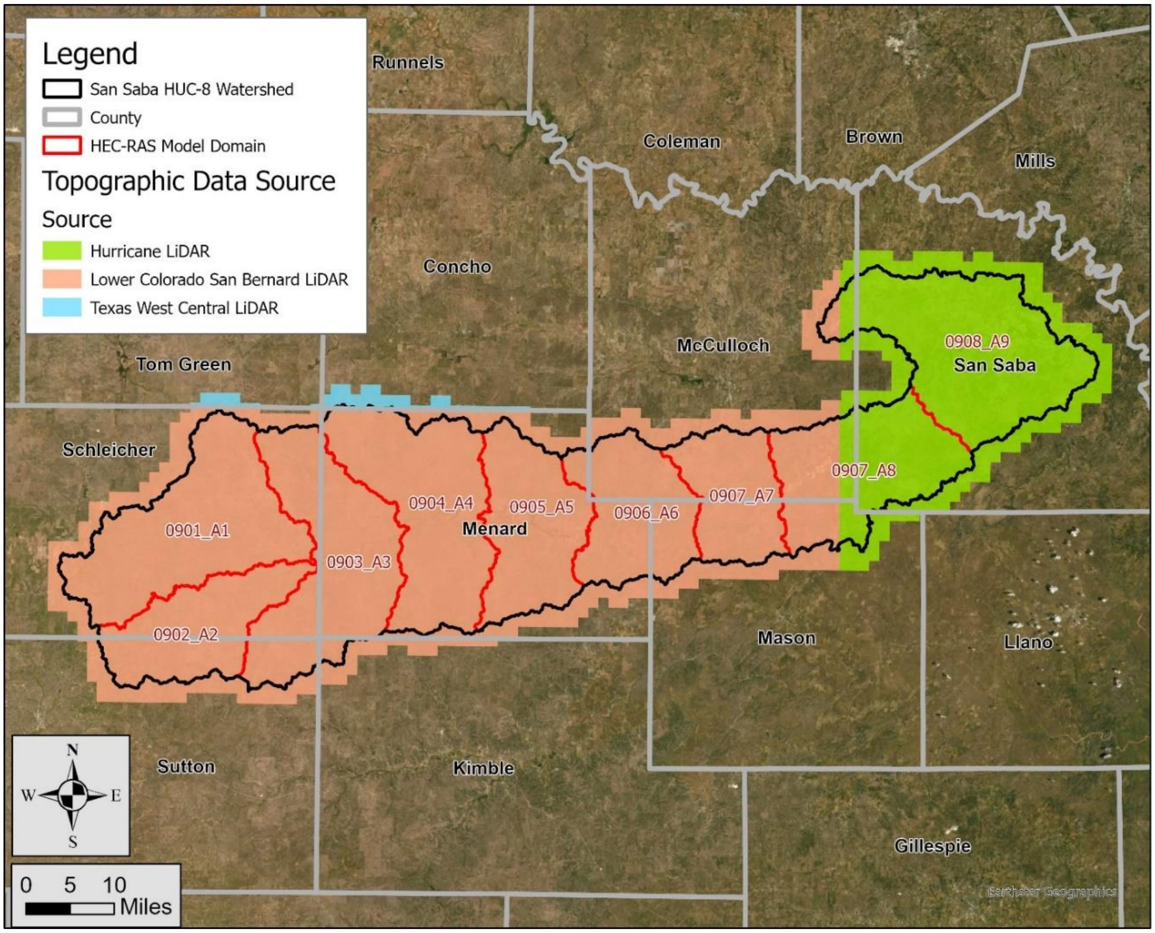


Figure 3: Topographic Data Extents in the San Saba Watershed

Table 3: Topographic Data Sources

County	Year Acquired	Vertical Accuracy	Source	Approximate Footprint (mi^2)
Lower Colorado San Bernard LiDAR (Mason, McCulloch, Menard, Kimble, Schleicher, and Sutton Counties)	2018	4.9 cm	USGS	2,223
Texas West Central LiDAR (Concho and Tom Green Counties)	2018	4.7 cm	USGS	38
Hurricane LiDAR (McCulloch, Mason, and San Saba Counties)	2019	3.8 cm	USGS	712

An overview of each topographic dataset follows. The vertical datum of all LiDAR datasets was the North American Vertical Datum of 1988 (NAVD 88).

Dataset One – Lower Colorado San Bernard River LiDAR

The U.S. Geological Survey's (USGS) Lower Colorado San Bernard River LiDAR dataset captured in 2018 contains data for 17,942 mi^2 across 26 counties in Texas. In the San Saba watershed, this dataset includes parts of Mason, McCulloch, Menard, Kimble, Schleicher, and Sutton counties. The vertical accuracy (RMSEz, or root mean square error in the z direction) of this dataset is 4.9 centimeters (cm). The native cell size of the data is 1 square meter (m^2).

Dataset Two – Texas West Central LiDAR

The USGS Texas West Central LiDAR captured in 2018 contains data for 42,557 mi^2 across 70 counties in Texas. In the San Saba watershed, this dataset includes parts of Concho and Tom Green counties. The vertical accuracy (RMSEz) of this dataset is 4.7 cm. The native cell size of the data is 1 m^2.

Dataset Three – Hurricane LiDAR

The USGS Hurricane LiDAR dataset captured in 2019 contains data for 14,512 mi^2 across 45 counties in Texas. In the San Saba watershed, this dataset includes parts of Mason, McCulloch, and San Saba counties. The vertical accuracy (RMSEz) of this dataset is 3.8 cm. The native cell size of the data is 1 m^2.

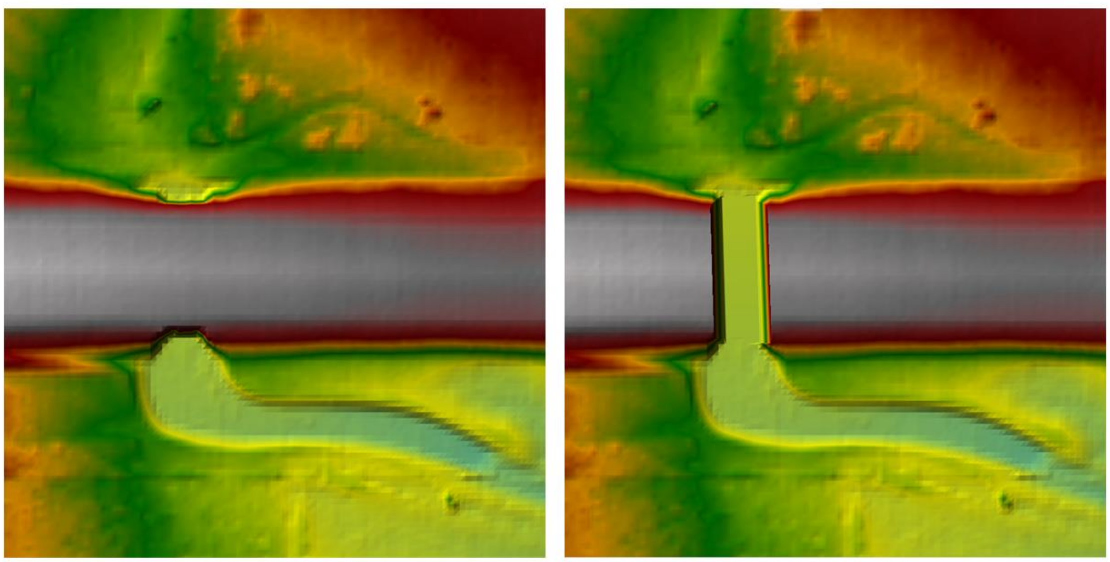
No modifications were made to this terrain surface. The goal was to use this terrain as-is in the hydraulic modeling, floodplain mapping, and grid development tasks. Maintaining the source terrain data in an unmodified state avoids customized changes to the terrain dataset that future users may not be able to replicate. It also reduces the chance of future users applying an outdated version of the terrain. Any changes that were required in the hydraulic model phase were made in the HEC-RAS terrain, not in the processed tiles.

1.1.2. Development of the Stream Networks and Drainage Basins

A hydro-conditioned terrain surface was developed to define the stream networks and drainage basins. A 1,000-meter buffer was applied to the HUC-8 boundary to capture the watershed divide. A 5-meter mosaicked DEM was developed from the source LiDAR data in the same projection as the source data. Using a 5-meter DEM for hydrologic network development maintained sufficient accuracy and produced datasets that were smaller in size and easier to manipulate.

The process for terrain preparation and network and basin delineation is outlined below:

- The flow direction grid, flow accumulation grid, hydrologic stream network, and hydrologic basins were developed.
- Burn lines were defined as needed at roadway/railroad crossings or where reservoirs/ponds artificially diverted the flow path from the natural alignment. The bridge/culvert crossing burn lines developed in this task were subsequently incorporated into the HEC-RAS terrain as terrain modification features (see example in Figure 4). Terrain modifications, when applied, allowed flow through roadways.



(a) without terrain modifications (b) with terrain modifications

Figure 4: HEC-RAS Terrain Modification at a Culvert Crossing to Allow Flow through a Roadway

- The streamlines and watershed delineations were reviewed and burn lines were continually added and adjusted until the flow paths, basins, and computed drainage areas were reasonable and justifiable.
- A drainage area grid was computed along the flow paths.
- There are three USGS gages with drainage areas greater than 1 mi^2 in the watershed. The table below summarizes the difference between the reported and computed values for the drainage area at each gage. The differences of less than 1 percent are acceptable.

Table 4: Reported and Computed Drainage Areas at Each USGS Gage

USGS Gages			Computed Values	
Site No.	Site Name	Drainage Area (mi^2)	Drainage Area (mi^2)	Difference
08144500	San Saba Rv at Menard, TX	1,135	1,133	-0.18%
08144600	San Saba Rv nr Brady, TX	1,633	1,633	0.00%
08146000	San Saba Rv at San Saba, TX	3,046	3,041	-0.16%

The following information has been placed in the terrain supplemental data folder:

- The computed watershed boundaries at the HUC-8, HUC-10, and HUC-12 levels developed during the terrain processing task.
- The 1-mi^2 stream network developed during the terrain processing task. These lines represent locations where the drainage area is 1 mi^2 or greater.
- Additional supporting layers such as roads, NHD waterbodies, and NHD flow lines.

1.2. Hydrologic and Hydraulic Analysis

A 2D BLE analysis of the San Saba watershed was completed using HEC-RAS Version 6.2. The analysis applied a rain-on-grid methodology over a 3D terrain. Average basin rainfall was applied to the 2D computational mesh, and losses were computed using the spatially-varied infiltration capabilities of HEC-RAS. In accordance with SID 84, the 10%, 4%, 2%, 1%, 0.2%, 1% plus, and 1% minus annual-chance events were simulated.

Model Layout

The San Saba watershed was split into nine model domains – 0901_A1, 0902_A2, 0903_A3, 0904_A4, 0905_A5, 0906_A6, 0907_A7, 0907_A8, and 0908_A9, as shown on Figure 5. The first 4 numbers in the model domain name are the final 4 numbers in the name of the HUC-10 watershed number. A1, A2, etc. in the model domain name is just a linear naming convention for the domains. Per recommendation from the TWDB, the model domains (work areas) were no larger than roughly 300 mi^2, which is the size of a typical HUC-10 watershed. The primary reason for having a domain size equal to or smaller than a HUC-10 watershed was to satisfy the assumption that the rainfall across the domain was uniform. The initial model domain boundaries were derived from revised HUC-10 watershed delineations that were established using the LiDAR data. A buffer of 1,000 feet was applied to each HUC-10 watershed boundary to create overlapping domain boundaries. The purpose of the overlap areas was to facilitate clean floodplain and Base Flood Elevation (BFE) transitions between models, to capture the full extent of the floodplain within the watershed, and to minimize the impact of model boundary conditions on model results. At the confluences of model domains, the overlap areas along the main channel were increased in some locations to facilitate tie-ins between model domains.

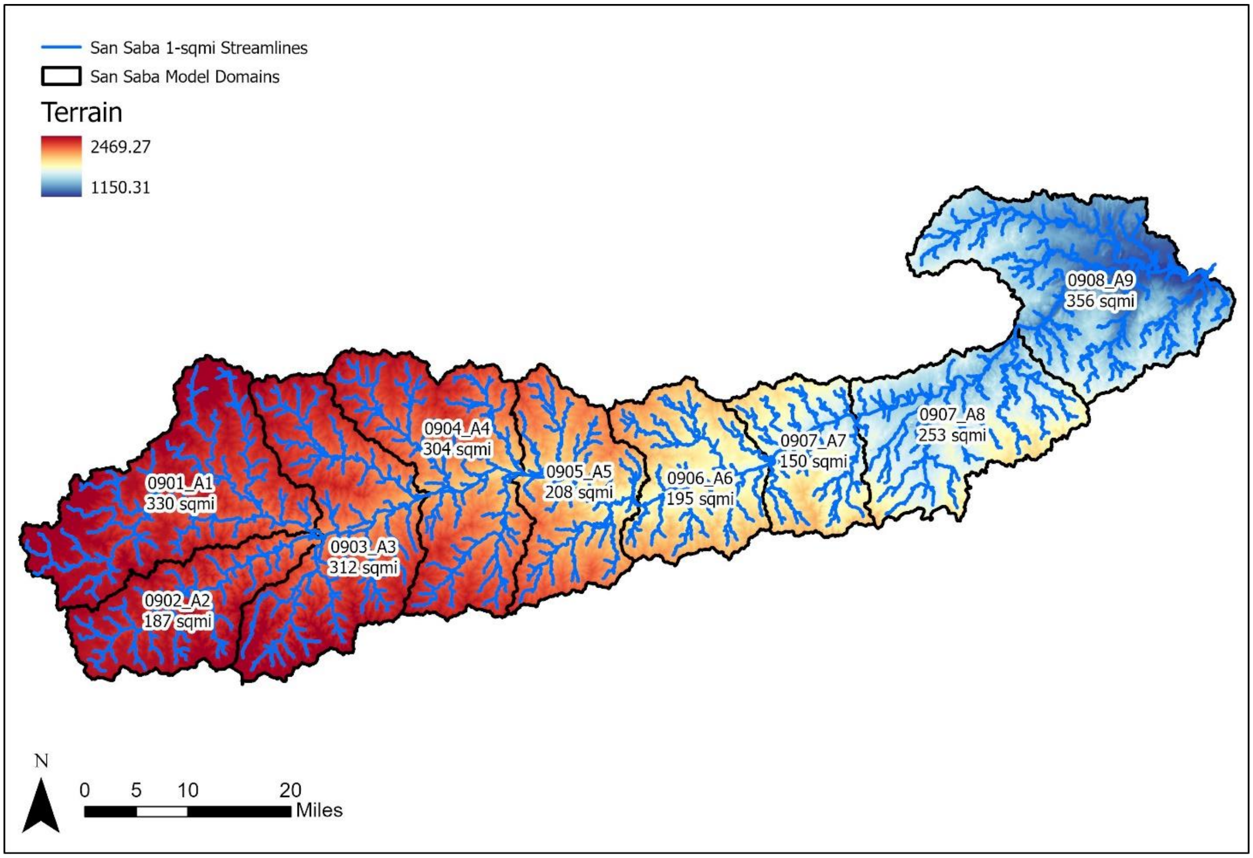


Figure 5: San Saba Model Domains and Linkages

1.2.1. Total Precipitation

Using NOAA's Atlas 14 precipitation statistics, an area-averaged precipitation frequency table was computed for each event in each model domain. For all events, a 24-hour rainfall distribution was calculated using an NRCS nested temporal distribution. The NRCS rainfall distribution development methodology is documented in Title 210, Part 630, Chapter 4, Section 630.0407 of the *National Engineering Handbook* (August 2019). To create the 24-hour rainfall distribution for an event, the model domain-averaged rainfall totals for the 5-minute, 10-minute, 15-minute, 30-minute, 1-hour, 2-hour, 3-hour, 6-hour, 12-hour, and 24-hour durations were calculated for that event. The ratio of each duration's precipitation total to the 24-hour duration's precipitation total was calculated to produce a preliminary symmetric rainfall distribution. These rain ratios were manipulated as described in Section 630.0407 to obtain the final 24-hour rainfall distribution for the event. This process was repeated for all events in the model domain. The results were exported to DSS (data storage system) files for input into the HEC-RAS models.

The 1% plus and 1% minus annual-chance rainfall totals were computed using the approach provided in subsection 2.2.3 of the TWDB's *2D BLE Guidance Version 1.0* (May 2022). The 1% plus and 1% minus storms were based on the NRCS temporal distribution described in Section 630.0407 of the *National Engineering Handbook* (August 2019). Additional checks were performed to confirm the 1% plus and 1% minus hyetographs did not cross the hyetographs for other events. The precipitation data used in this study have been included in the supplemental data folder.

1.2.2. Infiltration Losses

The NRCS CN loss rate method was used to account for infiltration losses. A spatially-varying infiltration layer for the study area was developed in HEC-RAS by using gridded soils and gridded land cover data sets.

To develop the soils dataset, the 2021 Gridded Soils Survey Geographic (gSSURGO) database was downloaded from NRCS's website (https://data.nal.usda.gov/dataset/gridded-soil-survey-geographic-database-gssurgo). The SSURGO database contained hydrologic soil type information, which was used to develop the gridded soils layer in HEC-RAS.

To develop the land cover dataset, the 2019 National Land Cover Database (NLCD) was downloaded from the Multi-Resolution Land Characteristics Consortium (MRLC) website (https://www.mrlc.gov/data/nlcd-2019-land-cover-conus). The land cover dataset provided land use classification codes and the extent of each land use. This information was used to create the gridded land cover dataset.

The infiltration layer was created in HEC-RAS by combining the soils and land cover gridded datasets. The CN values required for the loss rate computations were obtained from Table 2.4 of the TWDB's *2D Base Level Engineering Guidance Version 1.0* (May 2022) and are shown below in Table 5. An initial abstraction ratio of 0.2 was used to obtain the initial loss. During the model validation phase, the CN values were adjusted as needed to bring the model results into alignment with the validation data (e.g., stream gage data, effective discharges, etc.). CN values presented in Table 5 were based on average Antecedent Moisture Condition II (AMC II), and during validation, the values were revised by no more than ±10% of their initial values. In some cases, however, a 10% reduction in the AMC II CN values produced flows that continued to be too high to be considered validated. For these model domains, CN values corresponding to AMC I conditions were used to achieve model validation. AMC I CN values are shown in Table 6.

Research completed for this project revealed that antecedent moisture conditions in Texas vary from AMC II in the east to AMC I in the west, and the San Saba watershed resides within the transition from AMC II to AMC I. Therefore, the application of AMC I conditions to support validation was appropriate. Including AMC I CN values in these domains produced flows that were able to be validated while avoiding adjustments to the AMC I CN values. See Section 1.2.9 for more information about the use of AMC I and AMC II CNs in the San Saba watershed.

Table 5: AMC II Curve Number Values

Land Use Grid Code	NLCD Land Use Description	CN for Each 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	Grassland Herbaceous	49	62	74	85
81	Hay Pasture	39	61	74	80
82	Cultivated Crops	51	67	76	80
90	Woody Wetlands	72	80	87	93
95	Emergent Herbaceous Wetlands	72	80	87	93

Table 6: AMC I Curve Number Values

Land Use Grid Code	NLCD Land Use Description	CN for Each Hydrologic Soil Group			
		A	B	C	D
11	Open Water	98	98	98	98
21	Developed, Open Space	29	48	61	69
22	Developed, Low Intensity	40	56	67	74
23	Developed, Medium Intensity	64	75	81	85
24	Developed, High Intensity	77	83	87	89
31	Barren Land	21	40	54	63
41	Deciduous Forest	15	34	49	58
42	Evergreen Forest	15	34	49	58
43	Mixed Forest	15	34	49	58
52	Shrub Scrub	15	28	44	53
71	Grassland Herbaceous	29	41	54	70
81	Hay Pasture	21	40	54	63
82	Cultivated Crops	30	46	57	63
90	Woody Wetlands	52	63	74	85
95	Emergent Herbaceous Wetlands	52	63	74	85

Manning's n values were defined within the infiltration layer. These values were used to compute the energy losses as the flow was routed through the 2D computational mesh in the HEC-RAS model. For this study, the overbank Manning's roughness coefficients were obtained from Table 2.2 of the TWDB's *2D Base Level Engineering Guidance Version 1.0* (May 2022) and are presented in Table 7. Manning's n values for the main channel areas were refined by adding Manning's n override regions. The extents of the override regions in the channels were established by adding a typical buffer of 100 feet to the streamlines. For larger streams, where the channel polygon widths were wider than 200 feet, the channel polygons were adjusted by reviewing the typical channel widths on the terrain surface and aerial photography. Manning's n values in the main channels ranged from 0.040 to 0.050.

Table 7: Manning's n Values for Overland and Overbank Areas

Land Use Grid Code	NLCD Land Use Description	Typical n Value	n Value Range
11	Open Water	0.038	0.025 - 0.050
21	Developed, Open Space	0.040	0.030 - 0.050
22	Developed, Low Intensity	0.090	0.060 - 0.120
23	Developed, Medium Intensity	0.120	0.080 - 0.140
24	Developed, High Intensity	0.160	0.120 - 0.200
31	Barren Land	0.025	0.023 - 0.030
41	Deciduous Forest	0.150	0.100 - 0.160
42	Evergreen Forest	0.120	0.100 - 0.160
43	Mixed Forest	0.140	0.100 - 0.160
52	Shrub/Scrub	0.115	0.070 - 0.160
71	Grassland/Herbaceous	0.038	0.025 - 0.050
81	Hay/Pasture	0.038	0.025 - 0.050
82	Cultivated Crops	0.035	0.025 - 0.050
90	Woody Wetlands	0.098	0.045 - 0.150
95	Emergent Herbaceous Wetlands	0.068	0.050 - 0.085

1.2.3. 2D Computational Mesh

The 2D computational mesh is one of the key components of a rain-on-grid 2D model, and it has a significant impact on model outcomes. Per the TWDB's 2D BLE guidelines, a 200-foot by 200-foot nominal cell spacing was used for the 2D area, and a finer 100-foot by 100-foot cell spacing was used along the breaklines and within the refinement regions. Breaklines were included in the model to capture linear features in the topographic data that represented high ground or streamlines. Breaklines were added to capture roadways, railroads, dam crests, and embankments to force the terrain surface to drain properly. For main channel areas where flow depths and velocities are higher and in urban areas, refinement regions were added to enhance the identification of the flood hazards in these higher-risk areas.

The following list provides additional details of the mesh refinement that was performed:

- The stream centerlines defined during the hydro-enforcement task were applied as breaklines to align the mesh cells with the direction of flow. For undeveloped/rural areas, the 1-mi^2 stream centerlines were used to create the breaklines. For urban areas, the 0.5-mi^2 stream centerlines were used.

- Texas Department of Transportation (TxDOT) road lines (https://gis-txdot.opendata.arcgis.com/) were used as breaklines.
- Polygons computed by buffering the streamlines were used to establish channel refinement regions. The buffers were 200 feet wide for small streams (100 feet on either side) and increased for wider streams with larger drainage areas.
- Refinement regions were defined in urban areas.
- Breaklines were split into multi-parts at all intersections using the planarize tool in ArcGIS Pro.
- Since the model runtime increases as more breaklines and refinement regions are added, all breaklines and refinement regions were reviewed to confirm that they improved the quality of the model. Those that did not improve the quality were removed.
- The 2D perimeter, refinement regions, and breaklines were smoothed and cleaned using Geographic Information Systems (GIS) software to minimize mesh generation errors.
- As discussed in Section 1.1.2, the bridge/culvert crossing burn lines developed for this study were incorporated into the HEC-RAS terrain as terrain modification features to allow flow through roadways.

1.2.4. Model Boundary Conditions

The BLE analysis included four types of model boundary conditions—precipitation, flow hydrograph, stage, and normal depth. The following is a summary of where each type of boundary condition was applied.

Precipitation Boundary Conditions

As described previously, basin-averaged NOAA Atlas 14 precipitation depths were calculated for each model domain and were temporally distributed using an NRCS distribution. The precipitation hyetographs were applied to the 2D area using a precipitation boundary condition for the rain-on-grid analysis.

Flow Hydrograph Boundary Conditions

Flow hydrograph boundary conditions were added at major stream inflow locations. In this study, a direct-flow approach was used to transfer flows from upstream watersheds to downstream watersheds. In the direct-inflow method, the precipitation and upstream inflows assume the same annual-chance event is occurring simultaneously. So, for each event, the outflows from the upstream watersheds were directly applied as inflows to the model of interest without adjustments to the timing of the peaks.

Storage Area-2D (SA/2D) connections were added near the main channel outflow location in the upstream HEC-RAS model to compute the outflow from the upstream model. A flow boundary condition line was then added in the downstream model at a location that coincided with the SA/2D line to maintain consistency. The breaklines were enforced at the SA/2D connections and flow boundary condition lines to align the cell faces with the boundary. The purpose of adding SA/2D connections was to limit the impact of the boundary conditions on the inflow applied to the downstream models and to clearly document the flow transfer locations and hydrographs, as this information is stored in the DSS output files. The lengths of the inflow boundary condition lines for the downstream model were shortened to a length between the widths of the 1% and 10% floodplain limits to mimic the distribution of the inflow in the upstream model.

Stage Hydrograph Boundary Conditions

Stage hydrographs were applied at the main stem outflow locations to account for the downstream backwater elevations. This approach served two purposes. First, it facilitated the tie-ins of the water surface elevations at the model domain boundaries, which were required to be within 0.5 foot. Second, the application of the stage hydrograph boundaries accounted for the timing of the tailwater conditions in the downstream model. In short, the stage hydrograph in the upstream model was obtained from the downstream model at the upstream main channel's outflow location.

Figure 6 and Figure 7 show an example of the iterative process used to extract and apply a stage hydrograph at the transition of two model domains (which overlap) in the Jim Ned watershed. These figures show the location used to obtain the stage hydrograph between domains 0801_A2 (upstream domain) and 0802_A3 (downstream domain). A stage hydrograph was iteratively extracted from the downstream model results and applied to the upstream model as a boundary condition. This boundary condition was based upon the hydrograph results calculated from a SA/2D connection in the upstream model applied as a discharge in the downstream model. The iterative process was necessary to balance the upstream model's peak outflow within 10% of the downstream model's peak inflow while also achieving a WSEL tie-in of 0.5 foot or less at the transition location.

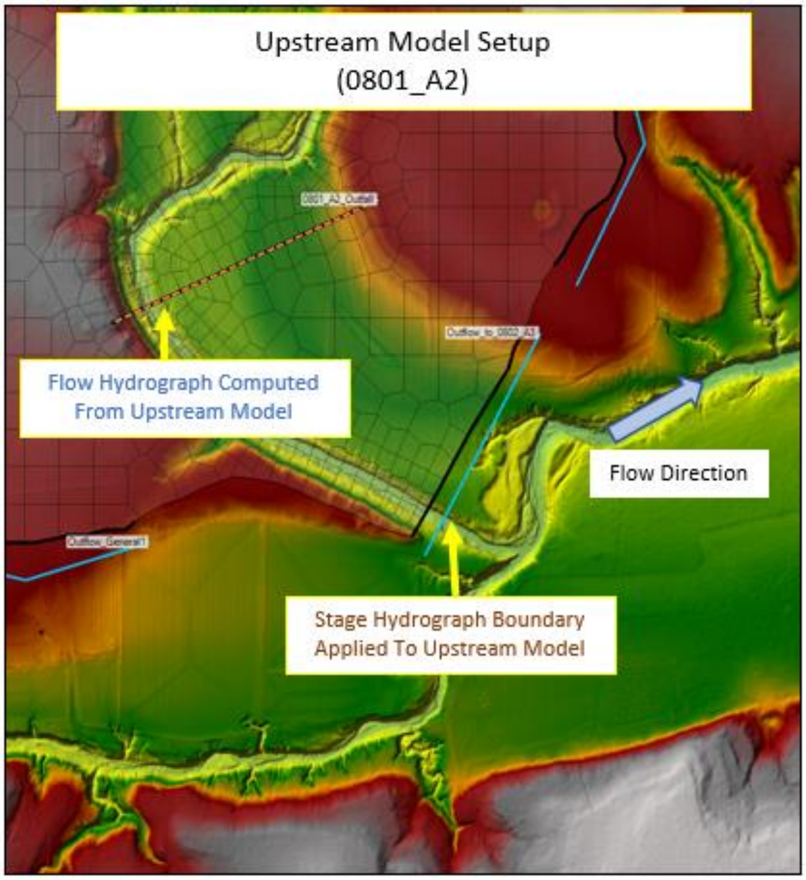


Figure 6: Extraction of Flow Hydrograph from the SA/2D Connection in the Upstream Domain for Use in the Downstream Domain

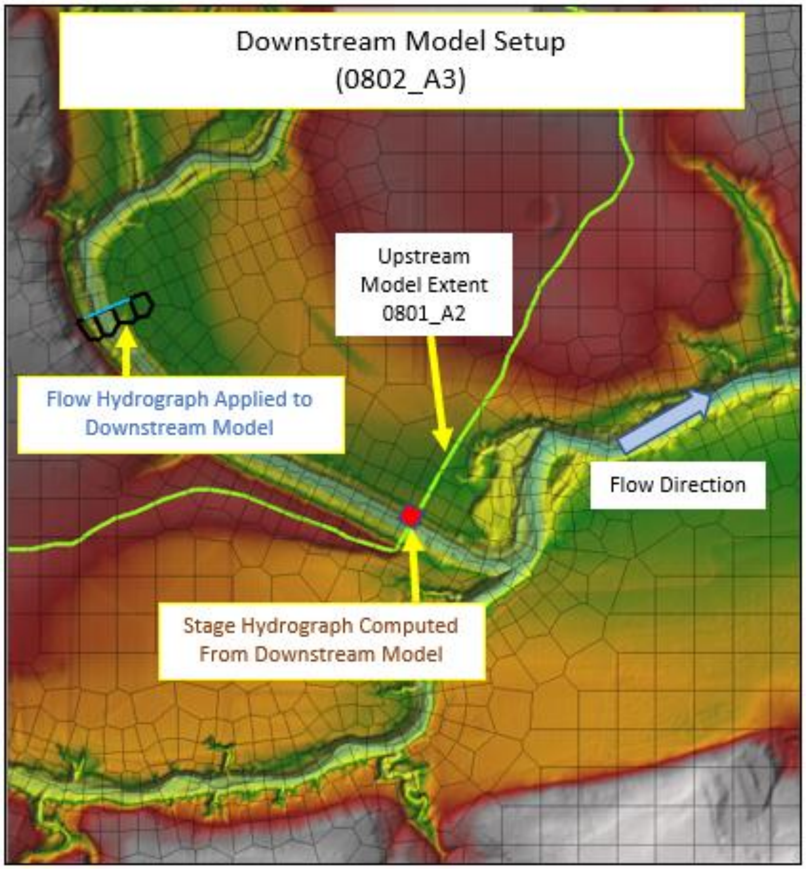


Figure 7: Application of Upstream Flow Hydrograph in the Downstream Domain

See Table 8 through Table 16 for a summary of the upstream and downstream peak discharges and WSELs at the downstream end of each domain in the San Saba watershed. These tables have been included to demonstrate that at the downstream end of each model domain, the peak discharges are within 6% of one another and the WSELs are within 0.5 feet for each profile.

Table 8: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0901_A1

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	18,275	18,274	-0.01%	2,107.87	2,107.48	0.39
4%	29,718	29,717	0.00%	2,110.26	2,110.08	0.18
2%	41,118	41,118	0.00%	2,111.89	2,111.83	0.06
1%	55,607	55,598	-0.02%	2,113.56	2,113.55	0.01
0.2%	101,723	101,754	0.03%	2,117.70	2,117.64	0.06
1% minus	34,567	34,566	0.00%	2,111.00	2,110.89	0.11
1% plus	78,853	78,890	0.05%	2,115.79	2,115.80	-0.01

Table 9: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0902_A2

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	11,256	11,256	0.00%	2,106.26	2,105.99	0.27
4%	18,700	18,705	0.03%	2,108.77	2,108.27	0.50
2%	25,819	25,840	0.08%	2,110.32	2,109.83	0.49
1%	34,268	34,340	0.21%	2,111.92	2,111.42	0.50
0.2%	62,444	62,865	0.67%	2,116.43	2,115.93	0.50
1% minus	21,529	21,543	0.06%	2,109.45	2,109.04	0.41
1% plus	48,198	48,397	0.41%	2,114.07	2,113.59	0.48

Table 10: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0903_A3

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	40,032	40,017	-0.04%	1,986.43	1,986.23	0.20
4%	63,099	63,166	0.11%	1,990.97	1,990.77	0.20
2%	86,287	86,295	0.01%	1,994.63	1,994.36	0.27
1%	111,122	111,134	0.01%	1,997.92	1,997.60	0.32
0.2%	202,113	202,076	-0.02%	2,006.86	2,006.41	0.45
1% minus	72,950	72,989	0.05%	1,992.64	1,992.36	0.28
1% plus	157,306	157,333	0.02%	2,002.96	2,002.53	0.43

Table 11: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0904_A4

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	34,022	34,103	0.24%	1,886.62	1,887.01	-0.39
4%	52,935	52,752	-0.35%	1,889.32	1,889.63	-0.31
2%	68,171	67,611	-0.83%	1,891.04	1,891.28	-0.24
1%	84,305	83,458	-1.01%	1,892.69	1,892.87	-0.18
0.2%	130,662	129,206	-1.13%	1,896.81	1,896.90	-0.09
1% minus	59,600	59,600	0.00%	1,890.12	1,890.38	-0.26
1% plus	107,918	107,918	0.00%	1,894.90	1,895.03	-0.13

Table 12: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0905_A5

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	48,254	47,845	-0.85%	1,768.57	1,768.14	0.43
4%	81,106	79,248	-2.34%	1,773.41	1,772.93	0.48
2%	110,991	106,993	-3.74%	1,776.84	1,776.37	0.47
1%	145,532	138,349	-5.19%	1,780.12	1,779.67	0.45
0.2%	254,313	254,603	0.11%	1,789.25	1,789.03	0.22
1% minus	93,921	91,142	-3.05%	1,774.96	1,774.48	0.48
1% plus	200,905	189,830	-5.83%	1,784.65	1,784.27	0.38

Table 13: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0906_A6

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	93,921	93,919	0.00%	1,623.58	1,623.38	0.20
4%	81,639	81,631	-0.01%	1,628.55	1,628.36	0.19
2%	110,359	110,365	0.01%	1,632.16	1,631.97	0.19
1%	142,934	142,933	0.00%	1,635.68	1,635.47	0.21
0.2%	265,277	264,064	-0.46%	1,645.86	1,645.71	0.15
1% minus	93,921	93,919	0.00%	1,630.17	1,629.98	0.19
1% plus	196,915	196,760	-0.08%	1,640.62	1,640.45	0.17

Table 14: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0907_A7

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	49,655	49,672	0.03%	1,537.56	1,537.46	0.10
4%	82,657	82,707	0.06%	1,542.93	1,542.84	0.09
2%	111,773	111,880	0.10%	1,546.67	1,546.54	0.13
1%	144,810	144,901	0.06%	1,550.23	1,550.03	0.20
0.2%	268,025	268,350	0.12%	1,560.14	1,559.99	0.15
1% minus	95,159	95,228	0.07%	1,544.62	1,544.51	0.11
1% plus	199,537	199,673	0.07%	1,555.09	1,554.93	0.16

Table 15: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0907_A8

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	51,579	51,515	-0.12%	1,321.66	1,321.57	0.09
4%	86,627	86,451	-0.20%	1,328.89	1,328.80	0.09
2%	120,409	120,027	-0.32%	1,334.31	1,334.20	0.11
1%	158,519	157,926	-0.38%	1,339.57	1,339.47	0.10
0.2%	278,439	277,105	-0.48%	1,351.68	1,351.56	0.12
1% minus	104,876	104,604	-0.26%	1,332.03	1,331.92	0.11
1% plus	217,272	216,239	-0.48%	1,345.93	1,345.80	0.13

Table 16: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0908_A9

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	75,458	74,937	-0.70%	1,171.34	1,170.84	0.50
4%	131,030	130,182	-0.65%	1,173.45	1,173.11	0.34
2%	184,345	183,087	-0.69%	1,175.27	1,174.80	0.47
1%	247,064	245,236	-0.75%	1,177.07	1,176.58	0.49
0.2%	430,890	427,588	-0.77%	1,181.37	1,180.92	0.45
1% minus	160,278	159,216	-0.67%	1,174.52	1,174.07	0.45
1% plus	340,623	338,169	-0.73%	1,179.46	1,179.00	0.46

Normal Depth Boundary Conditions

Since each 2D model domain extent included a buffer to the watershed boundary, the normal depth boundary conditions were applied along each 2D area perimeter to avoid ponding along the perimeter. At the main channel outflow or tributary inflow locations where other boundary conditions were already present, a normal depth boundary was not applied.

1.2.5. Reservoir Modeling

There were no major reservoirs in the San Saba watershed.

1.2.6. Computation Settings

The computation settings applied in the HEC-RAS models are listed below:

- The Diffusion Wave equation was used.
- A 96-hour simulation time was generally applied to capture the peaks and tails of the hydrographs.
- An advanced time step control based on the Courant number was applied as shown below in Figure 8. This option was chosen to decrease run times while generally maintaining Courant number values lower than 1.

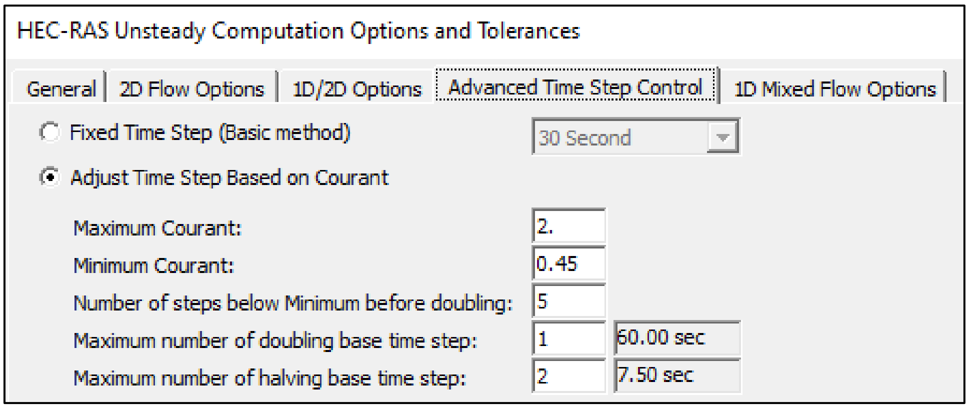


Figure 8: HEC-RAS Unsteady Computation Options and Tolerances

- Typical model run times with this advanced time step control setting were approximately 2 hours per simulation.
- The mapping and hydrograph output intervals were 10 minutes.

1.2.7. Regression Analysis

Regression flows were used for model validation where gage data was not available. The flow direction and flow accumulation grids created during the hydro-enforcement task were used to develop regression input parameter grids and regression peak flow grids for locations with drainage areas of 1 mi^2 or larger. The peak flows were computed using the regression equations documented in *Regression Equations for Estimation of Annual Peak-Streamflow Frequency for Undeveloped Watersheds in Texas Using an L-moment-Based, PRESS-Minimized, Residual-Adjusted Approach* (Asquith and Roussel 2009).

The contributing drainage area (A), mean-annual precipitation (P), dimensionless channel slope (S), and the basin-averaged OmegaEM parameter (Ω) were the input parameters for the regression equations. The regression equations are shown in Table 3 in the regression report (Asquith and Roussel 2009) and below on Figure 9.

Regression equation
$Q_2 = P^{1.398}\, S^{0.270} \times 10^{[0.776\Omega + 50.98 - 50.30A^{-0.0058}]}$
$Q_5 = P^{1.308}\, S^{0.372} \times 10^{[0.885\Omega + 16.62 - 15.32A^{-0.0215}]}$
$Q_{10} = P^{1.203}\, S^{0.403} \times 10^{[0.918\Omega + 13.62 - 11.97A^{-0.0289}]}$
$Q_{25} = P^{1.140}\, S^{0.446} \times 10^{[0.945\Omega + 11.79 - 9.819A^{-0.0374}]}$
$Q_{50} = P^{1.105}\, S^{0.476} \times 10^{[0.961\Omega + 11.17 - 8.997A^{-0.0424}]}$
$Q_{100} = P^{1.071}\, S^{0.507} \times 10^{[0.969\Omega + 10.82 - 8.448A^{-0.0467}]}$
$Q_{200} = P^{1.034}\, S^{0.531} \times 10^{[0.975\Omega + 10.61 - 8.058A^{-0.0504}]}$
$Q_{250} = P^{1.021}\, S^{0.541} \times 10^{[0.977\Omega + 10.56 - 7.943A^{-0.0516}]}$
$Q_{500} = P^{0.988}\, S^{0.569} \times 10^{[0.976\Omega + 10.40 - 7.605A^{-0.0554}]}$

Figure 9: Regression Equations for the San Saba Watershed

The lower and upper limits of the slope in the regression analysis were 0.00023 and 0.0703, respectively. The computed flows are sensitive to the channel slope and unreasonable flows tend to be computed when slopes are outside the range used in the regression analysis. Therefore, when the channel slope was less than 0.00023, 0.00023 foot per mile was used in place of the computed value. Similarly, when the channel slope exceeded 0.0703, 0.0703 was used in place of the computed value.

The average standard error of prediction (SEP) for the 1% annual-chance event was 64.8% according to the PRESS statistic in Table 3 of the regression report (Asquith and Roussel 2009). The 1% plus and 1% minus gridded flows were computed using the SEP as shown in the equations below. The 1% minus flows were not computed by multiplying the 1% flow by 1 minus SEP to avoid unreasonably low flows when the standard errors were large.

$$Q_{1\%plus} = Q_{100} \cdot (1.648)$$

$$Q_{1\%minus} = \frac{Q_{100}}{1.648}$$

1.2.8. Gage Analysis

The San Saba watershed was studied by the Interagency Flood Risk Management (InFRM) team's Watershed Hydrology Assessment (WHA) for the Lower Colorado River Basin. The WHA analyzed USGS gages 08144500 (San Saba River at Menard, TX), 08144600 (San Saba River near Brady, TX), and 08146000 (San Saba River at San Saba, TX) using the methodology in USGS Bulletin 17C to determine frequency-discharge curves for each gage.

The InFRM study computed two sets of frequency-discharge curves for the San Saba River at Menard gage and the San Saba River at San Saba gage. One set of curves was derived from the entire record of annual peak discharge data for the gage. The second set of curves was based on a subset of the full record of annual peak discharges. The WHA reported that research into trends in the peak annual discharges in the Colorado River basin have noted a statistically significant downward trend in most of the basin above San Saba, Texas, which includes the San Saba watershed. The InFRM study concluded that the streamflow declines could be attributed to the cumulative effect of multiple changes within the basin, such as increased evaporation due to reservoir and retention pond construction, increased reliance on irrigation use, and increased annual mean daily maximum temperatures. The timeframe when these decreases began varied from gage to gage. For the San Saba River at Menard gage, the inflection point was 1982. For the San Saba River at San Saba gage, the inflection point was 1981. To understand the potential effects of the downward trend in the peak annual flows on the frequency-discharge curves for the gages, the alternative analysis for each gage only considered the peak annual discharge data from the inflection year to 2020.

The InFRM study completed an alternative analysis for the San Saba River near Brady gage, but for different reasons. Peak annual discharge data was available for this gage from 1980-2020, whereas the period of record for the other two San Saba River gages was 1916-2020. The initial WHA Brady gage analysis considered the gage's original period of record (1980-2020). The alternative analysis used the annual discharge data from the Menard and San Saba gages (1916-2020) to statistically extend the Brady gage record to match the lengths of the Menard and San Saba records.

A description of the gage analyses in the WHA, the WHA's assumptions, and its results is included on pages 74 to 83, 86 to 93, and 151 of Chapter 5 of the InFRM's draft WHA report. A copy of these pages has been included in Appendix B of this report.

Table 17: Summary of the USGS Gages in the San Saba Watershed

Site No.	Site Name	Computed Drainage Area (mi^2)	Was Gage Analysis Performed?	Source of Gage Analysis	Reason Why Gage Analysis Was Not Performed to Support BLE Validation
08143905	N Valley Prong Trib nr Eldorado, TX	< 1	No	N/A	Drainage area was too small (less than 1 mi^2).
08144500	San Saba Rv at Menard, TX	1133.0	Yes	InFRM WHA	N/A
08144600	San Saba Rv nr Brady, TX	1633.2	Yes	InFRM WHA	N/A
08146000	San Saba Rv at San Saba, TX	3098.7	Yes	InFRM WHA	N/A

No additional gage analyses were performed for this BLE study.

The validation of the BLE results in the San Saba watershed considered the outcomes of the initial and alternative frequency-discharge analyses for each gage in the WHA. See Subsection 1.2.9 for additional details.

1.2.9. Model Validation

The San Saba BLE hydraulic models were validated using peak flow information available in the draft InFRM WHA and the effective Flood Insurance Study (FIS) report. For the streams where no InFRM or FIS flow information was available, the regression analysis previously discussed was used to validate the HEC-RAS models.

Validation checks were made at 79 locations throughout the San Saba watershed. The locations may be grouped as follows:

- Seventy-two validation locations compared the 1% BLE flows with the 1% minus, 1%, and 1% plus regression flows.
- Four validation locations compared the 1% BLE flows with the 1% minus, 1%, and 1% plus regression analysis flows and the 1% effective flow.
- One validation location compared the 1% BLE flow with the 1% minus, 1%, and 1% plus flows from the InFRM gage analysis; the 1% minus, 1%, and 1% plus regression flows; and the 1% effective flow.
- One validation location compared the 1% BLE flow with the 1% minus, 1%, and 1% plus flows from the InFRM gage analysis and the 1% effective flow.
- One validation location compared the 1% BLE flow with the 1% minus, 1%, and 1% plus flows from the InFRM gage analysis and the 1% minus, 1%, and 1% plus regression flows.

The validation locations were scattered throughout the watershed in locations that provided a comprehensive coverage of drainage areas and stream characteristics. Validation points were added where gage and effective flow information were available. The drainage areas of the validation points ranged from approximately 1 mi^2 to 3,099 mi^2.

The validation results may be summarized as follows:

- At the 78 locations where regression and/or gage flows were available, the validated BLE 1% flows were within the 1% plus and 1% minus range for 69 locations and outside the 1% plus and 1% minus bounds at 9 locations.
- At the 6 locations where the 1% effective flow was available, the BLE flow differed from the effective flow by a range of -57% to 62%. At 4 of the 6 locations, the BLE flows fell between the 1% minus and 1% plus regression flows or between the 1% minus and 1% gage flows. At one other location, the BLE flow fell outside of the regression range by only 7 cfs.

The 1% BLE flows, the 1% regression flows, the 1% gage flows, and the 1% effective flows applied during the validation process are shown in Table 22.

The first step of the validation effort was to review the initial BLE results. When the initial BLE flows fell outside of the 1% plus and 1% minus range of the gage or regression flows, the Manning's n and CN values were adjusted iteratively until the computed flows at as many validation points as possible were within the 1% plus and 1% minus range of the gage or regression flows. The Manning's n values were revised as needed, provided they remained within the ranges specified in Table 7. The AMC II CNs were adjusted by no more than ±10% of their initial values. If the computed flows were within the 1% plus and 1% minus range (i.e., valid), then the adjusted AMC II CNs and Manning's n values were used in the final model.

There were some model domains where these adjustments to the Manning's n and AMC II CN values did not sufficiently reduce the flows. In these domains, the Manning's n values were reset to their initial values and the baseline antecedent moisture conditions were revised from AMC II to AMC I. According to *Engineering Technical Note No. 210-18-TX5,* published by the Soil Conservation Service (SCS) in October 1990, antecedent moisture conditions in Texas vary from AMC II in the east to AMC I in the west. Since the San Saba watershed resides within the transition zone from AMC II to AMC I, it was reasonable to assume AMC I conditions were present in the watershed for validation purposes. See Figure 10 and Appendix B for a map from the SCS report showing the average antecedent moisture conditions across Texas.

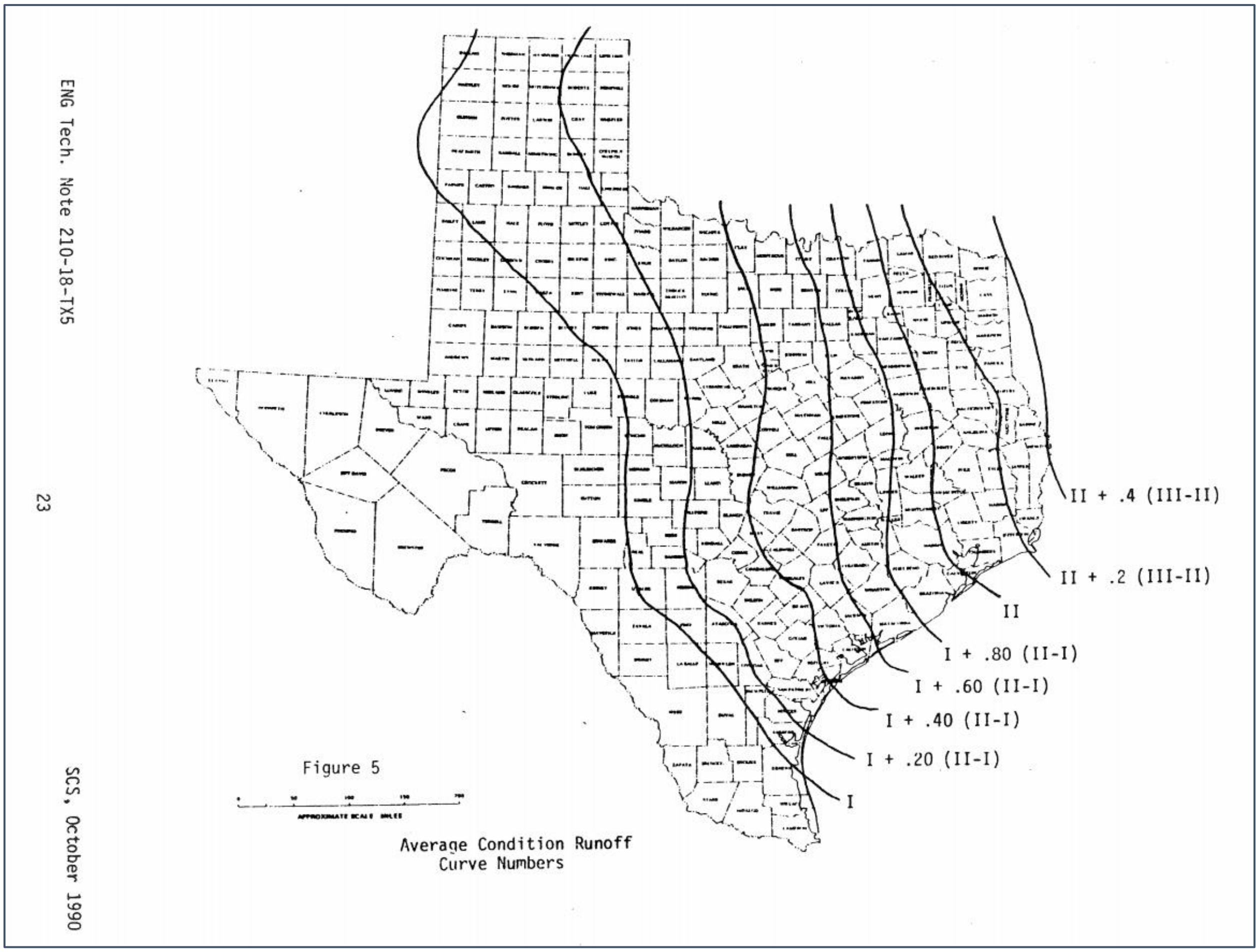


Figure 10: Typical Antecedent Moisture Conditions in Texas

A summary of the parameter adjustments made during the validation task is shown in Table 18.

Table 18: Summary of Parameter Adjustments Made in the San Saba Watershed

Model Domain	CN Adjustment	Overland n Adjustment	Channel n Adjustment	No. of Validation Locations	Pass	Fail
0901_A1	Reduced by 10% from AMC II	Maximum n	Raised to 0.045	6	6	0
0902_A2	Reduced by 10% from AMC II	Maximum n	Raised to 0.045	5	5	0
0903_A3	Reduced by 10% from AMC II	Maximum n	Raised to 0.05 for main channel and 0.045 for Tributaries	8	5	3
0904_A4	AMC I	Maximum n	Raised to 0.05 for main channel and 0.045 for Tributaries	14	13	1
0905_A5	Reduced by 10% from AMC II	No Change (Baseline n)	Raised to 0.045	16	15	1
0906_A6	Reduced by 5% from AMC II	No Change (Baseline n)	Raised to 0.045	7	7	0
0907_A7	Reduced by 5% from AMC II	No Change (Baseline n)	Raised to 0.045	7	7	0
0907_A8	No Change	No Change (Baseline n)	Raised to 0.050	7	6	1
0908_A9	AMC I	No Change (Baseline n)	Raised to 0.06 for main channel (from FIS) and 0.045 for Tributaries	9	6	3
			Total	**79**	**70**	**9**

During the validation process, domain-wide parameter adjustments were applied to the CNs and the Manning's n values to maximize the number of streams where the 1% BLE flows fell between the 1% minus and 1% plus regressions/gage flows. No particular area or tributary in a domain was considered a priority over the others when these adjustments were made. As a result, in areas where the stream/watershed characteristics were significantly different from the rest of the domain, some of the 1% BLE flows might fall outside of the 1% minus and 1% plus bounds. Other factors that contributed to the 1% BLE flows falling outside of the 1% minus and 1% plus bounds included differences in the regression, gage, effective, and 2D BLE analysis methodologies; the use of updated topographic data in the BLE analysis; and the higher NOAA Atlas 14 rainfall totals that were used in the BLE analysis.

The model validation process for domain 0908_A9 is described here. Iterative results from this process are presented in Table 19. This description is representative; a similar process was applied to all domains in the San Saba watershed. In Table 19, the flow values in green are within the 1% plus and 1% minus range of regression or gage flows, and the values in red are outside this range.

For Iteration 1, the baseline AMC II CNs and Manning's n values were simulated. The Iteration 1 results showed that the majority of the 1% BLE flows were higher than the 1% plus values. To reduce the computed flows, Iteration 2 lowered the AMC II CN values by 10% and increased the channel Manning's n value to 0.060 in the main channel and 0.045 along the tributaries. The Manning's n value of 0.060 for the San Saba main channel was obtained from the effective FIS report. These adjustments, however, continued to produce BLE flow rates higher than the 1% plus flows at 6 of the 9 validation locations.

To reduce the flows further, Iteration 3 reset the CNs from 90% of AMC II to baseline AMC I and maintained the higher channel Manning's n values of 0.060 in the main channel and 0.045 along the tributaries. Iteration 3 improved the validation results. Six validation locations were within 1% plus and 1% minus validation range and 3 validation locations were outside the 1% plus and 1% minus validation range. The results of Iteration 3 showed that for the smaller tributaries, the computed BLE flow values were similar to the 1% regression estimate, and for larger streams, such as the San Saba River, the computed flows were higher than the 1% regression estimates.

Table 19: Summary of the Model Validation Process for Domain 0908_A9

Validation Location	Name	Drainage Area (mi²)	Regression/Gage Flows (cfs)			Iteration 1	Iteration 2	Iteration 3
			1%-	1%	1%+	Initial CN and n	90% CN and Increased Channel n	AMC I and Increased Channel n
Pt 1	Unnamed Creek	1.6	656	1,082	1,783	2,195	2,200	1,154
Pt 2	Unnamed Creek	64.8	7,742	12,759	21,027	11,720	10,929	5,979
Pt 3	Wallace Creek	52.1	6,723	11,080	18,260	26,976	21,237	11,830
Pt 4	Richland Springs Creek	19.8	3,555	5,859	9,656	21,690	18,054	10,197
Pt 5	Dry Simpson Creek	5.9	1,403	2,312	3,811	6,168	5,017	2,826
Pt 6	Wallace Creek	45.3	6,271	10,335	17,032	21,295	17,120	9,493
Pt 7	Wallace Creek	14.4	2,591	4,270	7,037	4,474	2,907	1,559
Pt 8	Barnett Springs Creek	7.9	1,747	2,879	4,740	6,445	5,889	3,369
Outfall	San Saba River	3,098.7	87,800*	145,000*	360,000*	256,125	255,578	246,570

* Flow rate from InFRM gage analysis (USGS gage 08146000)

A comparison among the 1% BLE, effective, and gage flows from the InFRM study for the San Saba River is shown in Table 20.

At the three USGS gages in the San Saba watershed, the following observations were made.

- The 1% BLE flow was 2 to 10% higher than the InFRM 1% estimates for gage 08144500 (Menard, TX)
- At gage 08144600 (near Brady, TX), the 1% BLE flow was 2 to 20 % higher than the InFRM 1% estimates
- At gage 08146000 (San Saba, TX), the 1% BLE flow was 70 to 280% higher than the InFRM 1% estimates, however, it was within the 1% plus and 1% minus range for both gage analyses

Gage 08146000 is located near the downstream end of model domain 0908_A9. This gage is the most downstream gage on the San Saba River before its confluence with the Colorado River. In addition to including nearly all of the San Saba watershed in its contributing drainage area, the gage's drainage area also includes the Brady watershed (HUC-8 12090110). For the 1% BLE simulation, two inflows were applied to the 0908_A9 domain, one from the San Saba River and one from Brady Creek. The 1% inflow from the San Saba River was approximately 158,000 cfs, and the 1% inflow from Brady Creek was roughly 80,000 cfs. Furthermore, the BLE model received 1% rainfall as an additional hydrologic input. The combined peak 1% BLE flow at the gage was approximately 247,000 cfs.

Although the 1% BLE flow of 247,000 cfs was significantly higher than the 1% gages flows computed at the gage (145,000 cfs and 88,000 cfs), the 1% BLE flow fell between the 1% minus flows and the 1% plus flows computed at the gage. When compared with the effective 1% flow at the gage (151,366 cfs), the 1% BLE flow was 63% higher. One reason why the 1% BLE is higher than the 1% gages flows and the 1% effective flow is the BLE modeling approach assumed that the 1% storm occurs simultaneously over the entire study area, which included most of the San Saba watershed and all of the Brady watershed. Although the 1% event is not likely to occur simultaneously over an area of this size, modeling domain 0908_A9 in this fashion is an acceptable approach in a BLE assessment.

Finally, along the San Saba River between State Route 864 and the river's confluence with Twomile Creek, the effective 1% flow rates were 20% to 30% higher than the computed 1% BLE flows.

Table 20: Comparison of 1% BLE, Gage, and Effectives Flows along the San Saba River

Gage ID	Location	Area (mi^2)	BLE 1% Flow (cfs)	InFRM Bulletin 17C Analysis Gage Flows (cfs)			FIS 1% Flow (cfs)	% Difference	
				1% Minus	1%	1% Plus		BLE Vs. Gage	BLE Vs. FIS
n/a	San Saba River Upstream of State Route 864	632	99,232	-	-	-	124,000	-	-20.0
08144500	San Saba River at Menard, TX	1,133	138,528	84,200	136,000	305,000	177,000	1.9	-21.7
				Alternate analysis - 43,500	Alternate analysis - 126,000	Alternate analysis - 8,540,000		9.9	
n/a	San Saba River at Confluence with Two-mile Creek	1,356	138,424	-	-	-	190,000	-	-27.1
08144600	San Saba River nr Brady, TX	1,633	144,810	53,100	121,000	1,030,000	n/a	19.7	-
				Alternate analysis - 86,600	Alternate analysis - 141,000	Alternate analysis - 277,000		2.7	
08146000	San Saba River at San Saba, TX	3,046	246,570	87,800	145,000	360,000	151,366	70.0	62.9
				Alternate analysis - 39,900	Alternate analysis - 88,000	Alternate analysis - 559,000		280	

A comparison between the 1% BLE WSELs and select effective 1% WSELs for the San Saba River is presented in Table 21. The effective 1% WSELs were estimated using BFEs from a proprietary digitized effective floodplain mapping dataset developed by RMSI and acquired by AtkinsRéalis. The effective FIS reports for Menard County, TX and San Saba County, TX noted that the San Saba River in Menard County was studied from 1984 to 1986 using HEC-2 and in San Saba County from 1989 to 1990 using WSP-2. For the San Saba River, the 1% BLE WSELs were similar to those in the effective study. Factors that likely contributed to the differences in the WSELs include the study methodologies, the 1D nature of the effective analysis vs. the 2D approach in the BLE analysis, the lack of structures in the BLE analysis, the use of updated topographic data in the BLE analysis, and the higher NOAA Atlas 14 rainfall totals that were used in the BLE analysis.

Table 21: Comparison of 1% Effective WSELs and 1% BLE WSELs

Location	Effective 1% WSEL (feet)	BLE 1% WSEL (feet)	Difference (Eff. - BLE) (feet)
San Saba River at US Highway 864	2,065.25	2,062.74	2.51
San Saba River at Texas Forts Tri Rd	1,891.25	1,891.74	-0.49
San Saba River at USGS Gage 08144500	1,889.25	1,889.99	-0.74
San Saba River at 5B Ranch Rd	1,786.18	1,787.99	-1.81
San Saba River at USGS Gage 08146000	1,202.18	1,201.09	1.09
San Saba River in the City of San Saba at the downstream detailed study limit	1,196.12	1,196.19	-0.07

* A vertical datum conversion of +0.124 feet was used to convert the effective WSELs from NGVD 29 to NAVD 88.

See Figure 11 and Table 22 on the following pages for a summary of the 1% validation results at the validation points in the San Saba watershed.

The model overview and results spreadsheet (*San_Saba_Model_Overview_and_Results.xlsx*) has been placed in the task documentation folder of this submittal. The validation locations are included in the HEC-RAS models and may also be found on the validation location maps for each domain in the model overview and results spreadsheet.

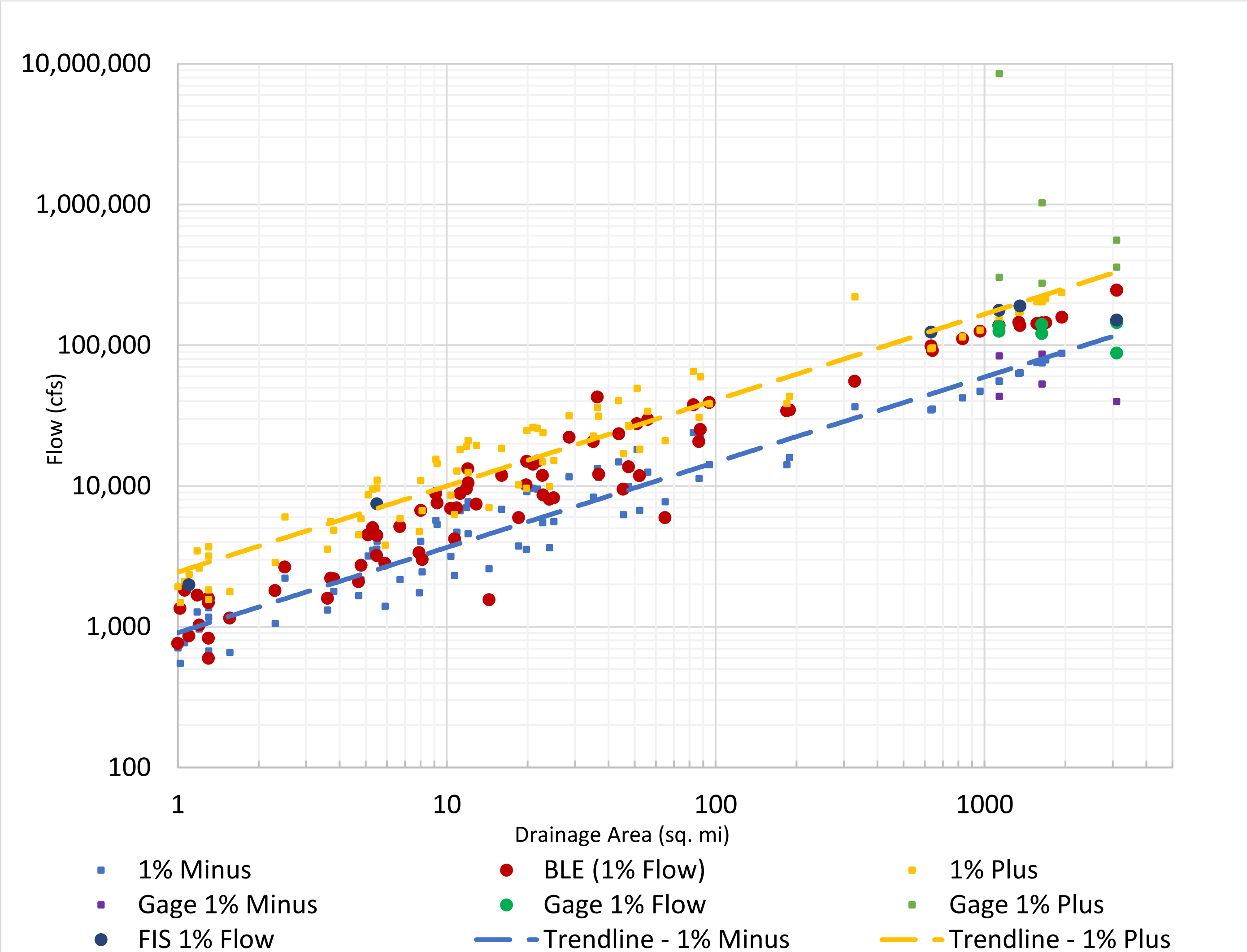


Figure 11: Computed Flow vs Drainage Area of Select BLE, Regression, FIS, and Gage 1% Flows

Table 22: 1% Peak Flow Validation Results for the San Saba Watershed

Point ID	Validation Point Name	Drainage Area (mi²)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Domain 0901_A1										
Pt1	North Valley Prong	188.1	15,955	26,294	43,332	34,696	-	-	-	-
Pt2	Unnamed	3.8	1,787	2,945	4,854	2,191	-	-	-	-
Pt3	Unnamed	18.5	3,754	6,186	10,194	5,964	-	-	-	-
Pt4	North Valley Prong	1.0	708	1,167	1,924	763	-	-	-	-
Pt5	North Valley Prong	4.8	2,160	3,559	5,866	2,730	-	-	-	-
Outfall	North Valley Prong	329.2	36,586	60,293	222,000	55,609	-	-	-	-
Domain 0902_A2										
Pt1	Unnamed	1.2	965	1,590	2,621	1,028	-	-	-	-
Pt2	Unnamed	3.7	2,058	3,391	5,589	2,213	-	-	-	-
Pt3	Unnamed	8.1	2,460	4,054	6,680	3,004	-	-	-	-
Pt4	Unnamed	22.7	5,489	9,046	14,908	11,914	-	-	-	-
Outfall	Middle Valley Prong	183.8	14,207	23,413	38,584	34,264	-	-	-	-

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Domain 0903_A3										
Pt1	San Saba River	640.0	35,365	58,281	96,047	91,973	-	-	-	-
Pt2	Unnamed	2.3	1,055	1,738	2,864	1,812	-	-	-	-
Pt3	Unnamed	12.0	4,594	7,571	12,477	10,528	-	-	-	-
Pt4	Unnamed	94.7	14,178	23,366	38,507	39,155	-	-	-	-
Pt5	Unnamed	5.1	3,186	5,251	8,654	4,499	-	-	-	-
FIS 1	San Saba River - Upstream of State Route 864	632.4	34,871	57,467	94,706	99,232	-	-	-	124,000
FIS 2	Rattlesnake Draw - Downstream of confluence of Stream RD-1	1.1	867	1,428	2,354	860	-	-	-	1,990
Outfall	Rocky Creek	827.9	42,309	69,724	114,906	111,122	-	-	-	-
Domain 0904_A4										
Pt1	Celery Creek	25.0	5,606	9,239	15,225	8,243	-	-	-	-
Pt2	Unnamed	4.7	1,664	2,742	4,519	2,094	-	-	-	-

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Pt3	North Fork Dry Creek	3.6	1,316	2,169	3,574	1,593	-	-	-	-
Pt4	Dry Creek	24.1	3,659	6,030	9,937	8,056	-	-	-	-
Pt5	Dry Creek	10.7	2,312	3,811	6,280	4,206	-	-	-	-
Pt6	Dry Creek	1.3	673	1,109	1,828	831	-	-	-	-
Pt7	Dry Creek	86.7	11,322	18,659	30,751	20,670	-	-	-	-
Pt8	Celery Creek	47.4	9,936	16,374	26,984	13,733	-	-	-	-
Pt9	Unnamed	1.3	577	951	1,567	598	-	-	-	-
Pt10	San Saba River	962.0	47,289	77,933	128,433	126,048	-	-	-	-
Pt11	Las Moras Creek	22.8	8,825	14,544	23,968	8,648	-	-	-	-
Pt12	West Las Moras Creek	36.7	11,546	19,028	31,358	12,153	-	-	-	-
Pt13	Las Moras Creek	87.8	22,036	36,316	59,849	25,208	-	-	-	-
Outfall	San Saba River	1,133.0	55,684	91,767	151,233	138,970	-	-	-	-
Domain 0905_A5										

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
FIS 1 (USGS Gage 08144500)	San Saba River	1,133.3	55,685	91,769	151,235	138,528	84,200 Alternate analysis - 43,500*	136,000 Alternate analysis - 126,000*	305,000 Alternate analysis - 8,540,000*	177,000
FIS 2	Harris Hollow	5.5	4,062	6,694	11,032	4,452	-	-	-	7,460
Pt1	Unnamed	10.9	4,705	7,754	12,779	7,002	-	-	-	-
Pt2	Scalp Creek	35.1	8,351	13,763	22,682	20,747	-	-	-	-
Pt3	Unnamed	16.0	6,841	11,273	18,578	11,896	-	-	-	-
Pt4	Elm Creek	36.3	13,339	21,983	36,228	42,947	-	-	-	-
Pt5	Elm Creek	28.5	11,648	19,196	31,636	22,230	-	-	-	-
Pt6	Unnamed	9.1	5,702	9,396	15,485	8,856	-	-	-	-
Pt7	Elm Creek	5.3	3,501	5,770	9,509	5,055	-	-	-	-
Pt8	Unnamed	1.3	1,171	1,930	3,180	1,488	-	-	-	-
Pt9	East Elm Creek	2.5	2,224	3,666	6,041	2,665	-	-	-	-
Pt10	East Scalp Creek	6.7	2,163	3,565	5,875	5,154	-	-	-	-
Pt11	Unnamed	8.0	4,041	6,660	10,975	6,704	-	-	-	-

Point ID	Validation Point Name	Drainage Area (mi²)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Pt12	Taylor Branch	11.2	6,699	11,041	18,195	8,843	-	-	-	-
Pt13	Taylor Branch	1.3	1,365	2,249	3,706	1,590	-	-	-	-
Outfall (0905_A5_ Outfall)	San Saba River	1,340.3	63,200	104,153	171,644	145,532	-	-	-	-
Domain 0906_A6										
Pt1	Unnamed	1.2	1,275	2,100	3,462	1,679	-	-	-	-
Pt2	Twomile Creek	9.2	5,333	8,789	14,484	7,576	-	-	-	-
Pt3	Calf Creek	55.9	12,536	20,660	34,048	29,693	-	-	-	-
Pt4	Fivemile Creek	19.8	9,144	15,070	24,835	15,004	-	-	-	-
Pt5	Tenmile Creek	21.8	9,504	15,662	25,812	15,076	-	-	-	-
FIS1	San Saba River	1,356.2	63,911	105,325	173,575	138,424	-	-	-	190,000
Outfall	San Saba River	1,565.1	75,460	124,358	204,942	142,934	-	-	-	-
Domain 0907_A7										
Pt1	Unnamed	1.0	549	904	1,490	1,355	-	-	-	-
Pt2	Staten Creek	10.3	3,174	5,231	8,621	6,938	-	-	-	-

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Pt3	Katemcy Creek	43.6	14,909	24,570	40,492	23,558	-	-	-	-
Pt4	Dry Prong Katemcy Creek	20.9	9,645	15,895	26,195	14,281	-	-	-	-
Pt5	Cavin Branch	11.8	7,059	11,633	19,170	9,561	-	-	-	-
Pt6 (USGS Gage 08144600)	San Saba River	1,633.2	75,354	124,183	204,654	144,200	53,100 Alternate analysis - 86,600*	121,000 Alternate analysis - 141,000*	1,030,000 Alternate analysis - 277,000*	-
Outfall	San Saba River	1,688.0	78,810	129,879	214,041	144,810	-	-	-	-
Domain 0907_A8										
Pt1	Unnamed	1.06	772	1,273	2,097	1,819	-	-	-	-
Pt2	Lost Creek	51.0	18,237	30,055	49,531	27,764	-	-	-	-
Pt3	Tiger Creek	82.6	24,048	39,632	65,313	37,794	-	-	-	-
Pt4	Tiger Creek	12.9	7,166	11,810	19,462	7,439	-	-	-	-
Pt5	Tiger Creek	5.5	3,565	5,875	9,682	3,208	-	-	-	-
Pt6	Deer Creek	12.0	7,757	12,784	21,068	13,259	-	-	-	-

Point ID	Validation Point Name	Drainage Area (mi²)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Outfall	San Saba River	1,938.1	87,652	144,450	238,054	158,519	-	-	-	-
Domain 0908_A9										
Pt1	Unnamed Creek	1.6	656	1,082	1,783	1,154	-	-	-	-
Pt2	Unnamed Creek	64.8	7,742	12,759	21,027	5,979	-	-	-	-
Pt3	Wallace Creek	52.1	6,723	11,080	18,260	11,830	-	-	-	-
Pt4	Richland Springs Creek	19.8	3,555	5,859	9,656	10,197	-	-	-	-
Pt5	Dry Simpson Creek	5.9	1,403	2,312	3,811	2,826	-	-	-	-
Pt6	Wallace Creek	45.3	6,271	10,335	17,032	9,493	-	-	-	-
Pt7	Wallace Creek	14.4	2,591	4,270	7,037	1,559	-	-	-	-
Pt8	Barnett Springs Creek	7.9	1,747	2,879	4,740	3,369	-	-	-	-
Outfall (USGS Gage 08146000)	San Saba River	3,098.7	-	-	-	246,570	87,800 Alternate analysis – 39,900*	145,000 Alternate analysis – 88,000*	360,000 Alternate analysis – 559,000*	151,366

* See Subsection 1.2.8 and Appendix B for details regarding the two analyses completed for each USGS gage.

1.3. Floodplain Delineation (10%, 1%, and 0.2% events)

Floodplains were delineated throughout the entire watershed for the 10%, 1%, and 0.2% annual-chance events. The 1% and 0.2% floodplains may be found in the FLD_HZD_AR feature class in the flood risk database. The 10% floodplain may be found in the TENPCT_FP feature class in the database.

The floodplains were derived from the raw modeled grids using the maximum water surface elevation and depth values in each cell of the mesh. These grids were exported from HEC-RAS as rasters in TIF format with an interpolated rendering that slopes values at the center and along the faces/edges of the computational mesh cells. Using GIS software, the TIF rasters were post-processed into 10%, 1%, and 0.2% annual-chance floodplains.

The following general steps were completed to delineate the floodplains:

- Export the depth rasters and WSEL rasters for the 10%, 1%, and 0.2% ACEs from the HEC-RAS models using a sloping water surface elevation render mode to a GIS environment. When exporting the model results, the "Raster based on terrain" parameter in HEC-RAS was changed from "Terrain.HydroEnforced" to "Terrain." This change was made so the original terrain surface was used to develop the floodplain mapping, not the hydro-enforced terrain surface. Using the hydro-enforced terrain would have led to mapping that would have incorrectly shown the roadway as being overtopped where the hydro-enforced culverts had been added.
- For each ACE, merge the raw WSEL rasters into a single raster that covers the entire watershed. Do the same for the depth rasters. Where the floodplain mapping needed to tie-in across two model domains, the model domain boundaries overlapped. Tie-in locations were identified in these overlap areas using split line shapefiles. Three split line shapefiles were created, one for each of the mapped events (i.e., 10%, 1%, and 0.2%). Split line alignments for each event were determined by creating difference rasters that subtracted the WSEL rasters from one another in the model domain overlap areas. Split lines were then drawn around the entire perimeter of each model domain through areas where the WSELs in the difference rasters were within 0.5 feet of each other. See the split line shapefiles in the *Supplement Data* folder to understand where the mapping tie-ins are located.
- To understand how a split line is placed, consider Figure 12 which shows two floodplains that overlap along a model domain boundary. The split line must be placed where the WSELs are within 0.5 feet of one another in the overlap area. To determine where the WSELs meet this criterion, a WSEL difference raster was created.

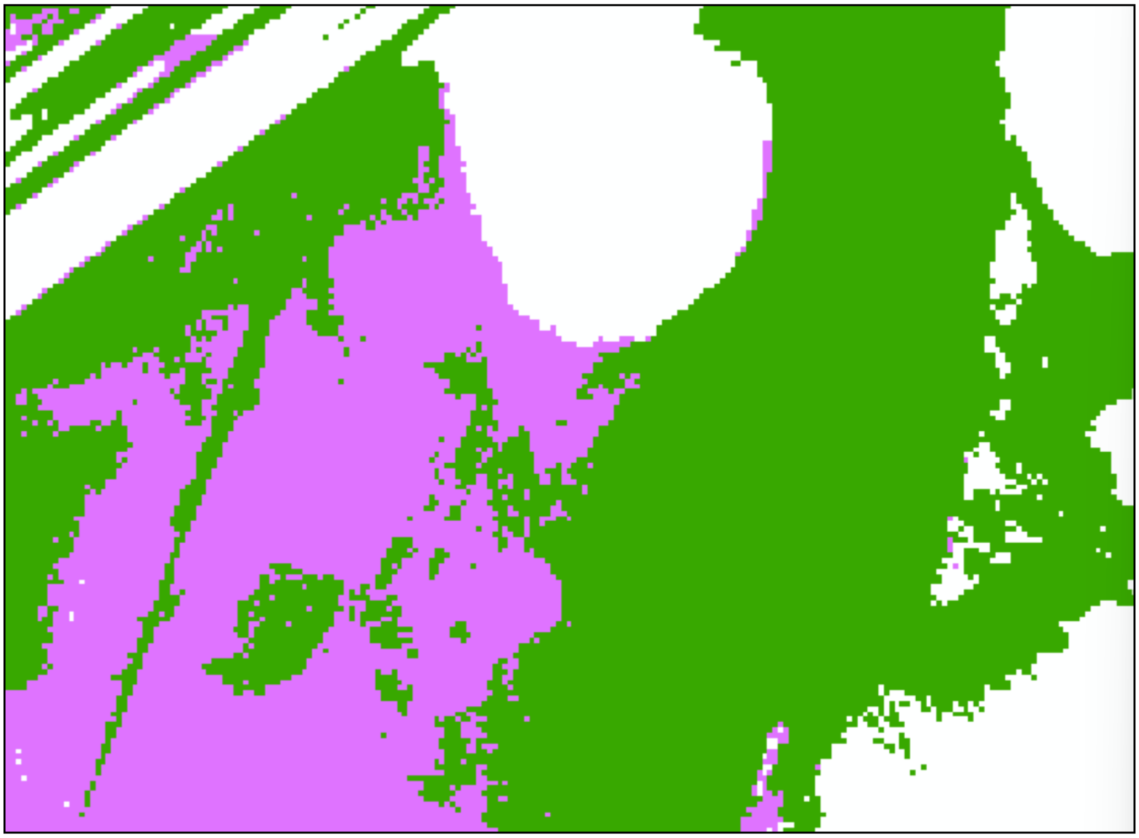


Figure 12: Example of Overlapping Mapping along a Model Domain Boundary

Figure 13 shows what the difference raster looks like for the area in Figure 12. Light green means the WSELs are within 0.5 feet of each other and red means they are not. The blue-black line is the split line. It has been aligned so that it crosses the difference raster where the raster is light green. To the south of this line, the purple raster in Figure 12 is the source of the floodplain mapping. To the north of the split line, the dark green raster is the source of the floodplain mapping. Along the split line is where the source of the mapping transitions from the purple mapping to the dark green mapping.

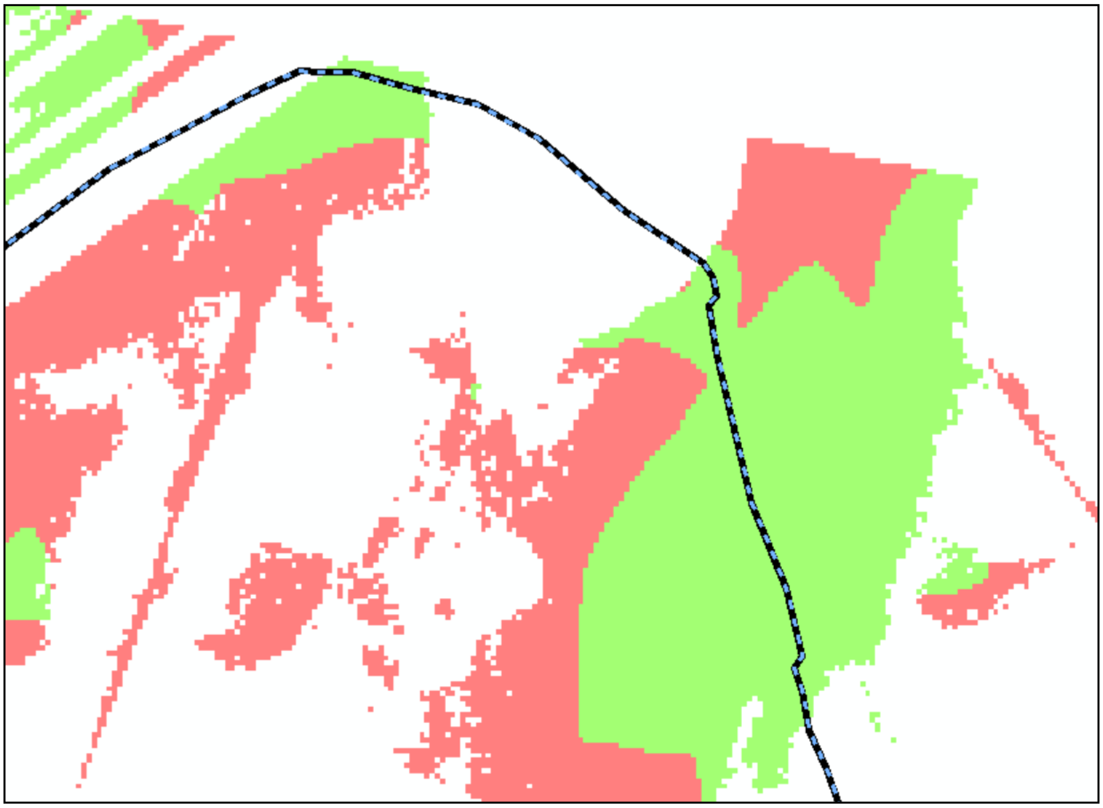


Figure 13: WSEL Difference Raster and Split Line for the Overlap Area

- The merged raw raster grids included connected and disconnected areas of potential flood hazard. To reduce the extent of these disconnected flood areas, process the rasters to filter and remove disconnected small, shallow areas of flooding. To do this, apply the TWDB's mapping threshold matrix to remove shallow depths, small areas of flood risk, and disconnected areas. According to Figure 3.1 in TWDB's 2D BLE guidelines, the watershed falls in the Inland Areas of Texas. Therefore, disconnected areas were removed if they met ***both*** of the criteria in Table 23.

Table 23: Inland Mapping Threshold Matrix

Area (acres)	Depth (feet)
Less than 0.33	Remove all flooding
0.33 to 0.50	Less than 0.33
0.50 to 1.0	Less than 0.25
1.0 to 2.0	Less than 0.10

- Fill the holes (i.e., islands) in the rasters using the Elevation Void Fill routine. For the 1% and 0.2% ACEs, holes in the rasters less than 2 acres were filled. For the 10% ACE, holes in the raster less than 0.5 acres were filled. Application of the Elevation Void Fill routine occasionally produces WSELs that are below the ground elevation. In cases where this phenomenon occurred, the WSELs were not revised from their subterranean values, but the depths at these locations were set to 0.1 feet.
- Convert each WSEL raster to a floodplain polygon.

- Many ponding areas were present throughout the watershed. Due to the large mesh cells used in the 2D modeling, the extent of the smaller ponds was not always mapped properly in the model output. To properly identify the flood hazard in these areas, transfer the ponding extents available in the National Hydrography Dataset into the 1% and 0.2% floodplain polygons. Do not transfer them into the 10% floodplain polygon.
- If any dams are present that have been catalogued by the National Inventory of Dams and include a normal pool storage of 200 acre-feet or more, review the spillway mapping along each dam. If the 1% and/or the 0.2% model output did not include any flooding along the spillway, manually revise the floodplain polygon(s) to flood the spillway.
- Add waterbodies of lake and reservoir inundation areas of 20 acres or greater to the WTR-LN and FLD_HAZ_AR feature classes. The National Inventory of Dams was used to identify dams with inundation areas greater than 20 acres. The areas of inundation were computed by measuring the areas of the normal pools visible on the aerial photography.
- Clean up each polygon by simplifying it and smoothing it. The intent of the simplify and smooth processes is to eliminate unnecessary/erroneous vertices, remove rough edges, and reduce the size and complexity of the raw floodplain polygons. Apply professional judgement to determine the appropriate tolerance for simplifying and smoothing the floodplain polygons. Set initial thresholds to 5 feet for simplifying and 25 feet for smoothing.
- Merge the 1%, and 0.2% ACE polygons into one feature class. Keep the 10% ACE polygon as a separate feature class.
- The extents of the final depth and WSEL grids must match the extents of the flood inundation polygons. Because of the clipping and smoothing procedures applied to the floodplain polygons, they will no longer match the extents of the rasters. Clip the depth and WSEL grids to each respective flood frequency inundation polygon to align the extents of the rasters with the extents of the floodplain polygons.
- Clip the rasters and the floodplain polygons using the HUC-8 watershed boundary.

Challenges

A handful of challenges were encountered during the San Saba BLE analysis. These challenges and their solutions are catalogued in the following subsections.

Balancing Flows between Small and Large Streams

The BLE models developed for the San Saba watershed are watershed-wide models. Each domain is similar in size to a HUC-10 watershed. As a result, streams with both large and small drainage areas are in the same model and cannot be isolated from one another. One of the main challenges of the BLE analysis was adjusting the model input parameters so that valid flows were produced along streams with both large and small drainage areas. For example, when the CNs were increased to increase flows that were too low along the smaller tributaries, this adjustment would occasionally lower the flows along the more significant streams to a point below the lower end of that which was considered valid, and vice versa. To address this challenge, a range of acceptable CNs and Manning's n values was established for the watershed. The parameters were adjusted only within this set range so that the model results did not skew the too heavily in favor of the larger streams or the smaller streams. Balancing the validation needs between the small and large stream was further enhanced by assigning an equal weight to all validation locations and choosing validation locations such that a representative coverage of drainage areas and stream characteristics was included.

Modeling of Hydraulic Structures

Although detailed modeling of hydraulic structures was outside the scope of this BLE analysis, completing ignoring the structures would have produced invalid model results. Therefore, hydraulic structures were modeled using as simplified approach. This included adding breaklines along dam crests, elevated roadways, and railroads to force the terrain surface to drain properly. Bridge and culvert openings were represented by hydro-enforcing burn lines that were roughly equal in width to the bridge and culvert opening sizes. The addition of breaklines at the dam crests throughout AtkinsRéalis' BLE study area typically resulted in an overestimation of the 1% BLE floodplain extents and WSELs on the upstream side of the dam. On the downstream side of the dams, the floodplains and flows tended to be underestimated.

Cupping

Within HEC-RAS, the RAS Mapper interface provides three render modes for visualization of floodplains: Horizontal, Sloping, and Hybrid. Currently, the results of only the horizontal and sloping render modes can be exported. While the horizontal render mode produces "bathtubs" of isolated ponding per cell, the sloping render mode produces "cupping." Cupping is a ramp-up of the depth in the overbanks occurring most often in areas of significant topographic relief. USACE's HEC is aware of this issue, which is an error caused by the WSEL projecting to the adjacent cell's average elevation. However, the timeframe for a solution to this error by the HEC is unknown. Since the TWDB mapping process is based on the sloping render mode output, this cupping effect can be identified in the final mapping products produced, as shown by the pink areas in Figure 14. The areas of cupping will not be removed or cleaned beyond the extents of the mapping cleanup process discussed herein. There is significant topographic relief throughout the San Saba watershed. Therefore, cupping is prevalent throughout the BLE mapping.

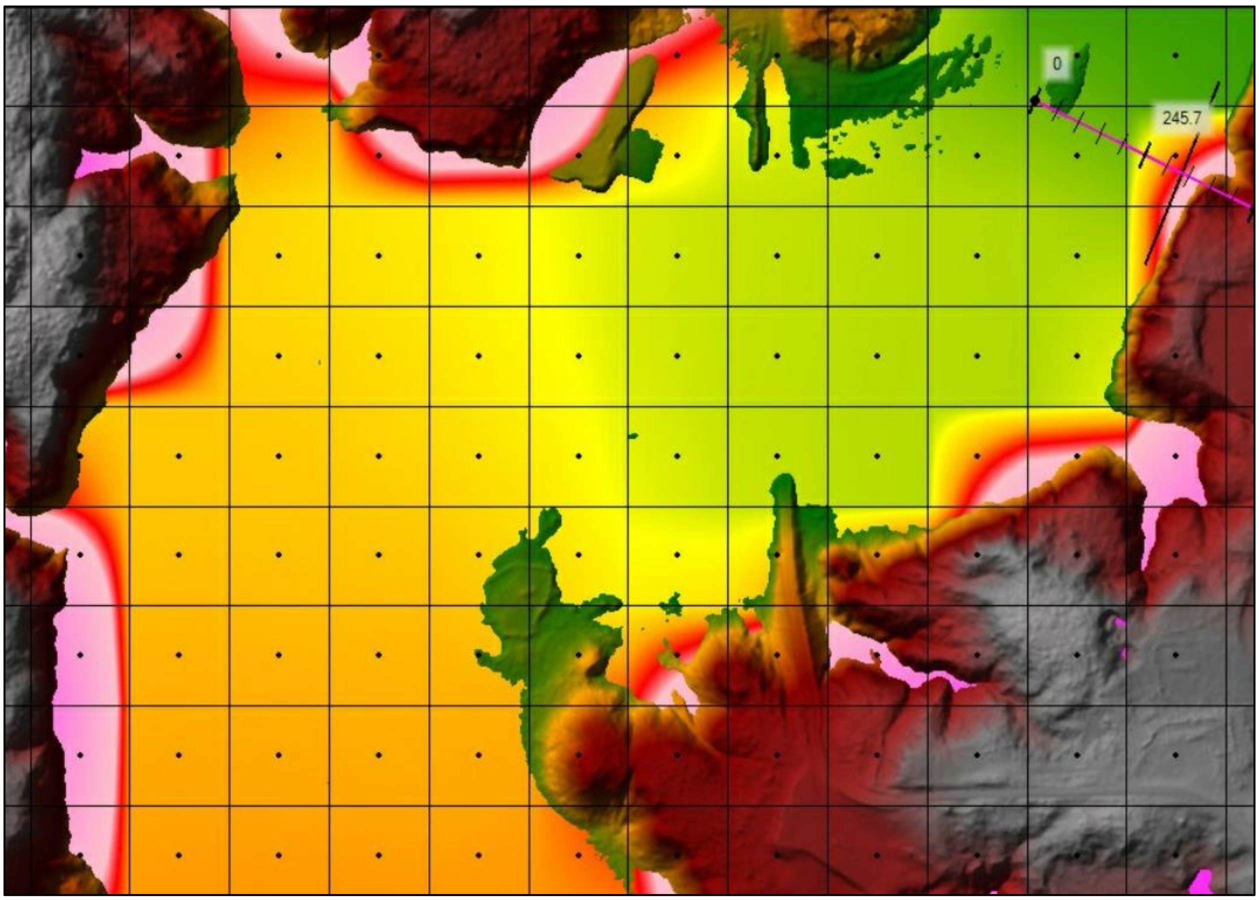


Figure 14: An Example of Cupping in 2D BLE Mapping

Results and Recommendations

The BLE results for the San Saba watershed produced floodplain boundaries that compare reasonably well with the effective Special Flood Hazard Areas (SFHA) in most cases, and provide an estimated 1% annual-chance floodplain in areas that are currently not mapped by FEMA. These results provide context for flood risk communication as part of the Discovery process and should be verified through community work map meetings before application to a regulatory product.

A map showing the BLE results for the San Saba watershed has been included as Appendix A.

The BLE floodplains were compared with the effective floodplains in the San Saba watershed. No digital mapping data was available in the National Flood Hazard Layer (NFHL) for the watershed. Digitized effective floodplain mapping was available in a proprietary dataset developed by RMSI and acquired by AtkinsRéalis. The RMSI dataset included digital floodplain boundaries for Menard, Sutton, and San Saba counties. A comparison of the effective and BLE 1% boundaries revealed that the updated BLE floodplain boundaries were more defined than the effective floodplains. The BLE floodplains exhibited generally good agreement with the effective mapping, although occasionally the effective floodplains were wider while, at other times, the BLE floodplains were wider.

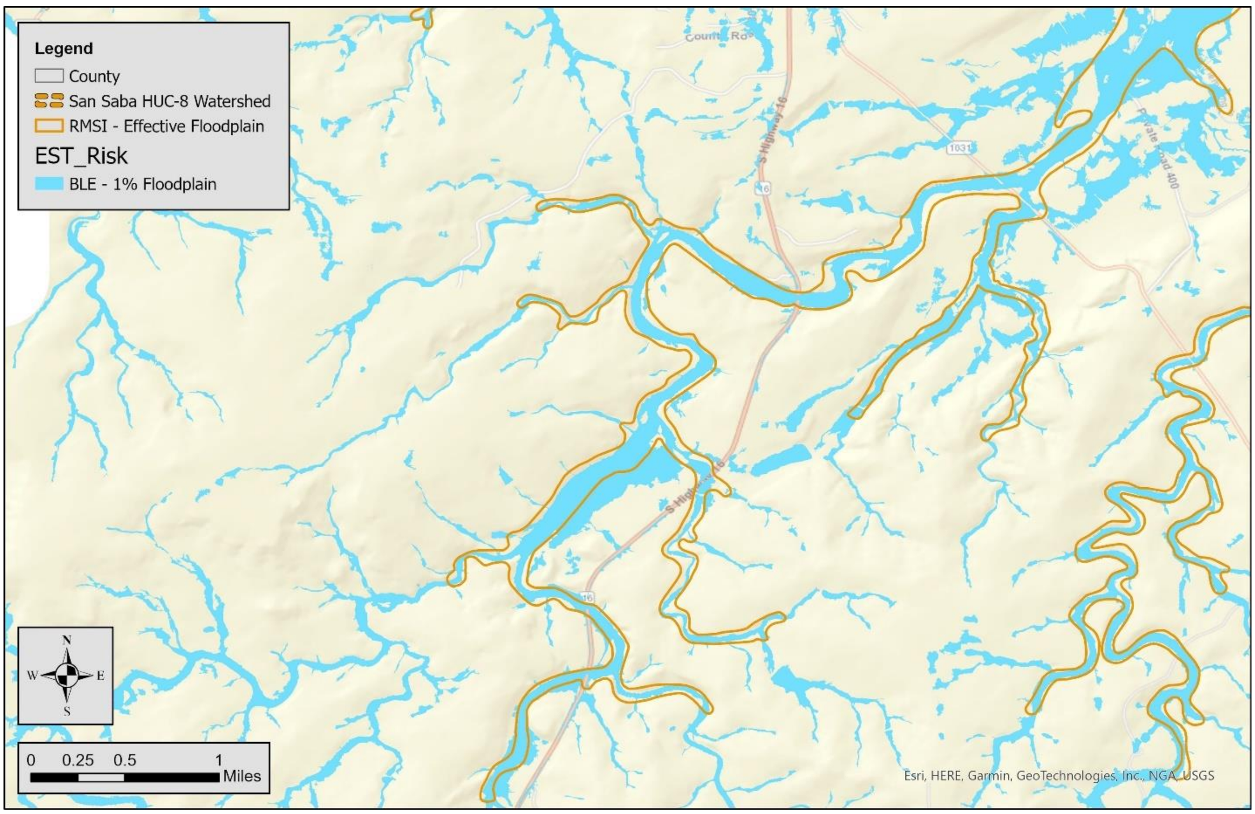


Figure 15: The Effective 1% Floodplain and the 1% BLE Floodplain in San Saba County, TX

Floodplain mapping for the San Saba watershed was also available from a contractor called Fathom. The TWDB acquired cursory floodplain data from Fathom to fill gaps in areas where no floodplain mapping was available in Texas. The Fathom floodplain dataset included pluvial, fluvial, and coastal storm surges produced using models developed at a 30-meter resolution for the entire state of Texas. The 30-meter Fathom models incorporated LiDAR data provided by the TWDB and NOAA Atlas 14 rainfall data in all areas of the state. Fathom model results were mapped to a 3-meter resolution. Fluvial and pluvial cells with depths less than 0.5 feet were removed from the results of the mapping dataset. The use of this dataset should be limited to areas where no other data source has been identified or areas where flood hazard information is outdated or unreliable. Limited use of this dataset is recommended due to limitations with accuracy, resolution, and age of the underlying datasets.

The 2D BLE results for the San Saba watershed were compared with the Fathom floodplain mapping. Figure 16 shows the 1% BLE mapping in blue with a transparency applied and the 1% Fathom mapping in black in the same area that is shown in Figure 15, but zoomed out to include San Saba River at the downstream end of the watershed (red line). In general, there was good agreement between the mapping from these two sources. However, there are examples of pluvial mapping in the figure that are more extensive in the BLE mapping than in the Fathom mapping.

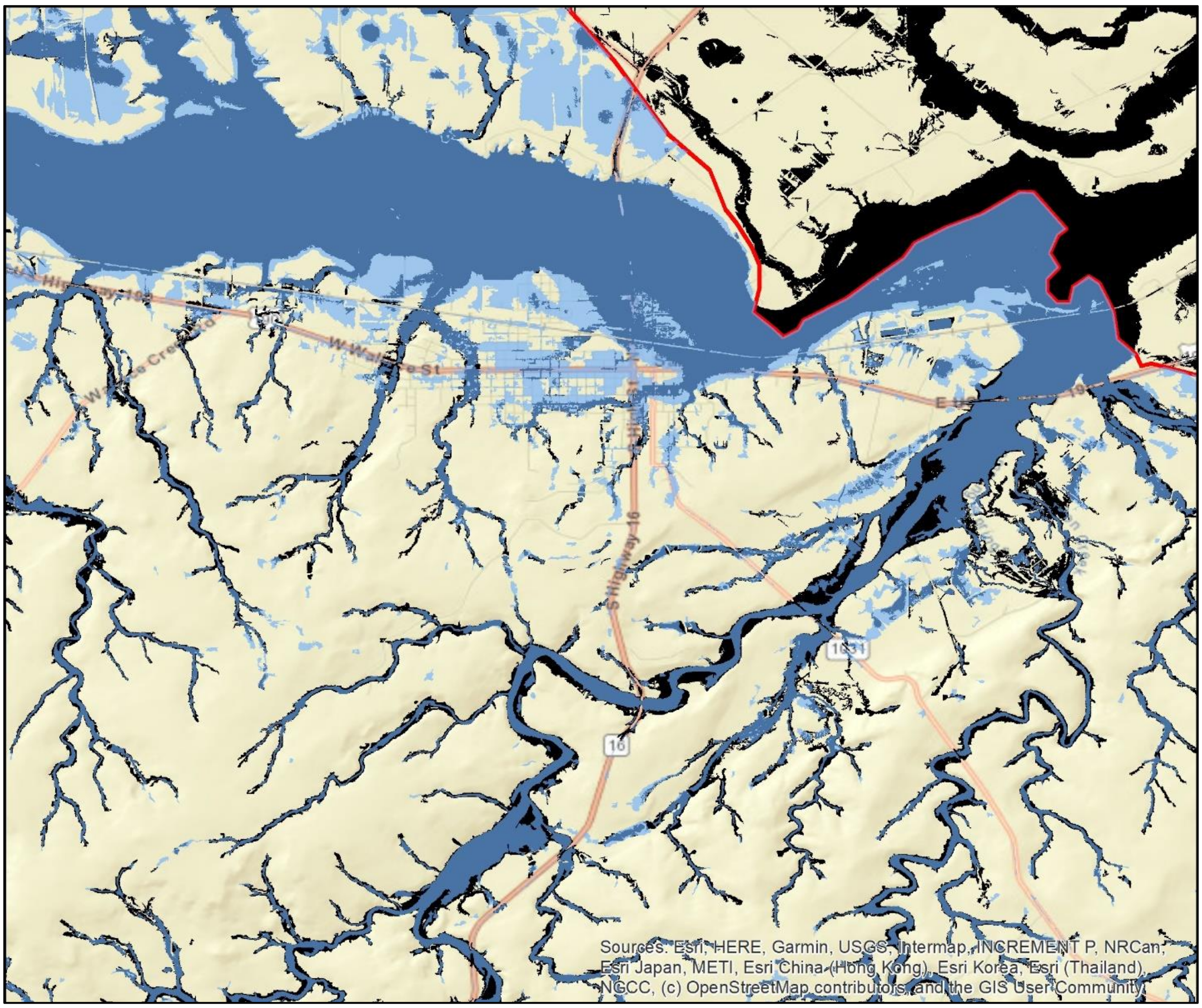


Figure 16: Comparison of 1% BLE Mapping (light blue with transparency) with Fathom 1% Mapping (black)

As part of the BLE assessment effort, a polygon file was prepared to detail areas where model refinements may be warranted. These areas may be found in the feature class S_AOMI_AR in the mapping database.

1.4. Quality Control

To guide its quality control (QC) reviews, AtkinsRéalis developed three custom QC checklists for its TWDB 2D BLE studies. The checklists were for the terrain processing, the modeling, and the mapping tasks. The terrain processing checklist included 17 items and the modeling checklist included 51 items. The mapping checklist included 20 checks for the spatial data and 244 checks for the attributes in the mapping database. These robust checklists documented the QC review process, capturing reviewer comments and originator feedback throughout the comment resolution process. Checklists were not considered final until reviewed and approved by project leadership.

As part of this QC process, the flood hazard area delineations created by the BLE analysis were reviewed for areas where the results were not ideal.

A major component of the QC process was an automated check that identified locations where the 1% annual-chance WSELs were crossed by another frequency or by the 1% plus or 1% minus profile. Significant effort was made to reasonably resolve all of these instances.

An Independent Technical Review (ITR) was completed on all BLE deliverables by a representative of the TWDB. AtkinsRéalis resolved all ITR comments prior to uploading the project deliverables to the MIP.

1.5. CNMS Validation of Effective Zone A Special Flood Hazard Area

Most of the Zone A streams in the San Saba watershed were classified as “UNVERIFIED” with a status type of “BEING STUDIED” (181.6 miles) with two reaches classified as “VALID” with a status type of “BEING STUDIED” (3.6 miles).

Initial Assessment A1 – Significant Topography Update Check

This check involved determining whether a topographic data source was available that was significantly better than that used for the effective Zone A modeling and mapping. For the San Saba watershed, USGS 1:24,000-scale topographic maps were used for the effective Zone A analysis. The LiDAR data used in the BLE analysis was a significant improvement over the effective data’s terrain data source. Therefore, the A1 check failed for all effective Zone A reaches.

Initial Assessment A2 – Check for Significant Hydrology Changes

This check involved first determining whether regression equations were used in the effective study. If they were, then it was determined whether new regression equations had become available since the date of the effective Zone A study. If newer regression equations existed for the area of interest, then an engineer determined whether these regression equations would significantly affect the 1% annual-chance flow. The effective hydrologic analysis was not based on a regression analysis, therefore the A2 check was set to pass.

Initial Assessment A3 – Check for Significant Development

This check involved using the National Urban Change Indicator (NUCI) dataset to assess increased urbanization in the watersheds with Zone A studies. If the percentage of urban area within a HUC-12 watershed containing an effective Zone A study is 15% or more, and has increased by 50% or more since the effective analysis, then the study would fail this check. Although the NUCI data provided year-to-year changes in urbanization, the NLCD also was needed to establish a baseline of urban land cover for this analysis. The San Saba watershed is generally rural with few villages, and there has not been significant development in the watershed. A significant development check for the study area was carried out using the NUCI dataset, which did not meet the urban change criteria. Therefore, the A3 check was set to pass for all reaches.

Table 24: Zone A Initial Assessment Results

Assessment Check	Pass/Fail	Comments/Notes
A1 - Topography	Fail	The LiDAR terrain data is a significant improvement over the terrain data used to develop the effective mapping.
A2 - Hydrology	Pass	The effective hydrologic analysis was not regression based.
A3 - Development	Pass	No significant development has occurred in the study area.

Initial Assessment 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, then a comparison of the BLE results and effective Zone A mapping was performed. There was no adequate documentation regarding how the engineering analysis supporting the effective study was performed. Therefore, the A4 check was set to fail for all reaches in this study.

Initial Assessment A5 – Comparison of BLE and Effective Zone A Floodplains

The BLE/effective Zone A comparison method leveraged the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach used the 1% plus and 1% minus flood extents and the horizontal and vertical tolerances described in the CNMS Technical Reference. For the comparison of the BLE mapping and effective Zone A mapping in the study area, the following vertical and horizontal tolerances were used to conduct the modified FBS procedure. These comparisons were made at points spaced at a 100-foot interval along the outer extents of the effective Zone A mapping.

Vertical Tolerance: Plus or minus 5 or 10 feet (one-half contour interval of assumed effective topographic source). See the shapefile USGS_24K_Index.shp in the Supplemental data folder to see how the vertical tolerance varied throughout the watershed.

Horizontal Tolerance: Plus or minus 75 feet (standard horizontal tolerance for BLE comparison testing).

The terrain data used to complete Initial Assessment A5 was the terrain surface created from the LiDAR data that was acquired for the San Saba BLE analysis.

The contour interval for the vertical tolerance was acquired from the USGS 1:24,000-scale topographic maps of the San Saba watershed.

The source of the effective Zone A mapping was FEMA's NFHL and mapping that was digitized from FEMA's paper FIRMs.

See Table 26 for a summary of the outcomes of Initial Assessment A5.

CNMS Validation Results

Based on the validation assessments and BLE comparisons described above, the CNMS Inventory of the Zone A studies in the San Saba watershed study area has been updated. The total miles in each of these categories are summarized in Table 25 and illustrated on Figure 17. The findings from the Initial Assessment A5 are in Table 26.

Table 25: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment
VALID	TO BE STUDIED	0	0
	BEING STUDIED	0	3.6
UNVERIFIED	TO BE STUDIED	182.3	0
	BEING STUDIED	0	181.6

Table 26: BLE Comparison Results

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)
Watershed Name	HUC-12 ID					
Bull Hollow	120901090204	384	72	312	81.3%	Fail
Campbell Draw	120901090304	21	17	4	19.0%	Fail
Celery Creek	120901090408	20	10	10	50.0%	Fail
Chapman Draw	120901090503	79	33	46	58.2%	Fail
China Creek-San Saba River	120901090808	1,626	772	854	52.5%	Fail
Coal Kiln Draw-Tarrett Draw	120901090301	1,222	436	786	64.3%	Fail
East Elm Creek-Elm Creek	120901090505	70	39	31	44.3%	Fail
Headwaters Middle Valley Prong	120901090201	628	216	412	65.6%	Fail
Las Moras Creek-San Saba River	120901090407	56	38	18	32.1%	Fail
Lower Richland Springs Creek	120901090806	2,030	976	1,054	51.9%	Fail
Menard Irrigation Company Canal-San Saba River	120901090502	413	154	259	62.7%	Fail
Scalp Creek	120901090501	52	25	27	51.9%	Fail
Sheen Draw-San Saba River	120901090305	23	5	18	78.2%	Fail
Simpson Creek	120901090807	4,393	1,831	2,562	58.3%	Fail
Taylor Branch-San Saba River	120901090506	1,184	270	914	77.2%	Fail
Terrett Draw-Talbot Lake	120901090302	454	106	348	76.7%	Fail
Twentymile Waterhole-Middle Valley Prong	120901090202	1,335	308	1,027	76.9%	Fail
Twomile Creek-San Saba River	120901090601	348	45	303	87.1%	Pass

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)
Watershed Name	HUC-12 ID					
Upper Richland Springs Creek	120901090805	1,178	614	564	47.9%	Fail
Wallace Creek-San Saba River	120901090804	1,372	696	676	49.3%	Fail

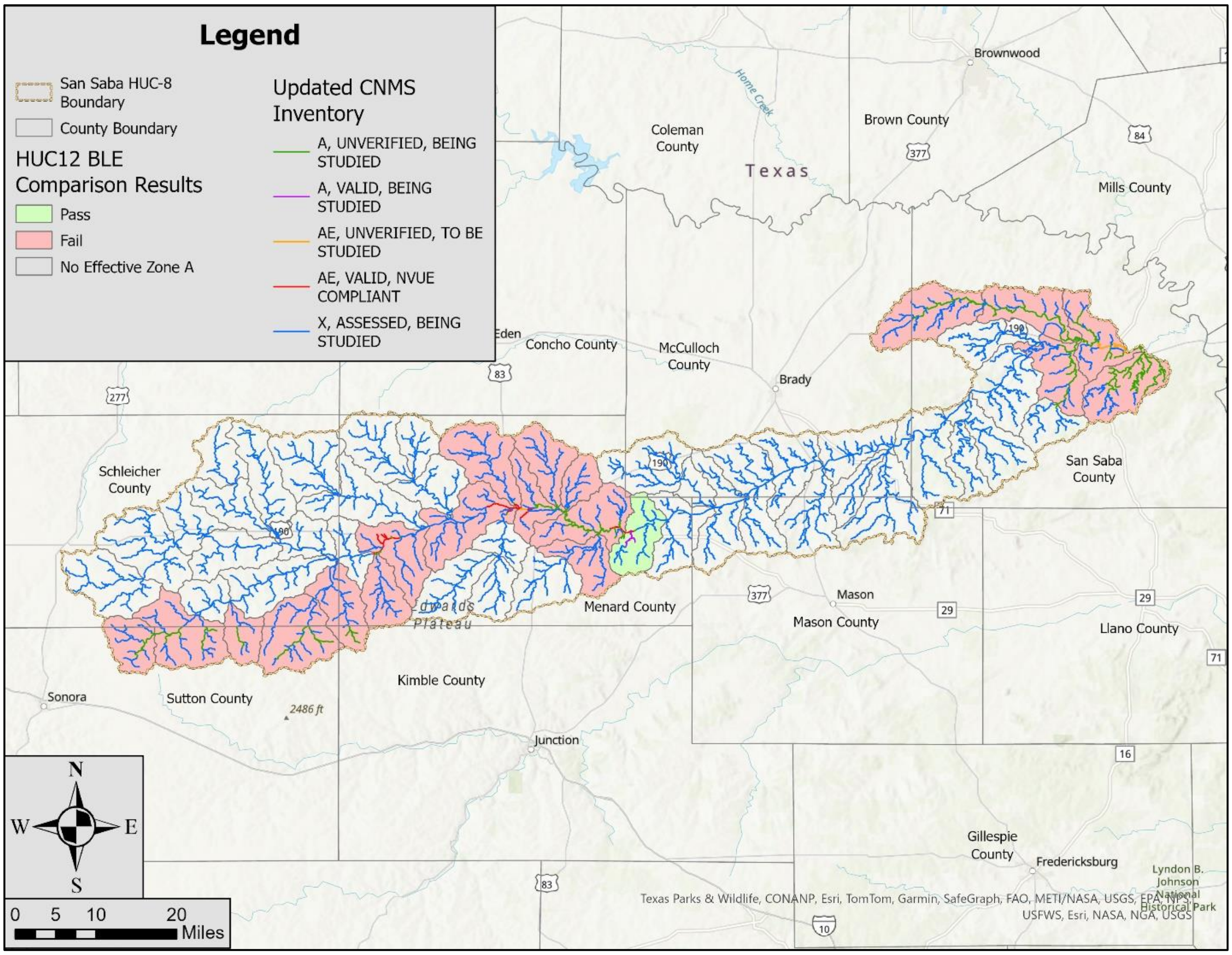


Figure 17: CNMS Validation Results

1.6. Flood Risk Analysis

A flood risk analysis was performed for the San Saba watershed. This analysis was completed using Hazus Version 5.1. Flood losses were based on the 1% annual-chance depth grids from the BLE analysis.

Additional inputs for the analysis were as follows.

S_AOMI_Ar

AoMIs are Areas of Mitigation Interest. This polygon feature class is intended to be used as a communication tool to direct users to areas that warrant further investigation or research for possible mitigation. The intent of this coverage area is to allow a visualization and depiction of areas that may be refined in future local, state, regional, or federal modeling efforts.

Areas typically identified by this feature class include:

- Areas of significant land use change – The source of land use data for this BLE assessment was the 2019 NLCD. The land uses captured by this database were compared with the land uses shown in the aerial imagery available in Google Earth when the floodplain mapping was being developed. Areas where the land use had changed significantly since 2019 were documented in the feature class.

- Intersections of significant streams with major roadways – Since structures were not explicitly included in the BLE models, these areas were identified as areas where additional analysis may be useful for refining the outcomes of the BLE study.

- Floodplain mapping tie-ins along the HUC-8 watershed boundary – Along the HUC-8 watershed boundaries where AtkinsRéalis completed BLE assessments for both watersheds, the floodplain mapping includes smooth tie-ins across the watershed boundaries. Along those HUC-8 watershed boundaries where AtkinsRéalis did not study both watersheds, the mapping tie-ins could not be smoothed since the BLE floodplain mapping in the neighboring watershed was not available. AoMIs were placed along these HUC-8 watershed boundaries to identify those tie-ins that potentially could be refined by a future modeling effort.

S_AOMI_Pt

This point feature class depicts hydraulic structures (e.g., bridges, culverts, dams, etc.), highwater marks, and low water crossings. Hydraulic structures data was obtained from available Texas GIS data sites. Essential facilities such as schools, police stations, and emergency centers were obtained from the Hazus essential facilities inventory.

Outputs from the analysis were as follows.

S_FRACT_Ar

This is the flood risk assessment polygon feature class. It is the output for a flood level 2 analysis using Hazus Version 5.1, which is based on a 1% annual-chance depth grid. The calculated loss results from Hazus are stored in the polygon feature and are based on dasymetric census blocks. Dasymetric census blocks have had additional “undeveloped” land areas (primarily wetlands and forest) clipped out of the original census block boundaries based on USGE land use/land cover data. Loss values are reported in whole dollar amounts. See Table 27 below for a summary of the losses computed by Hazus.

L_Source_Cit

The data sources used for S_AOMI_AR and S_AOMI_PT are documented in the L_Source_Cit table.

Table 27: Hazus Results for the San Saba Watershed

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Kimble County	$23,000	$9,066,000	$4,620,000
Sutton County	$3,810,000	$31,140,000	$27,198,000
Menard County	$62,453,000	$327,261,000	$178,521,000
San Saba County	$87,605,000	$438,996,000	$274,543,000
Mason County	$542,000	$63,502,000	$36,770,000
McCulloch County	$1,907,000	$53,317,000	$33,370,000
Schleicher County	$11,887,000	$61,099,000	$40,893,000
Total	**$168,227,000**	**$984,381,000**	**$595,915,000**

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This section includes a bibliographic list of the documents referenced throughout this document or used during the preparation of the BLE analysis.

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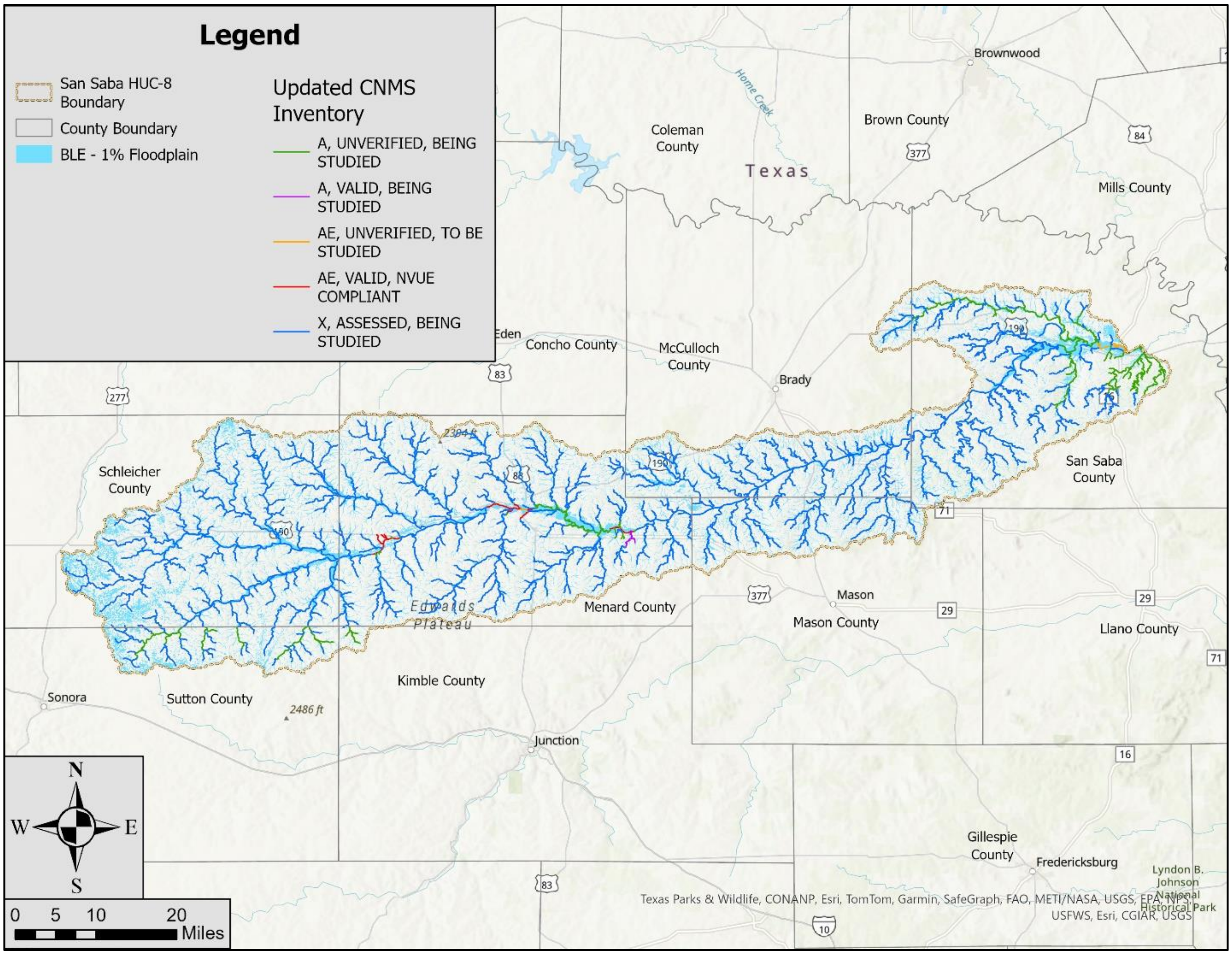
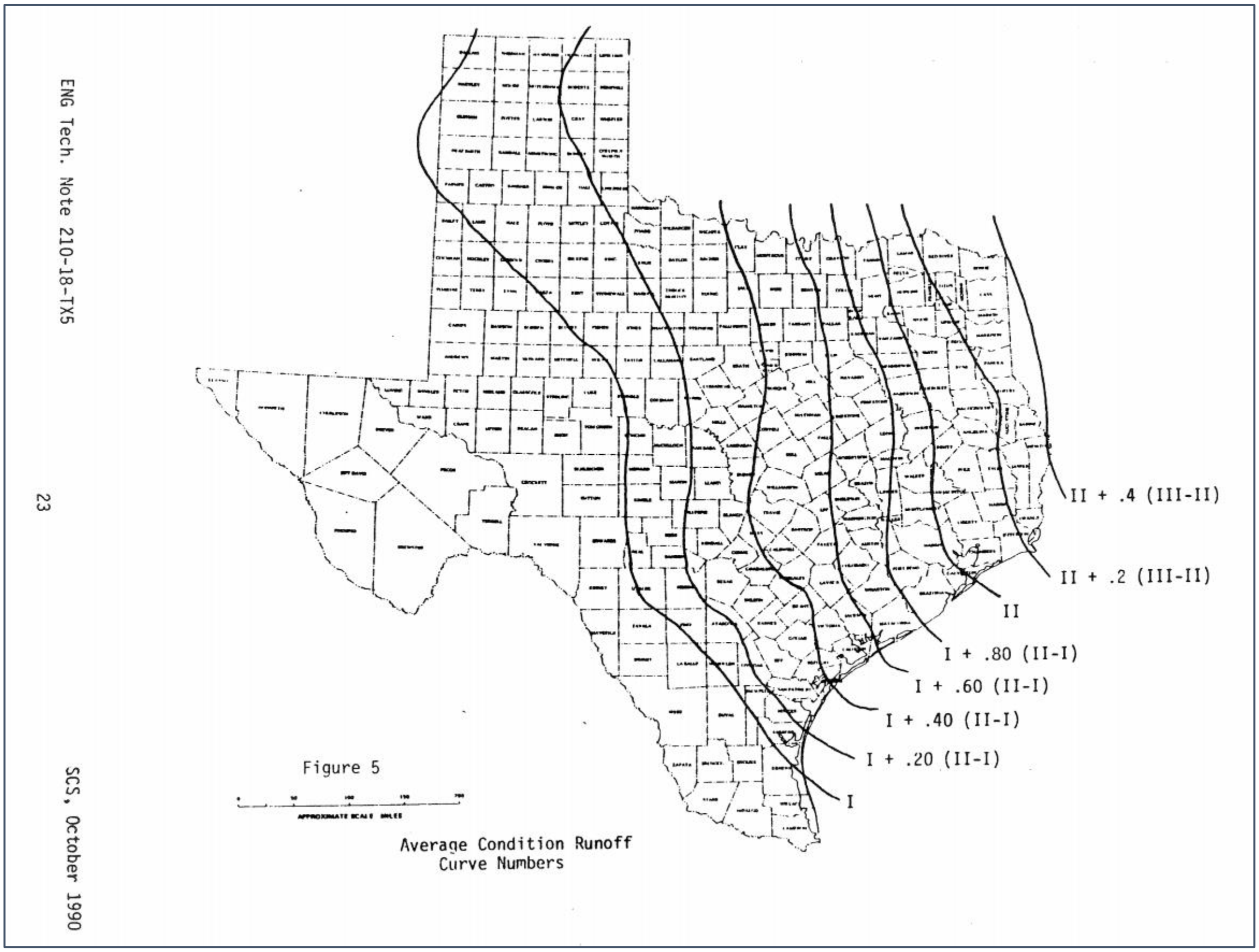
Appendix A – Base Level Engineering Results



Appendix B – Supporting Documentation

The following information may be found in Appendix B. These documents provide further details regarding the methodology and outcomes of the BLE analysis for the San Saba watershed.

- Page 23 from *Engineering Technical Note No. 210-18-TX5* titled Estimating Runoff For Conservation Practices – This is an excerpt showing a map of Average Runoff Conditions (ARC) across Texas. The term Antecedent Runoff Condition (ARC) used in the older literature is analogous to Antecedent Moisture Condition (AMC), which is the term that is commonly accepted today.



- Pages 74 to 83, 86 to 93, and 151 from Chapter 5 of the InFRM team's draft *Watershed Hydrology Assessment for the Lower Colorado River Basin.* This is an excerpt from a draft copy of this report. This excerpt includes the gage analyses for USGS gages 08144500 (San Saba River at Menard, TX), 08144600 (San Saba River near Brady, TX), and 08146000 (San Saba River at San Saba, TX).