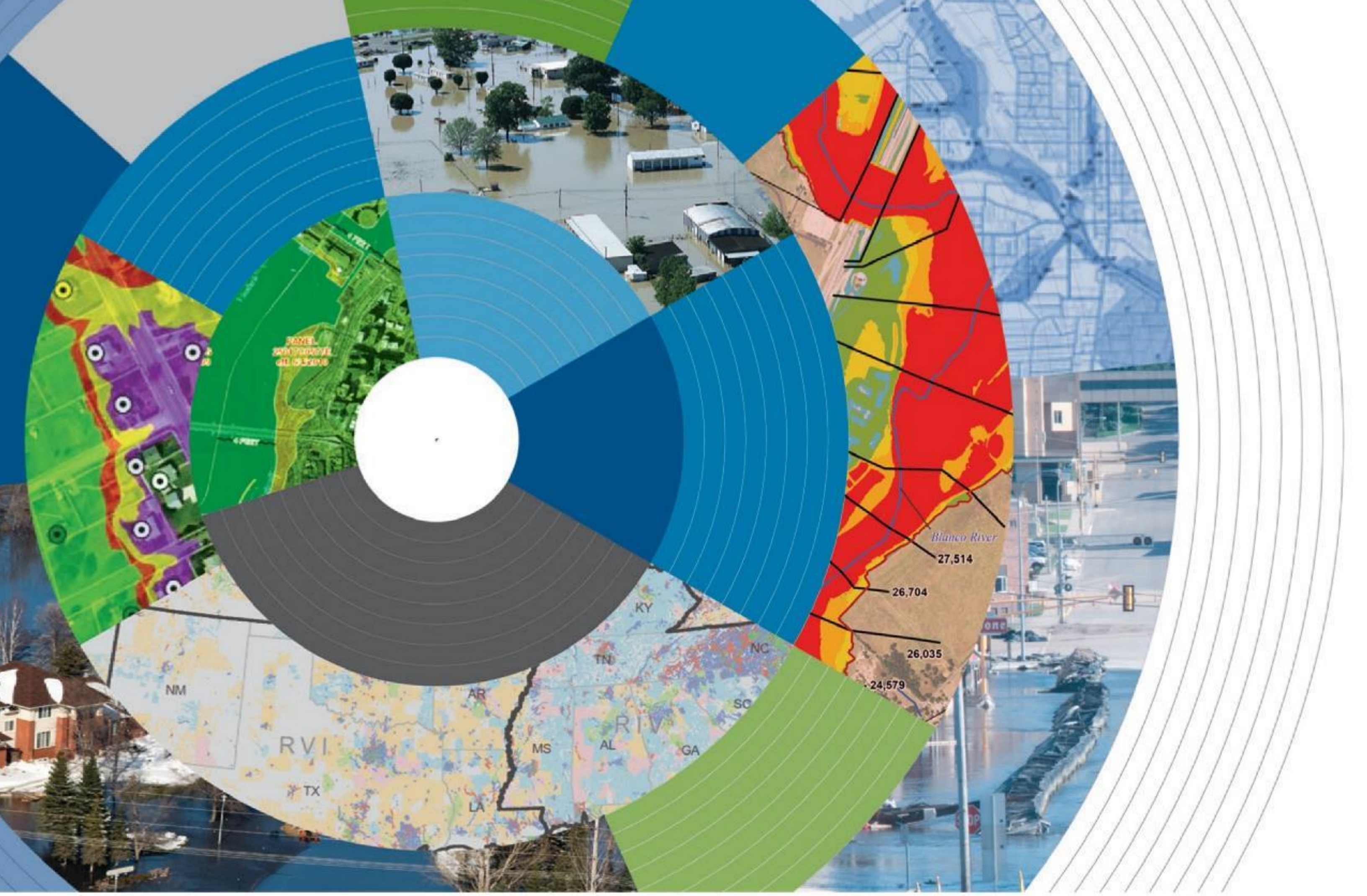

Base Level Engineering Report

Pecan Bayou (12090107)

Texas Water Development Board

January 31, 2025

Version 1.0

Report Prepared for:

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

FINAL REPORT FOR PECAN BAYOU (12090107)

PREPARED FOR:

Texas Water Development Board

Prepared By:

AtkinsRéalis USA, Inc.

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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 Pecan Bayou HUC-8 watershed (12090107). This watershed is located in Central Texas, southeast of Abilene, between Clyde, Texas and Goldthwaite, Texas. The watershed area is 1420 square miles (mi^2). A total of 1,485 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 Service's (NRCS) Curve Number (CN) loss rate method.

The Pecan Bayou watershed was divided into seven HEC-RAS model domains — 0701_A1, 0702_A2, 0703_A3, 0703_A4, 0704_A5, 0705_A6, and 0706_A7. Note that domain 0703_A4 includes the downstream end of the Jim Ned watershed (HUC-8 12090108). This domain was extended into the Jim Ned watershed because Lake Brownwood, a significant reservoir, is located at the confluence of the Jim Ned and Pecan Bayou HUC-8 watershed boundaries. Since there is no physical structure (e.g., a dam) at the downstream end of the Jim Ned watershed, splitting the lake across two HUC-8 watersheds did not make sense from a modeling perspective. Therefore, all of Lake Brownwood and its local drainage area in the Jim Ned watershed have been included in the Pecan Bayou watershed BLE analysis. The Pecan Bayou BLE outcomes for those areas within the HUC-8 boundary for the Jim Ned watershed have been uploaded to the MIP to the Jim Ned BLE folder (K:/FY2022/22-06-0047S/Hydraulics – BLE|FY21|Jim Ned (12090109)).

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 Pecan Bayou watershed is in Table 1 and Table 2 and shown in Figure 1.

Table 1: Summary of Stream Miles

Source	Stream Miles
Current Inventory - CNMS	521.8
New Study Streams - CNMS	962.7
Total (BLE) Stream Miles	**1,484.5**

Table 2: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment
VALID	NVUE COMPLIANT	13.4	0
	BEING ASSESSED	11.4	0
	BEING STUDIED	0	0.8
UNVERIFIED	BEING STUDIED	0	490.3
	TO BE STUDIED	458.8	0

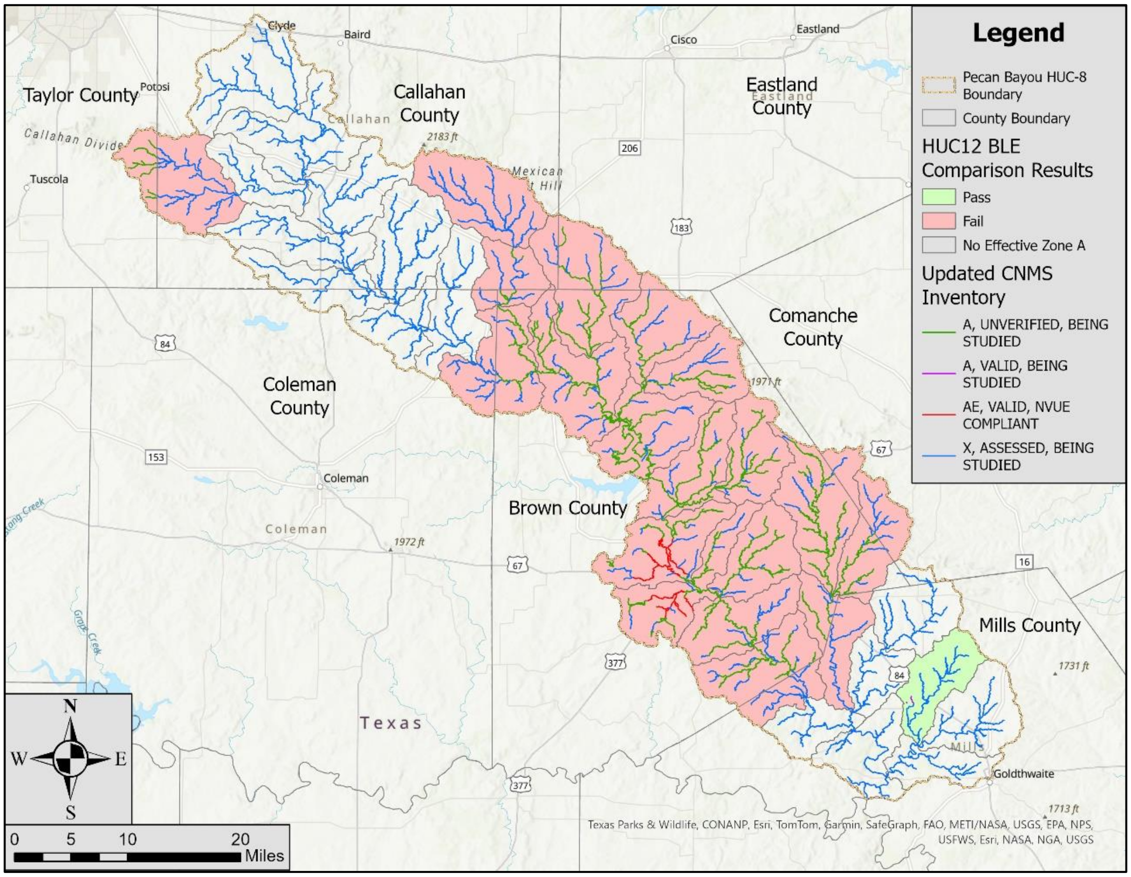


Figure 1: Pecan Bayou - 12090107 CNMS Validation Results

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 inputs and the modeling and mapping outcomes for 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 Pecan Bayou watershed (HUC-8 12090107). The watershed is mostly rural and the land is predominantly used for farming and ranching. The vast majority of the watershed is located in Brown, Callahan, and Mills counties. A small portion of the watershed falls within Coleman, Comanche, Eastland, and Taylor counties. The urban areas within this watershed include the cities of Blanket, Brownwood, Clyde, Early, Goldthwaite, and Mullin, and the town of Cross Plains. See Figure 2 for a map of the Pecan Bayou watershed.

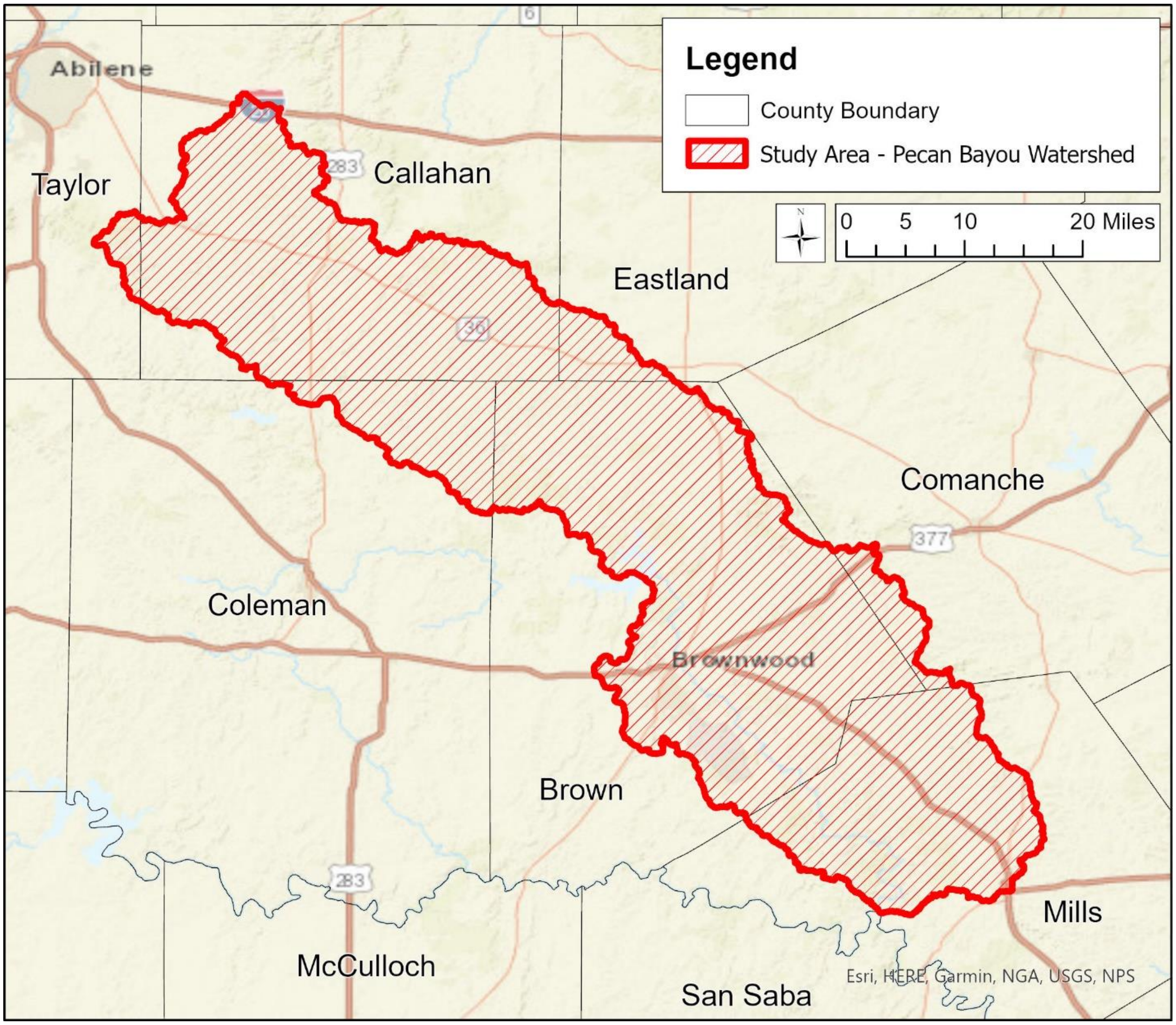


Figure 2: Pecan Bayou Watershed – HUC-8 12090107

The BLE assessment prepared a cursory engineering analysis for approximately 1,485 miles of stream reaches within the study area. The minimum drainage area tolerances were 1 mi^2 for undeveloped areas and 0.5 mi^2 for urban areas. The selection and extent of the stream reaches studied were based upon the number of stream miles meeting the minimum drainage area criteria and not the number of effective Zone A stream miles. Study reaches were extended above the minimum drainage areas 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 datasets used to develop the terrain surface for the Pecan Bayou watershed were the Texas West Central, Brown County, Hurricane, Brazos River Basin, Bandera & Lampasas Counties, and Upper Clear Fork Brazos River LiDAR collections and the United States Geological Survey (USGS) National

Elevation Dataset (NED). The six sets of LiDAR data in the format of Digital Elevation Models (DEMs) were either downloaded from TNRIS or provided by the TWDB.

Gaps in the LiDAR datasets were observed in the northwest end of the watershed between the Upper Clear Fork Brazos River and Brazos River Basin datasets. These gaps were filled using 30-meter DEMs from the NED.

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

- Texas West Central
- Brown County
- Hurricane
- Brazos River Basin
- Bandera & Lampasas Counties
- Upper Clear Fork Brazos River
- USGS NED

A description of the terrain data sources used in this study is in Table 3.

Table 3: Topographic Data Sources

County	Year Acquired	Vertical Accuracy	Source	Approximate Footprint (mi^2)
Texas West Central LiDAR (Brown and Coleman counties)	2018	4.7 cm	USGS	202
Brown County LiDAR (Brown County)	2019	5.0 cm	Texas Strategic Mapping Program (StratMap)	184
Hurricane LiDAR (Brown and Mills counties)	2019	3.8 cm	USGS	348
Brazos River Basin LiDAR (Brown, Callahan, Coleman, Comanche, Eastland, Mills, and Taylor counties)	2016	9.6 cm	USGS	1,017
Bandera & Lampasas Counties LiDAR (Mills County)	2014	4.4 cm	StratMap	38
Upper Clear Fork Brazos River LiDAR (Callahan and Taylor counties)	2014	6.6 cm	FEMA	24
USGS NED (Callahan and Taylor counties)	2016	2.4 m	USGS	14

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 – 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 Pecan Bayou watershed, this dataset includes parts of Brown and Coleman counties. The vertical accuracy (RMSEz, or root mean square error in the z direction) of this dataset is 4.7 centimeters (cm). The native cell size of the data is 1 square meter (m^2).

Dataset Two – Brown County LiDAR

The Texas Strategic Mapping Program (StratMap) Brown County LiDAR dataset captured in 2019 covers approximately 182 mi^2 of Brown County. In the Pecan Bayou watershed, this dataset resides within Brown County. The vertical accuracy (RMSEz) of this dataset is 5.0 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 Pecan Bayou watershed, this dataset includes parts of Brown and Mills counties. The vertical accuracy (RMSEz) of this dataset is 3.8 cm. The native cell size of the data is 1 m^2.

Dataset Four – Brazos River Basin LiDAR

The USGS Brazos River Basin LiDAR dataset captured in 2016 contains data for 12,623 mi^2 across 30 counties in Texas. In the Pecan Bayou watershed, this dataset includes parts of Brown, Callahan, Coleman, Comanche, Eastland, Mills, and Taylor counties. The vertical accuracy (RMSEz) of this dataset is 9.6 cm. The native cell size of the data is 1 m^2.

Dataset Five – Bandera & Lampasas Counties LiDAR

The StratMap Bandera & Lampasas counties LiDAR dataset captured in 2014 covers approximately 3,054 mi^2 across 12 counties in Texas. In the Pecan Bayou watershed, this dataset resides within Mills County. The vertical accuracy (RMSEz) of this dataset is 4.4 cm. The native cell size of the data is 1 m^2.

Dataset Six – Upper Clear Fork Brazos River LiDAR

The Upper Clear Fork Brazos River LiDAR dataset captured in 2014 touches 10 counties across 2,983 mi^2 in Texas. In the Pecan Bayou watershed, this dataset includes parts of Callahan and Taylor counties. The vertical accuracy (RMSEz) of this dataset is 6.6 cm. The native cell size of the data is 1 m^2.

Dataset Seven – USGS NED

The USGS NED is a national 1/3-arcsecond dataset with a native cell size of 30 m^2. The USGS NED includes data that intersects Callahan and Taylor counties in the Pecan Bayou watershed; however, NED data was used only in those areas where the was a gap in the LiDAR datasets. The vertical accuracy (RMSEz) of this dataset is 2.44 meters (m).

The above-mentioned LiDAR datasets were used to create a seamless set of tiled 5-foot DEMs for the Pecan Bayou 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 source and extents of the original DEMs used to create the mosaicked DEM are shown on Figure 3.

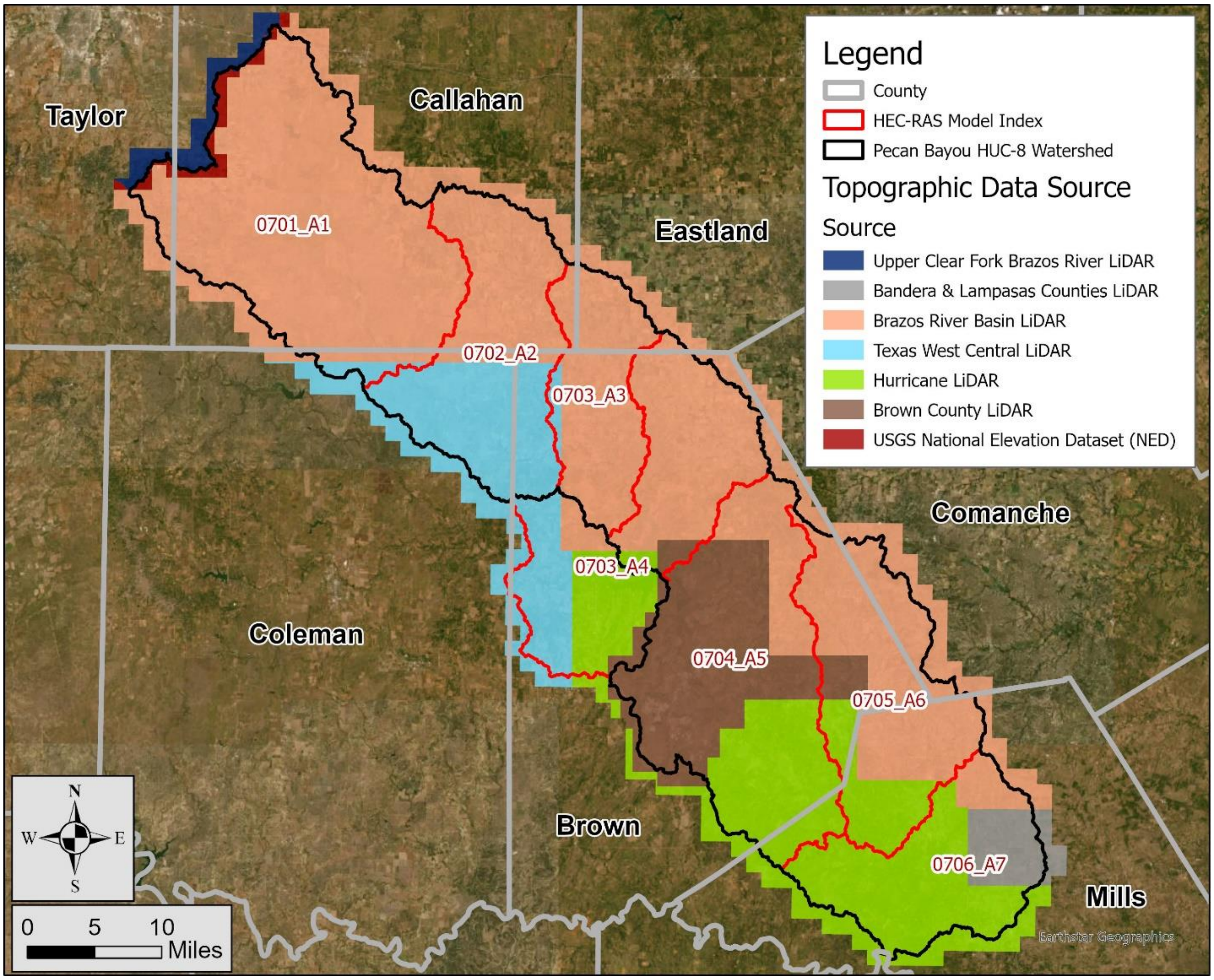


Figure 3: Topographic Data Extents in the Pecan Bayou Watershed

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.

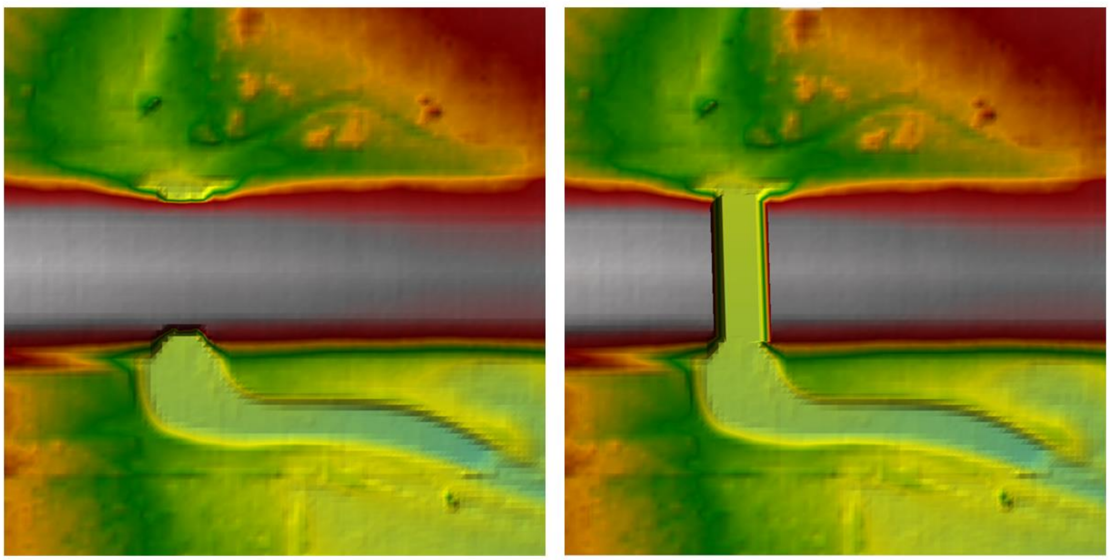
1.1.2. Development of the Stream Networks and Drainage Basins

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 were two USGS gages in the watershed. The first gage was 08143500 (Pecan Bayou at Brownwood, TX). This gage had a reported drainage area of 1,660 mi^2. The computed drainage area of 1,654 mi^2 was within 1 percent of the reported drainage area, which is acceptable. The second was gage 08143600 (Pecan Bayou nr Mullin, TX). This gage had a reported drainage area of 2,073 mi^2. The computed drainage area of 2,075 mi^2 was within 1 percent of the reported drainage area, which is acceptable.

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 was 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 Pecan Bayou 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 Pecan Bayou watershed was split into seven model domains — 0701_A1, 0702_A2, 0703_A3, 0703_A4, 0704_A5, 0705_A6, and 0706_A7, 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. Note that domain 0703_A4 includes the downstream end of the Jim Ned watershed (HUC-8 12090108). This domain was extended into the Jim Ned watershed because Lake Brownwood, a significant reservoir, is located at the confluence of the Jim Ned and Pecan Bayou HUC-8 watershed boundaries. Since there is no physical structure (e.g., a dam) at the downstream end of the Jim Ned watershed, splitting the lake across two HUC-8 watersheds did not make sense from a modeling perspective. Therefore, all of Lake Brownwood and its local drainage area in the Jim Ned watershed have been included in the Pecan Bayou watershed BLE analysis. The Pecan Bayou BLE outcomes for those areas within the HUC-8 boundary for the Jim Ned watershed have been uploaded to the MIP to the Jim Ned BLE folder (K:/FY2022/22-06-0047S/Hydraulics – BLE|FY21|Jim Ned (12090109)).

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.

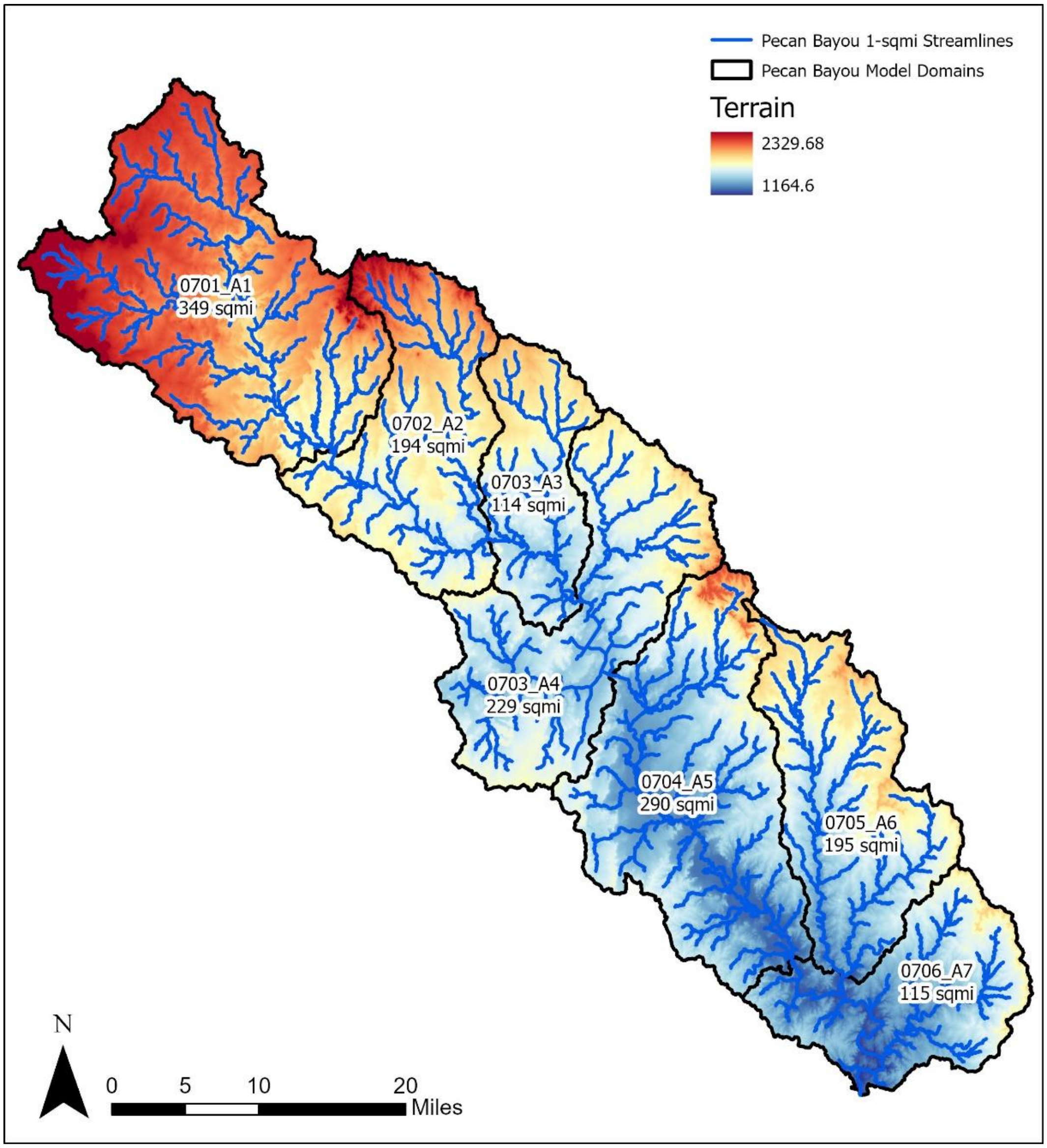


Figure 5: Pecan Bayou Model Domains and Linkages

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 has 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 datasets.

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 4. An initial abstraction ratio of 0.2 was used to obtain the initial loss. During the model validation phase, the CN values were adjusted to bring the model results into alignment with the validation data (e.g., stream gage data, effective discharges, etc.). The CN values presented in Table 4 are 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 of the AMC II CN values produced flows that continued to be too high to be considered valid. For these model domains, CN values corresponding to AMC I conditions were used to achieve model validation. See Table 5 for the AMC I CNs in the watershed.

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 Pecan Bayou 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 Pecan Bayou watershed.

Table 4: 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	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 5: 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	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), as shown below. 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 6: 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 - 0.12
23	Developed, Medium Intensity	0.12	0.080 - 0.14
24	Developed, High Intensity	0.16	0.12 - 0.20
31	Barren Land	0.025	0.023 - 0.030
41	Deciduous Forest	0.15	0.10 - 0.20
42	Evergreen Forest	0.12	0.080 - 0.16
43	Mixed Forest	0.14	0.080 - 0.20
52	Shrub Scrub	0.115	0.070 - 0.16
71	Herbaceous	0.038	0.025 - 0.050
81	Hay Pasture	0.038	0.025 - 0.050
82	Cultivated Crops	0.035	0.020 - 0.050
90	Woody Wetlands	0.098	0.045 - 0.15
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.
- Breaklines were placed on the spillways and crests of significant reservoirs.
- Polygons computed by buffering the streamlines were used to establish channel refinement regions. The buffers were 200 feet wide for small streams and increased for wider streams with larger drainage areas.

- Refinement regions were defined in urban areas, major reservoirs, and dam overflow 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.

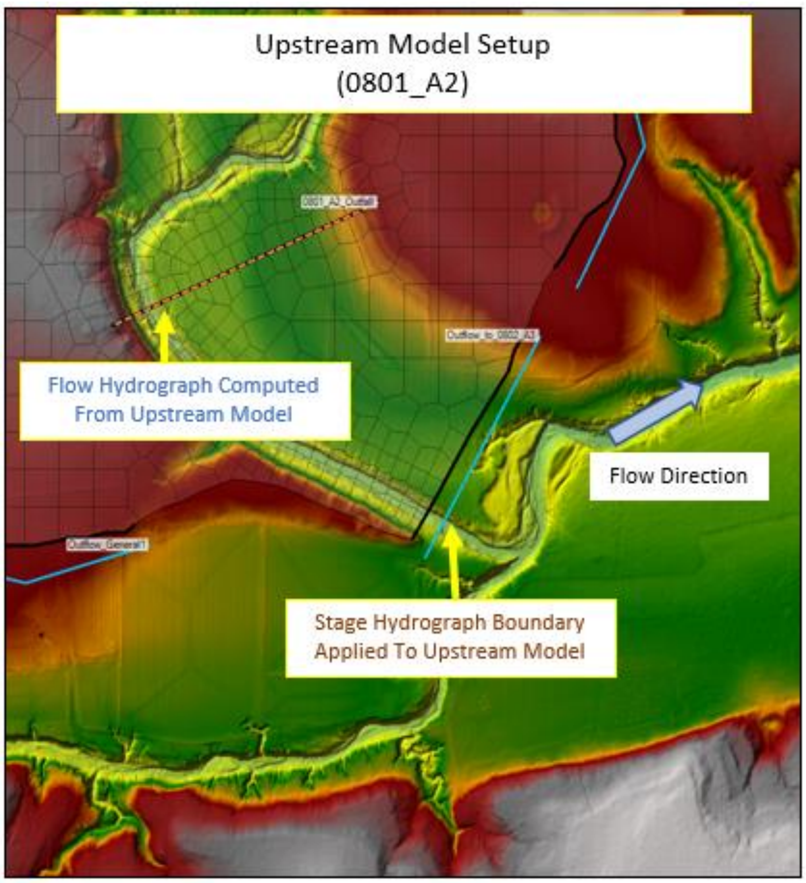


Figure 6: Extraction of Flow Hydrograph from the SA/2D Connection in the Upstream Domain for Use in the Downstream Domain

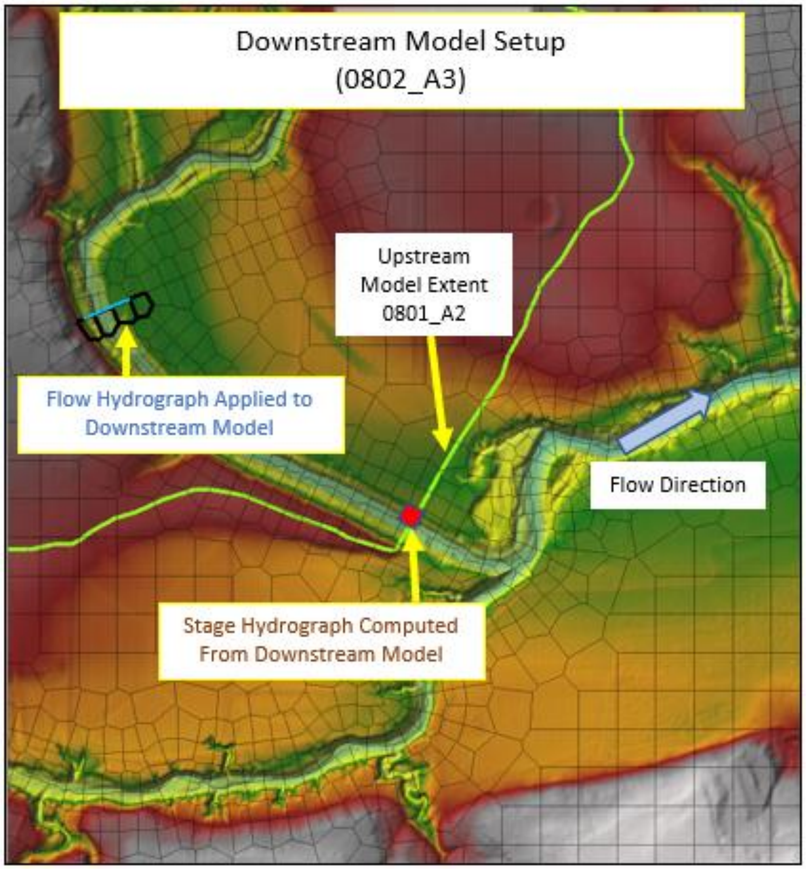


Figure 7: Application of Upstream Flow Hydrograph in the Downstream Domain

See Table 7 through Table 13 for a summary of the upstream and downstream peak discharges and WSELs at the downstream end of each domain in the Pecan Bayou watershed. Figure 8 through Figure 14 show a snapshot of each tie-in location.

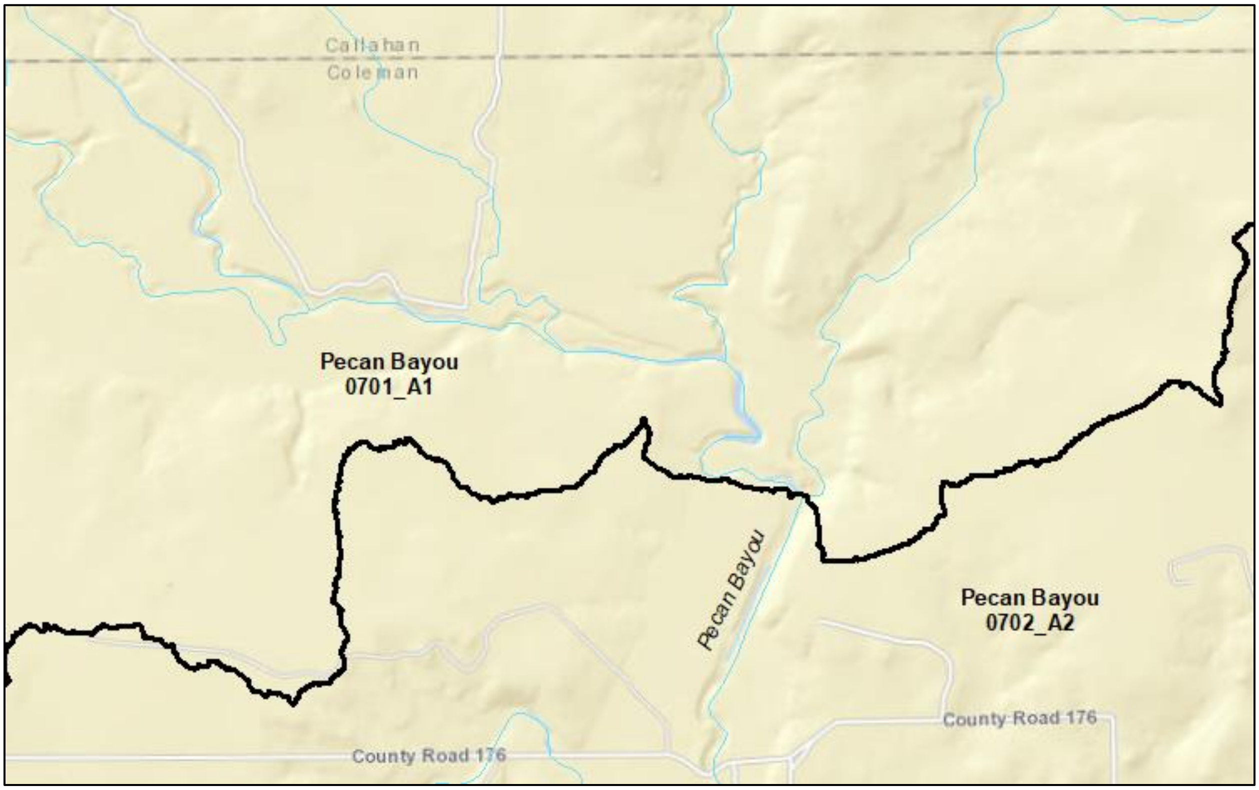


Figure 8: Pecan Bayou Domain 0701_A1 Outlet into Pecan Bayou Domain 0702_A2

Table 7: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0701_A1

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	7,047	7,194	-2.0%	1,584.38	1,584.32	0.06
4%	14,166	14,259	-0.7%	1,587.30	1,587.20	0.10
2%	21,847	22,046	-0.9%	1,588.58	1,588.49	0.09
1%	31,449	31,661	-0.7%	1,589.74	1,589.66	0.08
0.2%	64,272	65,259	-1.5%	1,592.76	1,592.71	0.05
1% minus	18,616	18,845	-1.2%	1,588.13	1,588.04	0.09
1% plus	45,899	46,510	-1.3%	1,591.20	1,591.15	0.05

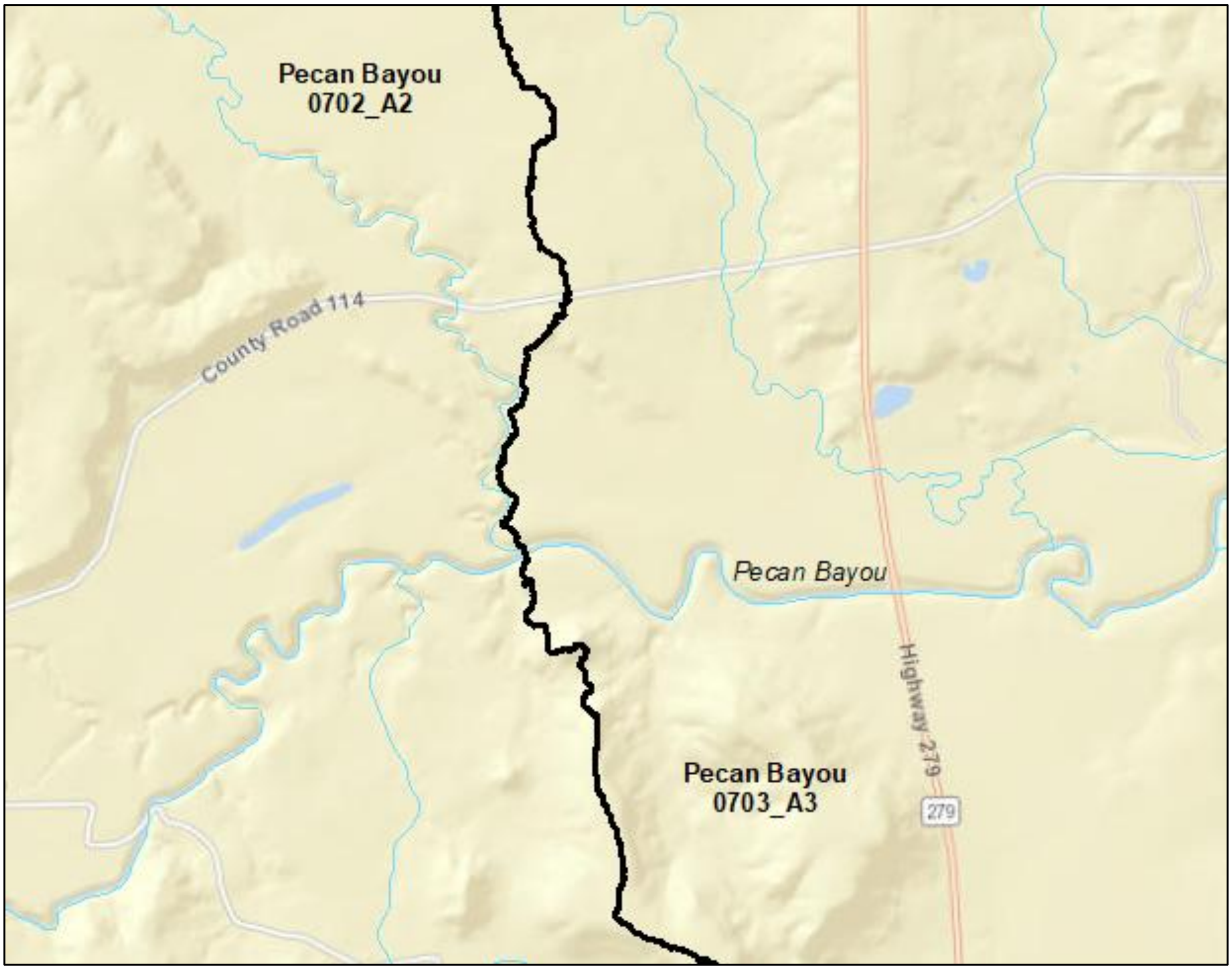


Figure 9: Pecan Bayou Domain 0702_A2 Outlet into Pecan Bayou Domain 0703_A3

Table 8: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0702_A2

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	10,221	10,958	-6.7%	1,479.67	1,479.22	0.45
4%	19,312	19,326	-0.1%	1,481.75	1,481.60	0.15
2%	29,186	29,181	0.0%	1,482.56	1,482.58	-0.02
1%	40,820	41,336	-1.2%	1,483.72	1,483.69	0.03
0.2%	90,880	92,241	-1.5%	1,487.14	1,487.17	-0.03
1% minus	25,115	25,213	-0.4%	1,482.33	1,482.20	0.13
1% plus	62,046	62,009	0.1%	1,486.11	1,486.39	-0.28

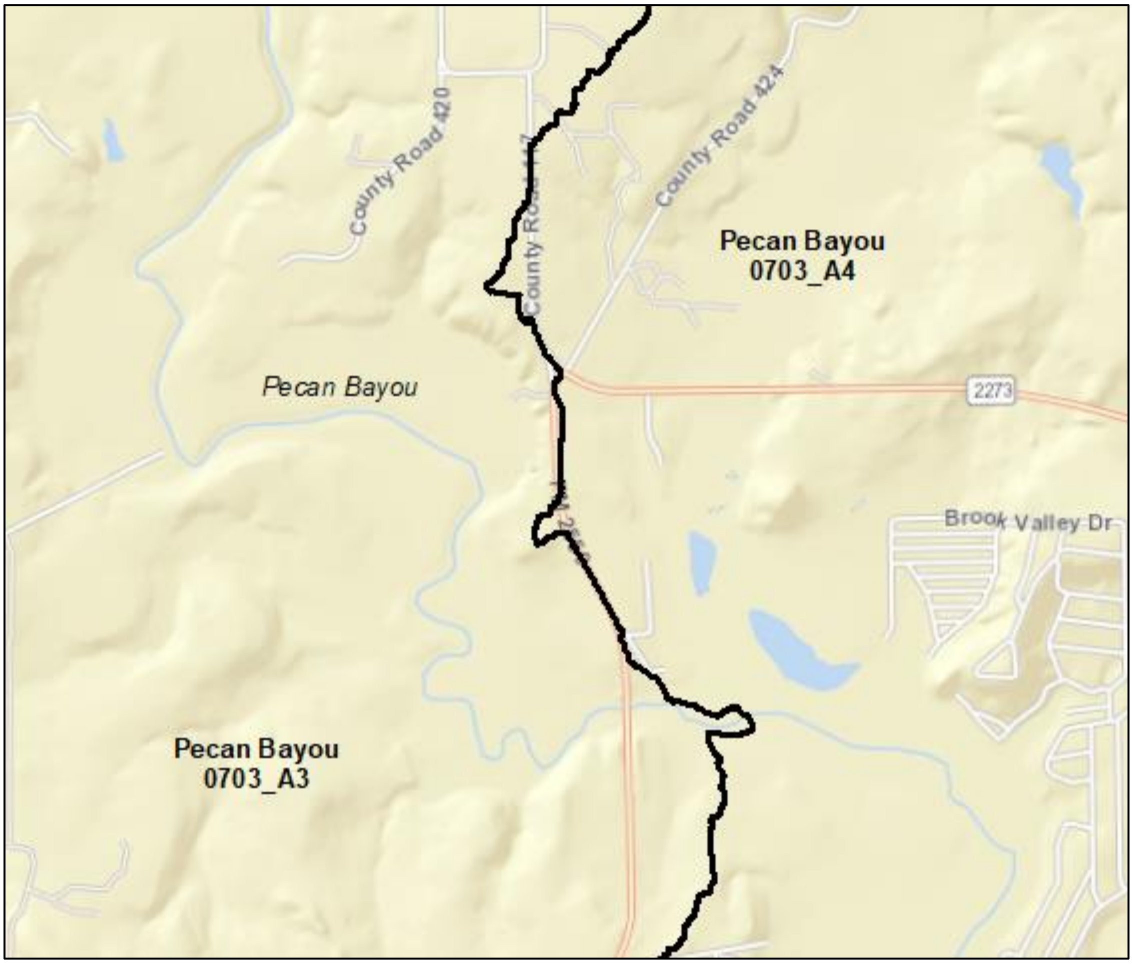


Figure 10: Pecan Bayou Domain 0707_A3 Outlet into Pecan Bayou Domain 0703_A4

Table 9: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0703_A3

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	12,041	11,559	4.2%	1,432.03	1,431.70	0.33
4%	20,473	20,359	0.6%	1,434.08	1,433.75	0.33
2%	29,873	30,531	-2.2%	1,435.94	1,435.60	0.34
1%	42,117	43,338	-2.8%	1,437.84	1,437.52	0.32
0.2%	90,767	94,360	-3.8%	1,443.48	1,443.28	0.20
1% minus	25,683	26,116	-1.7%	1,435.16	1,434.79	0.37
1% plus	62,874	64,847	-3.0%	1,440.65	1,440.39	0.26

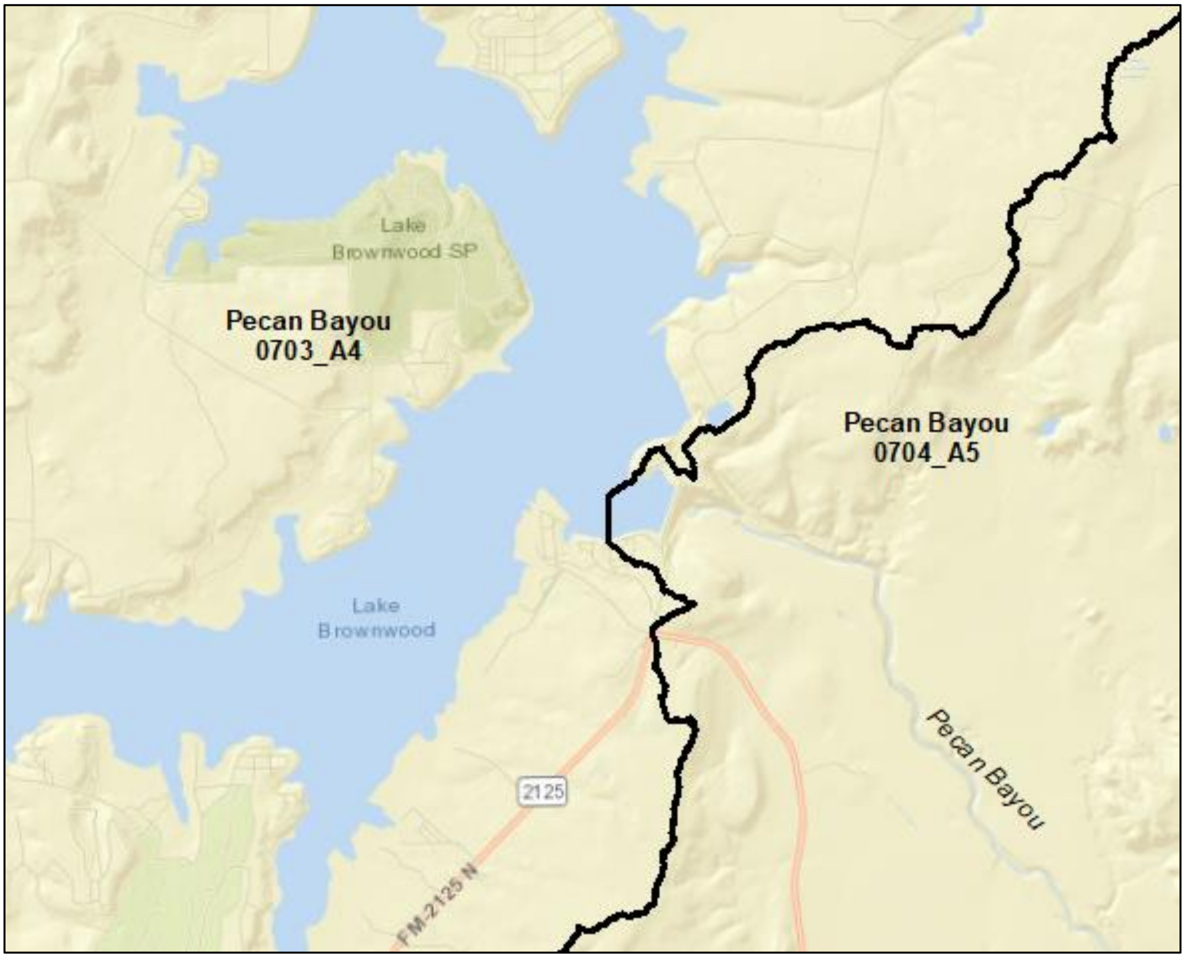


Figure 11: Pecan Bayou Domain 0703_A4 Outlet into Pecan Bayou Domain 0704_A5

Table 10: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0703_A4

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	7,739	7,802	-0.8%	1,376.34	1,376.18	0.16
4%	14,957	14,987	-0.2%	1,370.07	1,370.01	0.06
2%	24,421	24,453	-0.1%	1,373.30	1,373.20	0.10
1%	36,510	36,550	-0.1%	1,377.09	1,377.06	0.03
0.2%	84,807	84,657	0.2%	1,383.31	1,383.14	0.17
1% minus	19,729	19,772	-0.2%	1,371.78	1,371.69	0.09
1% plus	59,456	59,408	0.1%	1,380.21	1,380.00	0.21

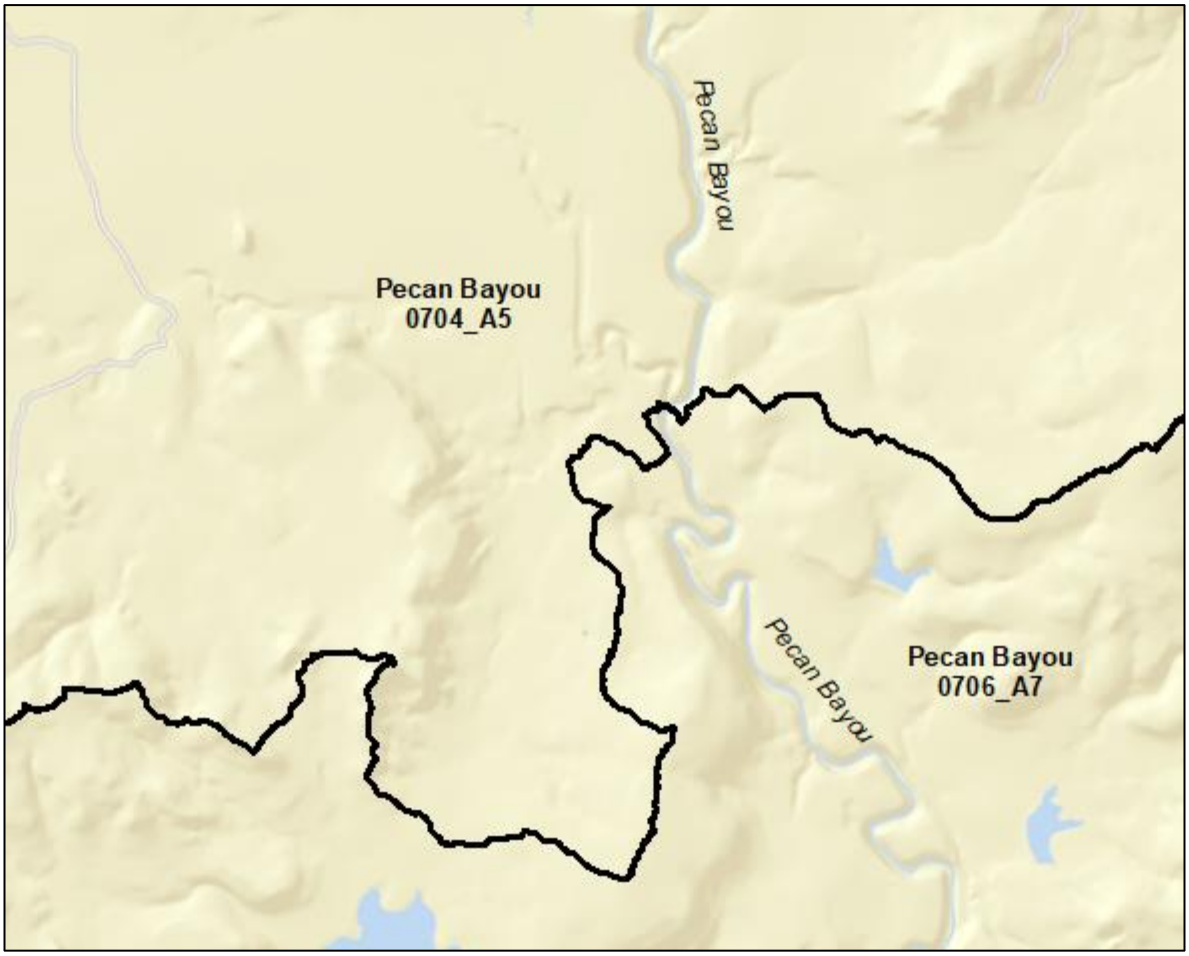


Figure 12: Pecan Bayou Domain 0704_A5 Outlet into Pecan Bayou Domain 0706_A7

Table 11: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0704_A5

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	8,177	8,233	-0.7%	1247.06	1246.56	0.50
4%	14,887	14,897	-0.1%	1251.07	1250.65	0.42
2%	23,623	23,634	0.0%	1254.60	1254.17	0.43
1%	35,930	35,937	0.0%	1257.68	1257.26	0.42
0.2%	84,635	84,712	-0.1%	1264.88	1264.45	0.43
1% minus	19,152	19,163	-0.1%	1252.98	1252.53	0.45
1% plus	58,908	58,853	0.1%	1261.54	1261.11	0.43

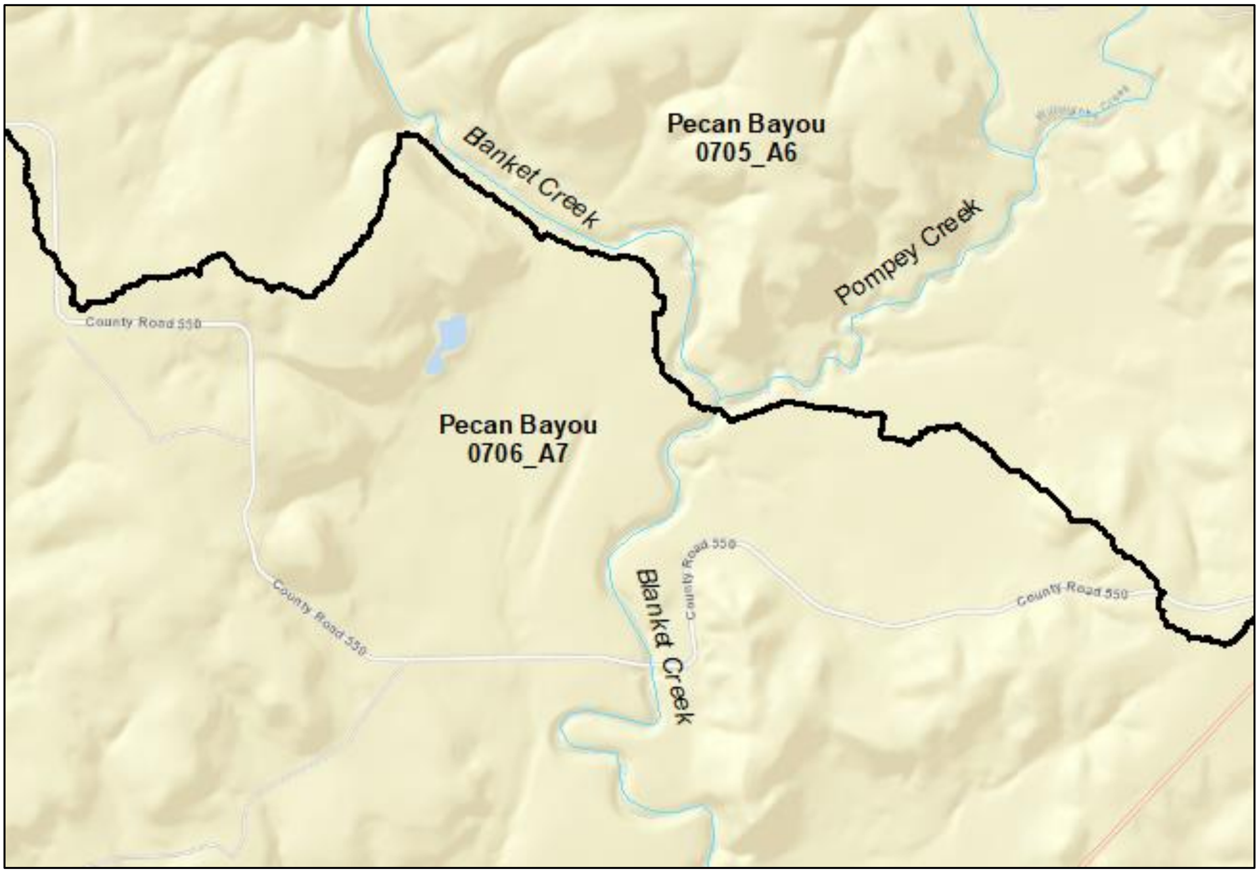


Figure 13: Pecan Bayou Domain 0705_A6 Outlet into Pecan Bayou Domain 0706_A7

Table 12: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0705_A6

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	6,483	6,483	0.0%	1,230.97	1,231.46	-0.49
4%	11,958	11,961	0.0%	1,234.55	1,234.42	0.13
2%	19,200	19,201	0.0%	1,237.64	1,237.53	0.11
1%	27,531	27,531	0.0%	1,240.52	1,240.64	-0.12
0.2%	53,198	53,203	0.0%	1,248.64	1,248.65	-0.01
1% minus	16,079	16,077	0.0%	1,236.42	1,236.24	0.18
1% plus	41,041	41,044	0.0%	1,244.82	1,244.82	0.00

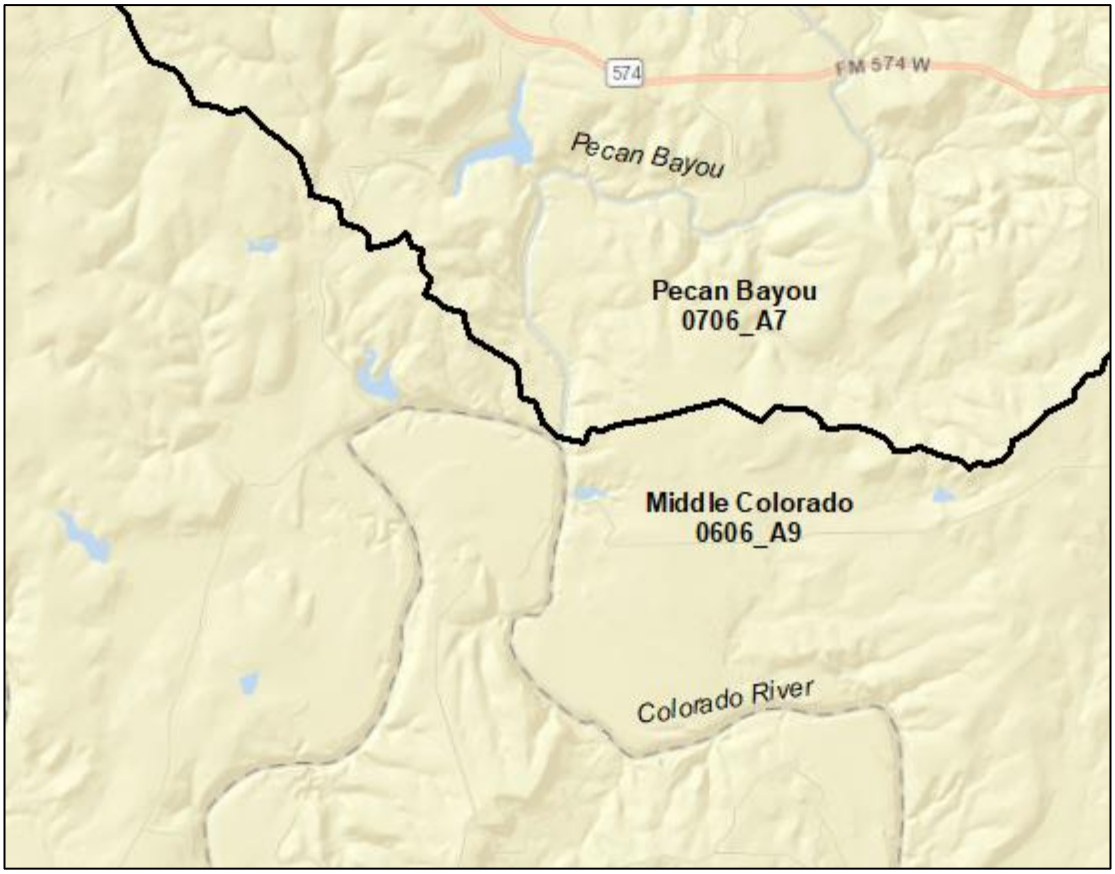


Figure 14: Pecan Bayou Domain 0706_A7 Outlet into Middle Colorado Domain 0606_A9

Table 13: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0706_A7

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	10,256	10,051	2.0%	1,204.09	1,204.09	0.00
4%	18,629	18,379	1.4%	1,210.43	1,210.43	0.00
2%	27,129	27,940	-2.9%	1,214.23	1,214.23	0.00
1%	39,961	40,881	-2.3%	1,217.28	1,217.29	-0.01
0.2%	88,648	88,844	-0.2%	1,224.87	1,224.88	-0.01
1% minus	23,089	22,542	2.4%	1,212.79	1,212.79	0.00
1% plus	63,348	63,349	0.0%	1,221.34	1,221.35	-0.01

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

Lake Brownwood is located in domain 0703_A4, where the Jim Ned watershed drains into the Pecan Bayou watershed. The reservoir's dam is an earthen dam that was constructed in 1933 and improved in 1982. The lake is owned and operated by Brown County Water Improvement District #1 for water supply and recreational purposes. The top-of-dam elevation is 1,470 ft NAVD 88. The crest elevation of the uncontrolled emergency spillway is 1,425 ft NAVD 88. There are no major outlet structures besides the emergency spillway. The dam controls a drainage area of 1,535 mi^2.

From a modeling perspective, it was not feasible for the lake to be modeled in two separate domains. Therefore, all of Lake Brownwood falls within Pecan Bayou domain 0703_A4. The outlet for this domain has been placed at the lake outlet, which drains into Pecan Bayou domain 0704_A5. It was assumed that the inflow to domain 0704_A5 was equal to the outflow from domain 0703_A4.

There are no floodgates at the lake's dam. Outflow at the dam mainly occurs through uncontrolled flow over the dam's spillway, which functions like a weir.

A SA/2D Connection was added at the dam. The stage-outflow frequency data developed by the Reservoir Frequency Analysis (RFA) included in the Interagency Flood Risk Management (InFRM) team's Watershed Hydrology Assessment (WHA) for the Lower Colorado River Basin were leveraged for this model. The stage elevations in the RFA were referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). A datum conversion of 0.30 foot was used to convert the NGVD 29 elevations to NAVD 88. The stage-outflow frequency data from the RFA may be viewed in the model overview and results spreadsheet (*Pecan_Bayou_Overview_and_Results.xlsx*) in the task documentation folder.

While the RFA produced stage-outflow frequency data for the reservoir, only the peak flow was available for each event. No information was available regarding the shape of the dam outflow hydrograph. The 1% peak flow out of the dam computed by the RFA was 33,685 cubic feet per second (cfs). The 1% peak flow out of the dam in the BLE model, which was computed using the stage-elevation-outflow table in the RFA and the lake stage calculated by the BLE model, was 36,510 cfs. Since the BLE model calculated a 1% flow similar to the RFA 1% flow, the rating table in the SA/2D Connection at the dam was used to compute the flows out of the dam instead of forcing the dam outflows to match the frequency-discharge table in the RFA. This avoided the need to compute the shape of the dam outflow hydrograph, which would have been challenging since no information on the dam outflow hydrograph shape was available except for the peak flow rate.

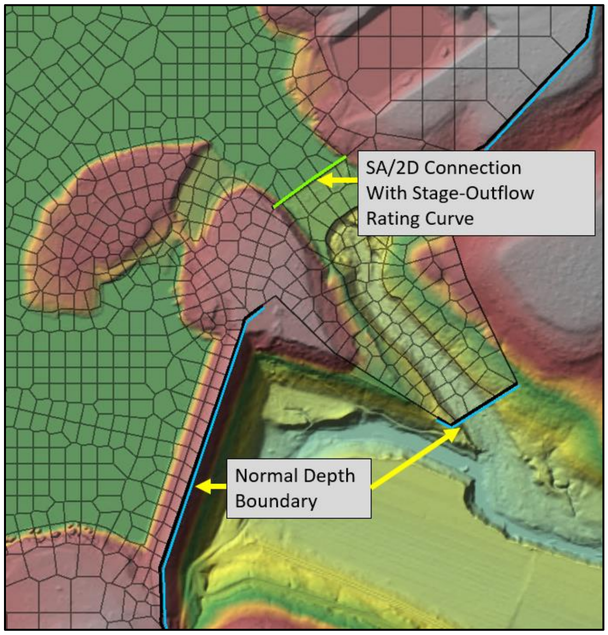


Figure 15: Model Setup for the Lake Brownwood Reservoir

Although it is much smaller than Lake Brownwood, Clyde Lake was another significant reservoir in the Pecan Bayou watershed. This reservoir is located in domain 0701_A1. The reservoir's dam is an earthen dam that was constructed in 1970. The lake is owned and operated by the city of Clyde for water supply and recreational purposes. The top-of-dam elevation is 1,892 ft NAVD 88. The crest elevation of the uncontrolled emergency spillway is 1,872 ft NAVD 88. There are no major outlet structures besides the emergency spillway. The dam controls a drainage area of 38 mi^2.

No operations data were available for this dam. To model the lake, a breakline was added along the dam crest and a refinement region was added throughout the extent of the lake.

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 16. This option was chosen to decrease run times while generally maintaining Courant number values less than 1.

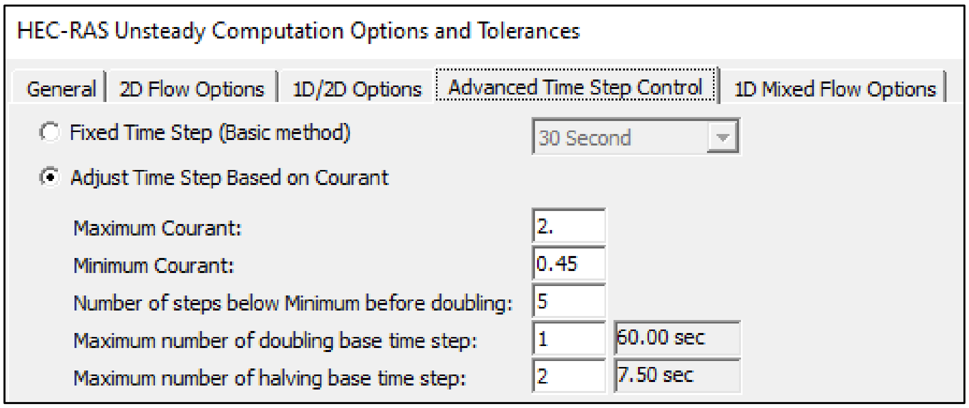


Figure 16: HEC-RAS Unsteady Computation Options and Tolerances

- Typical model run times with this advanced time step control setting were approximately 2 hours per simulation. Larger domains (e.g., 0701_A1) experienced run times of 5 to 6 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 17.

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 17: Regression Equations for the Pecan Bayou 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.

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

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

The flows resulting from the regression analysis were not used downstream of flow-regulating reservoirs or for streams with inflows from other HUC-8 watersheds.

1.2.8. Gage Analysis

The Pecan Bayou watershed is within the study footprint of the InFRM team's WHA for the Lower Colorado River Basin. USGS gages 08143500 (Pecan Bayou at Brownwood, TX) and 08143600 (Pecan Bayou near Mullin, TX) were analyzed by the WHA using Bulletin 17C methodology. These InFRM gage analyses were leveraged to support flow validation in the Pecan Bayou BLE model.

Table 14: Summary of USGS Gages in the Pecan Bayou 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
08140700	Pecan Bayou nr Cross Cut, TX	544	No	N/A	Not studied by InFRM WHA. Only 17 peak flows were available and gage record was not continuous (1969-1978 and 2016-2022).
08143500	Pecan Bayou at Brownwood, TX	1654.0	Yes	InFRM WHA	N/A
08143600	Pecan Bayou nr Mullin, TX	2075.4	Yes	InFRM WHA	N/A
08143700	Browns Ck Trib nr Goldthwaite, TX	2.5	No	N/A	Not studied by InFRM WHA. Although 23 peak flows were available, the gage record was not continuous (1966-1974 and 2007-2020). Plus, the drainage area is small.

A description of the analyses, their assumptions, and their results are available on pages 69, 70, 71, and 151 (gage 08143500) and on pages 72, 73, and 151 (gage 08143600) of Chapter 5 of the InFRM's draft WHA report. A copy of these pages has been included in Appendix B of this report.

No additional gage analysis was performed for this BLE study.

1.2.9. Model Validation

The Pecan Bayou BLE hydraulic models were validated using peak flow information available in the draft InFRM WHA and the effective 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 74 locations throughout the Pecan Bayou watershed. The locations may be grouped as follows:

- Sixty-six validation locations compared the 1% BLE flows with the 1% minus, 1%, and 1% plus regression flows.
- One validation location compared the 1% BLE flow with the 1% minus, 1%, and 1% plus gage flows.
- Six validation locations compared the 1% BLE flows with the 1% minus, 1%, and 1% plus gage flows and the 1% effective flows.
- One validation location compared the 1% BLE flow with the 1% minus, 1%, and 1% plus gage 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/or effective flow information were available. The drainage areas of the validation points ranged from approximately 1 mi^2 to 1,876 mi^2.

The validation results may be summarized as follows:

- At the 72 locations where the 1% BLE flows were validated against the 1% plus and 1% minus regression flows, the 1% BLE flows were between the 1% minus and the 1% plus regression flows at 60 locations, and they were outside of this range at 12 locations.

- At the 2 USGS gages, the 1% BLE flows were within the 1% plus and 1% minus gage flows. At gage 08143500 (Pecan Bayou at Brownwood, TX), the 1% BLE flow was 10% higher than the gage flow, and at USGS gage 08143600 (Pecan Bayou near Mullin, TX), the 1% BLE flow was 20% lower than the gage flow.

- There were 7 locations where the 1% BLE flows were validated against effective 1% flows. All 7 locations reside within domain 0704_A5. The 1% BLE flows at these points were 30% to 83% less than the effective 1% flows. Gages flows were available at 1 of these locations. Here the effective 1% flow was 18% greater than the 1% plus gage flow. At the other 6 locations, regression flows were available. At all 6 locations, the 1% effective flows fell outside of the range between the 1% minus and 1% regression flows, while the BLE 1% flows were within this range at 5 of the 6 locations. The poor agreement between the 1% effective flows and the gage and regression flows suggests that the effective study may not be a reliable study.

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 18.

The first step of the validation effort was to review the initial 1% BLE results. When the initial BLE flows fell outside the range between the 1% minus and 1% plus gage or regression flows, the overland Manning's n and CN values were adjusted iteratively until the computed flows were within this range. The overland Manning's n values were revised as needed provided they remained within the ranges specified in Table 6. The AMC II CN values were adjusted by no more than ±10% of their initial values. Following these adjustments, if the computed flows were between the 1% minus and 1% plus flows and were similar to the 1% flow, then the revised Manning's n and AMC II CN values were used in the final model.

There were some model domains where these adjustments to the overland Manning's n and AMC II CN values did not sufficiently reduce the flows. In these domains, the overland Manning's n values were reset to their initial values and the baseline antecedent moisture conditions were revised from AMC II to AMC I. In some cases, the main channel n values were adjusted to further refine the validation results. 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 Pecan Bayou 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 18 and Appendix B for a map from the SCS report showing the average antecedent moisture conditions across Texas. The application of AMC I CN values in the BLE models increased the number of locations where valid 1% BLE flows were computed to an acceptable level when compared with the regression or gages flows (62 out of 74).

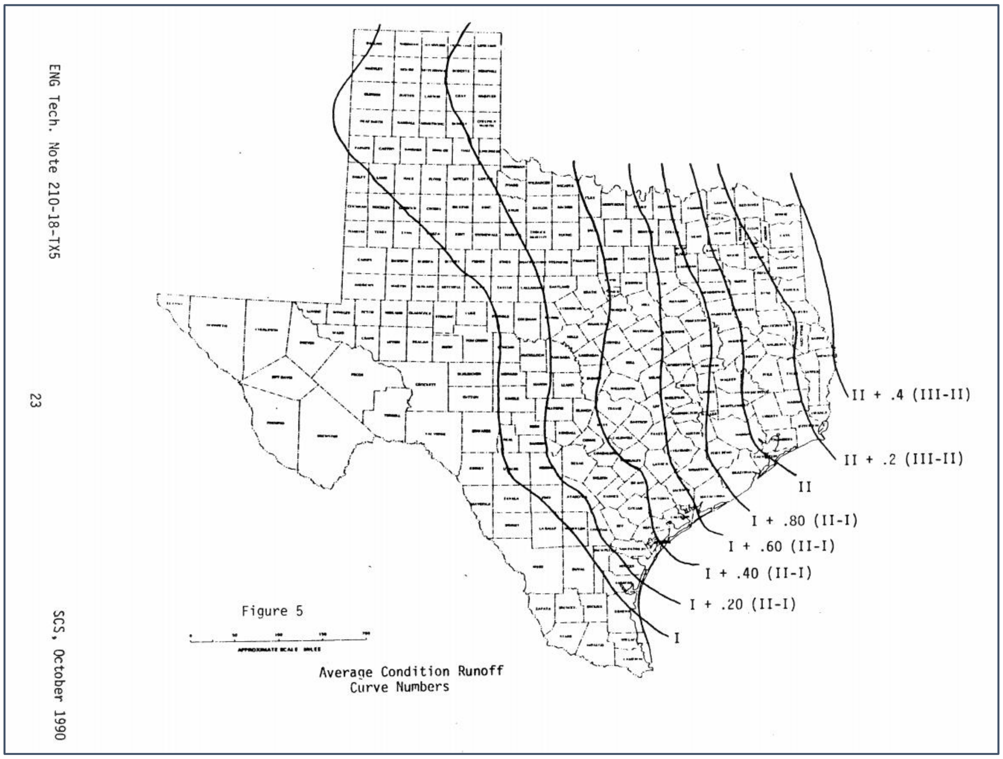


Figure 18: Antecedent Moisture Conditions in Texas

A summary of parameter adjustments made during the validation task is shown in Table 15.

Table 15: Summary of Parameter Adjustments Made During Validation in the Pecan Bayou Watershed

Model Domain	CN Adjustment	Overland n Adjustment	Channel n Adjustment	Number of Validation Locations	Pass	Fail
0701_A1	AMC I	No Change (Baseline n)	Raised to 0.050	11	9	2
0702_A2	Reduced by 10% from AMC II	No Change (Baseline n)	Raised to 0.050	10	9	1
0703_A3	AMC I	No Change (Baseline n)	Raised to 0.050	9	8	1
0703_A4	AMC I	No Change (Baseline n)	No Change	16	14	2
0704_A5	Reduced by 10% from AMC II	No Change (Baseline n)	Raised 0.040 to 0.050	12	9	3
0705_A6	Reduced by 10% from AMC II	No Change (Baseline n)	Raised 0.040 to 0.045	9	7	2
0706_A7	Reduced by 10% from AMC II	No Change (Baseline n)	No Change	7	6	1
			Total	**74**	**62**	**12**

During the validation process, domain-wide parameter adjustments were applied to the CN values 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, effective, gage, 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 0701_A1 is described as follows. Iterative results from this process are presented in Table 16. This description is representative; a similar process was applied to all domains in the Pecan Bayou watershed. In Table 16, the flows in green fall between the 1% minus and 1% plus regression flows, and the values in red are outside this range.

For Iteration 1, the baseline AMC II CN values and Manning's n values were applied. The Iteration 1 results showed that for all validation locations, the computed 1% BLE flows were higher than the 1% plus regression flows. To reduce the computed flows, Iteration 2 lowered the AMC II CN values by 10%, which brought some of the 1% BLE flows within the range of the 1% minus and 1% plus regression flows; however, the majority of the 1% BLE flows continued to exceed the 1% plus regression flows.

To reduce the flows further, Iteration 3 reset the CN values from 90% of AMC II to baseline AMC I and increased the channel Manning's n values from 0.040 to 0.050. Following these revisions, 9 of the 1% BLE flows were within the 1% plus and 1% minus range and 2 continued to exceed the 1% plus regression flows.

Table 16: Summary of the Model Validation Process for Domain 0701_A1

Validation Location	Name	Drainage Area (mi^2)	Regression Flows (cfs)			Iteration 1	Iteration 2	Iteration 3
			1%-	1%	1%+	Initial CN and n	90% CN	AMC I and 0.05 Channel n
Pt1	Pt1	219.6	10,110	16,662	27,459	31,231	24,183	12,585
Pt2	Pt2	259.1	11,050	18,210	30,011	40,992	31,850	16,785
Pt3	Pt3	24.4	3,190	5,258	8,665	20,368	15,658	8,369
Pt4	Pt4	4.52	802	1,322	2,178	6,792	5,579	3,642
Pt5	Pt5	291.6	11,959	19,709	32,480	58,203	44,542	23,466
Pt6	Pt6	20.8	2,992	4,931	8,127	23,758	18,452	11,074
Pt7	Pt7	56.5	5,890	9,707	15,998	19,163	14,191	6,811
Pt8	Pt8	190.4	9,302	15,330	25,264	30,828	23,820	12,327
Pt9	Pt9	106.2	6,309	10,397	17,134	17,313	13,287	6,874
Pt10	Pt10	1.11	251	414	682	1,124	757	311
SA2DConn_0701_A1	0701_A1_ Outfall	349.4	13,048	21,502	35,436	74,105	57,507	31,662

There were 2 USGS gages present in the Pecan Bayou watershed where flow-frequency analyses were completed. Gage 08143500 (Pecan Bayou at Brownwood, TX) resided in domain 0703_A4, and gage 08143600 (Pecan Bayou near Mullin, TX) fell within domain 0706_A7. At gage 08143500, the InFRM WHA reported a 1% flow of 28,900 cfs, and the BLE model computed a 1% flow of 31,727 cfs. The BLE 1% flow compares favorably with the InFRM WHA study at this location, with a difference of 10% between the two flows. At gage 08143600, the 1% BLE flow was 36,086 cfs and the 1% gage flow was 45,200 cfs, Although the BLE 1% flow was 20% lower than the gage 1% flow, the BLE 1% flow fell between the 1% minus and 1% gage flows.

Effective 1% flows were available at 7 locations in the watershed, all of which were located in domain 0704_A5. The effectives flows were from a 2018 countywide update for Brown County, Texas. The 1% BLE flows at these points were 30% to 83% less than the effective 1% flows. Gage flows were available at 1 of these locations (gage 08143500). Here the effective 1% flow was 18% greater than the 1% plus gage flow. At the other 6 locations, regression flows were available. At all 6 locations, the 1% effective flows fell outside of the range between the 1% minus and 1% regression flows, while the BLE 1% flows were within this range at 5 of the 6 locations. The poor agreement between the 1% effective flows and the gage and regression flows suggests that the effective study may not be a reliable study. Unfortunately, there was no information available in the FIS regarding the hydrologic methodology applied during the 2018 update, so it was not possible to learn more about why the effective 1% flows in this area are so high. Factors that likely contributed to the BLE 1% flows being so different from the effective 1% flows included differences in study 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.

A comparison between the 1% BLE WSELs and select effective 1% WSELs in the Pecan Bayou watershed is presented in Table 17. The effective 1% WSELs were obtained from the National Flood Hazard Layer (NFHL). All effective 1% WSELs were for streams located in domain 0704_A5. In general, the BLE 1% WSELs compared well with the effective 1% WSELs. Differences ranged from -4.5 feet to +4.4 feet with an average difference of -0.19 foot.

Factors that likely contributed to the differences between the BLE and effective WSELs include the study methodologies, the 1D nature of the effective analysis vs. the 2D approach in the BLE analysis, the higher flows in the effective 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 17: Comparison of Effective 1% WSELs with 1% BLE WSELs

Stream Name	Effective Stream Station	Effective XS Letter	Effective 1% WSEL (feet)	BLE 1% WSEL (feet)	Difference (Eff. - BLE) (feet)
Camp Bowie Reservoir Tributary	883	A	1,366.9	1,367.4	0.5
Camp Bowie Reservoir Tributary	3,252	C	1,375.0	1,374.7	-0.3
Camp Bowie Reservoir Tributary	6,206	E	1,389.1	1,388.3	-0.8
Camp Bowie Reservoir Tributary	7,555	G	1,400.2	1,398.9	-1.3

Stream Name	Effective Stream Station	Effective XS Letter	Effective 1% WSEL (feet)	BLE 1% WSEL (feet)	Difference (Eff. - BLE) (feet)
Canyon Creek	4,254	A	1,363.6	1,363.5	-0.1
Canyon Creek	5,572	C	1,380.7	1,380.7	0.0
Canyon Creek	7,208	E	1,405.1	1,405.3	0.2
Canyon Creek	8,789	G	1,418.6	1,419.1	0.5
Canyon Creek	10,465	I	1,428.9	1,428.2	-0.7
Canyon Creek	11,832	K	1,441.1	1,440.1	-1.0
South Willis Creek	2,533	A	1,338.0	1,342.4	4.4
South Willis Creek	4,130	C	1,347.7	1,348.9	1.2
South Willis Creek	5,170	E	1,351.7	1,353.2	1.5
South Willis Creek	5,726	G	1,356.3	1,356.4	0.1
South Willis Creek	8,016	I	1,363.5	1,364.7	1.2
South Willis Creek	10,558	K	1,373.6	1,373.4	-0.2
South Willis Creek	14,263	M	1,386.7	1,388.5	1.8
South Willis Tributary East	207	A	1,360.3	1,357.9	-2.4
South Willis Tributary East	2,068	C	1,383.8	1,383.1	-0.7
Tributary of South Willis Creek	1,403	A	1,362.4	1,364.5	2.1
Tributary of South Willis Creek	2,056	C	1,371.9	1,376.1	4.2
Tributary of South Willis Creek	3,720	E	1,393.3	1,393.3	0.0
Tributary of South Willis Creek	6,330	G	1,407.4	1,406.4	-1.0
Tributary of South Willis Creek	8,145	I	1,419.1	1,416.4	-2.7
Tributary of South Willis Creek	10,593	K	1,433.7	1,429.2	-4.5
Willis Creek	10,207	A	1,327.9	1,325.6	-2.3

Stream Name	Effective Stream Station	Effective XS Letter	Effective 1% WSEL (feet)	BLE 1% WSEL (feet)	Difference (Eff. - BLE) (feet)
Willis Creek	11,914	C	1,330.5	1,329.1	-1.4
Willis Creek	16,380	G	1,338.5	1,337.3	-1.2
Willis Creek	19,067	I	1,343.9	1,342.9	-1.0
Willis Creek	21,425	K	1,350.3	1,349.4	-0.9
Willis Creek	24,322	M	1,358.3	1,357.2	-1.1

* A vertical datum conversion of +0.030 feet was used to convert the effective WSELs from NGVD 29 to NAVD 88.

See Figure 19 and Table 18 on the followings pages for a summary of the 1% validation results at the validation points throughout the Pecan Bayou watershed.

The model overview and results spreadsheet (*Pecan_Bayou_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 in the model overview and results spreadsheet for each domain.

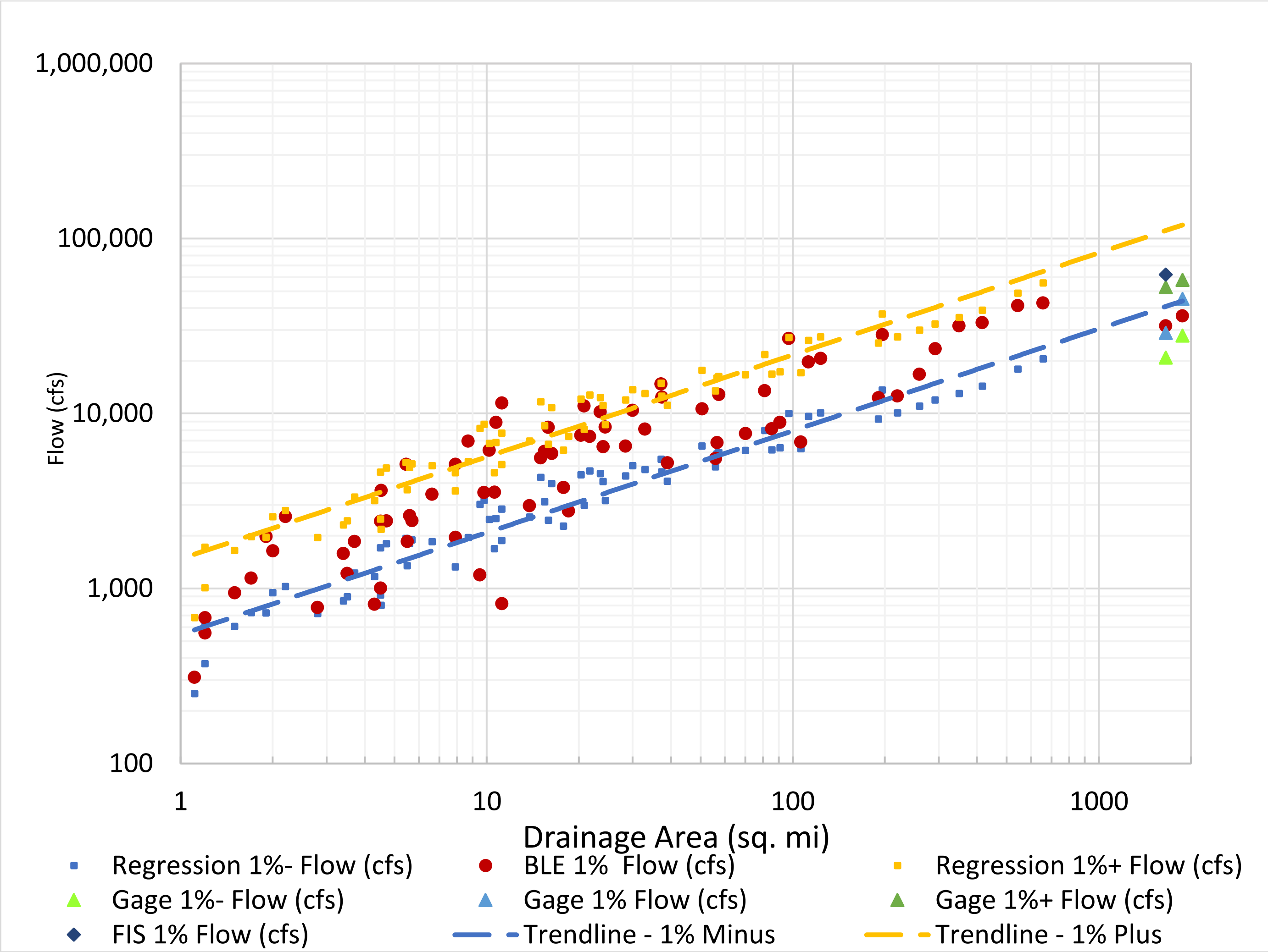


Figure 19: Computed Flow vs Drainage Area for Select 1% BLE, Regression, FIS, and Gage Flows

Table 18: 1% Peak Flow Validation Results for the Pecan Bayou Watershed

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 0701_A1										
0701_A1_ Outfall	Pecan Bayou	349.40	13,048	21,502	35,436	31,662	-	-	-	-
Pt1	Pecan Bayou	219.60	10,110	16,662	27,459	12,585	-	-	-	-
Pt2	Pecan Bayou	259.10	11,050	18,210	30,011	16,785	-	-	-	-
Pt3	Clear Creek	24.40	3,190	5,258	8,665	8,369	-	-	-	-
Pt4	Unnamed	4.52	802	1,322	2,178	3,642	-	-	-	-
Pt5	Unnamed	291.60	11,959	19,709	32,480	23,466	-	-	-	-
Pt6	Crooked Creek	20.80	2,992	4,931	8,127	11,074	-	-	-	-
Pt7	South Prong Pecan Bayou	56.50	5,890	9,707	15,998	6,811	-	-	-	-
Pt8	Pecan Bayou	190.44	9,302	15,330	25,264	12,327	-	-	-	-
Pt9	North Prong Pecan Bayou	106.16	6,309	10,397	17,134	6,874	-	-	-	-
Pt10	Unnamed	1.11	251	414	682	311	-	-	-	-
Domain 0702_A2										

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)
0702_A2_ Outfall (#1&#2)	Pecan Bayou	543.28	17,925	29,541	48,683	41,347	-	-	-	-
Pt1	Pecan Bayou	415.80	14,349	23,646	38,969	33,119	-	-	-	-
Pt2	Little Pecan Bayou	15.90	2,461	4,056	6,684	8,325	-	-	-	-
Pt3	Cottonwood Creek	3.40	852	1,405	2,315	1,588	-	-	-	-
Pt4	Turkey Creek	55.90	4,967	8,185	13,490	5,537	-	-	-	-
Pt5	Turkey Creek	85.30	6,199	10,216	16,836	8,172	-	-	-	-
Pt6	Unnamed	2.20	1,028	1,964	2,792	2,585	-	-	-	-
Pt7	Turkey Creek	18.50	2,734	4,507	7,427	2,778	-	-	-	-
Pt8	Turkey Creek	90.80	6,389	10,528	17,351	8,909	-	-	-	-
Pt 9	Cottonwood Branch	4.70	1,802	2,970	4,894	2,438	-	-	-	-
Domain 0703_A3										
0703_A3_ Outfall	Pecan Bayou	657.0	20,525	33,826	55,745	42,908	-	-	-	-
Pt1	Unnamed	1.20	372	613	1,011	681	-	-	-	-
Pt2	Unnamed	7.90	1,330	2,193	3,613	1,959	-	-	-	-

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)
Pt3	Paint Creek	38.90	4,114	6,781	11,175	5,227	-	-	-	-
Pt4	Holloway Creek	10.60	1,689	2,784	4,588	3,554	-	-	-	-
Pt5	Paint Creek	17.80	2,278	3,754	6,187	3,774	-	-	-	-
Pt6	Unnamed	2.0	948	1,562	2,574	1,644	-	-	-	-
Pt7	Unnamed	11.20	1,885	3,106	5,119	820	-	-	-	-
Pt8	Red River	70	6,150	10,136	16,704	7,703	-	-	-	-
Domain 0703_A4										
Pt1	Unnamed Tributary	1.20	635	1,047	1,726	558	-	-	-	-
Pt2	Rough Branch	4.30	1,174	1,934	3,188	814	-	-	-	-
Pt3	Panther Creek	20.30	4,464	7,357	12,125	7,512	-	-	-	-
Pt4	Sand Creek	16.30	3,983	6,565	10,819	5,917	-	-	-	-
Pt5	Hog Creek	80.90	7,999	13,182	21,725	13,506	-	-	-	-
Pt6	Rough Creek 2	1.70	730	1,203	1,982	1,146	-	-	-	-
Pt7	Rocky Creek	5.70	1,901	3,133	5,164	2,447	-	-	-	-

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)
Pt8	Unnamed Tributary	1.50	607	1,001	1,649	947	-	-	-	-
Pt9	Jim Ned Branch	3.70	1,228	2,023	3,334	1,862	-	-	-	-
Pt10	Lake Brownwood	5.50	1,350	2,225	3,666	1,861	-	-	-	-
Pt11	Unnamed Tributary	3.50	897	1,478	2,436	1,220	-	-	-	-
Pt12	Unnamed Tributary	2.80	721	1,189	1,959	779	-	-	-	-
Pt13	Lost Creek	4.50	919	1,514	2,496	1,007	-	-	-	-
Pt14	Bledsoe Branch	13.80	2,567	4,231	6,972	2,972	-	-	-	-
Pt15	Sand Creek	21.70	4,711	7,764	12,795	7,393	-	-	-	-
Pt16	Jim Ned Branch	5.60	1,811	2,985	4,919	2,612	-	-	-	-
Domain 0704_A5										
USGS Gage	08143500	1,654.0	-	-	-	31,727	20,900	28,900	52,600	62,247
Pt1	Salt Creek	37.11	5,480	9,031	14,884	14,763	-	-	-	-
Pt2	Mackinally Creek	15.45	3,134	5,164	8,511	6,084	-	-	-	-
Pt3	Steppes Creek	28.40	4,405	7,259	11,963	6,505	-	-	-	-

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)
Pt4	Gap Creek	11.20	2,852	4,700	7,745	11,481	-	-	-	-
Pt5	Unnamed	7.90	1,962	2,789	4,597	5,137	-	-	-	-
FIS 1	Tom Williams Creek - At US Highway 67	4.50	1,708	2,815	4,638	2,424	-	-	-	14,010
FIS 2	West Adams Branch - At Beaver Avenue	9.80	3,199	5,273	8,689	3,546	-	-	-	10,544
FIS 3	West Adams Branch - At Belle Plain Avenue	15.0	4,311	7,105	11,709	5,575	-	-	-	17,869
FIS 4	Willis Creek - Above confluence of Split Flow Channel	9.50	3,029	4,992	8,227	1,197	-	-	-	1,750
FIS 5 & FIS 5 Overbank	South Willis Creek - Below Tributary of South Willis Creek	10.20	2,488	4,100	6,757	6,180	-	-	-	8,791
FIS 6	Willis Creek - Below Eastern City Limits of Brownwood	23.50	4,538	7,478	12,324	10,244	-	-	-	14,767
Domain 0705_A6										

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)
0705_A6_ Outfall	Blanket Creek	196.0	13,634	22,469	37,028	28,212	-	-	-	-
Pt1	Unnamed	1.90	725	1,195	1,969	1,982	-	-	-	-
Pt2	Pompey Creek	8.70	1,956	3,224	5,312	6,969	-	-	-	-
Pt3	Blanket Creek	123.30	10,111	16,662	27,459	20,682	-	-	-	-
Pt4	Blanket Creek	57.30	5,989	9,869	16,264	12,840	-	-	-	-
Pt5	Dry Blanket Creek	24.0	4,096	6,749	11,123	6,455	-	-	-	-
Pt6	Blanket Creek	37.30	4,639	7,645	12,599	12,406	-	-	-	-
Pt7	Pompey Creek	50.50	6,517	10,740	17,700	10,618	-	-	-	-
Pt8	Blanket Creek	112.50	9,631	15,872	26,157	19,762	-	-	-	-
Domain 0706_A7										
Pt1	Unnamed	5.45	1,938	3,194	5,264	5,127	-	-	-	-
Pt2	Browns Creek	29.95	5,043	8,310	13,695	10,418	-	-	-	-
Pt3	Mullin Creek	32.86	4,800	7,910	13,036	8,136	-	-	-	-
Pt4	Browns Creek	97	10,022	16,517	27,220	26,820	-	-	-	-

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)
Pt5	South Browns Creek	10.71	2,519	4,151	6,841	8,898	-	-	-	-
Pt6	Rough Creek	6.63	1,857	3,060	5,043	3,460	-	-	-	-
Pt7 - Gage 08143600	Pecan Bayou	1,876.40	-	N/A	-	36,086	27,900	45,200	57,900	-

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 20, 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.

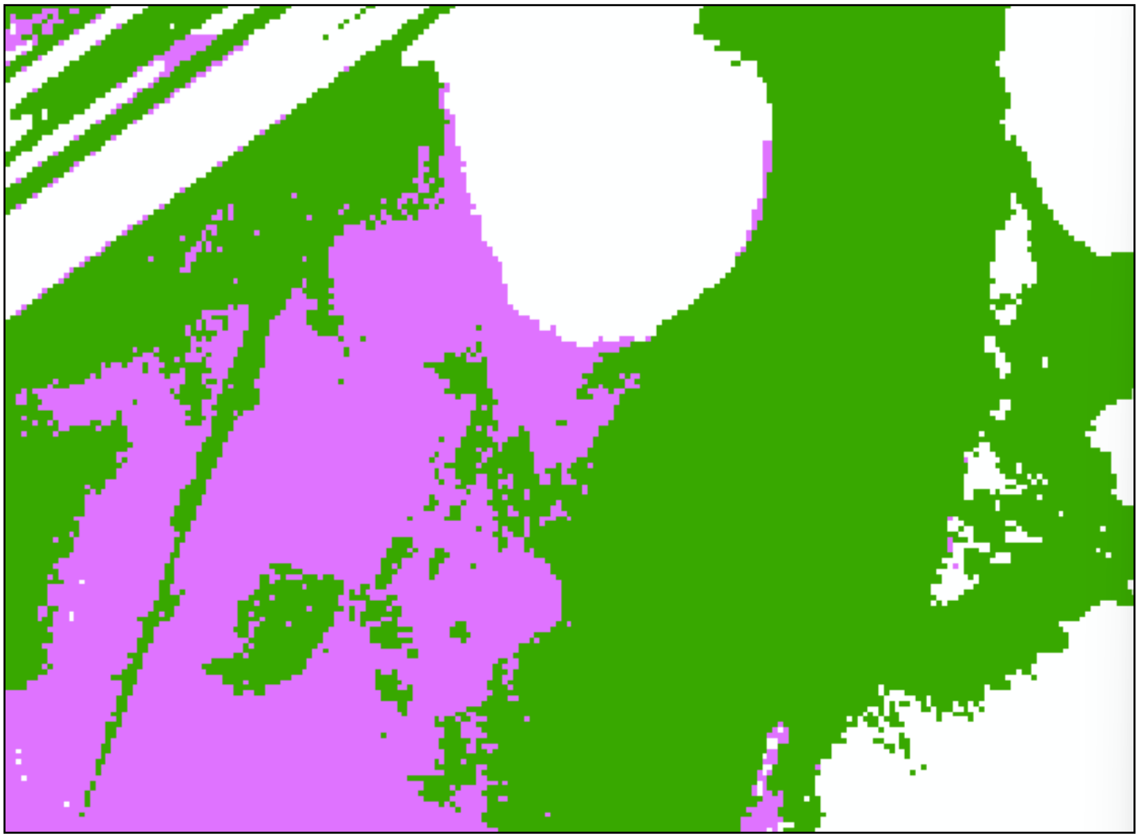


Figure 20: Example of Overlapping Mapping along a Model Domain Boundary

Figure 21 shows what the difference raster looks like for the area in Figure 20. 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 20 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.

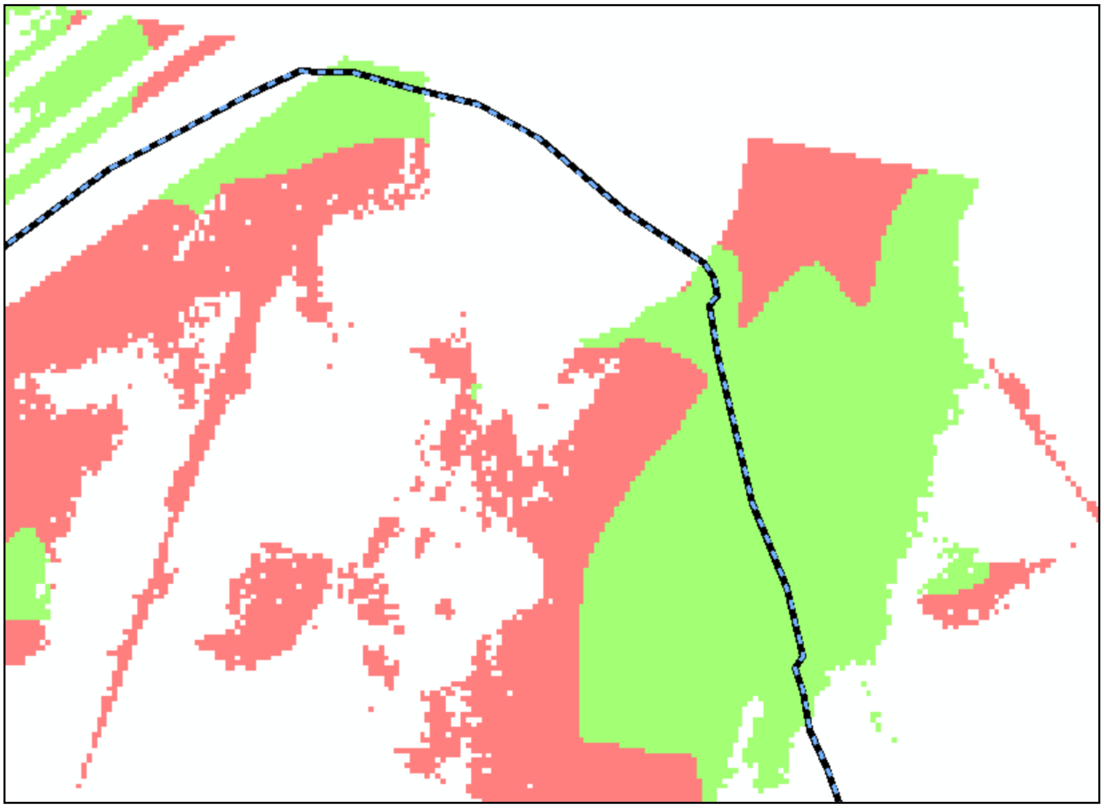


Figure 21: WSEL Difference Raster and Split Line for the Overlap Area

- 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 19.

Table 19: 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 Pecan Bayou 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 Pecan Bayou 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 CN values were revised 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 CN values 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 too heavily in favor of the larger streams or the smaller streams. Balancing the validation needs between the small and large streams 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, completely ignoring the structures would have produced invalid model results. Therefore, hydraulic structures were modeled using a 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 HEC's 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 22. 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 Pecan Bayou watershed. Therefore, cupping is prevalent throughout the BLE mapping.

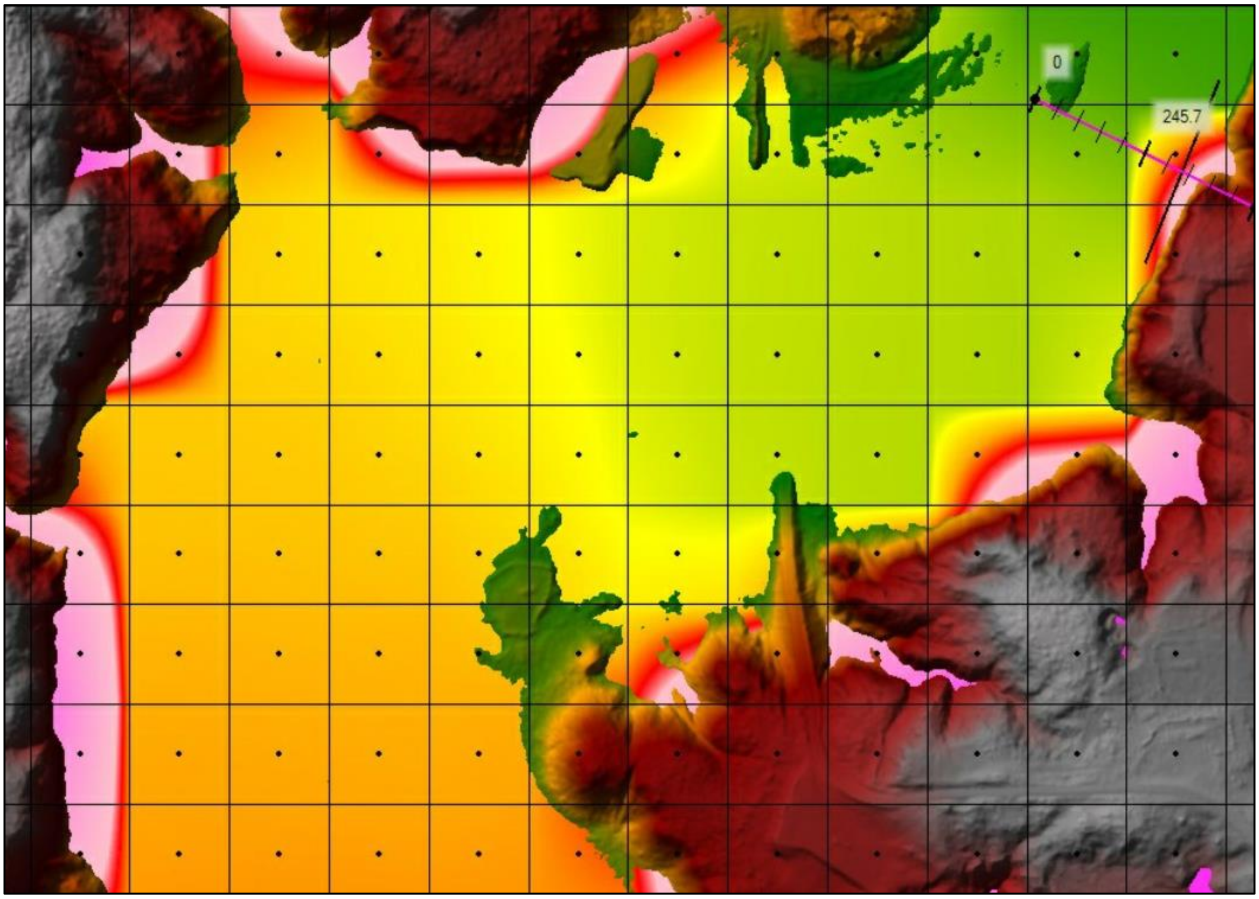


Figure 22: An Example of Cupping in 2D BLE Mapping

Results and Recommendations

The BLE floodplain mapping for the Pecan Bayou watershed compared reasonably well with the effective Special Flood Hazard Area (SFHA) in most cases, and provides an estimated 1% annual-chance floodplain in areas 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 Pecan Bayou watershed has been included as Appendix A.

The BLE floodplains were compared with the effective floodplains in the Pecan Bayou watershed. The NFHL for the watershed included digital data for Brown and Taylor counties. For counties in the watershed where digital floodplain data was not available, digitized effective floodplain mapping was available in a proprietary dataset developed by RMSI and acquired by AtkinsRéalis. The RMSI dataset included isolated digital floodplain boundaries for Eastland, Callahan, and Mills counties. A comparison of the digitized FEMA mapping with the 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 sometimes the effective floodplains were wider and other times the BLE floodplains were wider.

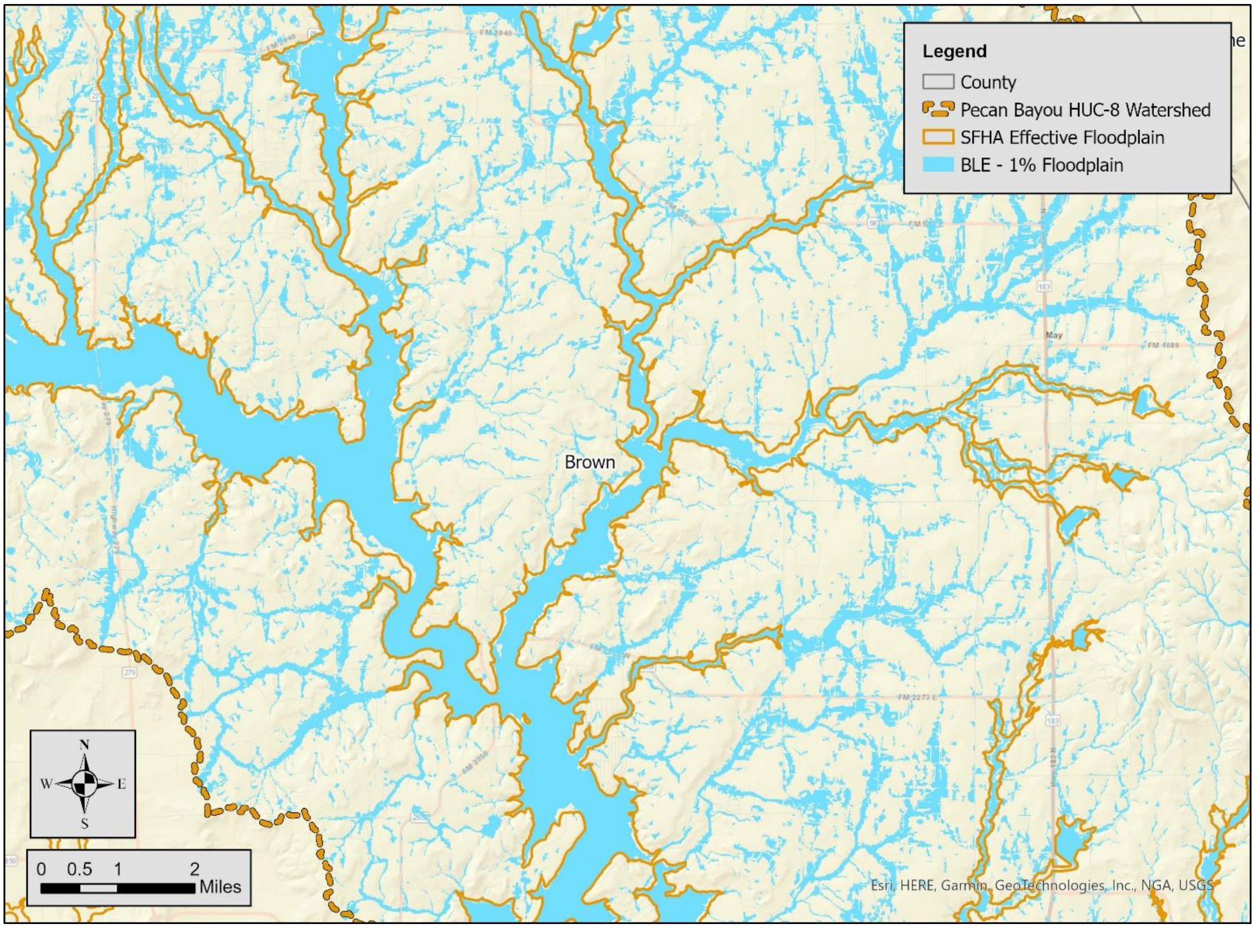


Figure 23: The Effective 1% Floodplain and the 1% BLE Floodplain in Brown County, TX

Floodplain mapping for the Pecan Bayou 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 Pecan Bayou watershed were compared with the Fathom floodplain mapping. Figure 24 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 23. 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.

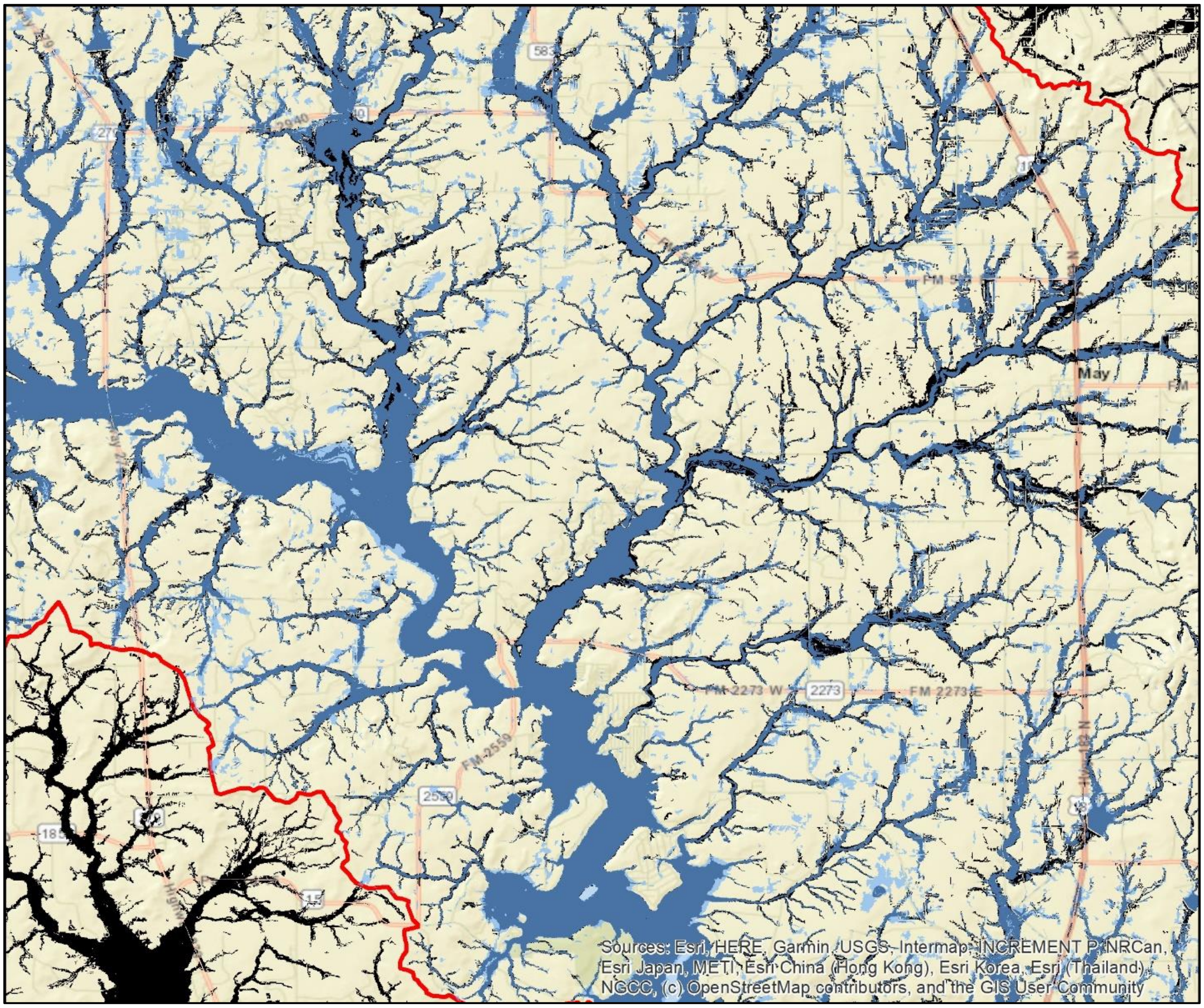


Figure 24: Comparison of 1% BLE Mapping (light blue with transparency) with Fathom 1% Mapping (black)

As a 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. 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.

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

The Zone A streams in the Pecan Bayou watershed were classified as either “UNVERIFIED” with a status type of “BEING STUDIED” (490.3 miles) or “VALID” with a status type of “BEING STUDIED” (0.8 mile).

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 Pecan Bayou 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. 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 HUC-12 watersheds with Zone A studies. If the percentage of urban area within the watershed containing the effective Zone A study was 15% or more, and had 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. This watershed is generally rural with few villages, and there has not been significant development in the watershed. A significant development check for the study areas 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 20: 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 passed all of the initial assessment checks described above were categorized as "Valid" in the CNMS Inventory when the effective Zone A study was supported by modeling or sound engineering judgment and all regulatory products were in agreement. If the effective Zone A study passed all initial assessment checks, but was not supported by modeling, or if the original engineering method used was unsupported or undocumented, then a comparison of the BLE results and effective Zone A mapping was performed. Most of the effective reaches (490.3 miles) were documented with HEC-1 as the model used for analysis. The A4 check was set to pass for those reaches. There were some reaches with no adequate documentation regarding how the engineering analysis supporting the effective study was performed (25.4 miles). Therefore, the A4 check was set to fail for those 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 Pecan Bayou BLE analysis.

The contour interval for the vertical tolerance was taken from the USGS 1:24,000-scale topographic maps of the Pecan Bayou 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 22 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 Zone A studies in the Pecan Bayou watershed study area has been updated. The total miles in each of these categories are summarized in Table 21 and illustrated on Figure 25. The findings from the Initial Assessment A5 are in Table 22.

Table 21: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment
VALID	NVUE COMPLIANT	13.4	0
	BEING ASSESSED	11.4	0
	BEING STUDIED	0	0.8
UNVERIFIED	BEING STUDIED	0	490.3
	TO BE STUDIED	458.8	0

Table 22: BLE Comparison Results

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)
Watershed Name	HUC-12 ID					
Upper South Prong Pecan Bayou	120901070103	1,380	297	1,083	78.5	Fail
Cottonwood Creek-Turkey Creek	120901070203	6	3	3	50.0	Fail
Dinner Branch-Turkey Creek	120901070204	632	210	422	66.8	Fail
Hay Branch-Pecan Bayou	120901070205	2,054	721	1,333	64.9	Fail
Paint Creek-Red River	120901070301	3,675	909	2,766	75.3	Fail
Holloway Creek-Pecan Bayou	120901070302	3,804	1,041	2,763	72.6	Fail
Bledsoe Branch-Lost Creek	120901070303	1,815	721	1,094	60.3	Fail
Headwaters Hog Creek	120901070304	2,020	902	1,118	55.3	Fail
Hog Creek-Lake Brownwood	120901070305	3,318	883	2,435	73.4	Fail
Gap Creek-Salt Creek	120901070401	3,337	666	2,671	80.0	Fail
Elm Creek-Pecan Bayou	120901070402	4,617	1,166	3,451	74.7	Fail
Adams Branch-Pecan Bayou	120901070403	1,692	491	1,201	71.0	Fail
Delaware Creek-Pecan Bayou	120901070404	2,706	780	1,926	71.2	Fail
Steppes Creek	120901070405	2,726	1,094	1,632	59.9	Fail
Double Creek-Pecan Bayou	120901070406	2,622	1,222	1,400	53.4	Fail
Mackinally Creek-Pecan Bayou	120901070407	2,583	683	1,900	73.6	Fail
Camp Creek-Blanket Creek	120901070501	5,061	1,321	3,740	73.9	Fail
Dry Blanket Creek	120901070502	1,879	819	1,060	56.4	Fail
Bee Branch-Blanket Creek	120901070503	1,375	277	1,098	79.9	Fail
Mullin Creek	120901070602	88	11	77	87.5	Pass

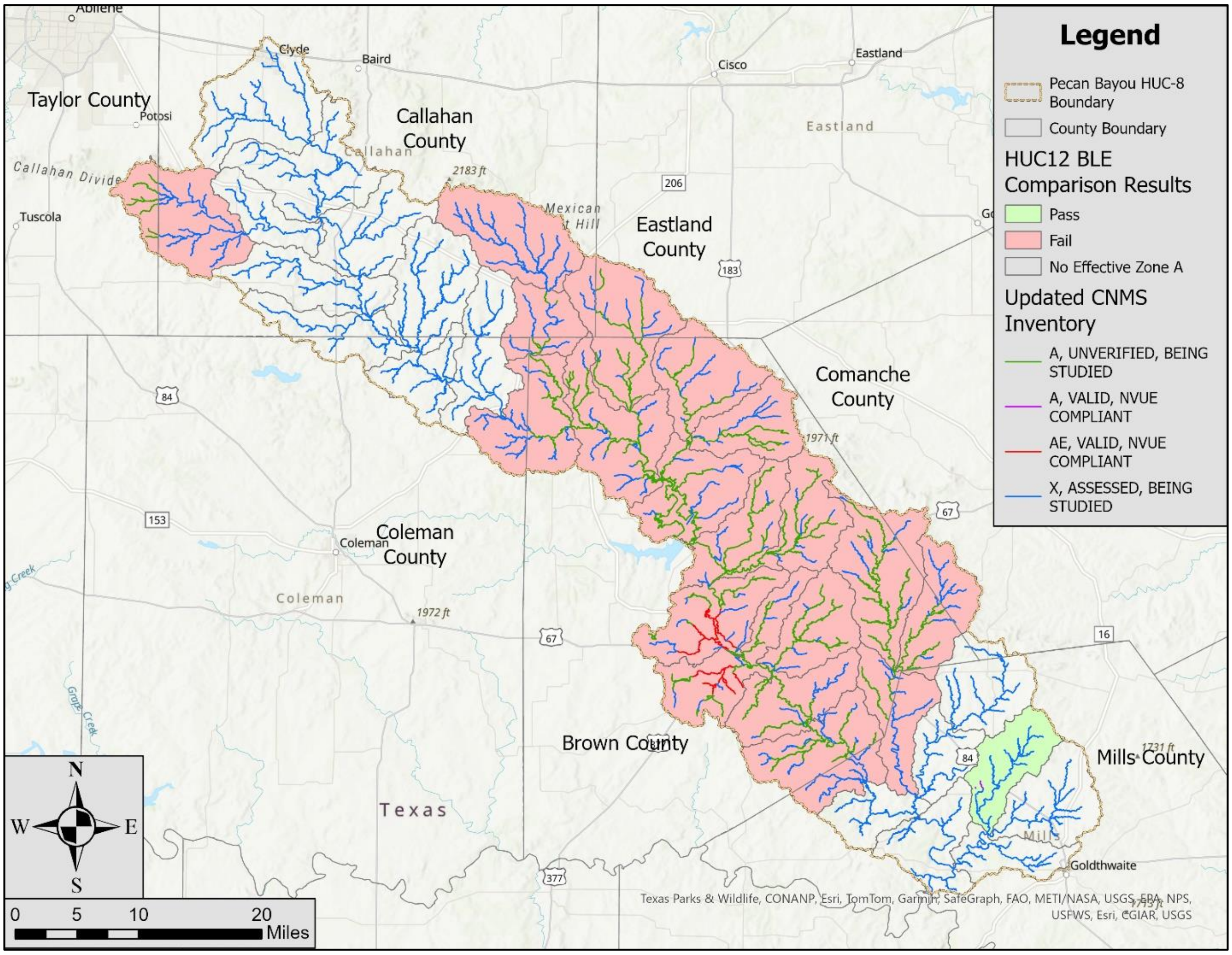


Figure 25: CNMS Validation Results

1.6. Flood Risk Analysis

A flood risk analysis was performed for the Pecan Bayou 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.

BLE projects for the TWDB are organized by HUC-8 watershed. Two of the HUC-8 watersheds studied by AtkinsRéalis for the TWDB were the Jim Ned watershed and the Pecan Bayou watershed. The confluence of the Jim Ned watershed with the Pecan Bayou watershed occurs in Lake Brownwood. From a modeling perspective, it was not feasible for the lake to be modeled in two separate domains or watersheds. Therefore, all of Lake Brownwood and the immediate area that drains into it were included in the modeling for Pecan Bayou domain 0703_A4.

Figure 15 on page 27 shows how the BLE model domains were delineated in the vicinity of Lake Brownwood. The red lines represent the HUC-8 watershed extents for the Jim Ned and Pecan Bayou watersheds. The black lines represent the BLE model domain extents in both watersheds. Cross hatching has been added to Pecan Bayou domain 0703_A4; note how the domain includes all of Lake Brownwood but falls in both the Jim Ned and Pecan Bayou watersheds.

Although a portion of the Jim Ned watershed was included in the BLE modeling for the Pecan Bayou watershed, the flood risk analysis deliverables have been organized by watershed. The Pecan Bayou Hazus results have been clipped to the Pecan Bayou HUC-8 watersheds extents, and the Jim Ned Hazus results have been clipped to the Jim Ned HUC-8 watersheds extents.

Additional inputs for the flood risk 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 USGS land use/land cover data. Loss values are reported in whole dollar amounts. See Table 23 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 23: Hazus Results for the Pecan Bayou Watershed

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Mills County	$9,217,000	$263,039,000	$149,242,000
Comanche County	$493,000	$13,702,000	$6,914,000
Brown County	$556,282,000	$3,197,006,000	$2,086,636,000
Eastland County	$588,000	$34,583,000	$18,514,000
Coleman County	$4,179,000	$40,642,000	$23,839,000
Taylor County	$74,000	$4,178,000	$2,544,000
Callahan County	$102,633,000	$930,026,000	$546,073,000
Total	**$673,466,000**	**$4,483,176,000**	**$2,833,762,000**

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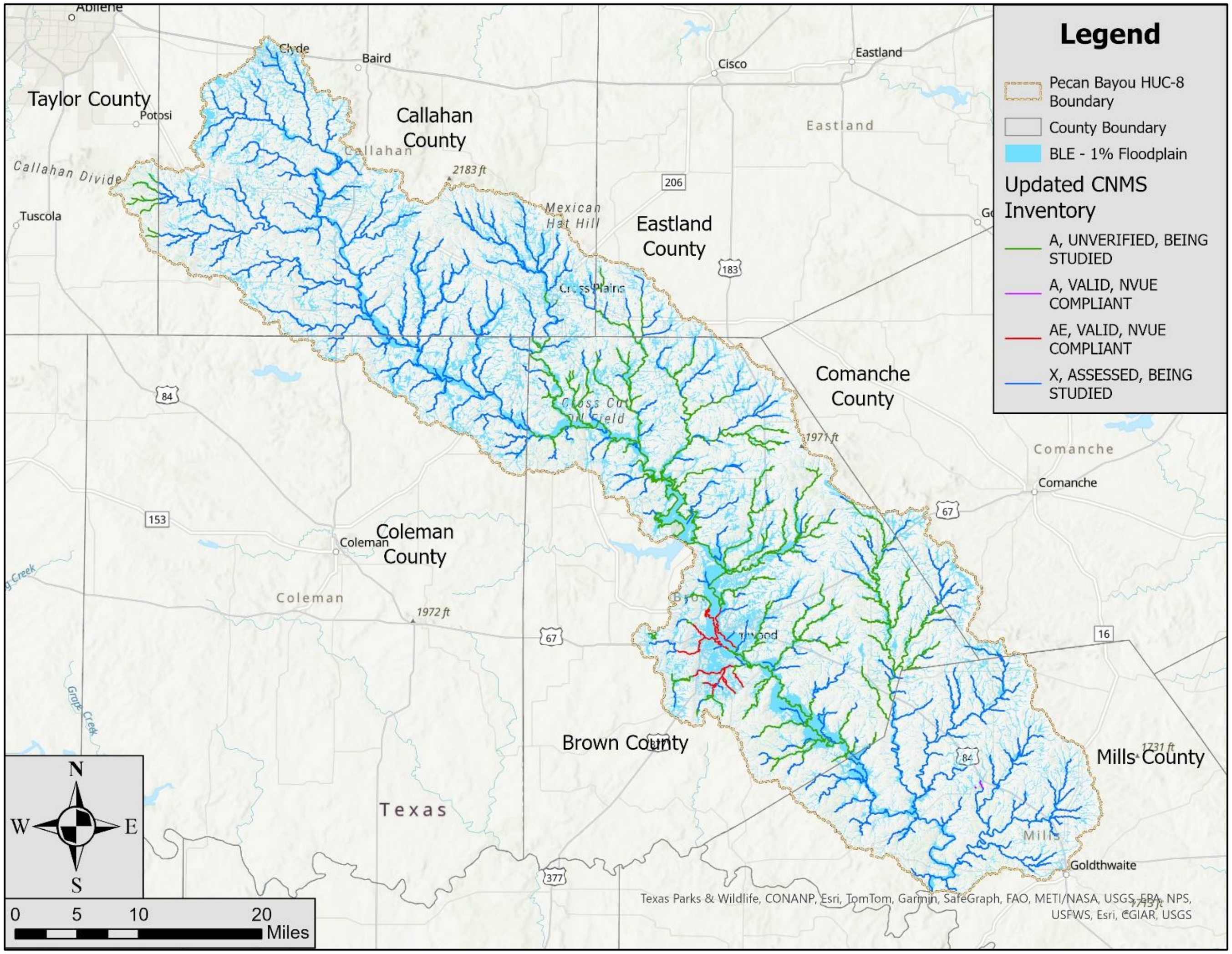
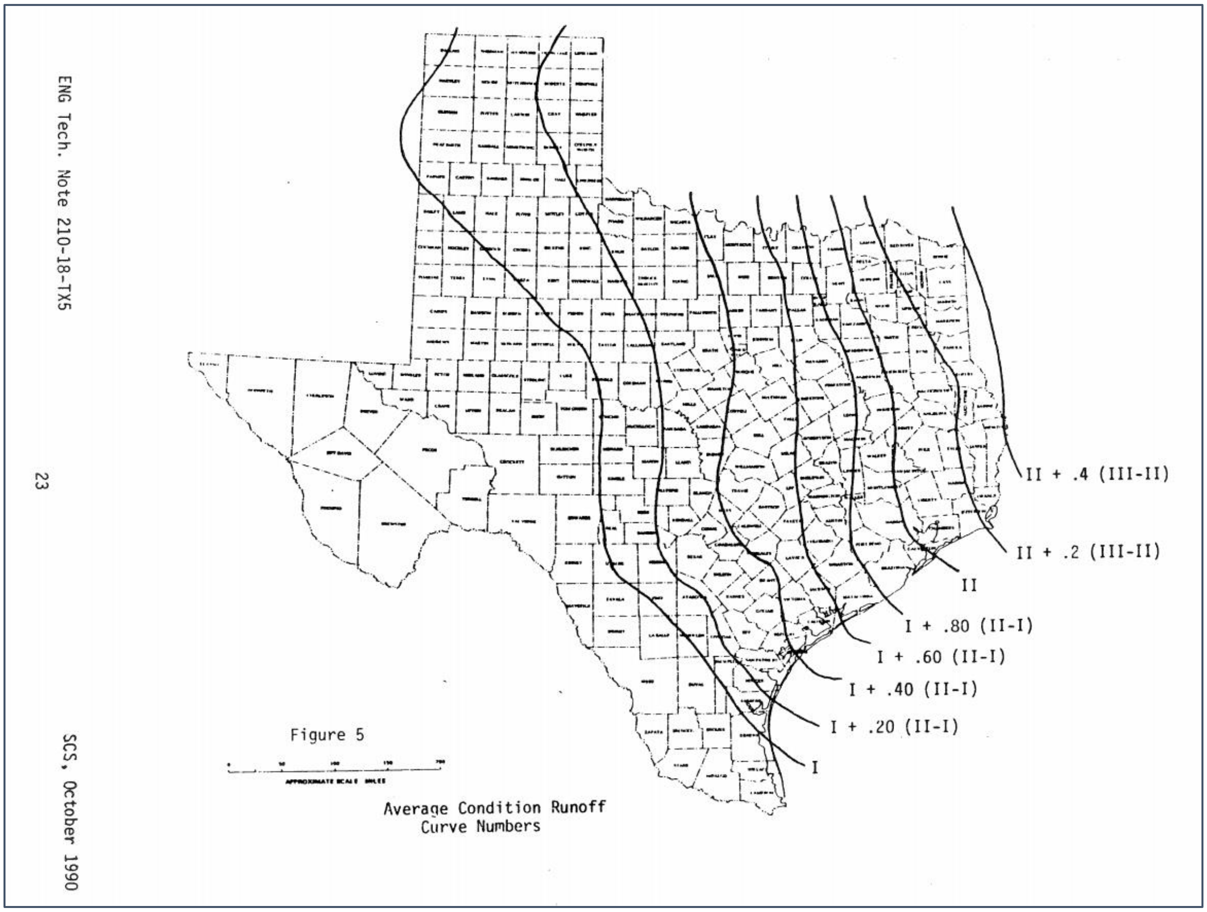
Appendix A – Base Level Engineering Results



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 Pecan Bayou 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 69, 70, 71, 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 analysis for USGS gage 08143500 (Pecan Bayou at Brownwood, TX).
- Pages 72, 73, 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 analysis for USGS gage 08143600 (Pecan Bayou near Mullin, TX).