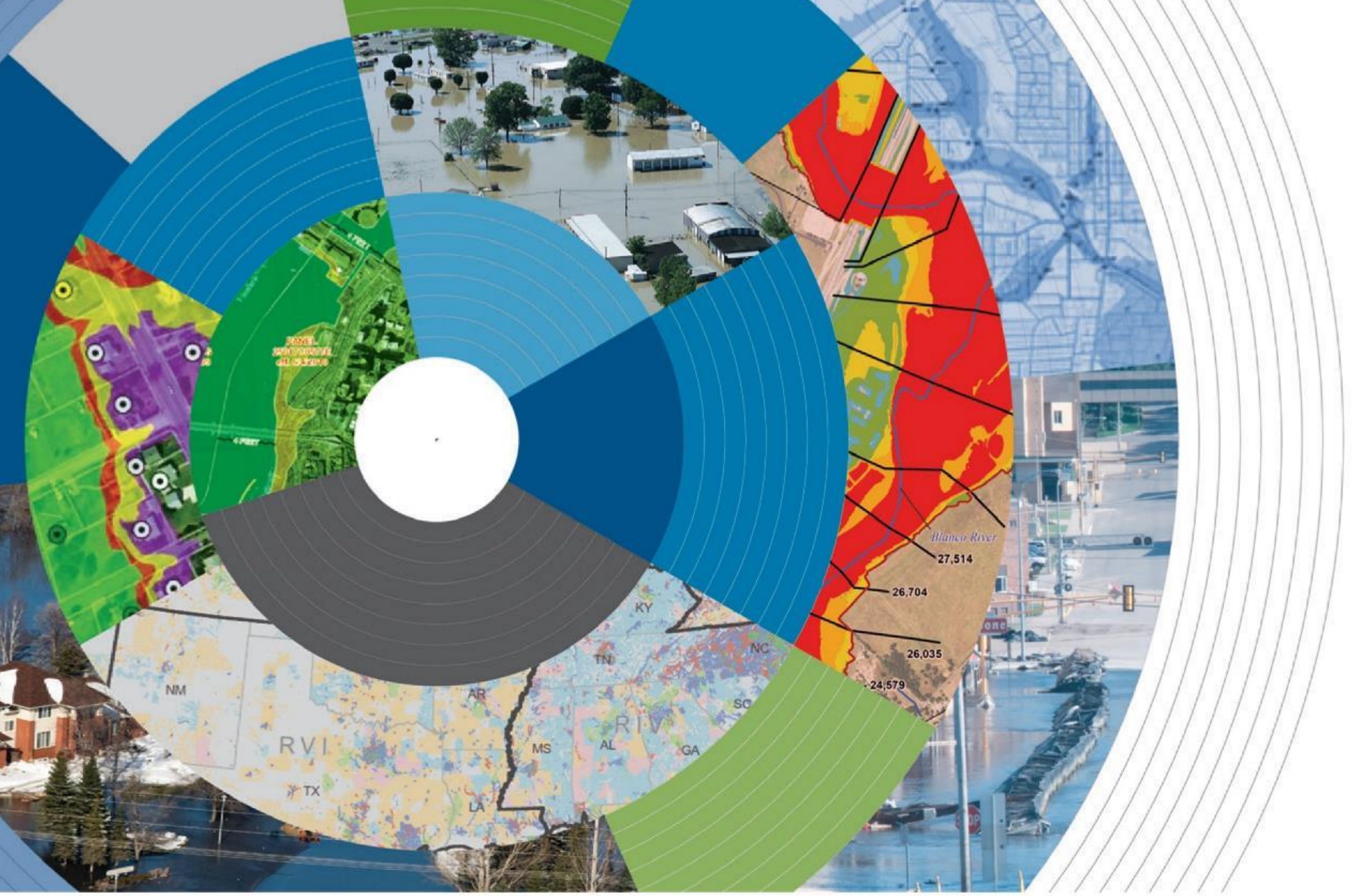

Base Level Engineering Report

Brady (12090110)

Texas Water Development Board

November 30, 2024

Version 1.0

Report Prepared for:

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Version Number	Version Date	Summary of Changes	Author
1.0	November 30, 2024	Initial report for the Estimated Base Flood Elevation viewer	AtkinsRéalis USA, Inc.

FINAL REPORT FOR BRADY (12090110)

PREPARED FOR:

Texas Water Development Board

Prepared By:

AtkinsRéalis USA, Inc.

Texas Registered
Engineering FIRM # 474

06/12/2025

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Executive Summary

The Texas Water Development Board (TWDB) contracted with AtkinsRéalis USA, Inc. (AtkinsRéalis) to complete two-dimensional (2D) Base Level Engineering (BLE) in the Brady HUC-8 watershed (12090110). This watershed is located in Central Texas, southeast of San Angelo. The watershed area is 804 square miles (mi^2). Approximately 699 miles of stream centerlines were modeled. The information produced during this assessment may be found on the U.S. Department of Homeland Security's Federal Emergency Management Agency's (FEMA) Mapping Information Platform (MIP) under case number 22-06-0047S.

The following guidance documents provided the methodologies for this project:

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

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

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

The Brady watershed was divided into four HEC-RAS model domains—1001_A1, 1001_A2, 1002_A3, and 1002_A4. 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 Brady watershed is in Table 1 and Table 2 and shown on Figure 1.

Table 1: Summary of Stream Miles

Source	Stream Miles
Current Inventory – CNMS	21.2
New Study Streams – CNMS	677.6
Total (BLE) Stream Miles	698.8

Table 2: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment
VALID	NVUE COMPLIANT	0	0
	BEING STUDIED	0	1.8
UNVERIFIED	BEING STUDIED	0	14.1
	TO BE STUDIED	16.0	0

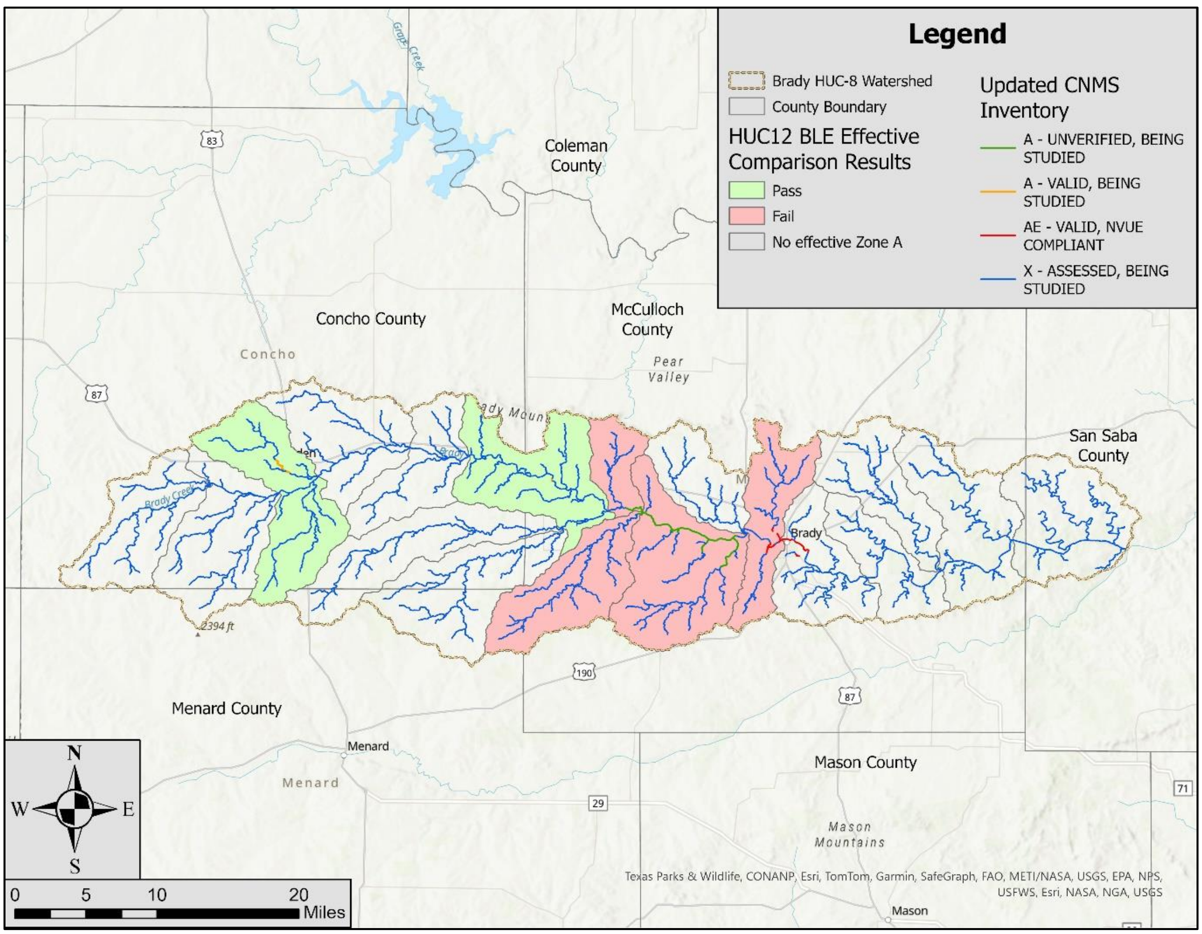


Figure 1: Brady - 12090110 CNMS Validation Results

1.0 Base Level Engineering (BLE) Methodology

Recent innovations and increased efficiencies in floodplain mapping have allowed FEMA to develop a process called BLE, which can be used to address current program challenges, including the validation of Zone A studies and the availability of flood risk data in the early stages of a Flood Risk Project. The BLE process involves using best available data and incorporating automated techniques with traditional model development procedures to produce regulatory-quality flood hazard boundaries for the 1% annual chance event as well as estimates of flood hazard boundaries for multiple recurrence intervals. The cost for developing the data and estimates resulting from the BLE process are lower than standard flood production costs. The BLE results may be used for eventual production of regulatory and non-regulatory products.

As described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e), once every 5 years, FEMA must determine whether the information on its Flood Insurance Rate Maps (FIRMs) reflects the current risks in flood-prone areas. FEMA makes this determination of flood hazard data validity by examining flood study attributes and change characteristics, as specified in the Validation Checklist of the CNMS Technical Reference. The CNMS Validation Checklist provides a series of critical and secondary checks to determine the validity of flood hazard areas studied by detailed methods (e.g., Zone AE, AH, or AO). While the critical and secondary elements in CNMS provide a comprehensive method of evaluating the validity of Zone AE studies, a cost-effective approach for evaluating Zone A studies has been lacking.

In addition to the need for Zone A validation guidance, FEMA standards require flood risk data to be provided in the early stages of a flood risk project. FEMA Program SID 29 requires that during 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 Brady watershed (HUC-8 12090110). The watershed is mostly rural and the land is predominantly used for farming and ranching. Parts of Concho, McCulloch, Menard, and San Saba counties fall within the watershed. The City of Brady, Eden, and the town of Melvin reside within the watershed. See Figure 2 for a map of the Brady watershed.

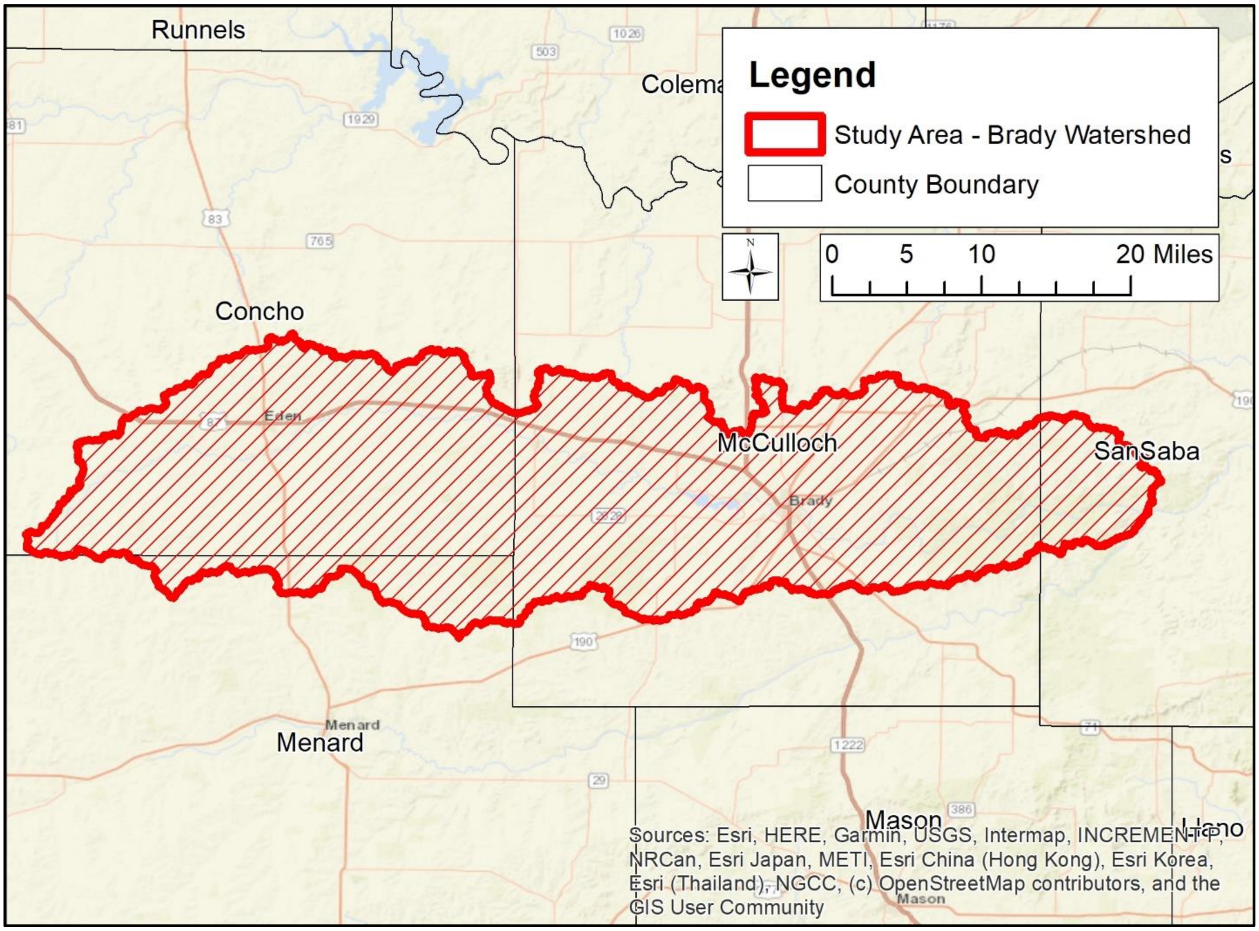


Figure 2: Brady Watershed – HUC-8 12090110

The BLE assessment prepared a cursory engineering analysis for approximately 699 miles of stream reaches within the Brady watershed with a minimum drainage area tolerance of 1 mi^2. The selection and extent of the stream reaches studied were based upon the number of stream miles meeting the minimum drainage area of 1 mi^2 and not the number of effective Zone A stream miles. Study reaches were extended above this 1-mi^2 threshold as appropriate so the entire effective Zone A floodplain received an updated analysis. The following sections summarize the BLE process and discuss the results, along with their recommended use.

1.1. Topographic Data

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

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

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

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

The above-mentioned LiDAR data sets were used to create a seamless set of tiled 5-foot DEMs for the Brady 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 the FEMA's Region 6 BLE guidance from 2019. After projecting the terrain into the Texas State Plane Zone 3 (Central) projection (North American Datum [NAD] 1983 [2011]) with units of U.S. feet, the tiles were mosaicked into one DEM. The sources and extents of the original DEMs used to create the mosaicked DEM are shown on Figure 3.

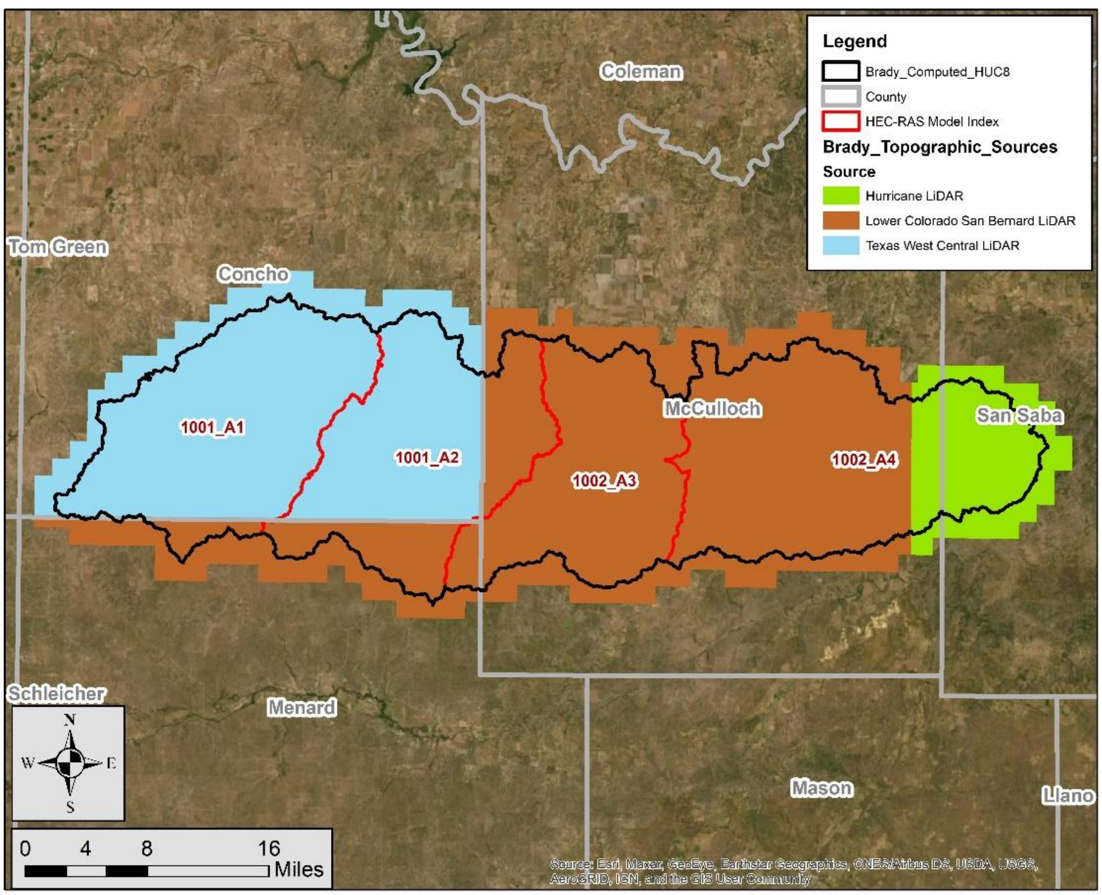


Figure 3: Topographic Data Extents in the Brady Watershed

Table 3: Topographic Data Sources

County	Year Acquired	Vertical Accuracy	Source	Approximate Footprint (mi^2)
Hurricane LiDAR (McCulloch and San Saba counties)	2019	3.8 cm	USGS	102
Texas West Central LiDAR (Concho, McCulloch, and Menard counties)	2018	4.7 cm	USGS	376
Lower Colorado San Bernard LiDAR (McCulloch and Menard counties)	2018	4.9 cm	USGS	582

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

Data Set One – Hurricane LiDAR

The U.S Geological Survey's (USGS) Hurricane LiDAR dataset captured in 2019 contains data for 14,512 mi^2 across 45 counties in Texas. In the Brady watershed, this dataset includes parts of McCulloch and San Saba counties. The vertical accuracy (RMSEz, or root mean square error in the z direction) of this dataset, is 3.8 centimeters (cm). The native cell size of the data is 1 square meter (m^2).

Data Set Two – Texas West Central LiDAR

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

Data Set Three –Lower Colorado San Bernard River LiDAR

The USGS's Lower Colorado San Bernard River LiDAR dataset captured in 2018 contains data for 17,942 square mi^2 across 26 counties in Texas. In the Brady watershed, this dataset includes parts of McCulloch and Menard counties. The vertical accuracy (RMSEz) of this dataset is 4.9 cm. The native cell size of the data is 1 m^2.

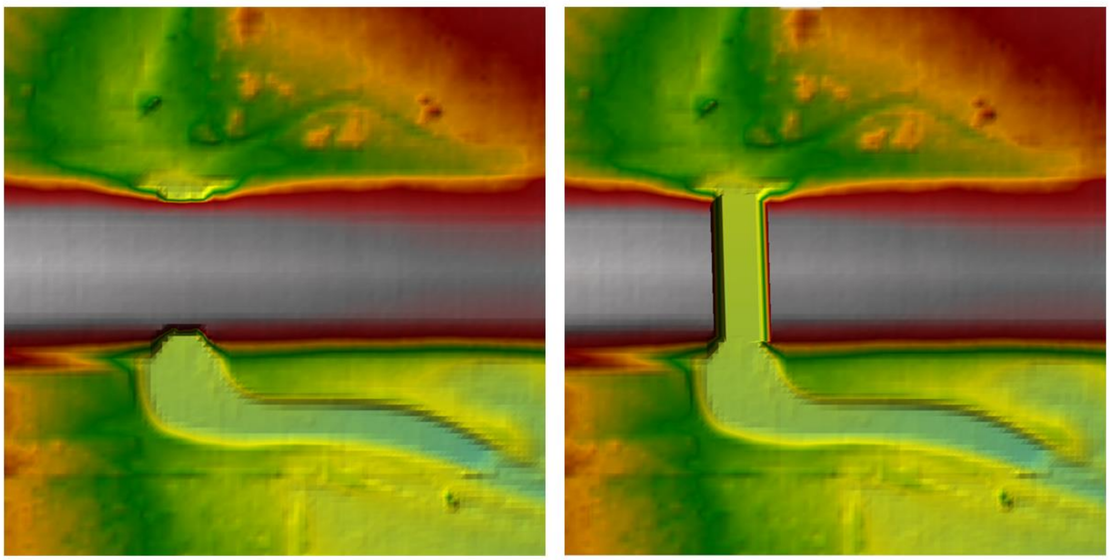
No modifications were made to this terrain surface. The goal was to use this terrain 'as is' in the hydraulic modeling, floodplain mapping, and grid development tasks. Maintaining the source terrain data in an unmodified state avoids customized changes to the terrain dataset that future users may not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

1.1.2. Development of the Stream Networks and Drainage Basins

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

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

- The flow direction grid, flow accumulation grid, hydrologic stream network, and hydrologic basins were developed.
- Burn lines were defined as needed at roadway/railroad crossings or where reservoirs/ponds artificially diverted the flow path from the natural alignment. The bridge/culvert crossing burn lines developed in this task were subsequently incorporated into the HEC-RAS terrain as terrain modification features (see example in Figure 4 below). Terrain modifications, when applied, allow 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 Brady watershed. The first gage was 08145000 (Brady Ck at Brady, TX). This gage had a reported drainage area of 588 mi^2. The computed drainage area of 589 mi^2 was within 10 percent of the reported drainage area, which is acceptable. The second was gage 08145100 (Brady Ck Trib nr Brady, TX). This gage had a reported drainage area of 4.05 mi^2. The computed drainage area of 4.17 mi^2 was within 10 percent of the reported drainage area, which is acceptable. Gage 08145100 had a period of record of only seven years from several decades ago (1967-1974). Because the flow data at this gage was old and limited, a gage analysis was not completed and the gage was not used during the validation task.

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

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

1.2. Hydrologic and Hydraulic Analysis

A 2D BLE analysis of the Brady 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 Brady watershed was split into four model domains—1001_A1, 1001_A2, 1002_A3, and 1002_A4, as shown in Figure 5. The first 4 numbers in the model domain name are the final 4 numbers in the name of the HUC-10 watershed number. A1, A2, etc. in the model domain name is just a linear naming convention for the domains. Per recommendation from the TWDB, the model domains (work areas) were no larger than roughly 300 mi^2, which is the size of a typical HUC-10 watershed. The primary reason for having a domain size equal to or smaller than a HUC-10 watershed was to satisfy the assumption that the rainfall across the domain was uniform. The initial model domain boundaries were derived from revised HUC-10 watershed delineations that were established using the LiDAR data. A buffer of 1,000 feet was applied to each HUC-10 watershed boundary to create overlapping domain boundaries. The purpose of the overlap areas was to facilitate clean floodplain and Base Flood Elevation (BFE) transitions between models, to capture the full extent of the floodplain within the watershed, and to minimize the impact of model boundary conditions on model results. At the confluences of model domains, the overlap areas along the main channel were increased in some locations to facilitate tie-ins between model domains. The downstream end of model domain 1002_A3 is aligned with the Brady Reservoir Dam. With all of the reservoir in one domain, a single WSEL could be established along the entire lake.

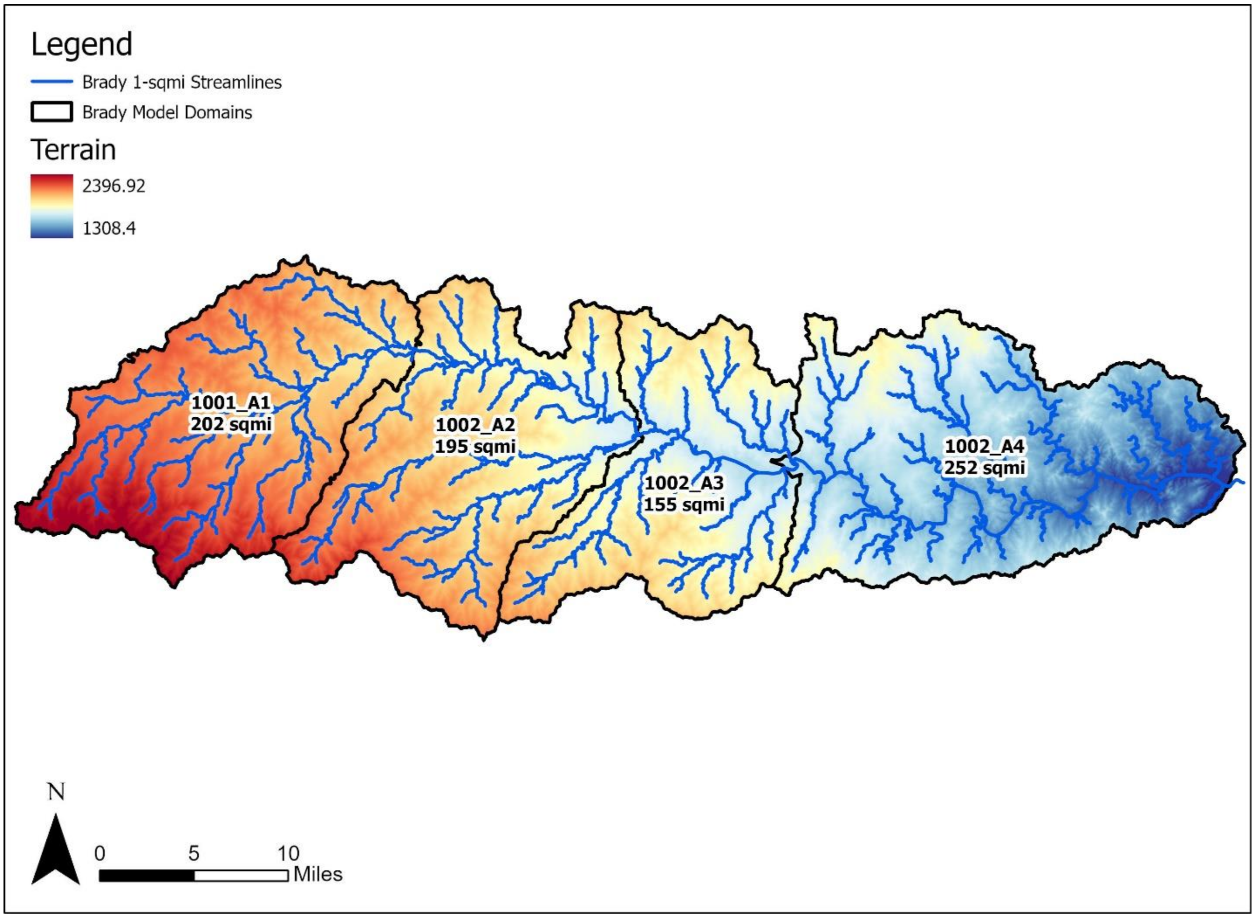


Figure 5: Brady Watershed Model Domains and Linkages (HUC 12090110)

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 data sets.

To develop the soils dataset, the 2021 Gridded Soils Survey Geographic (gSSURGO) database was downloaded from NRCS's website (https://data.nal.usda.gov/dataset/gridded-soil-survey-geographic-database-gssurgo). The gSSURGO 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. Curve numbers for this study were based on an average Antecedent Moisture Condition (AMC II). The initial abstraction ratio of 0.2 was used to obtain the initial loss. During the model validation phase, the CN values were adjusted as needed to bring the model results into alignment with the validation data (e.g., stream gage data, effective discharges, etc.). During validation, the CNs were revised by no more than ±10% of their initial values.

Table 4: Curve Number Values

Land Use Grid Code	NLCD Land Use Description	CN for Each Hydrologic Soil Group			
		A	B	C	D
0	No Data	75	75	75	75
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

Land Use Grid Code	NLCD Land Use Description	CN for Each Hydrologic Soil Group			
		A	B	C	D
90	Woody Wetlands	72	80	87	93
95	Emergent Herbaceous Wetlands	72	80	87	93

Note, there were no areas within the Brady watershed that had a NLCD land use description of "No Data" (Land Use Grid Code of 0); therefore, the CN and Manning's n values shown in Tables 4 and 5 for "No Data," respectively, do not apply. However, Figure 6, below, shows areas within the Brady watershed where soil classifications were not defined in the gSSURGO database. In these locations, a Hydrologic Soil Group of D was assumed since the neighboring soil types had a Hydrologic Soil Group of D.

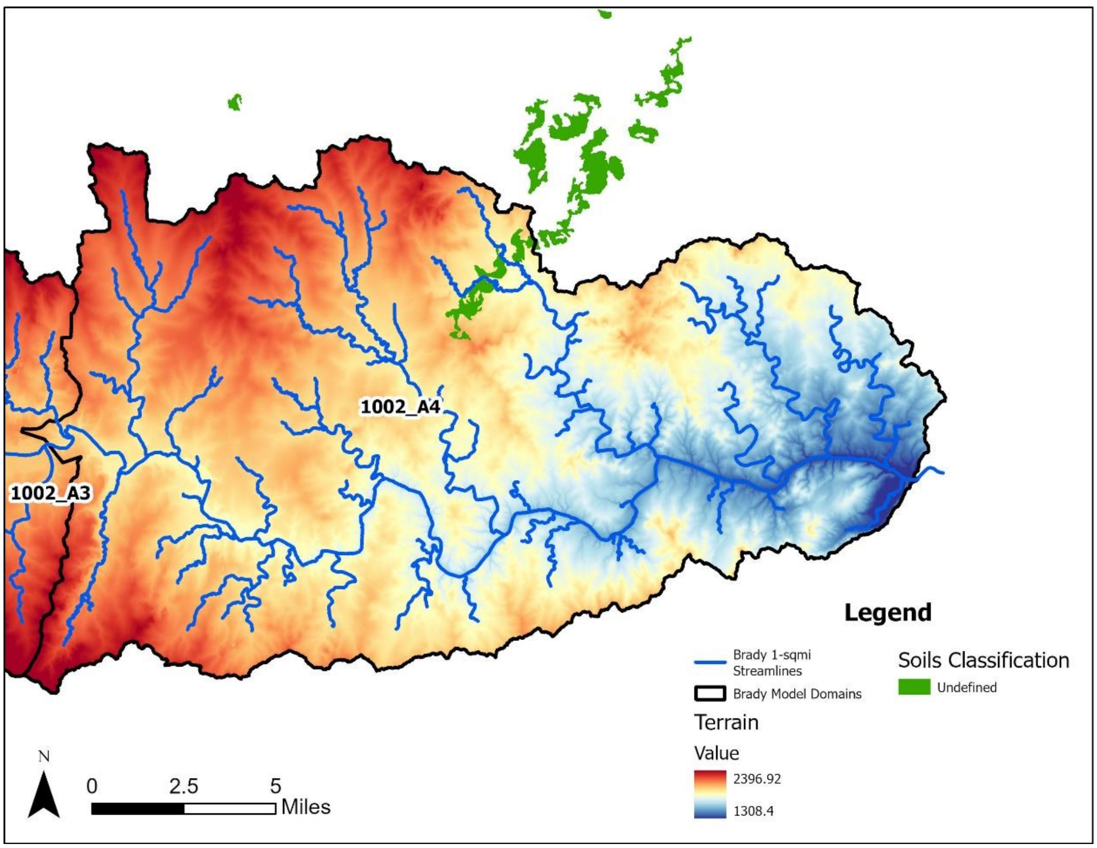


Figure 6: Extent of Undefined Soil Classification along the Brady Watershed

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 0.04 to 0.05.

Table 5: Manning's n Values for Overland and Overbank Areas

Land Use Grid Code	NLCD Land Use Description	Typical N Value	N Value Range
0	No Data	0.040	0.040 - 0.040
11	Open Water	0.038	0.025 - 0.050
21	Developed, Open Space	0.040	0.030 - 0.050
22	Developed, Low Intensity	0.090	0.060 - 0.120
23	Developed, Medium Intensity	0.12	0.080 - 0.140
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. No initial condition flows or elevations were 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.

Normal Depth Boundary Conditions

Since each 2D model domain extent included a buffer around the watershed boundary, normal depth boundary conditions were applied along each 2D area perimeter to avoid ponding along the perimeter.

At the downstream end of each domain, a normal depth boundary condition was initially used to account for the downstream backwater conditions. The hydrograph at the downstream end of the upstream domain was extracted and placed at the upstream end of the downstream domain. A normal depth slope at the transition between the two domains was assumed for this hydrograph and the model was run. This process was repeated iteratively until the peak flows in the two hydrographs differed by less than 10% and the WSELs were within 0.5 feet for all profiles.

During this process, the WSEL profiles for some events in some domains did not converge to within 0.5 feet of one another. To create profiles that tied in to within 0.5 feet, the boundary condition was changed to a stage hydrograph boundary condition for some events. See below for more information about the process that was followed to establish these stage hydrograph boundary conditions. Using a stage hydrograph boundary condition resolved the tie-in issues, leading to acceptable tie-ins for all profiles. Table 6 summarizes the boundary conditions used at the downstream end of each domain in the Brady watershed.

Table 6: Downstream Boundary Conditions Used in Each Domain

Domain	Profile (AEP)	Boundary Condition
1001_A1	10%	Normal Depth
	4%	Normal Depth
	2%	Normal Depth
	1%	Normal Depth
	0.2%	Normal Depth
	1% plus	Normal Depth
	1% minus	Stage Hydrograph
1001_A2	10%	Normal Depth
	4%	Normal Depth
	2%	Stage Hydrograph
	1%	Stage Hydrograph
	0.2%	Normal Depth
	1% plus	Stage Hydrograph
	1% minus	Normal Depth

Domain	Profile (AEP)	Boundary Condition
1002_A3	10%	Stage Hydrograph
	4%	Normal Depth
	2%	Stage Hydrograph
	1%	Stage Hydrograph
	0.2%	Stage Hydrograph
	1% plus	Stage Hydrograph
	1% minus	Stage Hydrograph
1002_A4	10%	Stage Hydrograph
	4%	Stage Hydrograph
	2%	Stage Hydrograph
	1%	Stage Hydrograph
	0.2%	Stage Hydrograph
	1% plus	Stage Hydrograph
	1% minus	Stage Hydrograph

One adverse impact of using both normal depth and stage hydrograph boundary conditions at a domain outlet was that occasionally the stage hydrographs would cross one another. This crossing was considered acceptable because the flow hydrographs never crossed and any crossing stage hydrographs occurred well after the peak stage had occurred. See the Challenges section for more information about this issue.

Stage Hydrograph Boundary Conditions

As described above, stage hydrographs were applied at the main stem outflow locations to account for the downstream backwater elevations when the normal depth boundary condition approach did not converge. 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 7 and Figure 8 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.

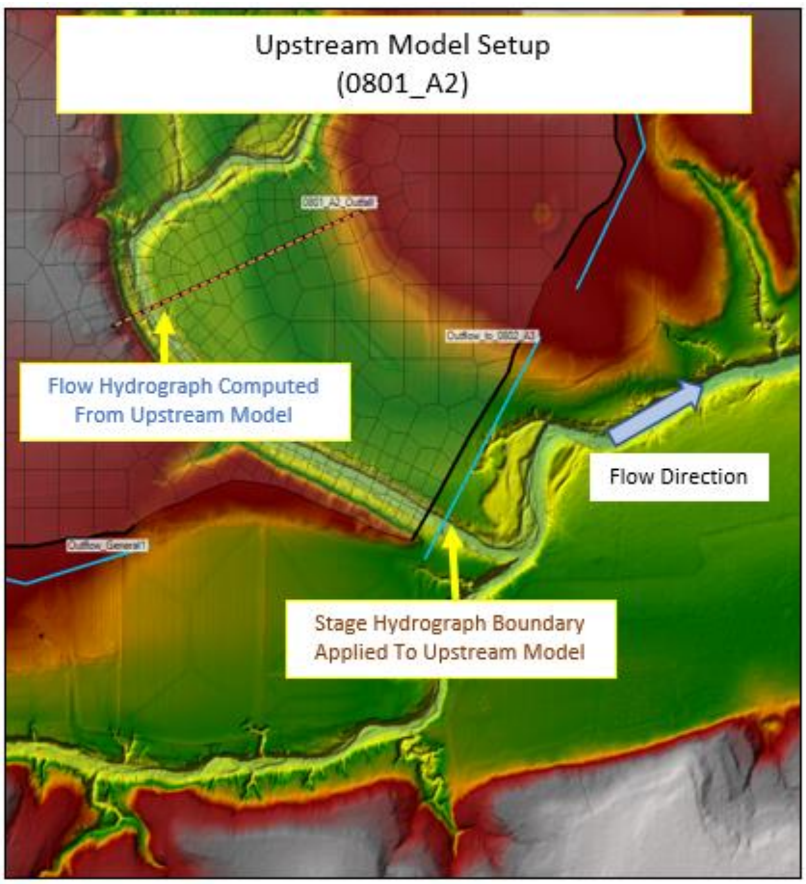


Figure 7: Extraction of Flow Hydrograph from the SA/2D Connection in the Upstream Domain for Use in the Downstream Domain

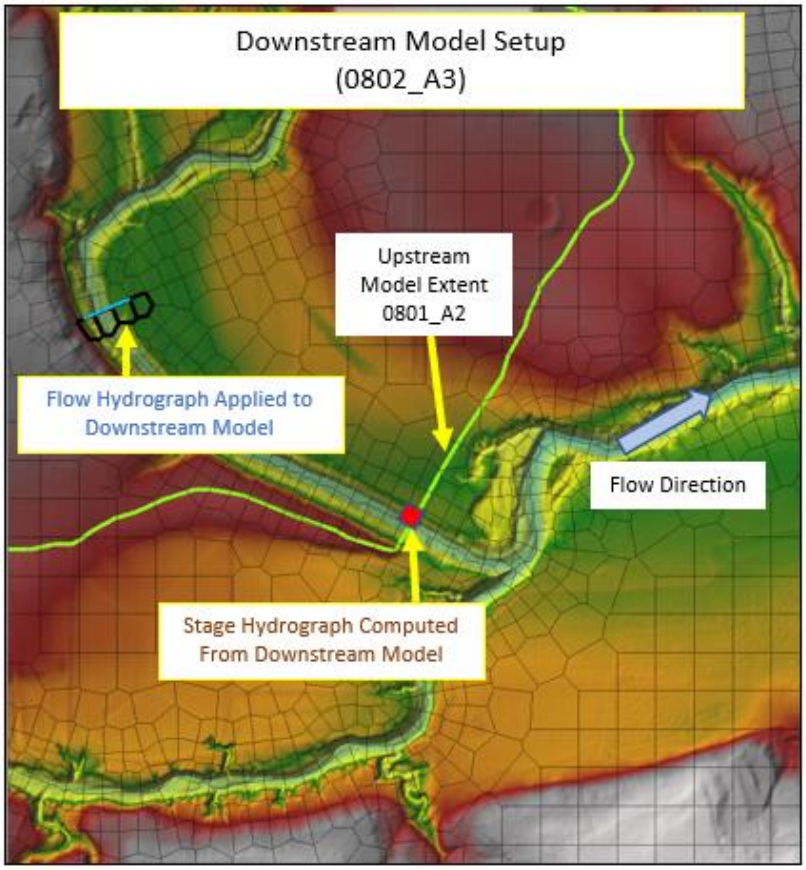


Figure 8: Application of Upstream Flow Hydrograph in the Downstream Domain

See Table 7 through Table 10 for a summary of the upstream and downstream peak discharges and WSELs at the downstream end of each domain in the Brady watershed. Figure 9 through Figure 12 show a snapshot of each tie-in location.

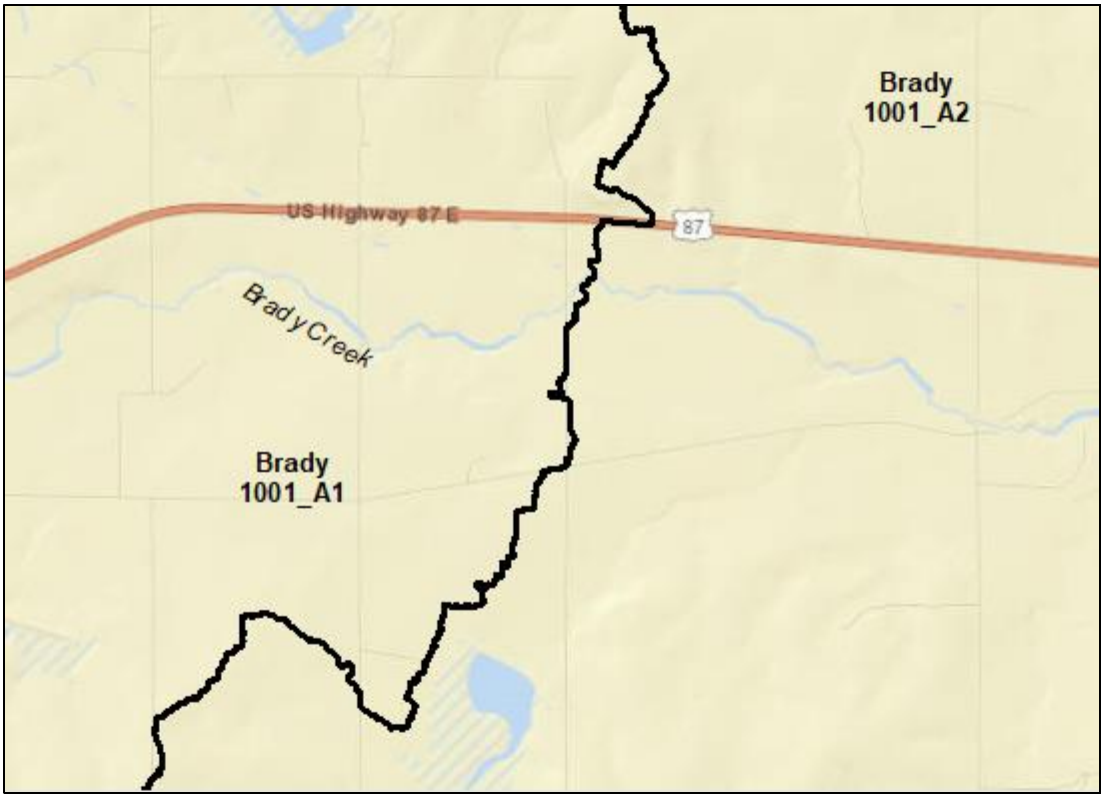


Figure 9: Brady Domain 1001_A1 Outlet into Brady Domain 1001_A2

Table 7: Comparison between Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 1001_A1

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	7,638	7,610	-0.4%	1,914.85	1,914.50	-0.35
4%	13,206	13,182	-0.2%	1,916.49	1,916.27	-0.22
2%	18,237	18,177	-0.3%	1,916.86	1,916.72	-0.14
1%	24,503	24,429	-0.3%	1,917.19	1,917.07	-0.12
0.2%	44,893	44,745	-0.3%	1,916.70	1,916.54	-0.16
1% minus	15,560	15,748	1.2%	1,917.67	1,917.55	-0.12
1% plus	34,389	34,389	0.0%	1,918.20	1,918.07	-0.13

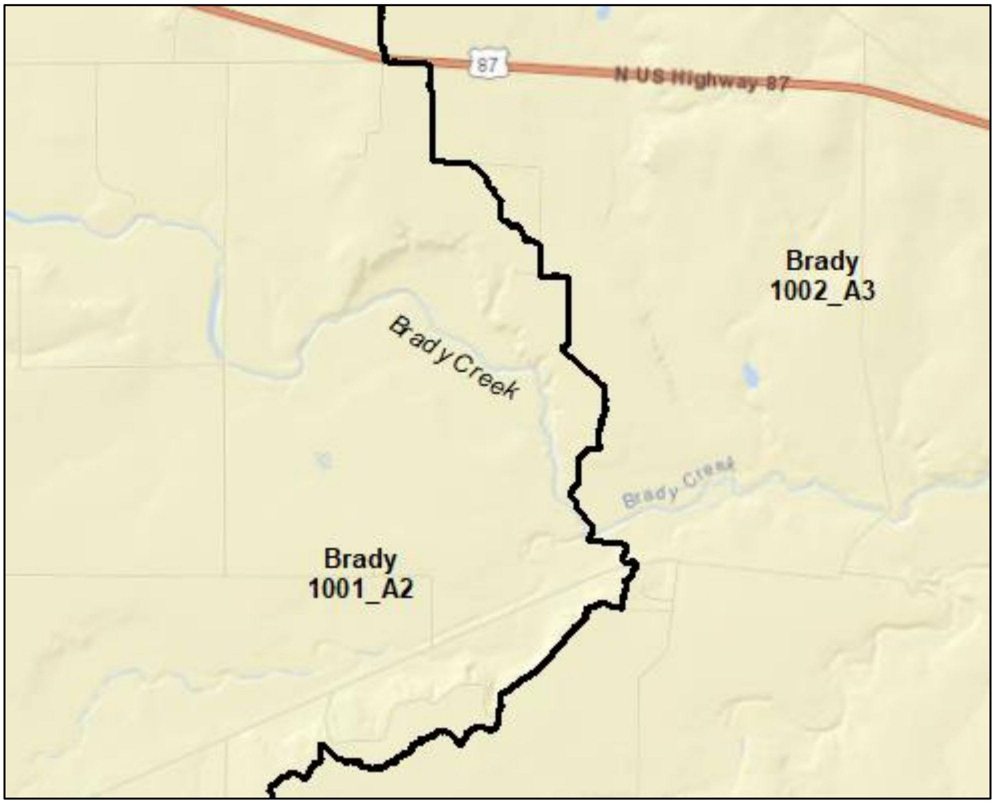


Figure 10: Brady Domain 1001_A2 Outlet into Brady Domain 1002_A3

Table 8: Comparison between Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 1001_A2

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	12,785	12,785	0.0%	1,766.98	1,767.10	0.12
4%	22,070	22,070	0.0%	1,768.80	1,769.09	0.29
2%	30,013	30,335	1.1%	1,770.59	1,770.57	-0.02
1%	39,827	39,827	0.0%	1,772.09	1,772.03	-0.06
0.2%	71,207	71,207	0.0%	1,774.74	1,775.36	0.62
1% minus	25,963	25,963	0.0%	1,769.43	1,769.81	0.38
1% plus	54,796	55,461	1.2%	1,773.80	1,773.86	0.06

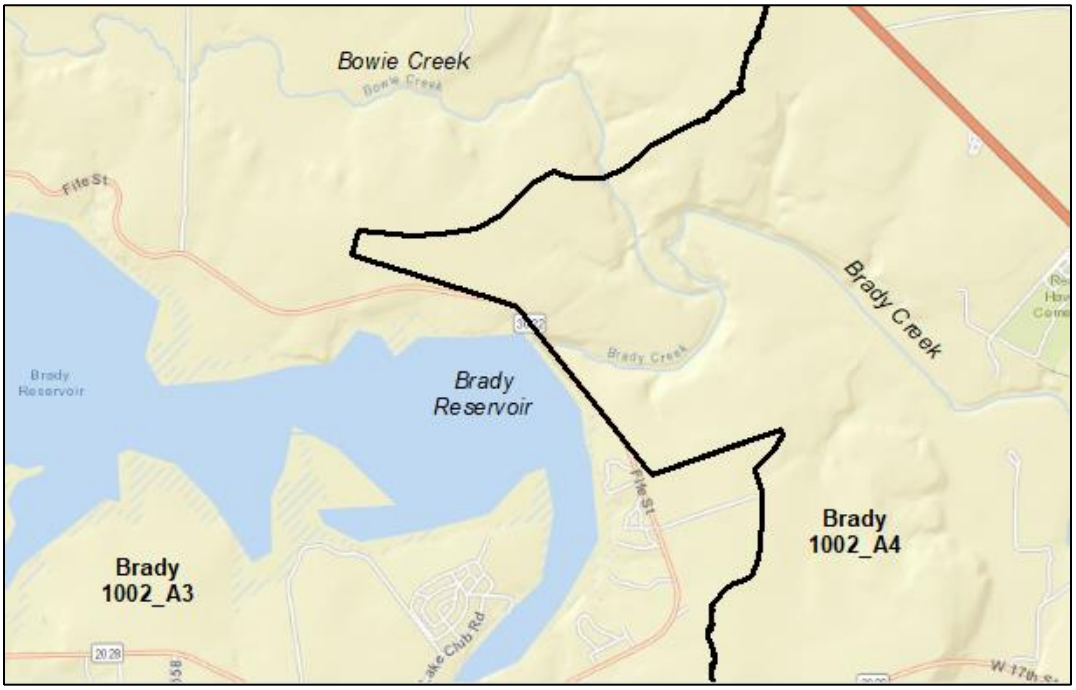


Figure 11: Brady Domain 1002_A3 Outlets (Bowie Creek and Brady Reservoir Dam) into Brady Domain 1002_A4

Table 9: Comparison between Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 1002_A3

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
Bowie Creek Outlet						
10%	2,823	2,828	0.2%	1,699.29	1,699.64	0.35
4%	5,174	5,147	-0.5%	1,701.16	1,701.12	-0.04
2%	7,585	7,609	0.3%	1,702.16	1,702.11	-0.05
1%	10,598	10,598	0.0%	1,703.40	1,703.13	-0.27
0.2%	20,510	20,491	-0.1%	1,706.11	1,705.75	-0.36
1% minus	6,432	6,452	0.3%	1,701.63	1,701.67	0.04
1% plus	15,110	15,100	-0.1%	1,704.56	1,704.40	-0.16
Brady Reservoir Dam Outlet						
10%	26	26	0.0%	1,759.14	1,759.22	0.08
4%	49	49	0.0%	1,759.22	1,759.35	0.13
2%	71	71	0.0%	1,759.28	1,759.45	0.17
1%	91	91	0.0%	1,759.33	1,759.54	0.21
0.2%	12,075	12,072	0.0%	1,762.47	1,762.42	-0.05
1% minus	62	62	0.0%	1,759.25	1,759.41	0.16
1% plus	4,130	4,130	0.0%	1,760.93	1,760.93	0.00

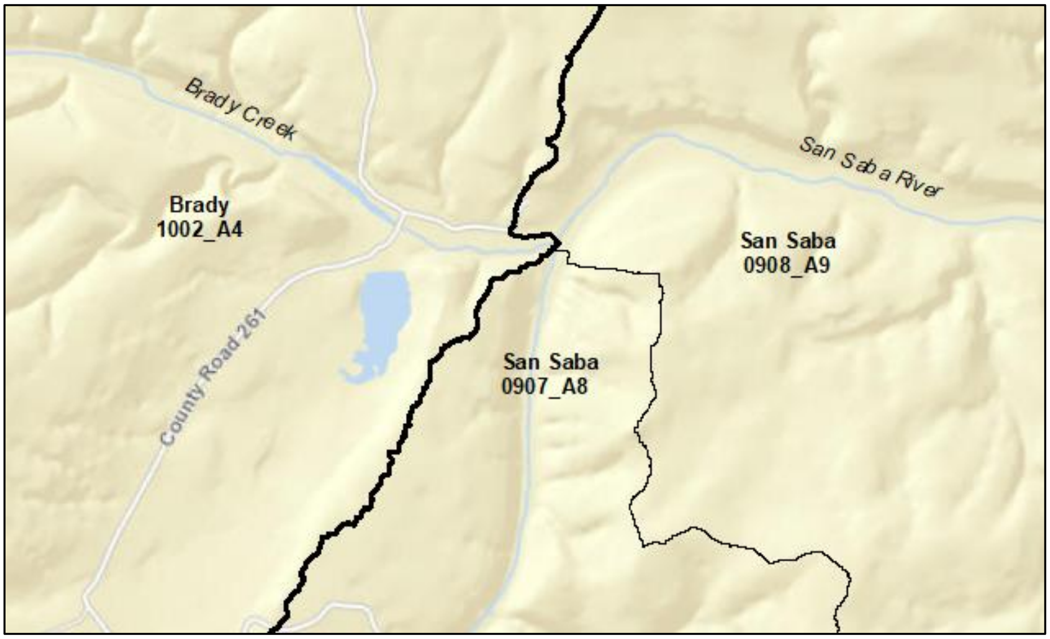


Figure 12: Confluence of Brady Domain 1002_A4 with San Saba Domains 0907_A8 and 0908_A9

Table 10: Comparison between Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 1002_A4

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
At 1002_A4 Confluence with San Saba 0907_A8						
10%	21,965	21,726	-1.1%	1,323.87	1,323.49	-0.38
4%	38,981	39,174	0.5%	1,331.14	1,330.72	-0.42
2%	56,338	56,813	0.8%	1,336.61	1,336.16	-0.45
1%	78,683	79,504	1.0%	1,341.97	1,341.50	-0.47
0.2%	151,799	152,670	0.6%	1,354.32	1,353.79	-0.53
1% minus	48,433	48,790	0.7%	1,334.30	1,333.88	-0.42
1% plus	113,020	114,056	0.9%	1,348.44	1,347.96	-0.48
At 1002_A4 Confluence with San Saba 0908_A9						
10%	21,965	21,726	-1.1%	1,323.87	1,323.81	-0.06
4%	38,981	39,174	0.5%	1,331.14	1,331.08	-0.06
2%	56,338	56,813	0.8%	1,336.61	1,336.55	-0.06
1%	78,683	79,504	1.0%	1,341.97	1,341.91	-0.06
0.2%	151,799	152,670	0.6%	1,354.32	1,354.26	-0.06
1% minus	48,433	48,790	0.7%	1,334.30	1,334.24	-0.06
1% plus	113,020	114,056	0.9%	1,348.44	1,348.37	-0.07

1.2.5. Reservoir Modeling

The Brady watershed includes Brady Lake Dam (National Inventory of Dams ID: TX01659), located at the Brady Reservoir in McCulloch County, approximately 3 miles west of Brady, Texas, along FM 3022. The dam is owned by the City of Brady and regulated by the Texas Commission on Environmental Quality (TCEQ). The earthen dam has a height of 104 feet and a dam crest elevation of 1,783 feet. The structure includes an uncontrolled concrete drop inlet structure as the principal/service spillway with a crest elevation of 1,743 feet, and a 1,007-foot-wide uncontrolled earthen emergency spillway with a crest elevation of 1,762.4 feet. USGS gage 08144900 is a stage gage referenced to NGVD 29, located on the upstream side of the dam, which has an estimated drainage area of approximately 524.4 square miles.

Since no reservoir operation data were available for the Brady Reservoir, and due to the high-level modeling approach used for BLE, the principal spillway for the dam was not modeled with a hydraulic structure in this study. However, a breakline was placed along the dam crest and a refinement region was added for the lake. In addition, a SA/2D connection was added along the emergency spillway crest to capture the overflow volume, and the spillway overflow was added as an inflow into the 1002_A4 domain located downstream of the dam. Future detailed studies in this area may consider coordination with the dam owner and TCEQ to more accurately model spillway discharges.

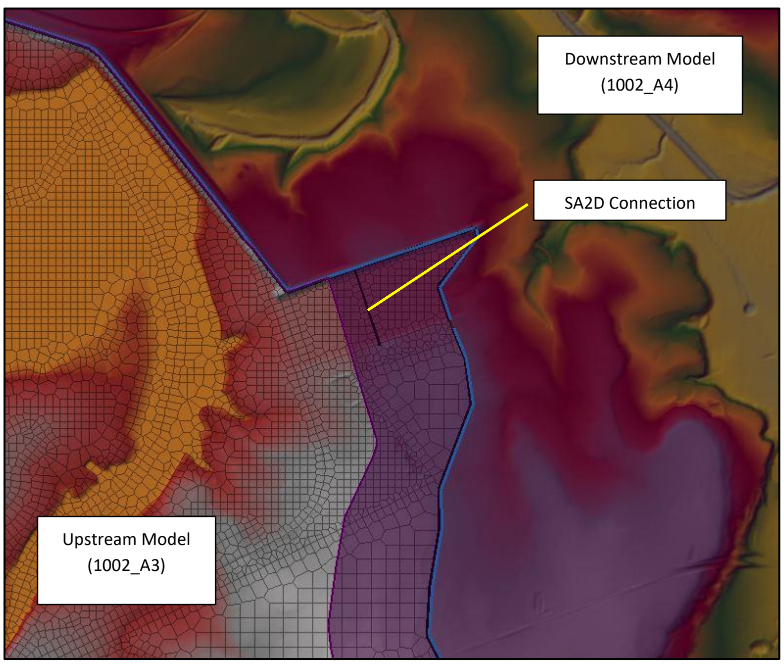


Figure 13: Brady Reservoir Outflow Location

For other dams in the Brady watershed, a simplified approach of adding breaklines along the dam crests was typically applied to force the terrain surface in the vicinity of the dam to drain properly during significant events.

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

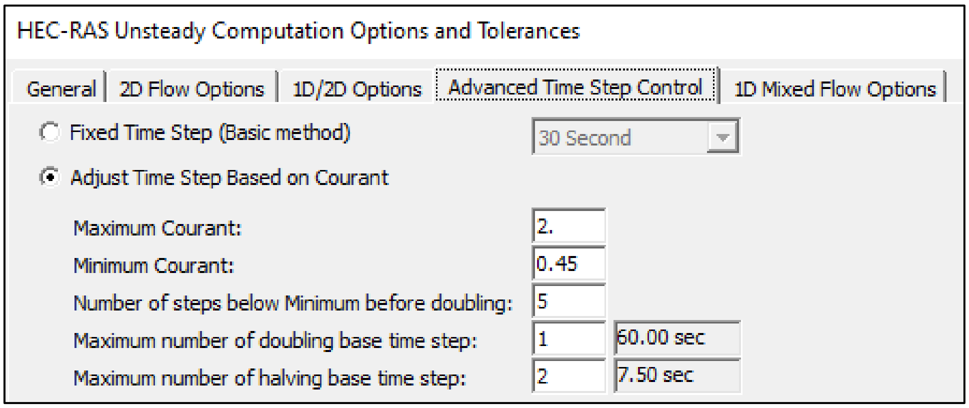


Figure 14: HEC-RAS Unsteady Computation Options and Tolerances

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

1.2.7. Regression Analysis

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

The contributing drainage area (A), mean-annual precipitation (P), dimensionless channel slope (S), and the basin-averaged OmegaEM parameter (Ω) were the input parameters for the regression equations. The regression equations are shown in Table 3 in the regression report (Asquith and Roussel 2009) and below on Figure 15.

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 15: Regression Equations for the Brady 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.

The 1% minus, 1%, and 1% plus regression flows computed for the Brady watershed are in Table 13.

1.2.8. Gage Analysis

As of August 2022, the Brady watershed was being studied as part of the Interagency Flood Risk Management (InFRM) team's Watershed Hydrology Assessment (WHA) for the Lower Colorado River Basin. USGS gage 08145000 (Brady Creek near Brady, TX), shown in Figure 16, below, was analyzed by the WHA. This InFRM gage analysis was leveraged to support flow validation in the Brady BLE model.

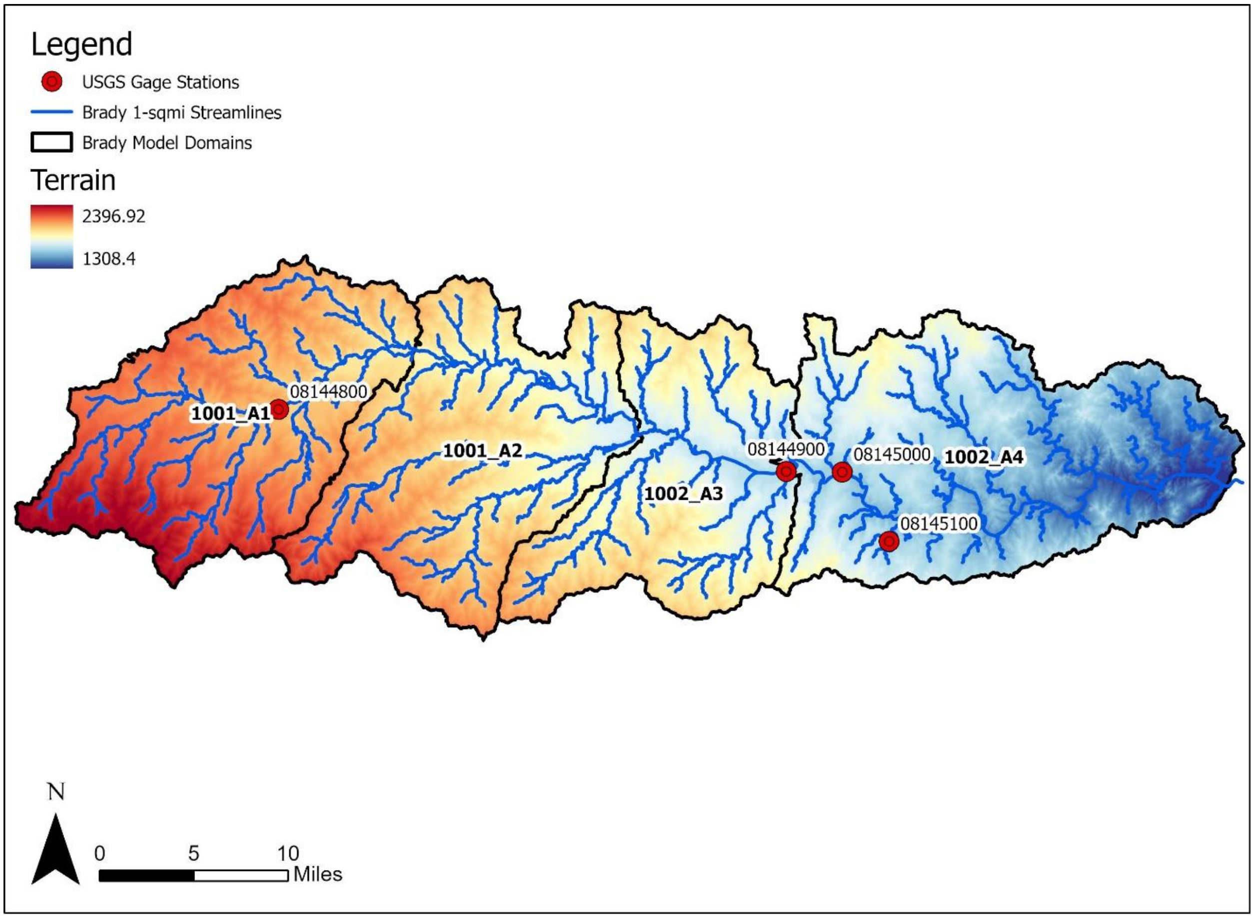


Figure 16: USGS Gages in the Brady Watershed

Gage 08145000, located downstream of Brady Reservoir, is within the City of Brady. The USACE Bulletin 17C analysis of this gage in the WHA accounted for both regulation and urbanization. A description of the analysis, its assumptions, and its results is included on pages 84, 85, and 151 of Chapter 5 of the InFRM's Draft WHA report. A copy of these pages has been included in Appendix B of this report. Table 6, below, provides more information on gages within the Brady watershed as well as sources of gage analysis information and reasons for not analyzing specific gages.

Table 11: Summary of USGS Gages in the Brady 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
08145000	Brady Ck at Brady, TX	589.3	Yes	InFRM WHA	N/A
08145100	Brady Ck Trib nr Brady, TX	4.2	No	N/A	The period of record was less than 10 years, and the flow data were old (1966-1973).
08144800	Brady Ck nr Eden, TX	101.9	No	N/A	The period of record was outdated (1960's to 1980's), and the gage was not analyzed in InFRM's WHA report
08144900	Brady Creek Res nr Brady, TX	524.4	No	N/A	This is a stage gage for Brady Reservoir. There is no flow data available for validation.

1.2.9. Model Validation

The Brady BLE hydraulic models were validated using peak flow information available in the draft InFRM WHA and the effective FIS report. Where no previous flow information was available, the regression analysis previously discussed was used to validate the HEC-RAS models.

Validation checks were made at 27 locations throughout the Brady watershed. The locations may be grouped as follows:

- Twenty-five 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 USGS gage flows.
- One validation location compared the 1% BLE flow with the 1% effective flow.

The validation locations were scattered throughout the watershed in locations that provided a comprehensive coverage of drainage areas and stream characteristics. Validation points were added where gage and effective flow information were available. The drainage areas of the validation points ranged from approximately 1 mi^2 to 589 mi^2. At the 26 locations where 1% plus and 1% minus regression or gage flows were available, the validated BLE 1% flows were within the 1% plus and 1% minus range at all locations. At the single location where the 1% effective flow was available, the 1% BLE flow was 18% less than the effective flow, which is acceptable. A comparison of the BLE 1% flows with the regression, gage, and effective 1% flows is shown in Table 13.

The first step of the validation effort was to review the initial BLE results. When the initial BLE flows fell outside the 1% plus and 1% minus range of the gage or regression flows, the Manning's n and CN values were adjusted iteratively until the computed flows were within the 1% plus and 1% minus range of the gage or regression flows. The Manning's n values were revised as needed provided they remained within the ranges specified in Table 5. The CNs were adjusted by no more than ±10% of their initial values.

During the validation process, domain-wide parameter adjustments were applied to the CNs and the Manning's n values to maximize the number of streams where the 1% BLE flows fell between the 1% minus and 1% plus regression and gage flows. No particular area or tributary in a domain was considered a priority over the others when these adjustments were made. As a result, in areas where the stream/watershed characteristics were significantly different from the rest of the domain, some of the 1% BLE flows might fall outside of the 1% minus and 1% plus bounds. Other factors that contributed to the 1% BLE flows falling outside of the 1% minus and 1% plus bounds included differences in the regression, gage, 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 validation effort first looked at domain 1002_A4 since it is the most downstream domain in the watershed. As documented in Table 13, there were nine validation locations in this domain; however, two of them were regulated (Pt 6 and Pt 9), so regressions flows were valid only at the seven non-regulated locations. At the two regulated locations, there was a USGS gage at one location and effective FIS flows were available at the other.

Prior to validation, the computed 1% flows were higher than the 1% plus regression/gage flows at five of the eight validation locations, and they were higher than the 1% regression/gage flows at all eight locations. The Manning's n values and the CNs throughout the domain were revised to lower the flows. The Manning's n values in the tributary channels were increased from 0.040 to 0.045. The CNs were reduced by 10%. Following these revisions, the BLE 1% flows were between the 1% minus and the 1% plus regression/gage flows at all eight validation locations, and they were higher than the 1% regression/gage flows at seven of the eight locations.

USGS gage 08145000 (Brady Creek at Brady, TX), located in domain 1002_A4, was the only useful gage in the watershed. Following validation, the InFRM WHA reported a 1% flow of 24,200 cubic feet per second (cfs) at the gage, and the BLE model computed a 1% flow of 20,288 cfs, which is within the range of the 1% minus and 1% plus flows at the gage, and 16% lower than the 1% flow.

Since increasing the Manning's n values and lowering the CNs by 10% in domain 1002_A4 led to successful validation at all nine points, the Manning n values and CNs were similarly adjusted in the other three domains. The Manning's n values were adjusted as follows:

- Domain 1001_A1 – Increased channel n values from 0.040 to 0.050.
- Domain 1001_A2 – Increased channel n values from 0.040 to 0.045.
- Domain 1002_A3 – Increased channel n values from 0.040 to 0.045.

The CNs were lowered by 10% in the three domains. Following these adjustments, the 1% flows were between the 1% minus and the 1% plus regression/gage flows at all 18 validation locations, and they were higher than the 1% regression/gage flows at 12 of the 18 locations.

The model overview and results spreadsheet (*Brady 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.

A comparison between the 1% BLE WSELs and select effective 1% WSELs for Brady Creek, Post Oak Creek, and Live Oak Creek are presented in Table 12. The effective 1% WSELs were estimated using BFEs available in the RMSI digitized floodplain mapping dataset. For Post Oak Creek and Live Creek, the BLE

WSELs were higher than the effective WSELs since the 1% BLE flows were 25% to 30% higher than the effective flows. Along Brady Creek, the 1% BLE WSEL was lower than the effective 1% WSEL since the BLE 1% flow was 18% lower than the effective flow.

Table 12: 1% Annual Chance WSEL Comparison Between Effective and BLE Study

Location	Effective 1% WSEL (feet)	BLE 1% WSEL (feet)	Difference (Eff. - BLE) (feet)
Brady Creek USGS Gage 08145000	1,668.3	1,666.1	-2.2
Post Oak Creek at 11th Street	1,680.2	1,679.5	0.7
Live Oak Creek 350 feet downstream of W White Street	1,675	1,673.2	1.8

* A vertical datum conversion of +0.2 feet was used to convert the effective WSELs in this table from NGVD 29 to NAVD 88.

The effective FEMA flood study was completed in 1981. The FIS report for the City of Brady, McCulloch County noted that the Weather Bureau's *Technical Paper 40: Rainfall Frequency Atlas of the United State for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years* (*TP40*) provided the rainfall data for the study. *TP40* was released in 1961. The BLE study used Atlas 14 rainfall data, and the point rainfall totals in Atlas 14 were higher than the totals in *TP40*. Other reasons why the BLE and effective WSELs are different include different hydrologic approaches (rain-on-grid vs SCS Unit Hydrograph), different topography (LiDAR vs late 1970s photogrammetric data), and different hydraulic approaches (2D HEC-RAS vs 1D HEC-2). Finally, the FEMA study included bridges and culverts in the models while the BLE study did not.

See Figure 17 and Table 13 on the following pages for a summary of the 1% validation results at the validation points in the Brady watershed.

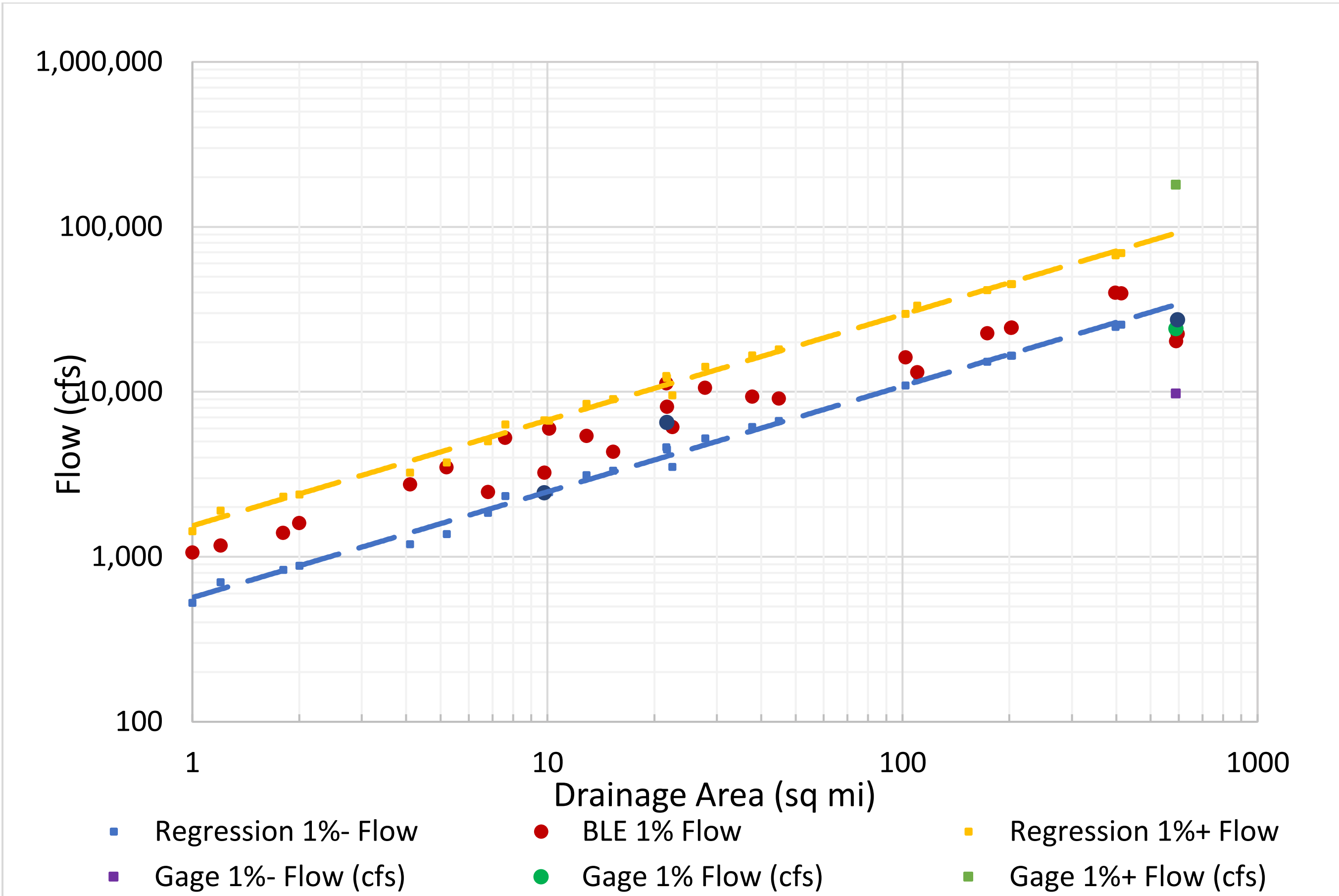


Figure 17: Computed Flow vs Drainage Area of Select 1% Annual Chance BLE, 1% Regression, 1% FIS, and 1% Gage Flows

Table 13: 1% Annual Chance Peak Flow Validation Results for the Brady 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 1001_A1										
Pt1	Unnamed	1.2	703	1,159	1,910	1,173	-	-	-	-
Pt2	Maverick Creek	5.2	1,374	2,264	3,731	3,493	-	-	-	-
Pt3	Live Oak Creek	12.88	3,126	5,151	8,490	5,403	-	-	-	-
Pt4	Harden Branch	22.48	3,508	5,781	9,527	6,124	-	-	-	-
Pt5	Brady Creek	101.9	10,928	18,009	29,680	16,226	-	-	-	-
Pt6	Brady Creek	173.2	15,259	25,148	41,443	22,641	-	-	-	-
Outfall	Brady Creek	202.1	16,579	27,322	45,027	24,429	-	-	-	-
Domain 1001_A2										
Pt1	Unnamed	1.8	835	1,406	2,318	1,399	-	-	-	-
Pt2	Reubes Creek	37.7	6,123	10,091	16,630	9,346	-	-	-	-
Pt3	South Brady Creek	110	12,264	20,149	33,308	13,128	-	-	-	-
Pt4	Brady Creek	203	16,611	27,375	45,114	24,485	-	-	-	-
Outfall	Brady Creek	397.42	24,796	40,864	67,343	39,827	-	-	-	-
Domain 1002_A3										
Pt1	Unnamed	2	883	1,455	2,397	1,602	-	-	-	-
Pt2	Saddle Creek	6.8	1,853	3,054	5,033	2,475	-	-	-	-
Pt3	Bowie Creek	15.3	3,330	5,489	9,046	4,340	-	-	-	-
Pt4	Cow Creek	44.8	6,676	11,003	18,132	9,107	-	-	-	-
Pt5	Brady Creek	413	25,590	42,173	69,501	39,570	-	-	-	-
Outfall	Bowie Creek	27.8	5,233	8,624	14,213	10,598	-	-	-	-

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 1002_A4										
Pt1	Unnamed	1	526	867	1,429	1,061	-	-	-	-
Pt2	Unnamed	4.1	1,196	1,971	3,249	2,749	-	-	-	-
Pt3	Unnamed	7.6	2,336	3,849	6,344	5,256	-	-	-	-
Pt4	Honey Creek	10.1	2,472	4,074	6,714	5,978	-	-	-	-
Pt5	Little Brady Creek	21.6	4,613	7,603	12,529	11,262	-	-	-	-
Pt6[1]	Brady Creek	589.3	-	-	-	20,288	9,750	24,200	180,000	-
Pt7	Live Oak Creek	21.7	4,475	7,376	12,155	8,125	-	-	-	6,520
Pt8	Post Oak Creek	9.8	2,474	4,077	6,719	3,244	-	-	-	2,450
Pt9[1]	Brady Creek	595.4	-	-	-	22,416	-	-	-	27,300

[1] The Brady Reservoir regulates the flows at this location. The regression estimates at this location were not considered during the validation task.

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 18, 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.

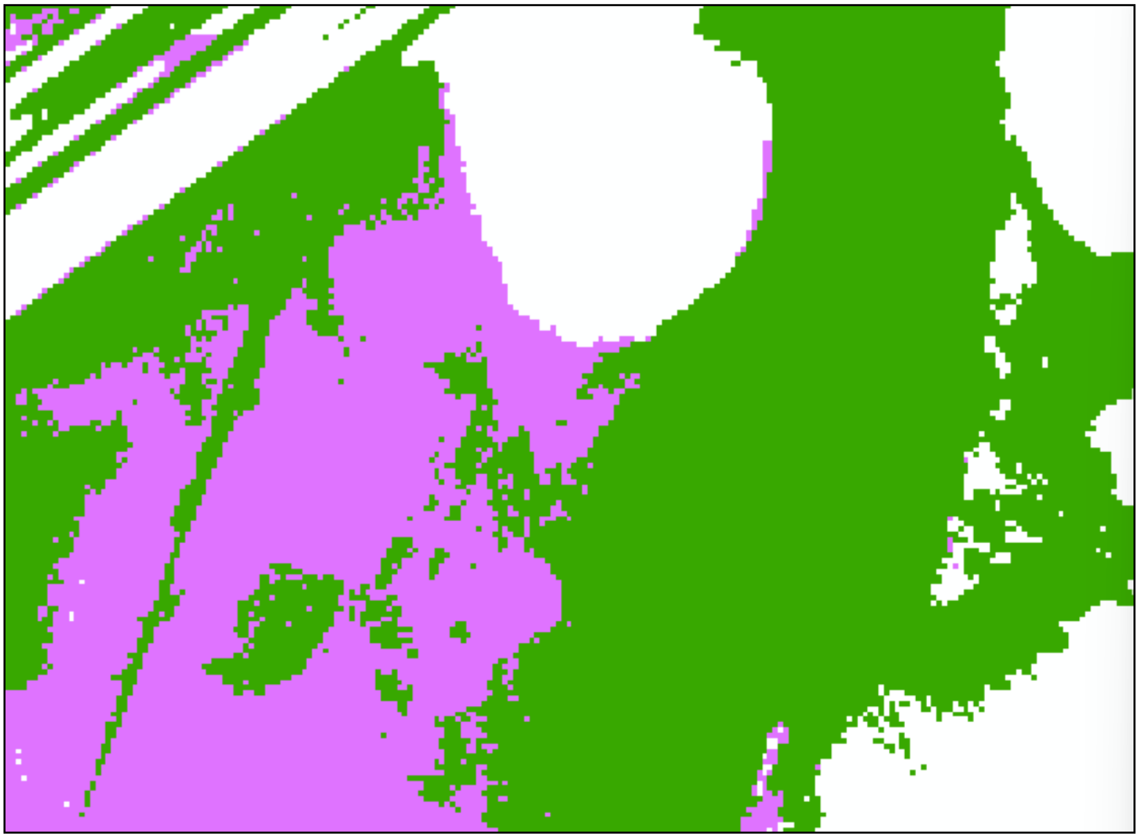


Figure 18: Example of overlapping mapping along a model domain boundary

Figure 19 shows what the difference raster looks like for the area in Figure 18. 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 18 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.

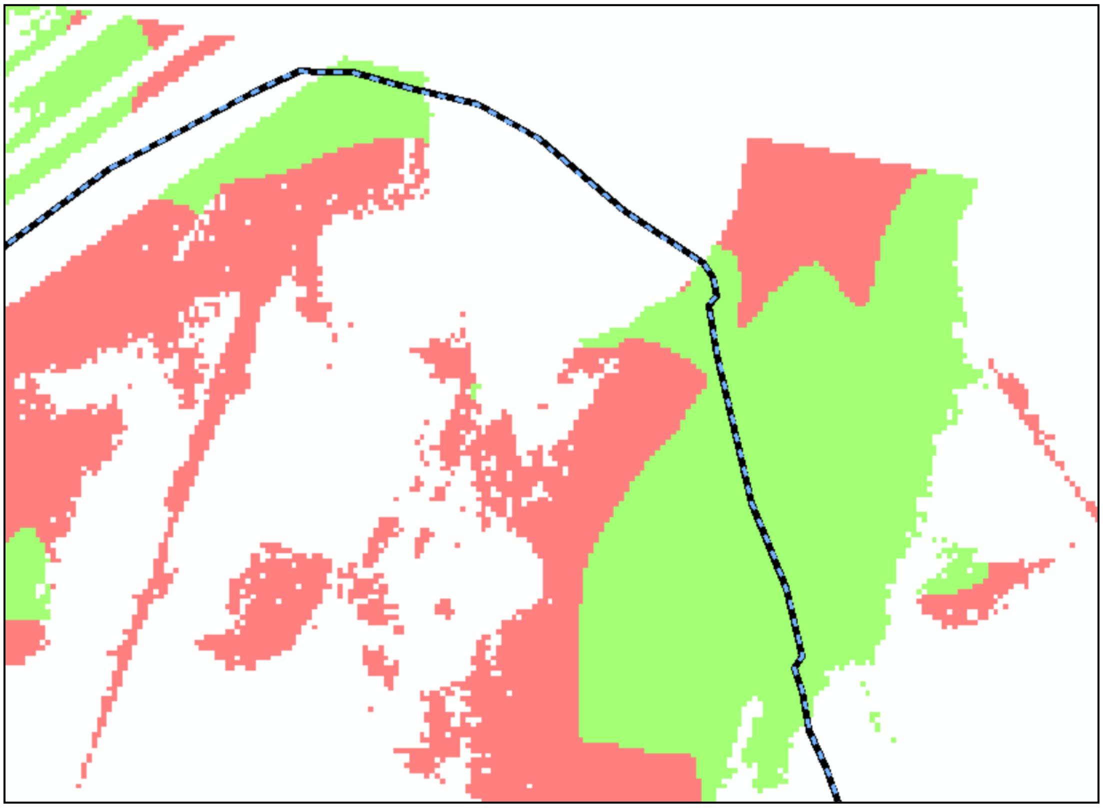


Figure 19: WSEL difference raster and split line for the overlap area

- 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 14.

Table 14: 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.

2.0 Challenges

A handful of challenges were encountered during the Brady 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 Brady watershed are watershed-wide models. Each domain is similar in size to a HUC-10 watershed. As a result, small and large streams are grouped in the same model and cannot be not 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 the results 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

Simplified approaches such as adding breaklines along dam crests, elevated roadways, and railroads were applied 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. As discussed in Section 1.1.2, the bridge/culvert crossing burn lines were incorporated into the HEC-RAS terrain as terrain modification features to allow flow through roadways.

The Brady Lake Dam, discussed in Section 1.2.5, was modeled by applying a SA/2D connection along the emergency spillway crest and adding the spillway overflow as an inflow to the downstream domain. This method was applied due to the limited reservoir operation data available, and due to the high-level modeling approach used for BLE. InFRM's draft WHA report does not include a rating curve for this dam, and most of the overflow was assumed to discharge through the emergency spillway for significant events. The addition of breaklines at the dam crests throughout AtkinsRéalis' BLE study area typically result 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 tend to be underestimated.

Limited Gage Data

The limited number of gages with relevant data within the watershed created challenges in estimating flows. While USGS gage 08144900 is located upstream of Brady Lake Dam, it provides stage information only, and not flow data. Other gages had limited or outdated periods of record. As discussed in Section 1.2.8, the only USGS gage analyzed for modeling purposes within the watershed was gage 08145000. Reasoning for decisions to analyze or not analyze each USGS gage in the Brady watershed is provided in Table 6.

Application of Normal Depth Boundary Conditions at Domain Outlets

At the downstream end of each domain, a normal depth boundary condition was initially used to account for the downstream backwater conditions. The hydrograph at the downstream end of the upstream domain was extracted and placed at the upstream end of the downstream domain. A normal depth slope at the transition between the two domains was assumed for this hydrograph and the model was run. This process was repeated iteratively until the peak flows in the two hydrographs differed by less than 10% and the WSELs were within 0.5 feet for all profiles. See Subsection 1.2.4 for more information.

During this process, the WSEL profiles for some events in some domains did not converge to within 0.5 feet of one another. To create profiles that tied in to within 0.5 feet, the boundary condition was changed to a stage hydrograph boundary condition for some events.

One adverse impact of using both normal depth and stage hydrograph boundary conditions at a domain outlet was that occasionally the stage hydrographs would cross one another. This crossing was considered acceptable because the flow hydrographs never crossed and any crossing stage hydrographs occurred well after the peak stage had occurred. At the downstream end of each domain, a normal depth boundary condition was initially used to account for the downstream backwater conditions. The hydrograph at the downstream end of the upstream domain was extracted and placed at the upstream

end of the downstream domain. A normal depth slope at the transition between the two domains was assumed for this hydrograph and the model was run. This process was repeated iteratively until the peak flows in the two hydrographs differed by less than 10% and the WSELs were within 0.5 feet for all profiles.

Figure 20 and Figure 21 show the flow hydrographs and the stage hydrographs, respectively, at the downstream end of domain 1001_A1. Note that no flow hydrographs cross in Figure 20. In Figure 21, there is one instance of a stage hydrograph crossing another stage hydrograph, but this crossing did not affect the mapped elevations (i.e., peak WSELs) since the crossing occurs well after the peak stage has passed.

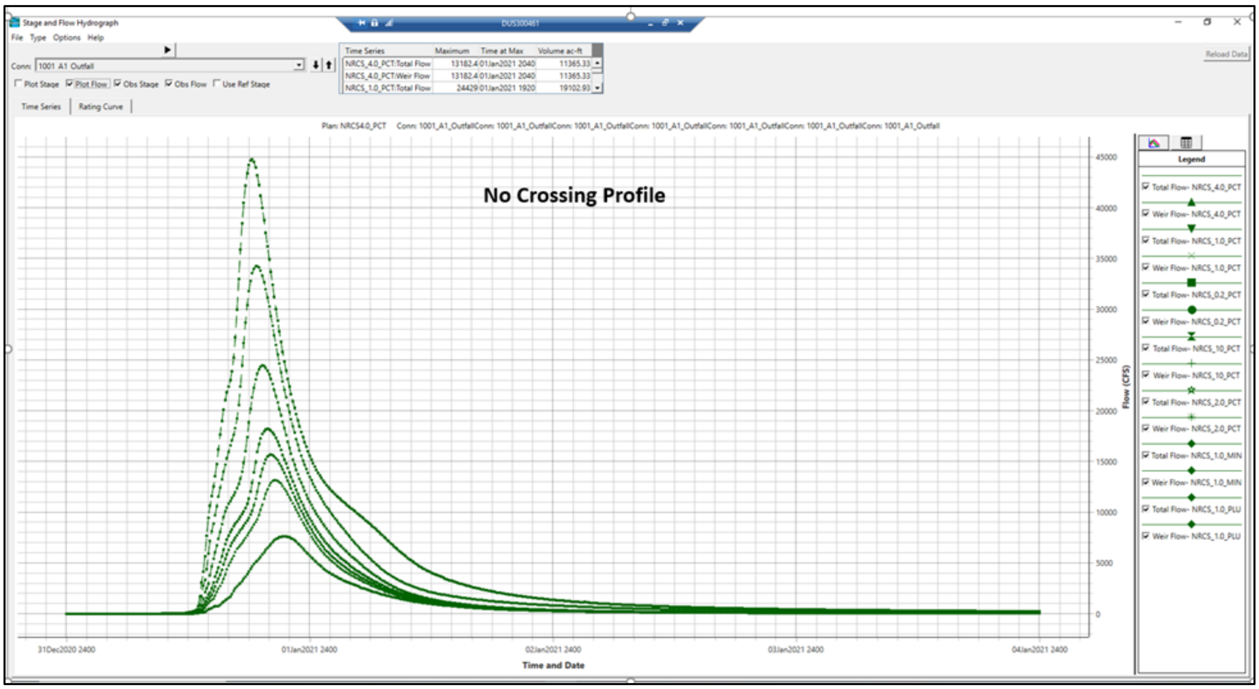


Figure 20: Flow hydrographs at the Downstream End of Domain 1001_A1

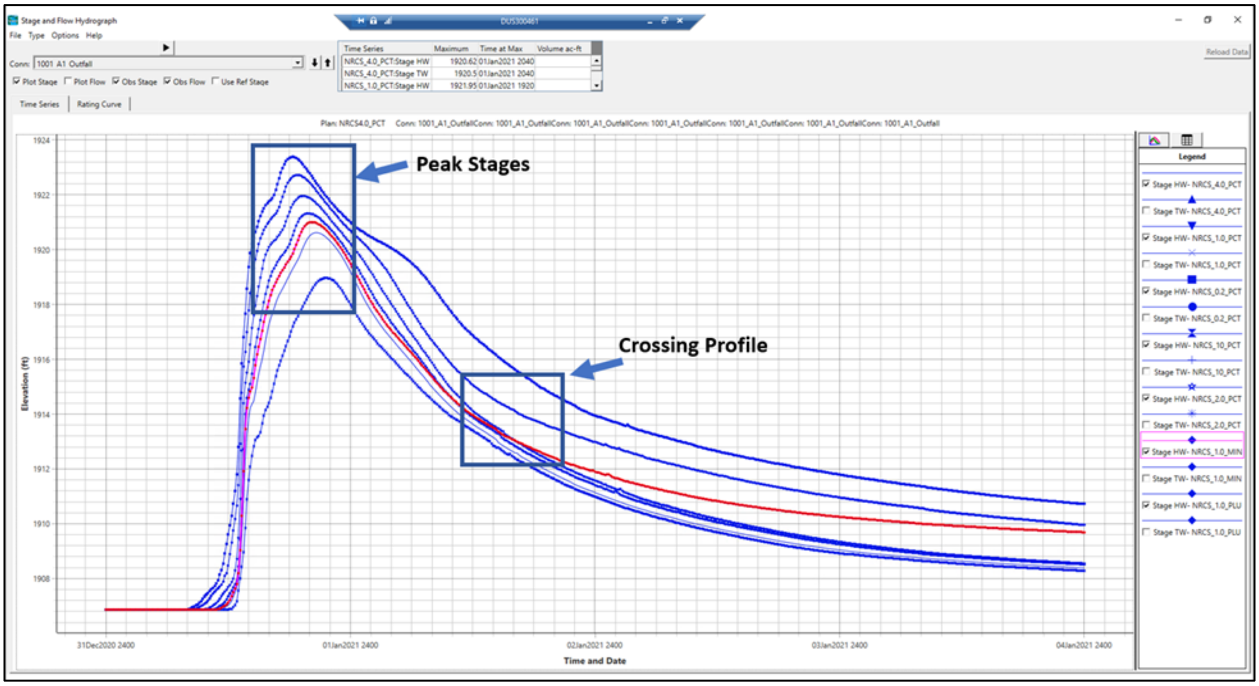


Figure 21: Stage Hydrograph at the Downstream End of Domain 1001_A1

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 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 Brady watershed. Therefore, cupping is prevalent throughout the BLE mapping.

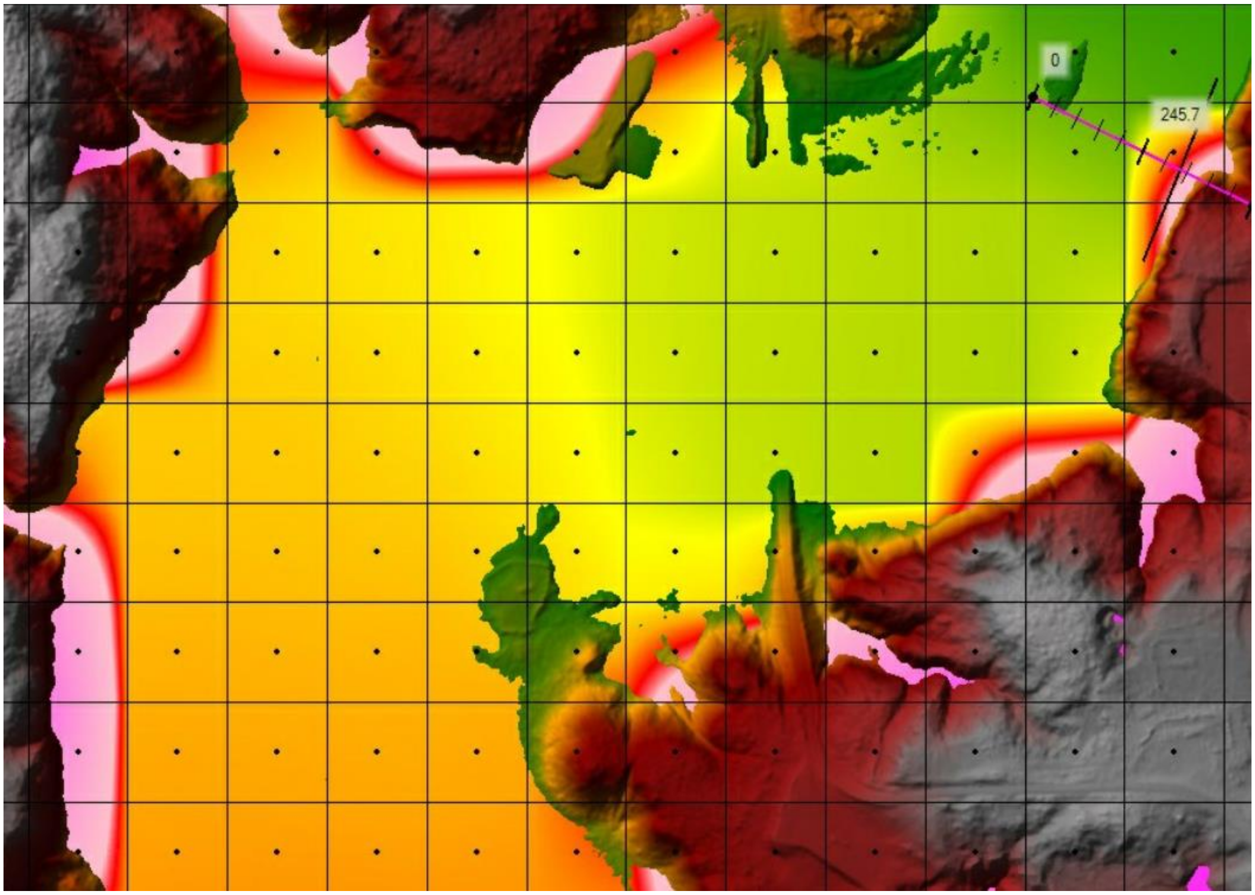


Figure 22: An Example of Cupping in 2D BLE Mapping

3.0 Results and Recommendations

The results of this BLE study provide an estimated 1% annual-chance floodplain in areas that are currently not mapped by FEMA. These results provide context for flood risk communication as part of the Discovery process and should be verified through community work map meetings before application to a regulatory product.

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

The BLE floodplains were compared with the effective floodplains in the Brady watershed. Effective floodplain mapping was available only at the Brady Reservoir; in the vicinity of the Brady, TX; and at two isolated locations in the watershed. No digital mapping data was available in the National Flood Hazard Layer (NFHL) for these locations. Digitized effective floodplain mapping was available in a proprietary dataset developed by RMSI and acquired by AtkinsRéalis. The 1% BLE boundaries and the effective SFHA matched well in the vicinity of the Brady Reservoir, although it appears the effective mapping was based on a single water surface elevation. In addition, at some of the roads, the effective mapping is arbitrarily clipped. See Figure 23 for the BLE mapping and effective mapping at the reservoir.

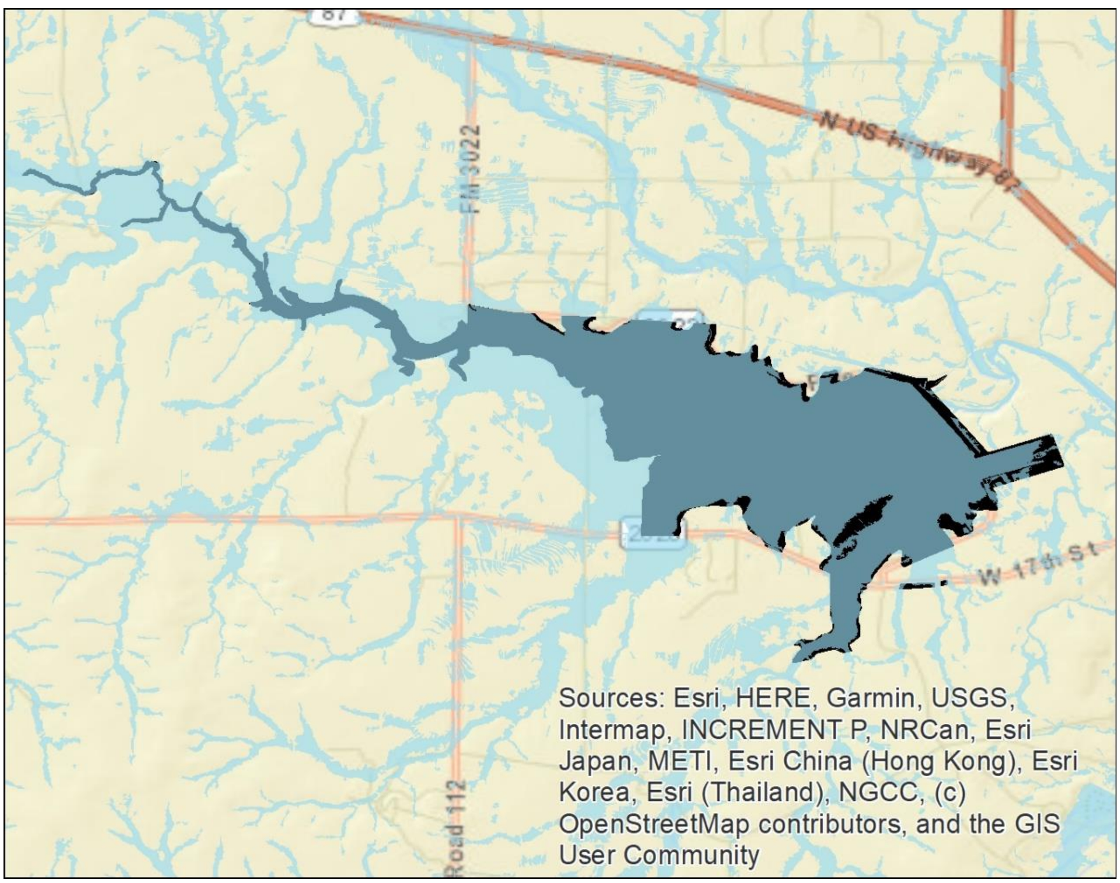


Figure 23: Comparison of 1% BLE mapping (light blue with 35% transparency) with effective Zone A SFHA at Brady Reservoir

Figure 24 compares the 1% BLE mapping with the effective mapping in Brady, TX. The BLE mapping is more extensive, but that is because the BLE includes pluvial mapping while the effective mapping is confined to Brady Creek. Along the creek, it is difficult to compare the two mapping outcomes since the straight edges along the effective mapping suggest it has been clipped to a political boundary.

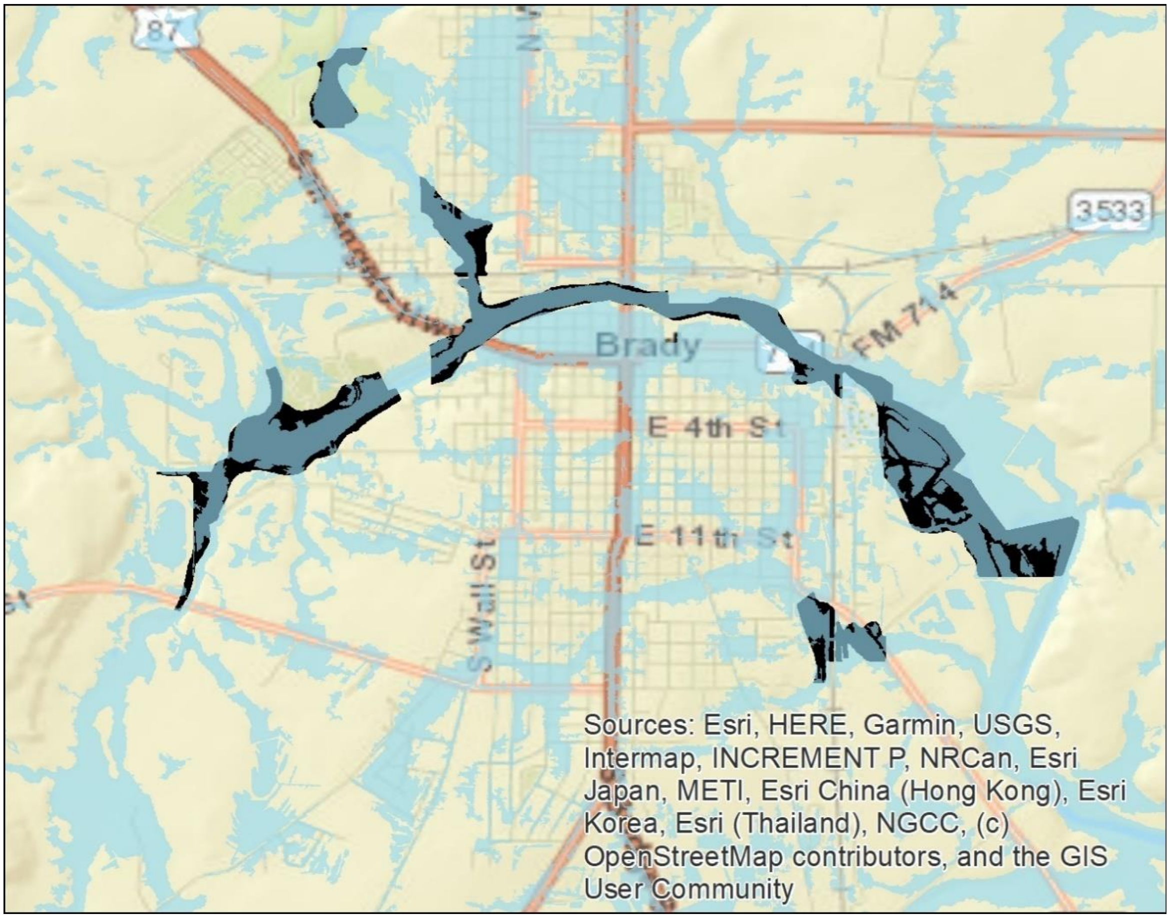


Figure 24: Comparison of 1% BLE mapping (light blue with 35% transparency) with effective Zone A SFHA in Brady, TX

Floodplain mapping for the Brady 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 Brady watershed were compared with the Fathom floodplain mapping. Figure 25 shows the 1% BLE mapping in blue with a transparency applied and the 1% Fathom mapping in black along the Brady Reservoir, along Brady Creek, and in Brady, TX. In general, there was good agreement between the mapping from these two sources. However, the BLE mapping in the reservoir is more extensive, likely because the BLE mapping modeled the reservoir while the Fathom mapping likely ignored the reservoir. There are also examples of pluvial mapping in the figure that are more extensive in the BLE mapping than in the Fathom mapping.

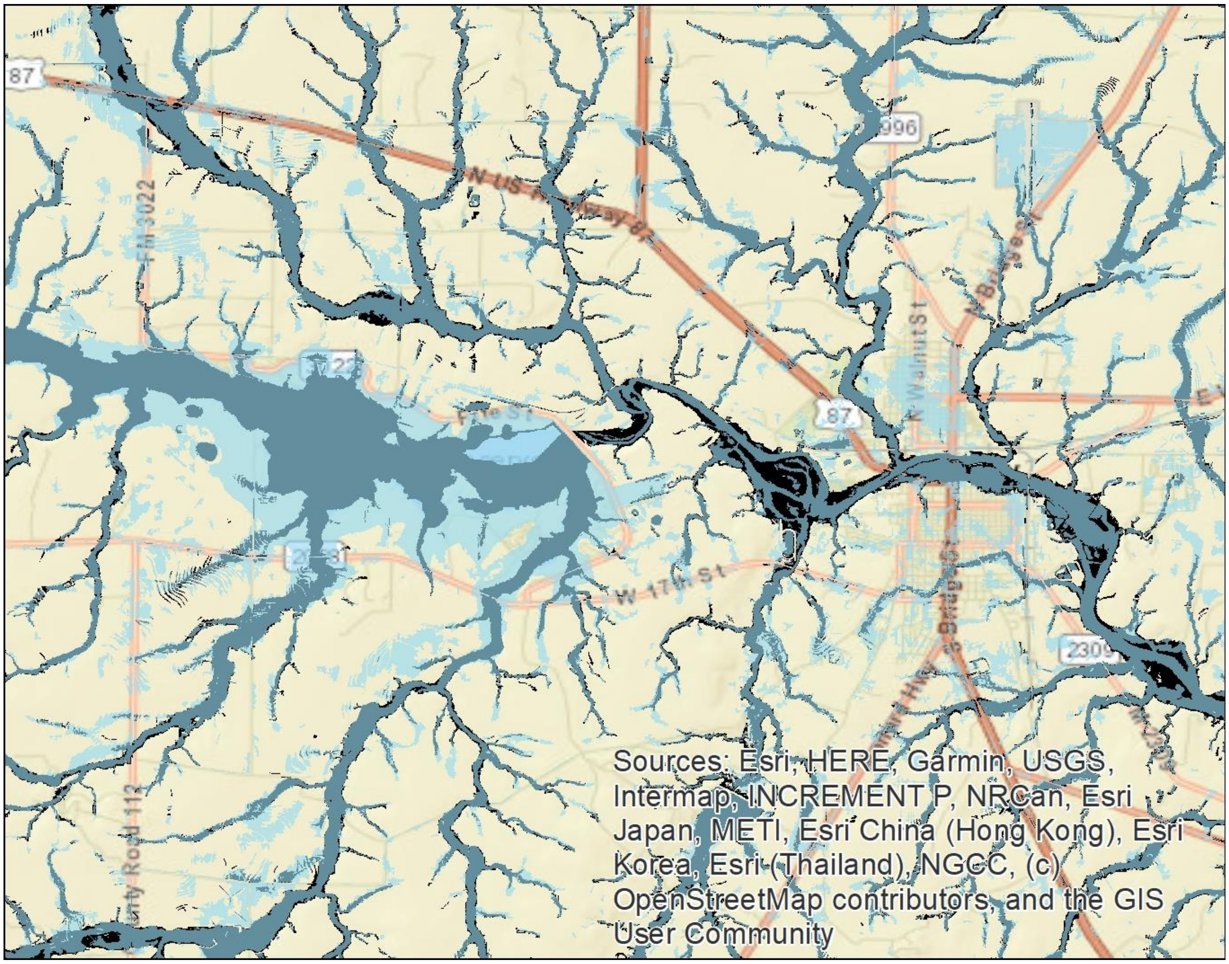


Figure 25: Comparison of 1% BLE mapping (light blue with transparency) with Fathom 1% mapping (black)

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.

3.1. 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.

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

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

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

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

There is limited effective Zone A data available in Brady watershed. A large portion of the Zone A streams (14.1 miles) in the Brady watershed were classified under “UNVERIFIED” and a status type of “BEING STUDIED.” An additional 1.8 miles of Zone A studies were classified as “VALID” and a status type of “BEING STUDIED.” There were no streams that had “VALID” status and a status type of “NVUE COMPLIANT.”

Initial Assessment A1 – Significant Topography Update Check

This check involves determining whether a topographic data source is available that is significantly better than that used for the effective Zone A modeling and mapping. For the Brady watershed, USGS 1:24,000-scale topographic maps were used for the effective Zone A analysis. The LiDAR data used in the BLE analysis is 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 involves first determining whether regression equations were used in the effective study. If they were, then it was determined if new regression equations have become available from the USGS since the date of the effective Zone A study. If newer regression equations exist for the area of interest, then an engineer must determine whether these regression equations would significantly affect the 1% 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 involves using the National Urban Change Indicator (NUCI) dataset to assess increased urbanization in the watershed of the Zone A study. If the percentage of urban area within the HUC-12 watershed containing the effective Zone A study is 15% or more, and has increased by 50% or more since the effective analysis, then the study would fail this check. Although the NUCI data provide year-to-year changes in urbanization, the NLCD also is needed to establish a baseline of urban land cover for this analysis. 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 15: Zone A Initial Assessment Results

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

Initial Assessment A4 – Check of Studies Backed by Technical Data

Zone A studies that pass all initial assessment checks described above may be categorized as "Valid" in the CNMS Inventory only if the effective Zone A study is supported by modeling or sound engineering judgment and all regulatory products are in agreement. If the effective Zone A study passes all initial assessment checks, but is not supported by modeling, or if the original engineering method used is unsupported or undocumented, then a comparison of the BLE results and effective Zone A mapping is performed. There was no adequate documentation regarding how the engineering analysis supporting the effective study was performed. Therefore, the A4 check was set to fail for all reaches in this study.

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

The BLE/effective Zone A comparison method leverages the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach uses the 1% 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 feet (one-half contour interval of assumed effective topographic source).

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 Brady BLE analysis.

The contour interval for the vertical tolerance was taken from the USGS 1:24,000-scale topographic maps of the Brady 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 17 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 Brady watershed study area has been updated. The total miles in each of these categories are summarized in Table 16 and illustrated on Figure 26. The findings from the Initial Assessment A5 are in Table 17.

Table 16: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment
VALID	NVUE COMPLIANT	0	0
	BEING STUDIED	0	1.8
UNVERIFIED	BEING STUDIED	0	14.1
	TO BE STUDIED	16.0	0

Table 17: BLE Comparison Results

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)
Watershed Name	HUC-12 ID					
Harden Branch-Brady Creek	120901100103	158	19	139	88.0%	Pass
South Brady Creek-Brady Creek	120901100108	45	4	41	91.1%	Pass
Town of Whiteland-Brady Creek	120901100201	167	157	10	6.0%	Fail
Needle Creek-Cow Creek	120901100202	49	48	1	2.0%	Fail
Brady Reservoir-Brady Creek	120901100203	1,298	720	578	44.5%	Fail
Live Oak Creek-Brady Creek	120901100205	4	1	3	75.0%	Fail-Insufficient points

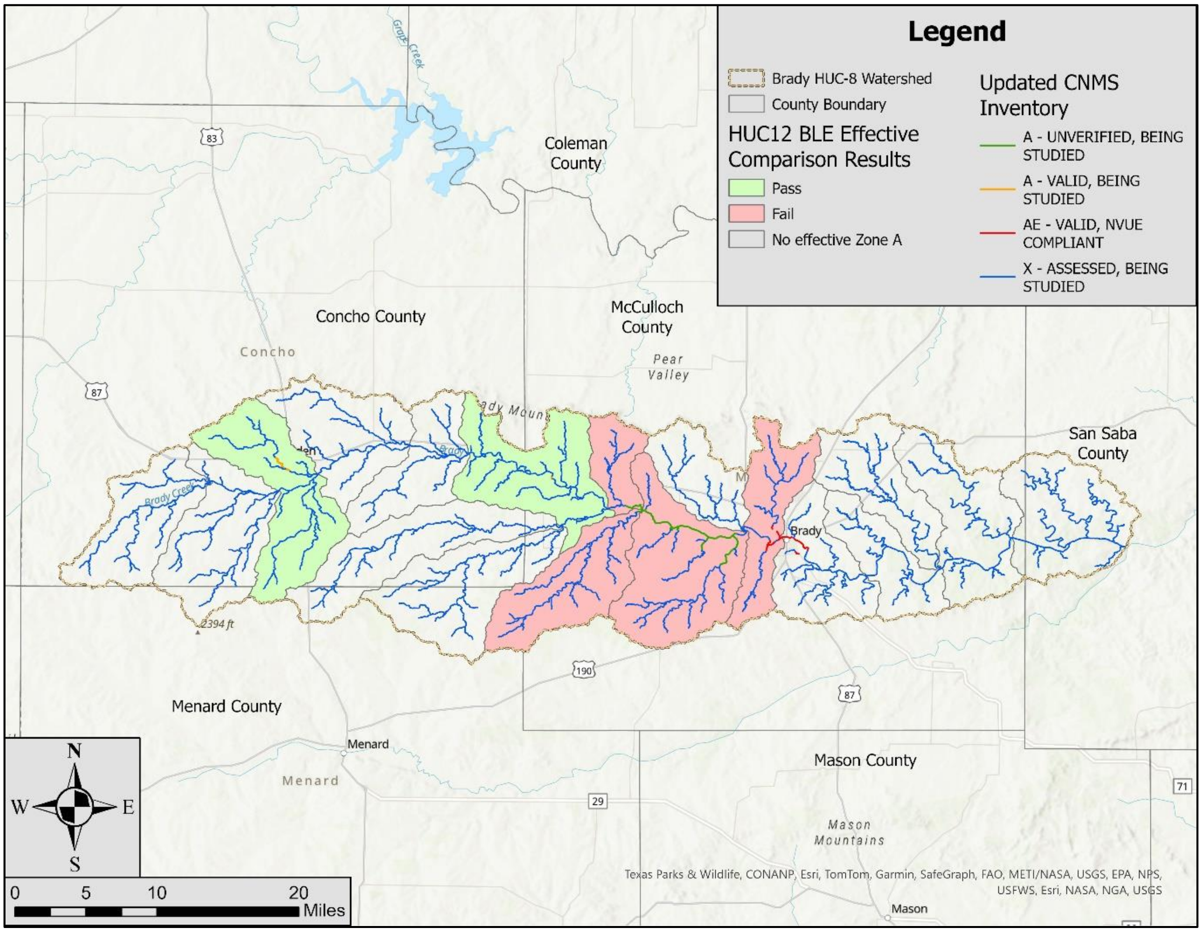


Figure 26: CNMS Validation Results

3.3. Flood Risk Analysis

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

Additional inputs for the analysis were as follows.

S_AOMI_Ar

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

Areas typically identified by this feature class include:

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

- Intersections of significant streams with major roadways – Since structures were not explicitly included in the BLE models, these areas were identified as areas where additional analysis may be useful for refining the outcomes of the BLE study.
- Floodplain mapping tie-ins along the HUC-8 watershed boundary – Along the HUC-8 watershed boundaries where AtkinsRéalis completed BLE assessments for both watersheds, the floodplain mapping includes smooth tie-ins across the watershed boundaries. Along those HUC-8 watershed boundaries where AtkinsRéalis <u>did not</u> 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 18 below for a summary of the losses computed by Hazus. Note that the full replacement loss (total loss) column is limited to those structures in the 1% floodplain while the dollar exposure columns considered all structures in the watershed.

L_Source_Cit

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

Table 18: Hazus Results for the Brady Watershed

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Menard County	$91,000	$7,343,000	$4,847,000
San Saba County	$10,000	$1,497,000	$750,000
McCulloch County	$130,105,000	$737,757,000	$467,313,000
Concho County	$41,305,000	$234,686,000	$149,433,000
Total	**$171,511,000**	**$981,283,000**	**$622,343,000**

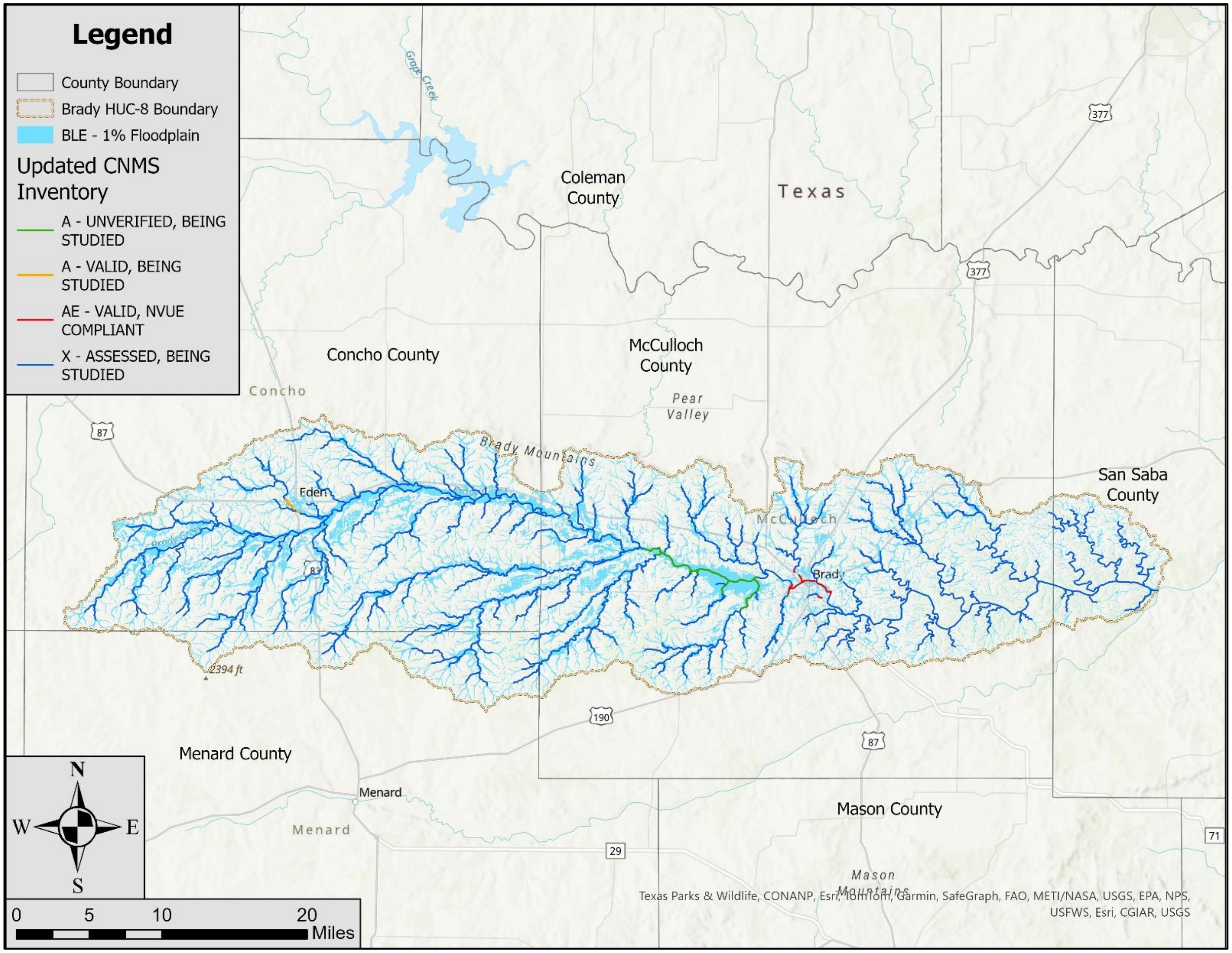
References

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

1. Chow, Ven T. *Open Channel Hydraulics*. Caldwell, NJ: Blackburn, 1959. *Development of Uniform Flow and Its Formulas*, pages 109-113. Print.
2. Federal Emergency Management Agency (FEMA). *Base Level Engineering – Region 6 Submittal Guidance*. January 2019. Main report and Appendix A. PDF.
3. Federal Emergency Management Agency (FEMA). *Coordinated Needs Management Strategy (CNMS) Technical Reference*. November 2021. Web. https://www.fema.gov/flood-maps/guidance-reports/guidelines-standards
4. Federal Emergency Management Agency (FEMA). Flood Insurance Study for the City of Brady, McCulloch County, Texas. April 15, 1981.
5. Federal Emergency Management Agency (FEMA). National Flood Hazard Layer (NFHL). Web. https://hazards-fema.maps.arcgis.com/apps/webappviewer/index.html?id=8b0adb51996444d4879338b5529aa9cd
6. Interagency Flood Risk Management (InFRM) Team. *Watershed Hydrology Assessment for the Lower Colorado River Basin*. DRAFT PDF. Chapter 5, pages 84, 85, and 151. 2021-08-13.
7. Natural Resources Conservation Service. Gridded Soil Survey Geographic Database (gSSURGO). 2021 version. Web. https://data.nal.usda.gov/dataset/gridded-soil-survey-geographic-database-gssurgo
8. Natural Resources Conservation Service. *National Engineering Handbook*, Title 210, Section 630, Chapter 4. August 2019 Version. Web. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=43924.wba
9. Sanja Perica, Sandra Pavlovic, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Orlan Wilhite. *NOAA Atlas 14 Volume 11 Version 2, Precipitation-Frequency Atlas of the United States, Texas*. 2018. NOAA, National Weather Service, Silver Spring, MD.
10. Texas Water Development Board (TWDB). *Texas Two-Dimensional Base Level Engineering Guidelines, Version 1.0*. May 21, 2022. PDF.
11. United States Army Corps of Engineers (USACE). Hydrologic Engineering Center-River Analysis System (HEC-RAS), Version 6.2. March 11, 2022.
12. United States Geological Survey (USGS). Hurricane LiDAR, 2019-02-20. Web. https://data.tnris.org/collection?c=6ddcc1e6-2059-4fa2-a2cf-4ab163e2c97e#6.55/29.436/-97.594
13. United States Geological Survey (USGS). Lower Colorado San Bernard LiDAR, 2018-06-17. Web. https://data.tnris.org/collection?c=b246f8f7-9c79-4c89-91f7-9c7f44955fca#5.37/29.889/-99.969
14. United States Geological Survey (USGS). Multi-Resolution Land Characteristics Consortium. National Land Cover Database 2019. https://www.mrlc.gov/data/nlcd-2019-land-cover-conus
15. United States Geological Survey (USGS). Texas West Central LiDAR, 2018-05-27. Web. https://data.tnris.org/collection?c=de1b77e1-3110-41e7-a6a5-81cbbdda5ec3#6.22/32.737/-99.594

16. William H. Asquith, Meghan C. Roussel. *Regression Equations for Estimation of Annual Peak-Streamflow Frequency for Undeveloped Watersheds in Texas Using an L-moment-Based, PRESS-Minimized, Residual-Adjusted Approach.* USGS Scientific Investigations Report 2009-5087. June 2009.

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 Brady watershed.

- Pages 84, 85, 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 gages analysis for USGS gage 08145000 (Brady Creek at Brady, TX).