

# Caddo Lake HUC-8 Watershed, Texas Base Level Engineering (BLE) Results

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## Executive Summary

The Texas Water Development Board (TWDB) contracted Halff Associates (Halff) to complete a Base Level Engineering (BLE) analysis for the HUC-08 watershed No. 11140306 – Caddo Lake in Northeast Texas, to support the U.S. Department of Homeland Security’s Federal Emergency Management Agency’s (FEMA) Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHAs). The BLE process involves using best available data and incorporating automated techniques with standard 2-dimensional (2D) model development procedures to produce regulatory-quality flood hazard boundaries for the 1-percent annual chance event as well as estimates of flood hazard boundaries for multiple recurrence intervals.

The source digital terrain data used for surface model development in support of hydrologic and hydraulic analysis as well as mapping activities were leveraged from various local, State, and Federal partners. Details regarding the different datasets used are provided below in Section 2.1.

Precipitation depths for this study were established using NOAA Atlas 14 rainfall. An average precipitation depth was computed for the study area. The Hydrologic Engineering Center’s (HEC) Hydrologic Modeling System (HMS) was used to develop a simplified hydrologic model to compute excess rainfall which was then used in a rain-on-grid, 2D hydraulic modeling using HEC-RAS. The hydraulic model was used to compute flood depths and peak water surface elevations within the study area.

The stream mile network that was validated for this watershed was compiled using FEMA’s Community Needs Management Strategy (CNMS) inventory. CNMS is an inventory of flood hazard studies and flood hazard mapping needs for areas where a study is needed. This data is helpful for community officials in analyzing and depicting flood hazards to enhance the understanding of flood risks. Communities may use this information to make informed decisions on their planning and flood mitigation efforts. Table ES-1.1.1 lists the stream miles associated with this validation analysis.

**Table ES-1.1: Summary of Stream Miles**

| Source | Caddo Lake Stream Miles |
|--------|-------------------------|
| CNMS   | 3,625                   |

The full inventory of Zone A studies in the watershed were classified in CNMS. Total miles validated in CNMS are summarized in Table ES-1.2.

**Table ES-1.2: Aggregated Zone A Validation Results**

| Validation Status | Status Type   | Total Miles |
|-------------------|---------------|-------------|
| VALID             | BEING STUDIED | 198.0       |
| UNVERIFIED        | BEING STUDIED | 624.1       |

## 01 Introduction

Recent innovations and efficiencies in floodplain mapping have allowed the U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) to develop a process called Base Level Engineering (BLE), which can be used to address current program challenges, including the validation of Zone A studies and the availability of flood risk data in the early stages of a flood risk project. The BLE process involves using best available data and incorporating automated techniques with standard 2-dimensional (2D) model development procedures to produce regulatory quality flood hazard boundaries for the 1-percent annual chance event as well as estimates of flood hazard boundaries for multiple recurrence intervals. The cost for developing the data and estimates resulting from the BLE process are lower than standard flood production costs. The BLE results may be used for eventual production of regulatory and non-regulatory products.

As described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e), once every five years, FEMA must evaluate whether the information on Flood Insurance Rate Maps (FIRMs) reflects the current risks in 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 Standard SID #29 requires that during Discovery, data must be identified that illustrates potential changes in flood elevation and mapping that may result from the proposed project scope. If available data does not clearly illustrate the likely changes, an analysis is required that estimates the likely changes. This data and any associated analyses should be shared, and results should be discussed with stakeholders.

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

The Texas Water Development Board (TWDB) contracted Halff Associates (Halff) to complete a BLE analysis for the Caddo Lake Watershed in Northeast Texas to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHA). The study extents include portions of Morris, Cass, Marion, Harrison, and Caddo (LA) Counties, and include the following communities: The Cities of Hughes Springs, Jefferson, Scottsville, Uncertain, Naples, and Linden, the Towns of Marietta, Mooringsport, and Avinger, and the Communities of Karnack, Bivins, and Lodi. The study area consists of four HUC-10 basins: French Creek – Big Cypress Bayou, Black Cypress Creek – Black Cypress Bayou, Jim Bayou – Frazier Creek, and Big Cypress Bayou – Frontal Caddo Lake. Figure 1.1 shows the orientation of the Caddo Lake HUC-8 basin with respect to the counties.

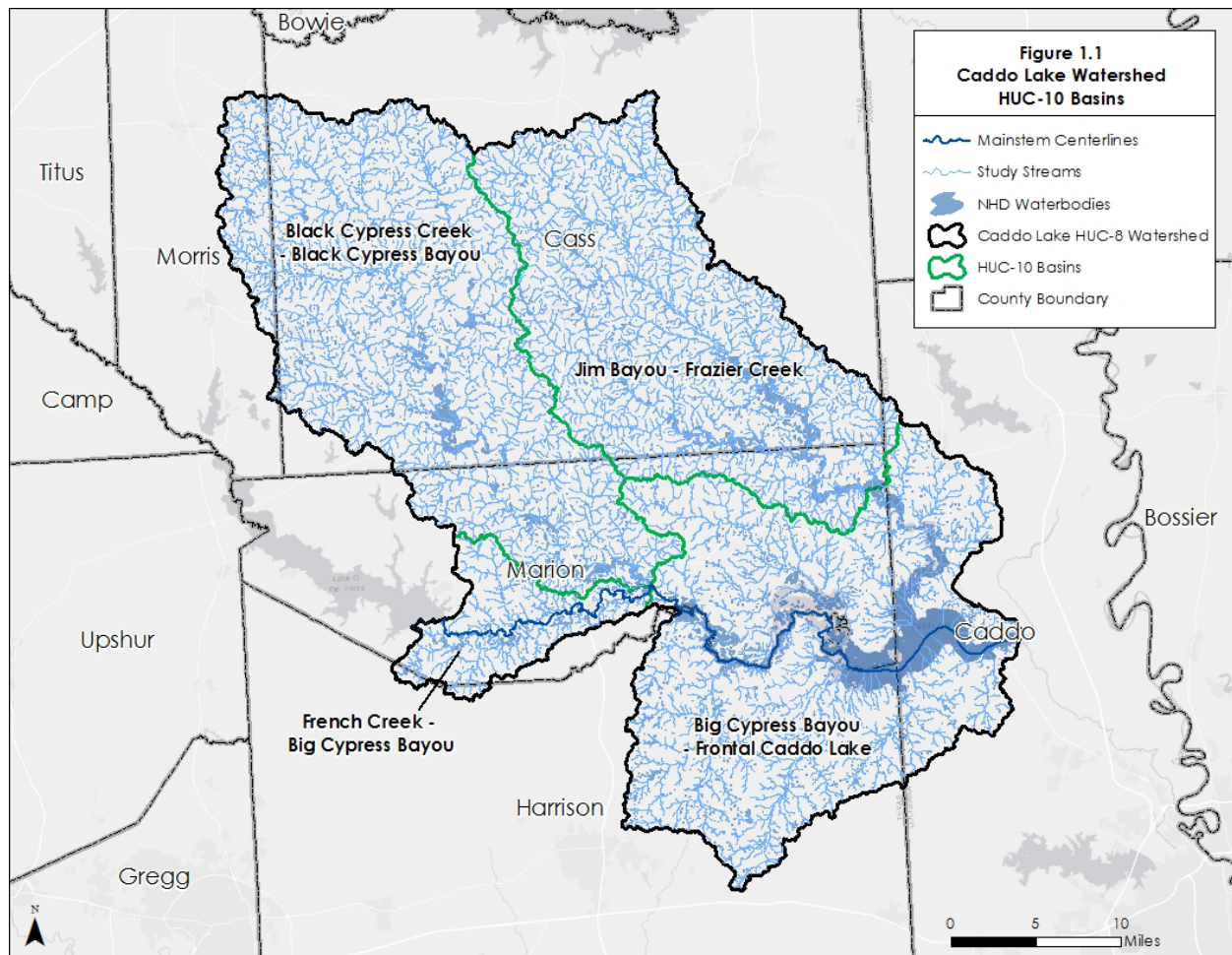


Figure 1.1: Caddo Lake Watershed

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## 02 2D BLE Modeling Inputs and Controls

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

### 2.1 Topographic Data

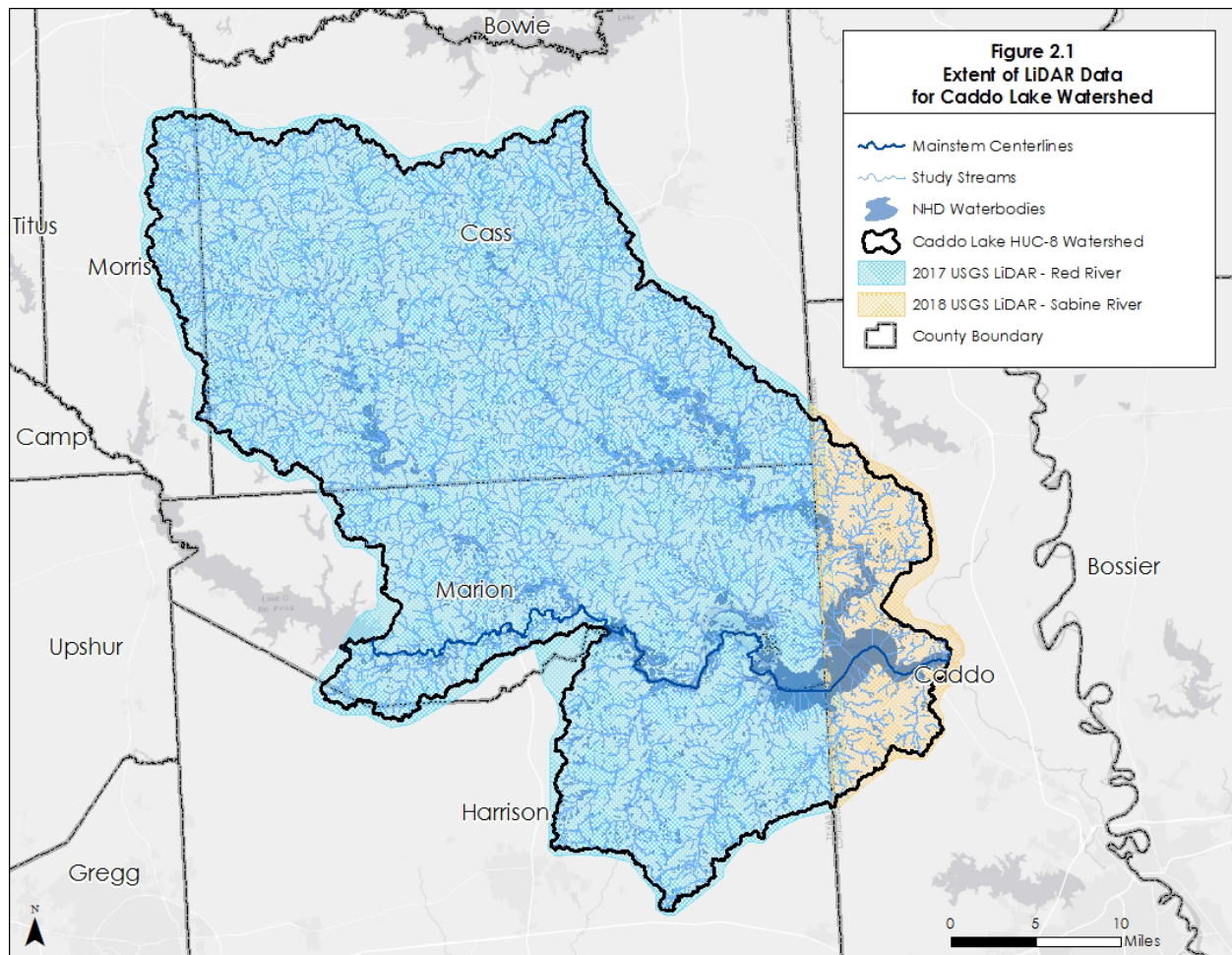
A high-resolution Digital Elevation Model (DEM) is a fundamental component for 2D engineering analyses by providing a detailed representation of the ground surface for hydraulic routing through the model area. As such, DEMs were developed for the Caddo Lake BLE project by leveraging available high-resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the entire State of Texas. The 10-foot DEM developed to support the 2D BLE modeling and analysis, within the Caddo Lake Watershed, was executed using the following steps:

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

Documentation regarding leveraged data including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables, and text within the following sections. All vertical accuracy specifications were obtained from the metadata or survey reports provided with the leverage datasets. All available metadata, survey reports, and other leverage documentation are included in the FEMA Data Capture Technical Reference compliant submittal content for the Caddo Lake Watershed.

#### 2.1.1 Inventory

An inventory of existing topographic data was conducted for the Caddo Lake BLE project footprint. Figure 2.1 depicts the datasets identified for leverage across the project area. FEMA, National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and other State and Federal agencies were queried to build the inventory with the most current and available data sources.



**Figure 2.1: Caddo Lake Watershed BLE Source Terrain Data**

**2017 TNIRIS Red River LiDAR**– The 2017 Red River LiDAR was acquired from January 2017 to March 2017. The measured RMSE was documented at 10.9 cm Non-Vegetative Accuracy. The reported Z (vertical) Accuracy meets the 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using  $RMSE(z) \times 1.9600$  as defined by the National Standards for Spatial Data Accuracy (NSSDA) and was assessed and reported following National Digital Elevation Program (NDEP)/ASRPS Guidelines.

**2018 USGS Sabine Louisiana LiDAR**– The 2018 USGS Sabine Louisiana LiDAR was acquired from February to March 2018. The measured NVA RMSE was documented as 10.9 cm. The reported Z (vertical) Accuracy meets the 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using  $RMSE(z) \times 1.9600$  as defined by the National Standards for Spatial Data Accuracy (NSSDA) and was assessed and reported following National Digital Elevation Program (NDEP)/ASRPS Guidelines.

### 2.1.2 Evaluation

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

- Data meet FEMA vertical accuracy standards (Table 2.1)
- Date of origination
- Data density and coverage

Table 2.1 depicts the Risk Map SID 43 vertical accuracy requirements based on flood risk and terrain slope within the floodplain being mapped.

**Table 2.1: FEMA Vertical Accuracy Requirements for Leveraged Data**

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

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

Table 2.2 depicts the complete list of source elevation data and attributes leveraged for the Caddo Lake Watershed BLE project. All datasets used for hydraulic analyses and mapping meet the highest specification level defined in Table 2.1. Further explanation of the Table 2.2 datasets can be referenced in section 2.1.2.1.

**Table 2.2: Source Topographic Data Available for the Caddo Lake Watershed**

| Year | Description             | Data Type      | RMSE      | Source/Owner |
|------|-------------------------|----------------|-----------|--------------|
| 2018 | 2018 Sabine River Lidar | Airborne LiDAR | 9.4cm NVA | USGS         |

| Year | Description          | Data Type      | RMSE       | Source/Owner |
|------|----------------------|----------------|------------|--------------|
| 2017 | 2017 Red River Lidar | Airborne LiDAR | 10.9cm NVA | TNRIS        |

### 2.1.2.1 Caddo Lake Watershed Source Terrain Data

The source elevation data for the Caddo Lake Watershed are DEMs derived from USGS, TWDB and FEMA LiDAR data. Preprocessed Bare-earth Hydro-enforced DEMs from the acquiring entity (via TNRIS) were projected and adjusted as needed into one seamless DEM in Texas State Plane 4204 NAD83, Vertical Feet NAVD88. Bare-earth LIDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the processed LiDAR returns. Figure 2.1 depicts the extent of the data defined in Table 2.2. Please see brief descriptions of the lidar sources below. For more detailed information, please see the attached LiDAR project report for each individual project.

**2017 TNRIS Red River LiDAR**– The 2017 Red River LiDAR was acquired from January 2017 to March 2017. The measured RMSE was documented at 10.9 cm Non-Vegetative Accuracy. The reported Z (vertical) Accuracy meets the 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using  $RMSE(z) \times 1.9600$  as defined by the National Standards for Spatial Data Accuracy (NSSDA) and was assessed and reported following National Digital Elevation Program (NDEP)/ASRPS Guidelines.

**2018 USGS Sabine Louisiana LiDAR**– The 2018 USGS Sabine Louisiana LiDAR was acquired from February to March 2018. The measured NVA RMSE was documented as 10.9 cm. The reported Z (vertical) Accuracy meets the 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using  $RMSE(z) \times 1.9600$  as defined by the National Standards for Spatial Data Accuracy (NSSDA) and was assessed and reported following National Digital Elevation Program (NDEP)/ASRPS Guidelines.

### 2.1.3 Data Development Methodology

The source topographic data were processed for an area covering the Caddo Lake Watershed and contributing drainage areas for the Caddo Lake BLE modeling efforts. The topographic data for Caddo Lake Watershed was projected horizontally, as needed, to North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS) Texas S Central in feet (4204-SPC83). All topographic data were adjusted vertically, as needed, to NAVD88 in feet. Halff used a combination of ArcGIS and other software tools to apply any vertical datum shifts and/or any horizontal projection transformations to the topographic data.

### 2.1.4 DEM QA/QC

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

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

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

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

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

The final DEM data developed for the Caddo Lake Watershed are assured to meet FEMA standards and present a representative surface developed from leveraged elevation data for the purposes of this BLE project.

## 2.2 2D BLE Methods

The following sections describe the 2D computational mesh and program setting considerations, followed by discussion and tabulation of hydrologic and hydraulic engineering methods and model inputs.

### 2.2.1 2D Computational Mesh and Settings

The HEC-RAS 2D computational mesh defines the extents of the 2D flow and can affect the accuracy of the 2D calculations. A denser mesh may provide more accurate results, but it can dramatically increase model run times. The original 2D mesh for the model was established as evenly spaced cells at approximately 200 feet. The mesh was further refined by placing breaklines along roads, berms, ridges, and other high ground that can impede flow as well as stream centerlines to allow flow conveyance. To ensure the entire Caddo Lake Watershed was represented, an approximately 5,000-foot buffer was added to the HUC boundary. This buffer was used to capture inflows and produce mapping through the full extents of the HUC-8 boundary. It should be noted, the buffer was applied to the USGS HUC-8 boundary that was not modified based on topography. A hydro-corrected HUC-8 boundary was not used to meet FEMA's requirement to provide mapping through the full extent of the USGS HUC-8 watershed.

The HEC-RAS 2D computational mesh was created for Caddo Lake Watershed based on the USGS HUC boundaries using ArcGIS toolsets, such as smoothing and simplification routines; ultimately, significantly reducing the need for manual edits to mesh cells within HEC-RAS that happen to generate errors. The 2D mesh consists of 988,188 cells with a 200-foot nominal mesh cell size. Factors that result in either larger or smaller cell sizes include:

- Proximity to the edge of the 2D mesh
- Presence of breaklines
- Refinement of mesh for significant flood control features (levees, dams, etc.).

A 30-second time step was used in the HEC-RAS model, applying the Diffusion Wave (simplified Full Momentum) equations.

### 2.2.2 Model and Boundary Condition Setup

Using HEC-RAS rain-on-grid modeling requires establishing a 2D computational mesh boundary as discussed previously, and often requires defining inflow boundary conditions in addition to excess precipitation applied to the mesh. For the Caddo Lake Watershed, inflow hydrographs from Lake O'the Pines and Little Cypress were used, along with excess precipitation applied to the mesh and a stage curve from Cross Bayou. Figure 2.2 shows the 2D computational mesh for the Caddo Lake Watershed, along with USGS peak streamflow gages pertinent to the study area. Figures 2.3 and 2.4 show the inflow boundary condition locations for Lake O'the Pines and Little Cypress basins, respectively. The development of the inflow hydrographs, and excess precipitation hyetographs for the 2D mesh, is described in Section 2.2.3.

Outflow boundary conditions, allowing flow to leave the computational 2D mesh, were utilized along basin boundaries. Unique outflow normal depth boundary conditions were established for riverine flows, while the remaining boundaries were added to allow flow to leave the model area freely. Normal depth was used for non-unique outflow boundary conditions using approximate energy grade-line slopes estimated from the LiDAR terrain data.

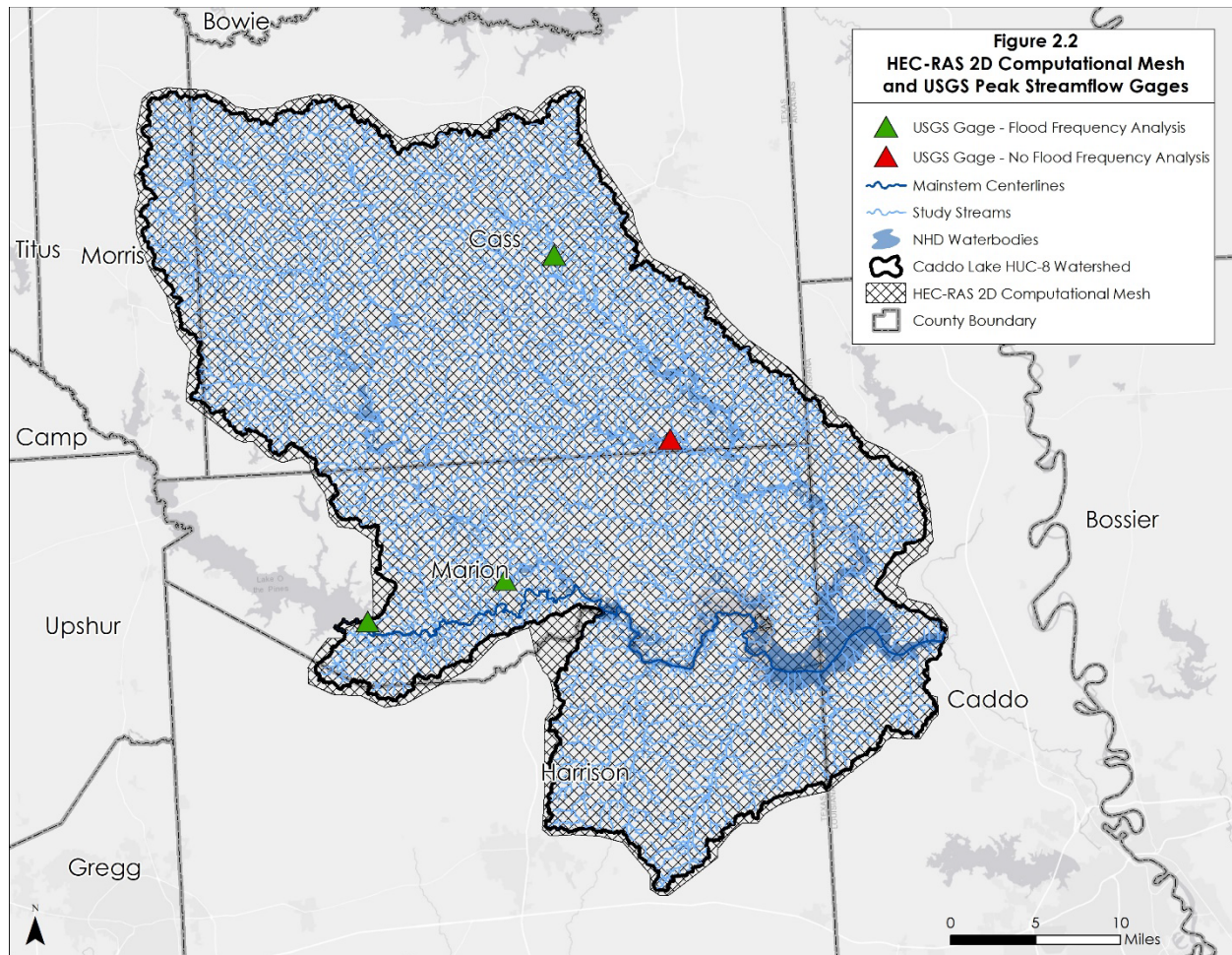
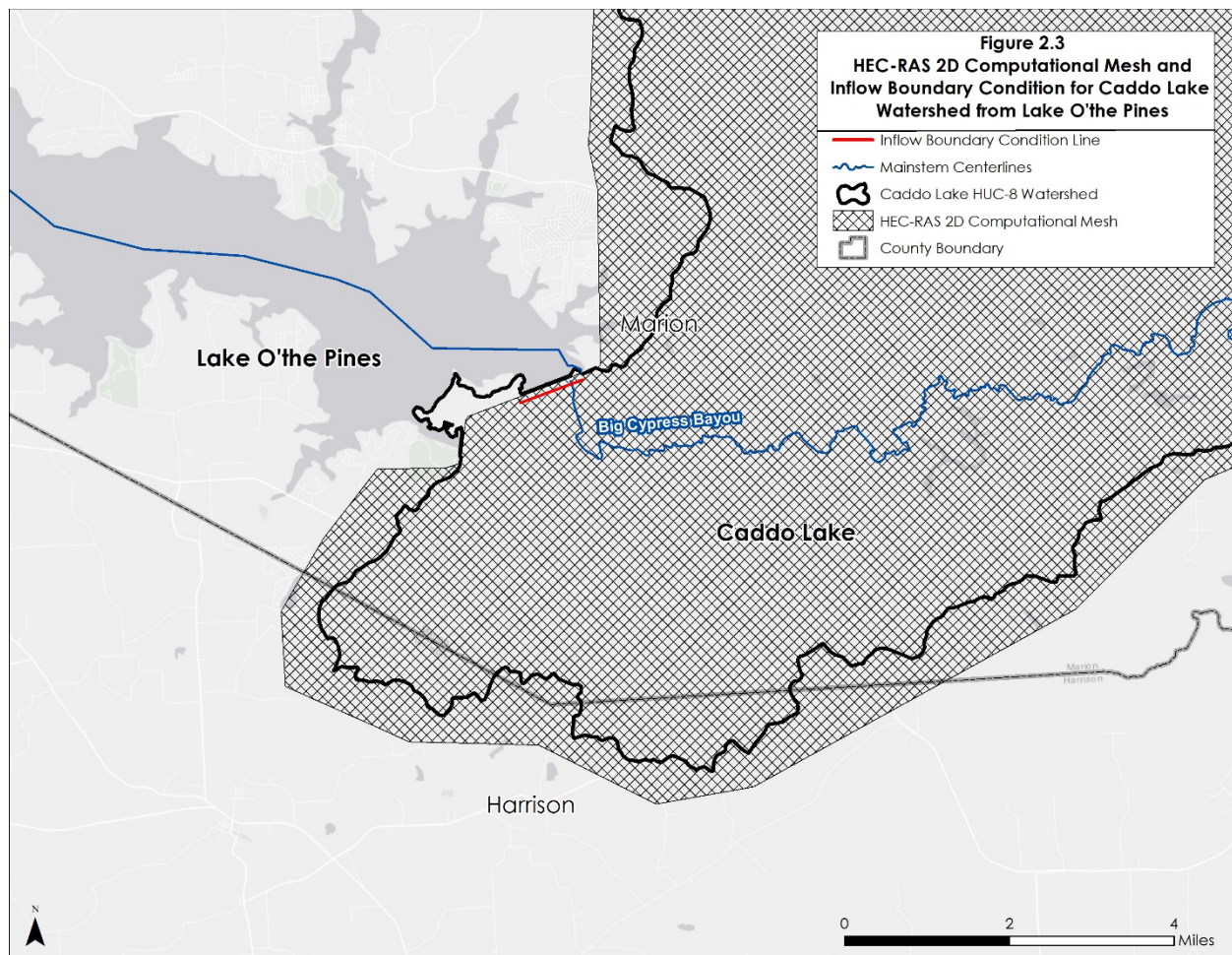


Figure 2.2: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages



**Figure 2.3: HEC-RAS 2D Computational Mesh and Inflow Boundary Condition for Caddo Lake Watershed from Lake O'the Pines**

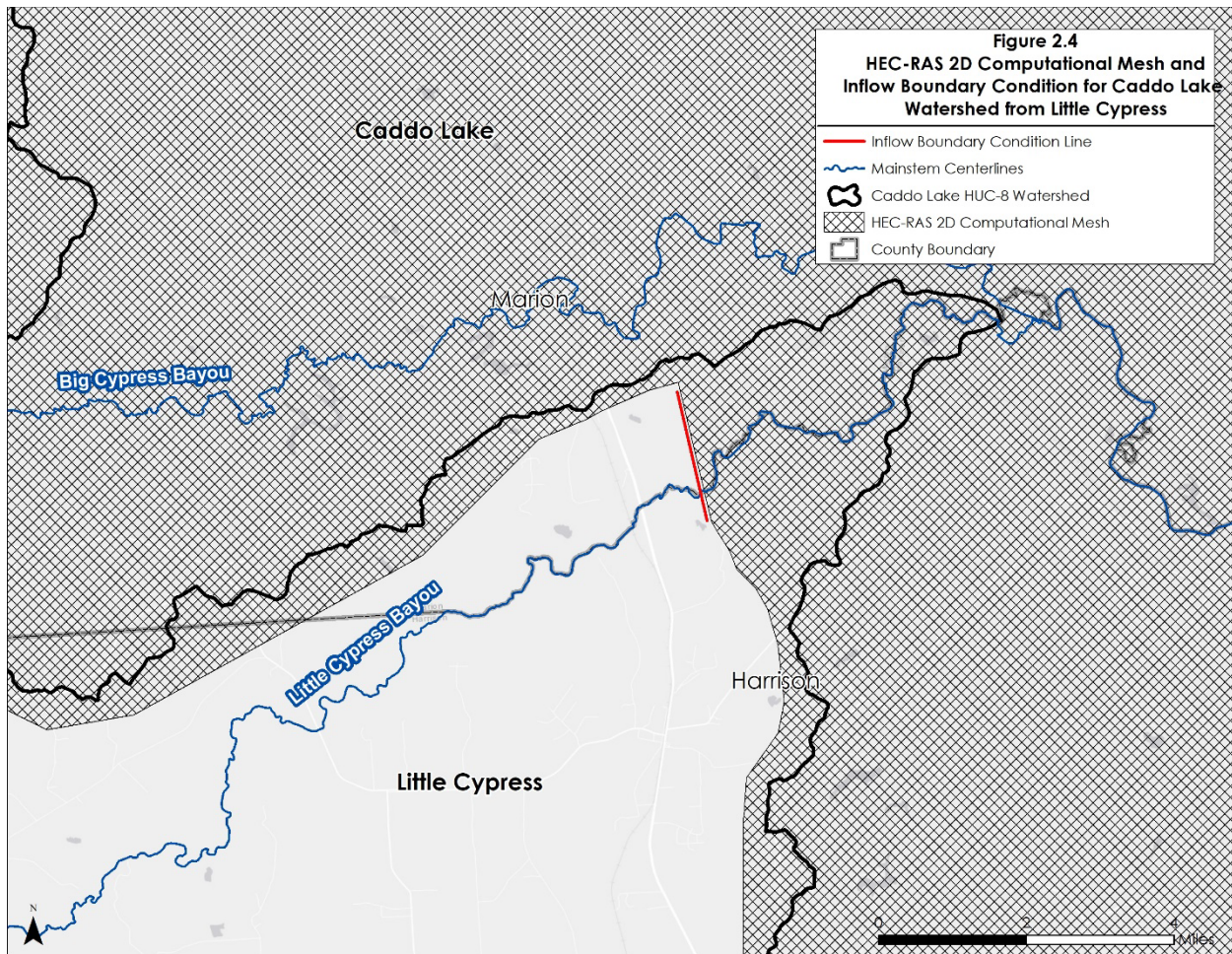


Figure 2.4: HEC-RAS 2D Computational Mesh and Inflow Boundary Condition for Caddo Lake Watershed from Little Cypress

### 2.2.3 Hydrology

HEC-HMS, Version 4.8, was used solely for the development of excess precipitation hyetographs which were applied to the 2D mesh. Precipitation frequency data published in NOAA Atlas 14, Volume 11 Version 2.0 (NOAA, 2018) were used for this study. These data were obtained from NOAA's Precipitation Frequency Data Server (PFDS) (<http://hdsc.nws.noaa.gov/hdsc/pfds/index.html>). The 10-, 4-, 2-, 1-, and 0.2-percent annual chance 24-hour precipitation depths for the watershed were determined by area-weighted intersection of gridded PFDS data within the study area. Excess precipitation for the 2D mesh was developed as described in Section 2.2.3.1, and inflow hydrographs from Lake O'the Pines and Little Cypress were used.

A total of four (4) USGS gages are found within Caddo Lake Watershed. No peak flow record data was found for the USGS Gage No. 07346120— Jims Bayou near Kildare, TX and was excluded from the analysis. The other three (3) USGS gages including: 07346000 – Big Cypress Bayou nr Jefferson, TX, 07346045 – Black Cypress Bayou at Jefferson, TX, and 07346140 – Frazier Ck nr Linden, TX had streamflow gage data that was leveraged to estimate peak flows for downstream gages within each work area for model validation purposes, as discussed in Section 2.3.1. The gages utilized for this study are presented in Table 2.3.

**Table 2.3: USGS Peak Streamflow Gages**

| Gage ID  | Flooding Source and Location         | Published Drainage Area (mi <sup>2</sup> ) | Period of Record |
|----------|--------------------------------------|--------------------------------------------|------------------|
| 07346000 | Big Cypress Bayou nr Jefferson, TX   | 850                                        | 1925-2020        |
| 07346045 | Black Cypress Bayou at Jefferson, TX | 365                                        | 1969-2020        |
| 07346140 | Frazier Ck nr Linden, TX             | 48                                         | 1965-1991        |

Annual chance peak flows were calculated at each gage using USGS Bulletin 17B and 17C (EMA) methodology. The peak flows were computed using both methodologies and evaluated based on confidence of the gage analysis. Calculated discharges for the 1%, 1% plus, and 1% minus events used for comparison of flow validation within the upper (1% plus) and lower (1% minus) confidence intervals are presented in Table 2.4 for each gage utilized in this study.

**Table 2.4: USGS Peak Streamflow Gage Analysis Results**

| Gage ID  | Flooding Source and Location         | 1% Peak Q (cfs) | 1%- Peak Q (cfs) | 1%+ Peak Q (cfs) |
|----------|--------------------------------------|-----------------|------------------|------------------|
| 07346000 | Big Cypress Bayou nr Jefferson, TX   | 4,480           | 4,272            | 4,749            |
| 07346045 | Black Cypress Bayou at Jefferson, TX | 11,620          | 9,950            | 13,980           |
| 07346140 | Frazier Ck nr Linden, TX             | 14,340          | 10,010           | 22,560           |

#### 2.2.3.1 Excess Precipitation for 2D Computational Mesh

HEC-HMS, Version 4.8 was used to apply the SCS Curve Number method to calculate losses and define excess precipitation for each watershed. Temporal distributions of point rainfall totals were defined using frequency storm distributions. The plus and minus standard error for the 1-percent annual chance

precipitation depths were determined as the upper and lower 84% confidence limits on the nominal 1-percent depth, assuming a normal distribution of the logarithms for the precipitation depths.

In addition to recurrence interval precipitation estimates, NOAA Atlas 14 provides 90% confidence intervals of reported precipitation values. On a normal distribution curve, 90% confidence intervals (i.e. the upper and lower 95% confidence limits) correspond to  $\pm 1.645$  standard deviations. The 1% plus and minus events are defined to be one standard deviation above and below the 1% event.

Curve Numbers were computed by intersecting the National Land Cover Dataset (NLCD) 2019 coverage and NRCS soils data based on the matrix presented in Table 2.5.

**Table 2.5: Land Use-Soils-CN Matrix for Computing Initial Curve Numbers**

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

The time of concentration for the study area was approximated as the square root of the drainage area, then multiplied by 0.6 to compute the lag time. The lag time does not impact the excess rainfall hyetograph, so it was not necessary to compute a more accurate basin travel time. The table below shows the curve numbers and lag time values used in this study.

**Table 2.6: Rainfall-Runoff Parameters (Curve Number, Lag Time)**

| Sub-basin Description | CN | Tlag (min) |
|-----------------------|----|------------|
| Caddo Lake            | 70 | 1,245      |

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including curve numbers for defining rainfall losses and lag time for transforming the runoff temporally. No routing was considered in the rainfall-runoff modeling. Frequency storm distributions were used for defining temporal distributions of point rainfall totals. Weighted average rainfall depths were calculated for the 10-, 4, 2, 1, and 0.2-percent ACEs. The weighted average rainfall depths for 1-percent plus and 1-percent minus rasters were also calculated using the upper and lower confidence intervals for the 1-percent event. These steps were performed for durations of 5-min, 15-min, 1-hr, 2-hr, 3-hr, 6-hr, 12-hr and 24-hr. The weighted average rainfall depths were used to determine the excess precipitation in the HEC-HMS model.

Areal reduction was applied using TP40 curves and an assumption of storm area equivalent to approximately one half of the total study area. Table 2.7 provides the total rainfall depth for a 24-hour storm duration used for determining excess precipitation.

**Table 2.7: Rainfall depths for estimating Excess Precipitation for HEC-RAS 2D Computational Mesh**

| Sub-basin Description | Percent Annual Chance Precipitation Total (in) | Rainfall Duration (in) |        |      |      |      |      |       |       |
|-----------------------|------------------------------------------------|------------------------|--------|------|------|------|------|-------|-------|
|                       |                                                | 5 min                  | 15 min | 1 hr | 2 hr | 3 hr | 6 hr | 12 hr | 24 hr |
| Caddo Lake            | 10yr                                           | 0.70                   | 1.37   | 2.53 | 3.20 | 3.63 | 4.42 | 5.28  | 6.23  |
|                       | 25yr                                           | 0.81                   | 1.60   | 2.95 | 3.77 | 4.31 | 5.30 | 6.41  | 7.63  |
|                       | 50yr                                           | 0.90                   | 1.77   | 3.27 | 4.21 | 4.84 | 6.00 | 7.33  | 8.77  |
|                       | 100yr                                          | 0.99                   | 1.94   | 3.59 | 4.66 | 5.38 | 6.74 | 8.32  | 10.02 |
|                       | 100yr minus                                    | 0.77                   | 1.51   | 2.79 | 3.66 | 4.25 | 5.36 | 6.68  | 8.12  |
|                       | 100yr plus                                     | 1.20                   | 2.37   | 4.38 | 5.66 | 6.52 | 8.11 | 9.95  | 11.93 |
|                       | 500yr                                          | 1.19                   | 2.34   | 4.39 | 5.81 | 6.80 | 8.69 | 10.98 | 13.43 |

Figure 2.5 shows the excess precipitation hyetographs applied to the 2D computational mesh.

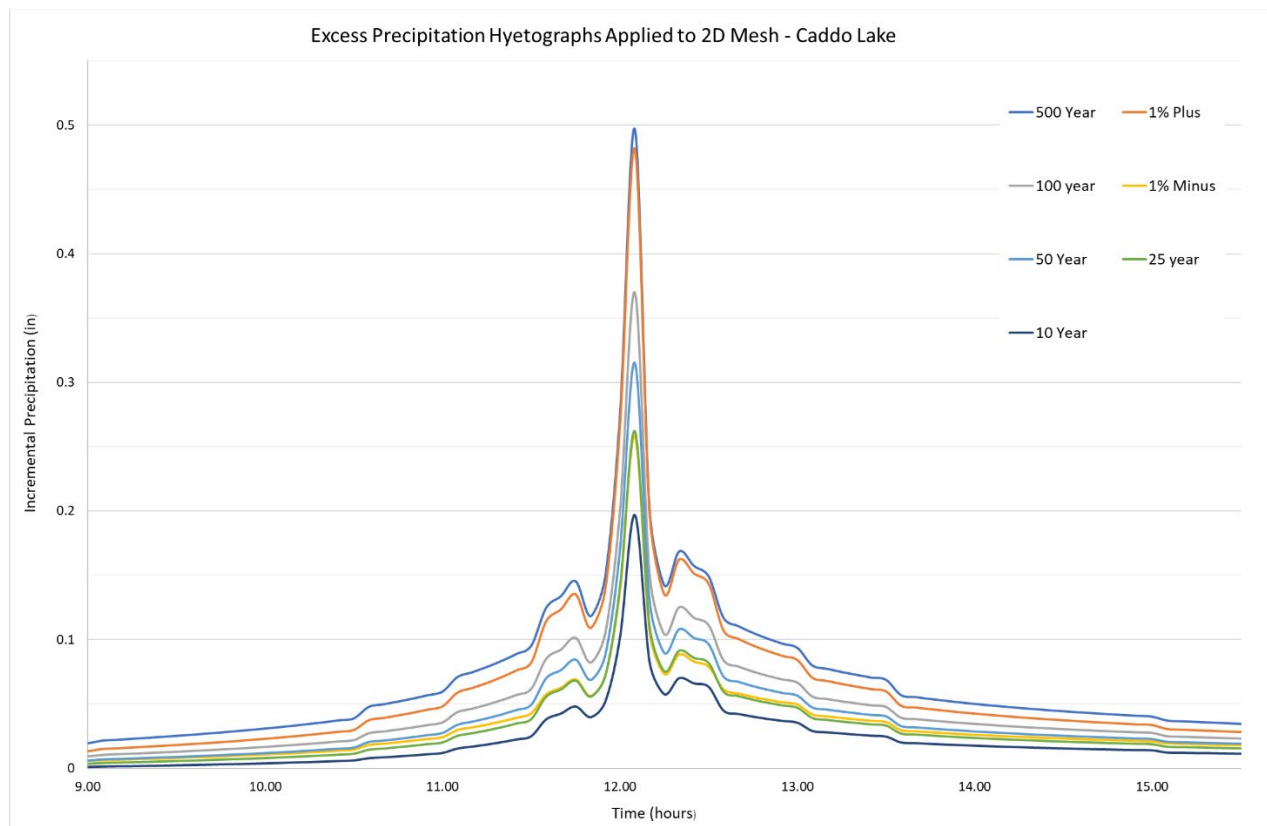


Figure 2.5: Excess Precipitation Hyetographs Applied to the Computational Mesh

### 2.2.3.2 Rainfall-Runoff Hydrograph Boundary Conditions

This section discusses the drainage areas for which inflow hydrographs, developed from rainfall-runoff modeling, were used as boundary conditions to the 2D computational mesh. The following figures show the inflow hydrographs for each contributing flooding source applied to the 2D computational mesh. Note that Figures 2.6 and 2.7 include the Lake O'the Pines drainage area and Little Cypress drainage area contributing inflow hydrographs to Caddo Lake. Figure 2.8 shows the stage hydrograph from Cross Bayou. The stage hydrograph from Cross Bayou was used to model the backwater which would occur from Cross Bayou into the downstream portions of the Caddo Lake Watershed.

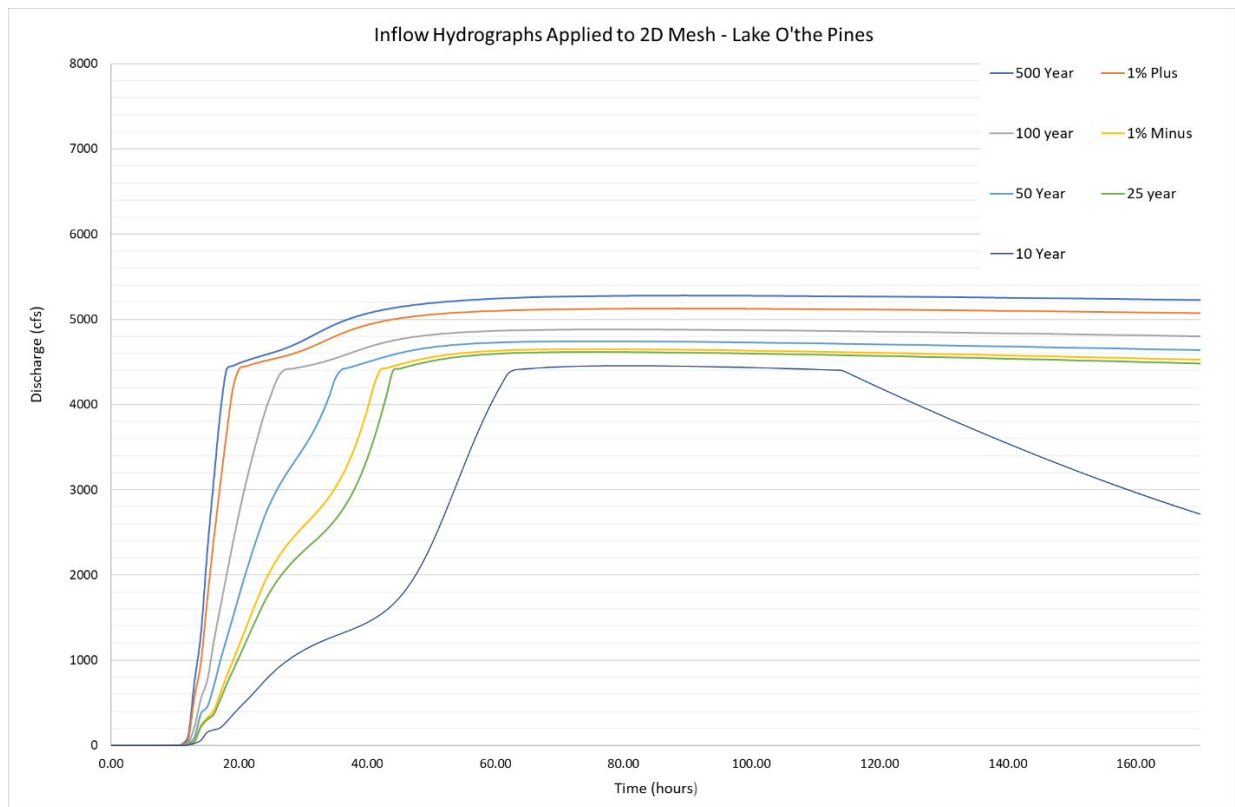
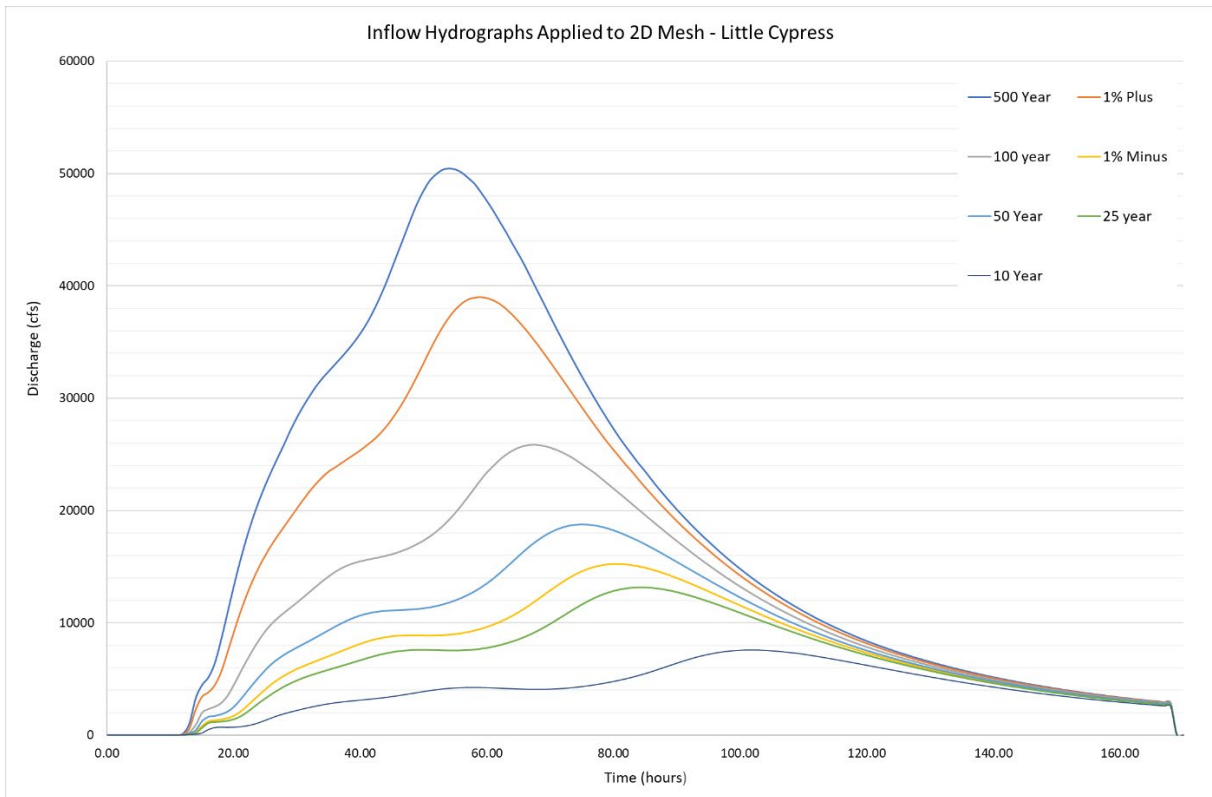
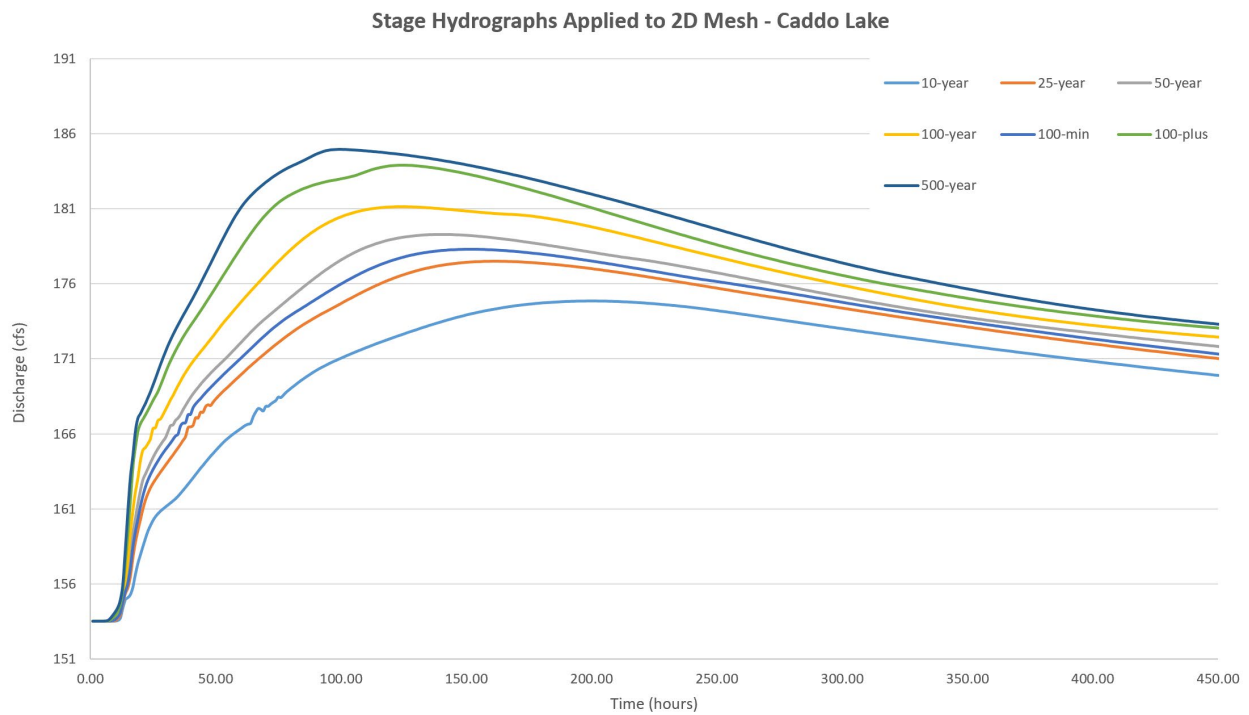


Figure 2.6: Lake O'the Pines Watershed – Contributing Drainage Area Inflow Hydrographs



**Figure 2.7: Little Cypress Watershed – Contributing Drainage Area Inflow Hydrographs**



**Figure 2.8: Stage Hydrograph applied to Caddo Lake**

## 2.2.4 Hydraulics

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

### 2.2.4.1 Roughness Coefficients

A Manning’s n roughness coverage was developed for the 2D computational mesh using typical values for roughness for given NLCD land classifications. In several areas, the channel section land use indicated a Manning’s n-value inappropriate for channel conveyance. A 20-foot buffer zone was created by automated processes around each stream centerline (mainstem and tributaries) to create a main channel roughness zone. The channel roughness zone was given a Manning’s n value of 0.045, obtained from the HEC-RAS User’s Manual, to ensure the channel 2D cells have appropriate conveyance. The table below shows a typical land use-roughness matrix used in defining the roughness coverage for the study area as well as the final Manning’s roughness used based on the model validation.

**Table 2.8: NLCD 2019-Manning’s N Roughness Matrix**

| NLCD Classification         | Manning’s N | Minimum | Normal | Maximum |
|-----------------------------|-------------|---------|--------|---------|
| Open Water                  | 0.03        | 0.025   | 0.038  | 0.050   |
| Developed, Open Space       | 0.03        | 0.030   | 0.040  | 0.050   |
| Developed, Low Intensity    | 0.04        | 0.060   | 0.090  | 0.120   |
| Developed, Medium Intensity | 0.06        | 0.080   | 0.120  | 0.160   |
| Developed, High Intensity   | 0.075       | 0.120   | 0.160  | 0.200   |
| Barren Land                 | 0.025       | 0.023   | 0.025  | 0.030   |
| Deciduous Forest            | 0.100       | 0.100   | 0.150  | 0.200   |
| Evergreen Forest            | 0.100       | 0.080   | 0.120  | 0.160   |
| Mixed Forest                | 0.100       | 0.080   | 0.140  | 0.200   |
| Scrub/Shrub                 | 0.035       | 0.070   | 0.115  | 0.160   |
| Grassland/Herbaceous        | 0.025       | 0.025   | 0.038  | 0.050   |
| Pasture/Hay                 | 0.03        | 0.025   | 0.038  | 0.050   |
| Cultivated Crops            | 0.025       | 0.020   | 0.035  | 0.050   |
| Woody Wetlands              | 0.08        | 0.045   | 0.098  | 0.150   |
| Emergent Herbaceous Wetland | 0.075       | 0.050   | 0.068  | 0.085   |
| Main Channel <sup>1</sup>   | 0.045       |         |        |         |

Source: HEC-RAS 2D Modeling User’s Manual

<sup>1</sup> Clean, winding, some pools and shoals, some weeds and stones, lower stages, more ineffective slopes and sections with a default 20 feet buffer from centerlines

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#### **2.2.4.2 Breaklines**

Breaklines align grid cell faces and were used within the 2D mesh area to define prominent features including, road embankments and hydraulic structures as well as stream centerlines. Road embankments were identified in ArcGIS and imported into HEC-RAS as breaklines to ensure that water was not routed past roads until it was deep enough to overtop the road. County, interstate, state recognized, and U.S. roads were incorporated for road breaklines from the ESRI North America Detailed Streets layer. The stream centerlines were input as breaklines to ensure cells lined up perpendicular to the stream and to capture stream conveyance. Stream centerlines were simplified to speed up editing and run times in HEC-RAS. Levees from the National Levee Inventory, and railroads from the TIGER Railroads layer were also incorporated. Additionally, several private dams and embankments were added as breaklines to better represent flow patterns through and around these structures.

##### **2.2.4.2.1 Roads**

Culvert crossings specifically were identified by intersections of the stream centerlines and road lines by automated processes and were modeled by burning channels through the embankment in the DEM to prevent unnecessary impoundment of water. This approach was used for most hydraulic structures because it could be implemented in ArcGIS on a large scale with much less effort than alternative methods. Since this an automated process, it was not possible to isolate specific culverts to burn through the DEM, thus conservative assumptions on width of opening were applied to not overestimate the release of water through the crossing.

Bridge/culvert crossings that were not processed out of the terrain data were modeled by inserting v-notches into the road breaklines at the points of intersection with the bridge/culvert crossings. The v-notches cause the grid cells to realign around the embankment and allow water to be routed across the embankment without creating artificial backwater. An example of the v-notch breakline approach is shown below.

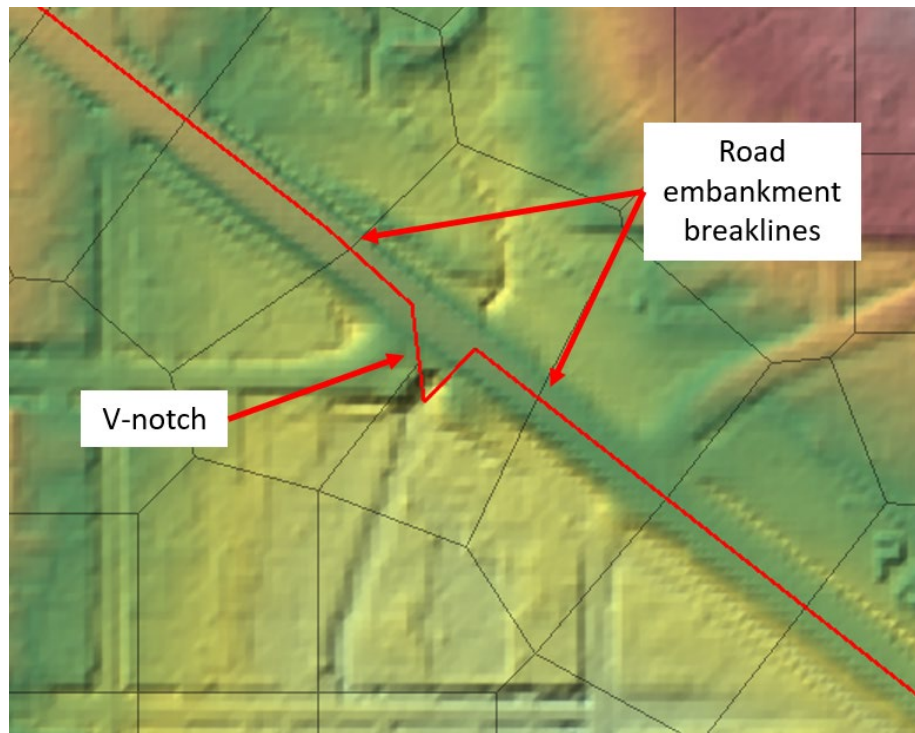


Figure 2.9 : Offset Breakline Approach at Bridge Crossing

### 2.2.4.3 Initial Conditions

Initial conditions were not used in the Caddo Lake 2D BLE model.

### 2.2.5 Special Assumptions

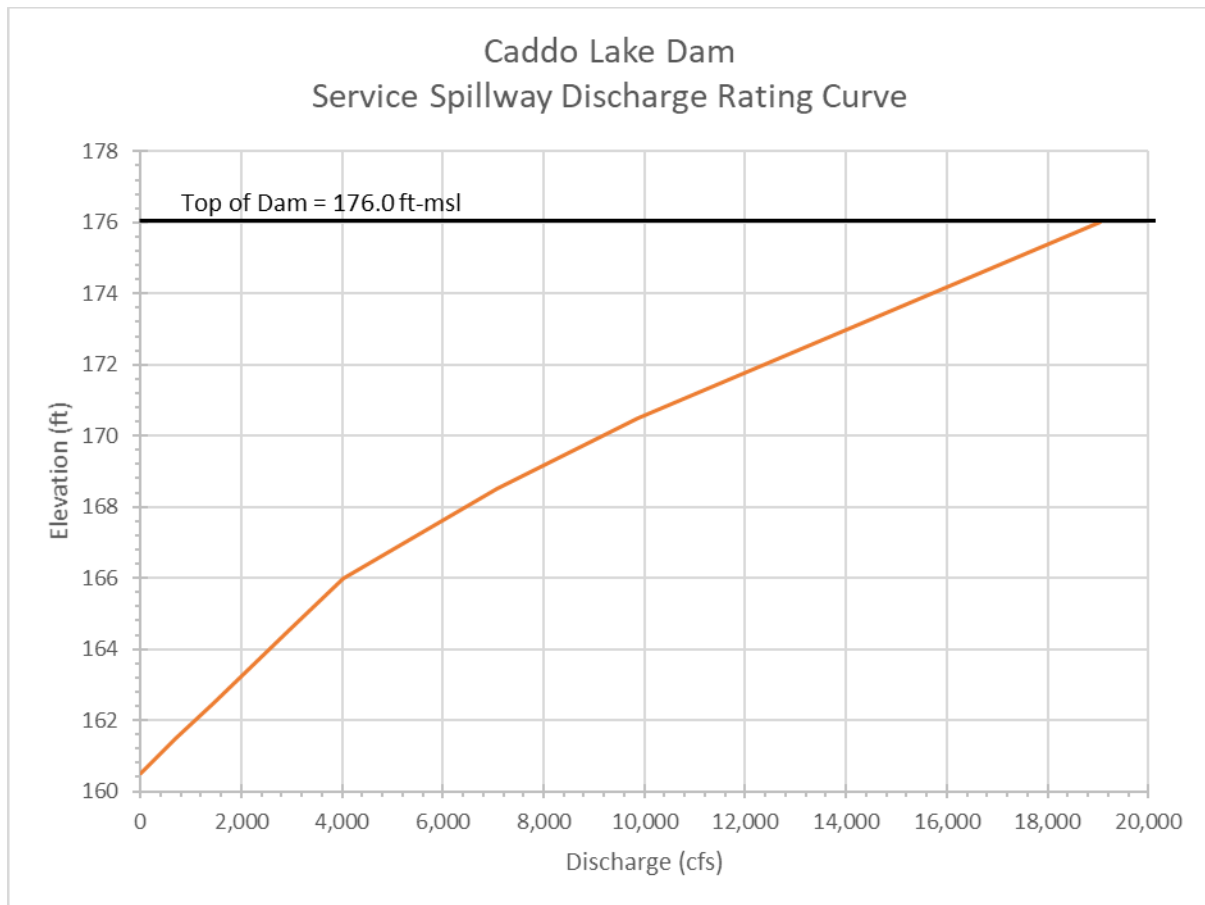
Within the Caddo Lake Watershed is the Caddo Lake Dam. This dam and reservoir provide significant flood protection within the watershed and thus required a more detailed modeling approach than typically used in BLE. Data for the dam was obtained from the TWBD.

Caddo Lake Dam consists of 60-foot-wide service spillway at crest elevation 160.5 ft-msl and a concrete broad-crested emergency spillway with a split crest elevation. The emergency spillway is composed of a central section approximately 1,200 feet long with a crest elevation of 168.5 msl-ft and two adjoining sections with a slightly higher crest elevation of 170.5 msl-ft. The top of dam is at elevation 176.0 ft-msl. To model this structure in HEC-RAS, 2D connector lines were used. The service spillway was modeled using a discharge rating curve developed using the weir equation outside of HEC-RAS. The emergency spillway was modeled using weir equation within HEC-RAS. It was split into three 2D connectors according to the different crest elevations, and each connector had a weir coefficient of 2.8, representative of the broad-crested spillway shape. Table 2.9 provides the summary information for the dam. Figure 2.10 shows the discharge rating curve applied to the service spillway within the model.

Due to limited information and the high-level modeling approached used for BLE, additional information was not acquired for the gate operations of this structure. Future detailed studies in this area may consider coordination with TCEQ and the dam owner to represent the spillway discharges more accurately.

**Table 2.9: Caddo Lake Watershed Dam Summary**

| Dam Name   | ID Number | Source of Information | Owner                                           | County | Outfall Structure Type                                            | Top of Dam Elevation (ft) |
|------------|-----------|-----------------------|-------------------------------------------------|--------|-------------------------------------------------------------------|---------------------------|
| Caddo Lake | LA00181   | TWDB                  | Board of Commissioners,<br>Caddo Levee District | Caddo  | Uncontrolled service spillway and uncontrolled emergency spillway | 176.0                     |



**Figure 2.10: Caddo Lake Dam Service Spillway Discharge Rating Curve**

## 2.3 Model Results

The 2D BLE results for the study produced an SFHA that compared reasonably well with the effective SFHA flood hazard mapping in most cases and provides additional estimated SFHA in areas that do not currently have an SFHA mapped. There were no effective BFEs to compare with the model results. While the results provide context for flood risk communication as part of the Discovery process, and are scalable, the results require further analysis to be used for regulatory purposes. The validity of the 2D BLE results should be verified through community work map meetings before being applied to a regulatory product

### 2.3.1 Calibration & Sensitivity Analysis

Known USGS gages within the model area with more than 10-years of flow record were used for calibration and validation of the 1-percent ACE. Peak flows within the model were compared with Bulletin 17B Analyses and EMA (Bulletin 17C) analyses of the gage data using PeakFQ, Version 7.3. Results of the flow comparisons are presented in Table 2.10.

**Table 2.10: 1% Annual Chance Reasonability Comparisons**

| Flooding Source     | USGS Gage Used for Verification | HEC-RAS 6.1 (2D) |                 | Reference              |                 |
|---------------------|---------------------------------|------------------|-----------------|------------------------|-----------------|
|                     |                                 | WSEL (ft)        | Discharge (cfs) | WSEL (ft) <sup>1</sup> | Discharge (cfs) |
| Big Cypress Bayou   | 07346000                        | 202.82           | 4,882           | 202.29                 | 4,480           |
| Black Cypress Bayou | 07346045                        | 191.59           | 11,662          | 191.11                 | 11,620          |
| Frazier Creek       | 07346140                        | 242.94           | 14,579          | 242.50                 | 14,340          |

<sup>1</sup> Water surface elevation is approximate based on PeakFQ input data and adjusted to NAVD 88 Datum.

To determine which factors were significantly impacting the model results, a sensitivity analysis was run to evaluate the impact of five specific parameters: Manning's roughness values, breaklines, hydrologic losses, initial conditions, and boundary conditions. Further discussion of the roughness coefficients can be found in Section 2.2.4.1. It was determined that enforced breaklines at major roads and centerlines were needed and are discussed further in Section 2.2.4.2. No changes were made to the precipitation. Table 2.11, Table 2.12 and Table 2.13 summarizes the results of each run at each of the USGS gages.

**Table 2.11: Sensitivity Analysis Results at USGS Gage 07346000**

| Iteration | Manning's N Zones                                                                           | Breaklines                                      | Hydrologic Losses    | Initial Conditions/<br>Computational Interval | Boundary Conditions | Peak Flow (cfs) | Peak Elevation (ft) |
|-----------|---------------------------------------------------------------------------------------------|-------------------------------------------------|----------------------|-----------------------------------------------|---------------------|-----------------|---------------------|
| 1         | Land Use with pasture/hay 0.03                                                              | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 585             | 198.59              |
| 2         | Land Use with med developed 0.08, high developed 0.1, woody wetlands 0.08, pasture/hay 0.03 | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 585             | 198.24              |
| 3         | Land Use with shrub/scrub 0.05, woody wetlands 0.08, pasture/hay 0.03                       | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 585             | 198.2               |

| Iteration      | Manning's N Zones                                                      | Breaklines                                      | Hydrologic Losses    | Initial Conditions/<br>Computational Interval | Boundary Conditions | Peak Flow (cfs) | Peak Elevation (ft) |
|----------------|------------------------------------------------------------------------|-------------------------------------------------|----------------------|-----------------------------------------------|---------------------|-----------------|---------------------|
| 4              | Land Use with shrub/scrub 0.05, woody wetlands 0.08, pasture/hay 0.03; | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 7,195           | 204.72              |
| 5 <sup>1</sup> | Land Use values set to minimums                                        | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 4,882           | 202.82              |
|                |                                                                        |                                                 |                      |                                               | Gage Analysis:      | 4,480           | 202.29 <sup>2</sup> |

<sup>1</sup> Parameters from Iteration 5 were used for the final model, however additional computational mesh revisions were implemented following the results of the sensitivity analysis.

<sup>2</sup> Water surface elevation is approximate based on PeakFQ input data.

**Table 2.12: Sensitivity Analysis Results at USGS Gage 07346045**

| Iteration      | Manning's N Zones                                                                           | Breaklines                                      | Hydrologic Losses    | Initial Conditions/<br>Computational Interval | Boundary Conditions | Peak Flow (cfs) | Peak Elevation (ft) |
|----------------|---------------------------------------------------------------------------------------------|-------------------------------------------------|----------------------|-----------------------------------------------|---------------------|-----------------|---------------------|
| 1              | Land Use with pasture/hay 0.03                                                              | None                                            | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 9,069           | 192.24              |
| 2              | Land Use with med developed 0.08, high developed 0.1, woody wetlands 0.08, pasture/hay 0.03 | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 11,321          | 192.3               |
| 3              | Land Use with shrub/scrub 0.05, woody wetlands 0.08, pasture/hay 0.03                       | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 11,418          | 192.31              |
| 4              | Land Use with shrub/scrub 0.05, woody wetlands 0.08, pasture/hay 0.03                       | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 11,424          | 192.43              |
| 5 <sup>1</sup> | Land Use values set to minimums                                                             | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth        | 11,662          | 191.59              |
|                |                                                                                             |                                                 |                      |                                               | Gage Analysis:      | 11,620          | 191.11 <sup>2</sup> |

<sup>1</sup> Parameters from Iteration 5 were used for the final model, however additional computational mesh revisions were implemented following the results of the sensitivity analysis.

<sup>2</sup> Water surface elevation is approximate based on PeakFQ input data.

Table 2.13: Sensitivity Analysis Results at USGS Gage 07346140

| Iteration      | Manning's N Zones                                                                           | Breaklines                                      | Hydrologic Losses    | Initial Conditions/<br>Computational Interval | Boundary Conditions <sup>1</sup> | Peak Flow (cfs) | Peak Elevation (ft) |
|----------------|---------------------------------------------------------------------------------------------|-------------------------------------------------|----------------------|-----------------------------------------------|----------------------------------|-----------------|---------------------|
| 1              | Land Use with pasture/hay 0.03                                                              | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth                     | 13,518          | 244.38              |
| 2              | Land Use with med developed 0.08, high developed 0.1, woody wetlands 0.08, pasture/hay 0.03 | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth                     | 15,079          | 244.20              |
| 3              | Land Use with shrub/scrub 0.05, woody wetlands 0.08, pasture/hay 0.03                       | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth                     | 15,080          | 244.48              |
| 4              | Land Use with shrub/scrub 0.05, woody wetlands 0.08, pasture/hay 0.03                       | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth                     | 15,089          | 244.24              |
| 5 <sup>1</sup> | Land Use values set to minimums                                                             | Major Roads w/Centerlines Enforced - Simplified | Excess Precipitation | Dry / 30 sec                                  | Normal Depth                     | 14,579          | 242.94              |
|                |                                                                                             |                                                 |                      |                                               | Gage Analysis:                   | 14,340          | 242.50 <sup>2</sup> |

<sup>1</sup> Parameters from Iteration 5 were used for the final model.

<sup>2</sup> Water surface elevation is approximate based on PeakFQ input data.

## 2.4 Challenges

Major challenges included a lack of peak streamflow records within the watershed. There were only three gages with significant data to validate. There were no gages on many of the tributaries to help validate flows beyond the mainstem. With limited gage data, the resulting mapping was compared to the FEMA effective mapping to ensure validity of the model. Within the watershed, there are two distinct terrain types: high ground with distinct channels mainly in the northern half of the watershed and low, flat ground at the southern portion of the watershed. The difference in terrain caused the time step used to be a factor in model stability. The two dams modeled in the Caddo Lake Watershed are close in proximity, which also caused a need for a smaller time step to be used. It was determined that a time step (30 second) would be needed to stabilize the model in the lake portion of the watershed, which caused longer model runtimes.

The estimation of the discharge rating curve for the Caddo Lake Dam within Caddo Lake Watershed was another significant challenge. Multiple iterations were performed to stabilize the model and the model validation. Due to limited information on this dam and the high-level modeling approach used for BLE, additional information was not acquired for the gate operations of this structure.

Structures have not been added to the BLE model despite evidence of cross structures which allow the streams to convey water through numerous structures. In these locations, the model may be overestimating the water surface elevation upstream of the road until the road is overtopped and underestimating the water surface elevation downstream of the road.

HEC-RAS, Version 6.1, has an apparent bug that was identified in reviewing isolated areas of flooding. In these areas, the lower frequency events (ex. 10-percent) showed higher water surface elevations than the higher frequency events (ex. 0.2-percent). This was reviewed in multiple versions of HEC-RAS and was confirmed to occur in Version 5.7, 6.1 and 6.2. It is unknown why this may occur; however, the model does not experience instabilities and the mainstem floodplains have not shown this occurring when reviewing profile lines. In review of the model setup, stability and results, the flood extent results appear appropriate and impacts due to the bug are likely negligible.

HEC-RAS, Version 6.1 has a known error in the rain on mesh interpolation of flood depths between adjacent cells in the overbank area. This error produces artificially higher depths of flooding on the flood fringe referred to as cupping. Since this is a known issue in HEC-RAS and HEC is working on a solution, effort to remove these errors from the flood extents was not performed. Figure 2.11 below provides an example of cupping for reference. Once a solution is provided by HEC, it may be possible to update mapping to reduce and/or remove the cupping effects on the fringe of the floodplains.

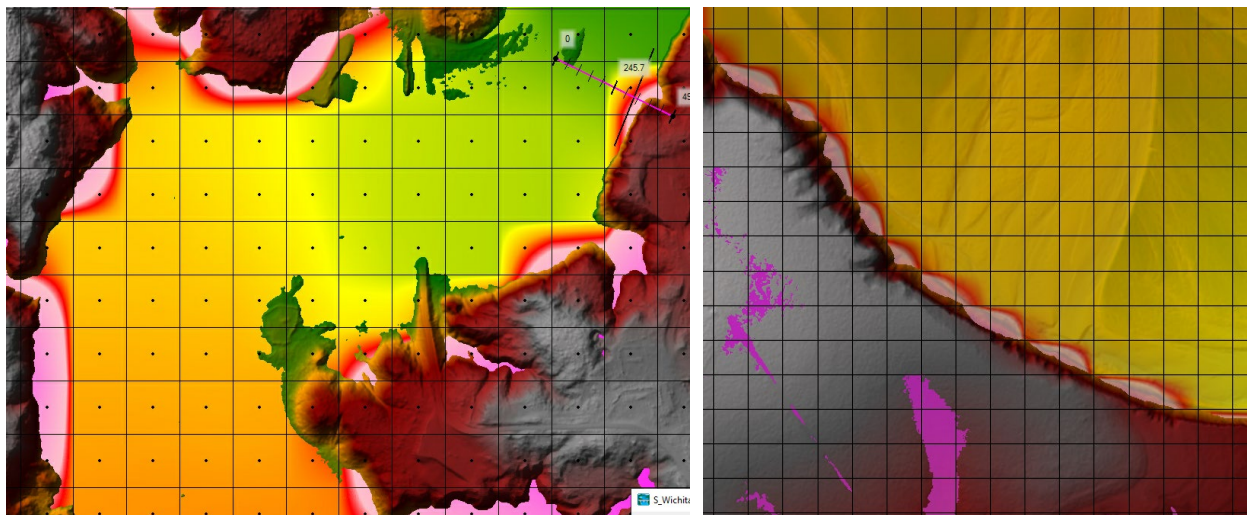


Figure 2.11: Cupping Examples

## 2.5 Recommendations

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

## 03 Floodplain Mapping and Effective Zone A Validation

The following sections provide a synopsis of how raw modeled depths were translated into SFHAs. In addition to developing a new SFHA, the BLE model data was leveraged to validate the effective zone A studies within the project footprint. The results of the validation effort can be found below in Section 3.2.

### 3.1 Special Flood Hazard Area

#### 3.1.1 Model Outputs

The floodplains are derived from the raw modeled depth grids using the maximum value. These depth grids are exported from HEC-RAS as TIFF format rasters with an interpolated rendering that slope values at the center and along the faces/edges of the computational mesh cells. Using GIS, the TIFF rasters are post processed into a 10-percent non-regulatory feature class, 1-percent ACE SFHAs and 0.2-percent shaded X polygons.

#### 3.1.2 Methodology

The use of 2D modeling methods results in water surface elevation values at every cell in the model's computational mesh. In order to represent the desired model results and eliminate extraneous disconnected cells, post processing of the depth grids is required. For the purposes of the Caddo Lake BLE study, floodplain mapping delineation was completed using connected raster cells at the extent of the CNMS mapped and unmapped features in the project footprint. Converting the raster data to polygon features enabled an intersection of modeled results to the CNMS and effective zones to create the SFHA and 0.2-percent shaded X features. Because the new mapping, based on gridded engineering, retains the blocky shape of a raster, a simplification process was applied using GIS to smooth the boundaries using a 10-foot smoothing threshold. These processes remove unnecessary points, bends, and angles while preserving the natural shape of the polygon. Furthermore, small voids, or "holes" inside of the floodplain were aggregated with the larger surrounding polygons to merge them and make the floodplain complete. In alignment with the TWDB's 2D BLE Guidelines (May 2022) floodplain polygons were cleaned against the criteria provided below in Table 3.1 which provides thresholds for mapping removal based on depth and area of flood risk.

**Table 3.1: Mapping Threshold Matrix**

| Area (ac)  | Depth (ft) |
|------------|------------|
| < 0.33     | -          |
| 0.33 - 0.5 | < 0.33     |
| 0.5 - 1.0  | < 0.25     |
| 1.0 - 2.0  | <0.1       |

For example, if flooding polygons were disconnected from a flooding source and less than two acres in area and 0.1 feet of depth, the polygon was removed from the SFHA. These edits align to the mapping standards adopted by the TWDB and those required by FEMA.

In addition to the SFHA, all other flooding associated with the 1- and 0.2-percent raw results were retained as "on the shelf" data that may be leveraged for future needs and analysis. This information is available in the included Supplemental Data associated with this study.

### 3.1.3 Flood Hazard Area Layer

Special Flood Hazard Areas (SFHA), as noted above, were developed to at least the extent of the CNMS features and up to 0.1 square mile drainage area and effective zone A study locations. The Regional CNMS database, National Flood Hazard Layer, and paper inventory were used as reference data to ensure extent of the BLE results represents appropriate current flooding extent coverage, at a minimum.

The 0.2-percent flood areas were produced using the same methods as the 1% SFHA. After both layers were developed, a union of the two products was performed to develop the deliverable format EBF<sub>E</sub>\_FLD\_HAZ\_AR.

### 3.1.4 Mapping Considerations

#### 3.1.4.1 Ponds

Numerous ponds exist throughout the Caddo Lake Watershed. Due to the nature of 2D BLE and the large mesh cells used for modeling, the entire extent of smaller, isolated ponding areas is not always fully mapped in the raw model output. To identify flood risk in these areas, the pond footprints were merged in by automated processes using the best available National Hydrography Dataset. This dataset has its own limitations in that it is not current to current topography or LiDAR and may not align completely to the present-day pond footprints. However, it was used as the best available at the time of the study. A nominal depth of 0.1-foot was used for any areas merged into the floodplain that were not in the raw model results and the water surface elevation was interpolated. The water surface elevations in these areas should not be considered correct and would require further study to refine the correct water surface elevation based on detailed modeling.

#### 3.1.4.2 Mapping Tie-Ins

Watershed tie-ins required manual review and coordination between HUCs to ensure tie-ins could be met within the required 0.5-foot FEMA requirement. For Caddo Lake, a significant tie-in occurs downstream of the Lake O'the Pines watershed, on the downstream side of the Ferrells Bridge Dam at Lake O'the Pines. This portion of the Caddo Lake Watershed was modeled in both the Caddo Lake 2D HEC-RAS model and the Lake O'the Pines 2D model using an overlapping mesh to determine the appropriate tie-in location. The Lake O'the Pines results replaced mapping in a portion of the Caddo Lake HUC. A second significant tie-in occurs at the downstream side of the Caddo Lake Dam. This area downstream of the dam is located in the Cross Bayou Watershed. However, it is modeled as part of the Caddo Lake BLE model using an overlapping mesh to determine the appropriate mapping tie-in location and the mapping is incorporated into the Cross Bayou mapping. A third significant tie-in occurs at the downstream side of the Little Cypress Watershed. This area is also modeled as part of the Caddo Lake BLE model using an overlapping mesh to determine the appropriate mapping tie-in location and the mapping is incorporated into the Little Cypress mapping.

Minor fringe watershed tie-ins to adjacent HUCs were checked to ensure they met the 0.5-foot tie-in requirement. Mapping changes to the floodplain extents and grids were not made to the minor fringe tie-ins if within the 0.5-foot mapping tolerance.

#### 3.1.4.3 Centerline Alignment

After completion of the FLD\_HAZ\_AR, the S\_WTR\_LNs (centerlines) were reviewed for containment within the 1-percent ACE floodplain. Any centerlines that were 50-feet or greater in length outside of the 1-percent floodplain extent were realigned for containment.

### 3.2 Validation of Effective Zone A SFHA

The following summarizes the results of the CNMS validation assessments for the effective Zone A studies in the Caddo Lake Watershed.

#### 3.2.1 Initial Assessment A1 – Significant Topography Update Check

The significant topography update check determines whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. If the effective studies were based on topographic data derived from LiDAR then A1 is set to PASS. If the effective studies were not based on LiDAR then A1 is set to FAIL. If the topographic data source was not provided, then an assumption of studies with effective dates prior to 2000 were assumed to be non-LiDAR based studies and studies completed after 2000 were assumed to have used LiDAR.

#### 3.2.2 Initial Assessment A2 – Check for Significant Hydrology Changes

The significant hydrology changes check determines whether new regression equations have become available from the USGS since the date of the effective Zone A study. If newer regression equations exist for the area of interest, then an engineer must determine whether these regression equations would significantly affect the 1-percent ACE flow. New regression equations were made available for Texas in 2009. Thus, effective studies completed prior to 2009 are assumed to FAIL the A2 assessment while studies completed after 2009 are assumed to PASS the A2 assessment. If already attributed as PASS in the CNMS database, then A2 classification was maintained as such.

#### 3.2.3 Initial Assessment A3 – Check for Significant Development

The significant development check, using the National Urban Change Indicator (NUCI) dataset, assesses increased urbanization in the study watershed. If the percentage of urban area within a HUC-12 watershed containing the effective Zone A study is 15 percent or more and has increased by 50 percent or more since the effective analysis, the study would fail this check. The check for significant development in the Caddo Lake Watershed was completed by evaluating percentage of urban change at the HUC-12 level. The entire watershed is classified as rural, and all reaches were set to PASS for this assessment.

Table 3.2 presents the summarized results of checks A1 through A3.

**Table 3.2: A1-A3 Validation Results**

| Assessment Checks | Pass / Fail | Notes                                                                                              |
|-------------------|-------------|----------------------------------------------------------------------------------------------------|
| A1 – Topography   | Pass/Fail   | LiDAR significantly better than effective USGS topo source/Effective mapping leveraged LiDAR data. |
| A2 – Hydrology    | Pass/Fail   | Effective hydrology methods are unknown                                                            |
| A3- Development   | Pass/Fail   | Less than 15% of study area is under urban cover/>50% increase in urban area in an urban HUC-12    |

#### 3.2.4 Validation Check A4 – Check of Studies Backed by Technical Data

Zone A studies that pass all initial assessment checks described above may be categorized as “Valid” in the CNMS Inventory only if the effective Zone A study is supported by modeling or sound engineering judgment and all regulatory products are in agreement. If the effective Zone A study passes all initial assessment checks, but is not supported by modeling, or if the original engineering method used is unsupported or undocumented, a comparison of the BLE results and effective Zone A’s is performed.

If the effective study was model backed, then A4 is set to PASS. If the effective study was not model backed, then A4 is set to FAIL. If it was unknown if the study was model backed or not, then it was assumed it was not model backed and the A4 assessment was set to FAIL.

Due to lack of documentation of the original engineering methods in the Caddo Lake Watershed, check A4 has been marked as FAIL for most parts of this study and left as PASS if it was already identified as such in previous CNMS.

### 3.2.5 Validation Check A5 – Comparison of BLE and Effective Zone A

The effective Zone A comparison was performed at the full extent of the Caddo Lake Watershed. The validation of the effective Zone A boundaries using 2D flood hazard products differ from the standard 1D methods due to the lack of cross sections and their use with standard FBS methodology. For this 2D study, the effective A zone boundaries were compiled using the National Flood Hazard Layer and Core Logic effective digital uplift product. These data were dissolved to one continuous A-zone layer, which then had test points placed along its perimeter at least every 200 feet.

For each test point, a 75-foot buffer polygon was created. Using this buffer, the minimum and maximum values of the DEM were extracted, as a proxy for the effective base flood elevation. The minimum value of the 1% minus raster, and the maximum value of the 1% plus raster are also extracted. These 1% plus maximum and 1% minus minimum values are products of the new 2D BLE study and act as the vertical tolerance. The test point passes if the DEM maximum value is less than or equal to the 1% plus maximum value and the DEM minimum value is greater than or equal to the 1% minus minimum value. This can be visualized as a short 75-foot radius cylinder, with a height of 1% plus maximum – 1% minus minimum. This test verifies that at least one point from the ground surface (i.e. proxy BFE) falls both vertically and horizontally within this range.

### 3.2.6 Validation Results

All 822.1 total miles of available CNMS features representing the effective Zone A studies were categorized as shown in Table 3.3 and illustrated in Figure 3.1. Table 3.4 summarizes the validation results based on the individual HUC 12 watersheds within Caddo Lake Watershed.

Table 3.3: Aggregated Zone A Validation Results

| Validation Status | Status Type   | Total Miles |
|-------------------|---------------|-------------|
| VALID             | BEING STUDIED | 198.0       |
| UNVERIFIED        | BEING STUDIED | 624.1       |

Table 3.4: HUC 12 Zone A Validation Results

| HUC-12 Watershed                        |                  | Total FBS points | Fail | Pass  | %Pass | BLE Comparison Pass? (>85%) |
|-----------------------------------------|------------------|------------------|------|-------|-------|-----------------------------|
| Watershed Name                          | Watershed Number |                  |      |       |       |                             |
| Maddox Branch-Big Cypress Bayou         | 111403060102     | 366              | 116  | 250   | 68.3  | FAIL                        |
| Watson Creek-Kelly Creek                | 111403060201     | 2,330            | 415  | 1,915 | 82.2  | FAIL                        |
| Bear Creek-Kelly Creek                  | 111403060202     | 1,790            | 475  | 1,315 | 73.5  | FAIL                        |
| Kelly Creek-Black Cypress Creek         | 111403060203     | 2,068            | 613  | 1,455 | 70.4  | FAIL                        |
| Mill Creek-Flat Creek                   | 111403060204     | 2,673            | 610  | 2,063 | 77.2  | FAIL                        |
| Flat Creek-Black Cypress Creek          | 111403060205     | 2,162            | 548  | 1,614 | 74.7  | FAIL                        |
| Cawhorn Creek-Hughes Creek              | 111403060206     | 2,751            | 545  | 2,206 | 80.2  | FAIL                        |
| Black Cypress Creek-Black Cypress Bayou | 111403060207     | 2,533            | 556  | 1,977 | 78.0  | FAIL                        |
| Scotts Creek-Black Cypress Bayou        | 111403060208     | 110              | 18   | 92    | 83.6  | FAIL                        |
| Henderson Creek-Frazier Creek           | 111403060301     | 2,489            | 725  | 1,764 | 70.9  | FAIL                        |
| Colley Creek                            | 111403060302     | 778              | 226  | 552   | 71.0  | FAIL                        |
| Bee Creek-Johns Creek                   | 111403060303     | 2,121            | 733  | 1,388 | 65.4  | FAIL                        |
| Leek Creek-Frazier Creek                | 111403060304     | 2,613            | 473  | 2,140 | 81.9  | FAIL                        |
| Cole Creek-Frazier Creek                | 111403060305     | 1,582            | 276  | 1,306 | 82.6  | FAIL                        |
| Wilburn Creek-Jim Bayou                 | 111403060306     | 2,768            | 812  | 1,956 | 70.7  | FAIL                        |
| Bear Creek-Jim Bayou                    | 111403060307     | 1,075            | 237  | 838   | 78.0  | FAIL                        |
| Hunts Creek-James Bayou                 | 111403060308     | 764              | 96   | 668   | 87.4  | PASS                        |
| Deboldin Creek                          | 111403060401     | 2,013            | 377  | 1,636 | 81.3  | FAIL                        |
| Karnack Creek-Haggerty Creek            | 111403060402     | 1,441            | 291  | 1,150 | 79.8  | FAIL                        |
| Beckum Creek-Big Cypress Bayou          | 111403060403     | 1,726            | 666  | 1,060 | 61.4  | FAIL                        |
| Carter Lake-Big Cypress Bayou           | 111403060404     | 329              | 182  | 147   | 44.7  | FAIL                        |
| Harrison Bayou                          | 111403060406     | 2,869            | 596  | 2,273 | 79.2  | FAIL                        |
| Kitchen Creek-Frontal Caddo Lake        | 111403060407     | 1,048            | 410  | 638   | 60.9  | FAIL                        |

| HUC-12 Watershed                |                  | Total FBS points | Fail | Pass  | %Pass | BLE Comparison Pass? (>85%) |
|---------------------------------|------------------|------------------|------|-------|-------|-----------------------------|
| Watershed Name                  | Watershed Number |                  |      |       |       |                             |
| Watson Bayou-Frontal Caddo Lake | 111403060408     | 2,386            | 389  | 1,997 | 83.7  | FAIL                        |
| Harold Creek-Frontal Caddo Lake | 111403060409     | 1,686            | 122  | 1,564 | 92.8  | PASS                        |
| Tiger Branch-Frontal Caddo Lake | 111403060410     | 884              | 10   | 874   | 98.9  | PASS                        |
| Tete Bayou-Frontal Caddo Lake   | 111403060411     | 1,400            | 74   | 1,326 | 94.7  | PASS                        |

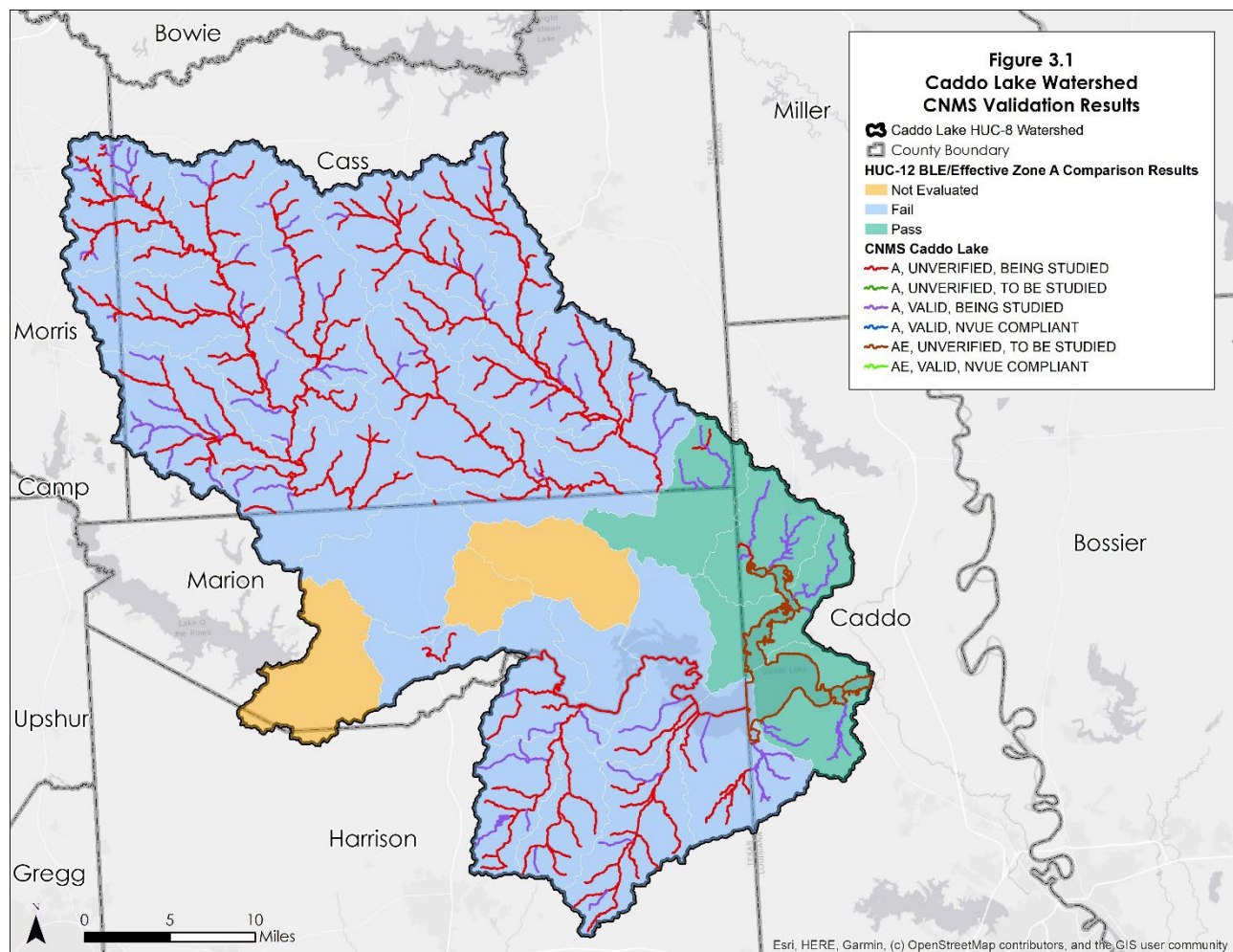


Figure 3.1: Caddo Lake Watershed CNMS Validation Results

### 3.3 Flood Risk Analysis

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

Hazus Version 5.1 (SP02) was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus Version 5.1 (SP02) uses dasymetric census blocks. Dasymetric mapping removes undeveloped areas (such as areas covered by bodies of water, wetlands, or forests) from the census blocks, changing their shape and reducing their size in these areas. For more information on dasymetric data visit FEMA's Media Library for the Hazus-MH Data Inventories: Dasymetric vs. Homogenous, or Hazus 3.0 Dasymetric Data Overview.

Hazus analysis was performed by county within the project watershed extents for the 1-percent return period to ensure proper model processing. A summary of results per county for the 1-percent ACE scenario is shown in Table 3.5.

**Table 3.5: Hazus 5.1 (SP02) Results for 1-percent-annual-chance (100 year) scenario for Caddo Lake Watershed, Texas**

| County       | Full Replacement – Total Loss | Dollar Exposure (Replacement Value) - Buildings | Dollar Exposure (Replacement Value) - Contents |
|--------------|-------------------------------|-------------------------------------------------|------------------------------------------------|
| Caddo        | \$22,011,000.00               | \$6,467,000.00                                  | \$4,740,000.00                                 |
| Cass         | \$65,536,000.00               | \$14,672,000.00                                 | \$13,424,000.00                                |
| Harrison     | \$84,422,000.00               | \$37,945,000.00                                 | \$22,779,000.00                                |
| Marion       | \$70,341,000.00               | \$11,937,000.00                                 | \$14,777,000.00                                |
| Morris       | \$6,592,000.00                | \$1,470,000.00                                  | \$1,022,000.00                                 |
| <b>Total</b> | <b>\$248,902,000.00</b>       | <b>\$72,491,000.00</b>                          | <b>\$56,742,000.00</b>                         |

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