Lower Sulphur 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. 11140302 – Lower Sulphur 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 National Oceanic and Atmospheric Administration (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 risk. Communities may use this information to make informed decisions on their planning and flood mitigation efforts. Table ES-1.1 lists the stream miles associated with this validation analysis.

Table ES-1.1: Summary of Stream Miles

Source	Lower Sulphur Stream Miles
CNMS	5,150

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	183.2
Unverified	Being Studied	1,208.3

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 Lower Sulphur 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 Lamar, Red River, Bowie, Delta, Hopkins, Franklin, Titus, Morris, Cass, Miller, and Lafayette Counties, and include the following communities: The Cities of Atlanta, Avery, Clarksville, Deport, Domino, Maud, Naples, Nash, New Boston, Paris, Queen City, Redwater, Reno, Talco, Texarkana, and Wake Village, the Towns of Annona, Bloomburg, Blossom, Bogata, DeKalb, Detroit, Douglassville, Red Lick, and Sun Valley, and the Communities of Pattonville and Simms. The study area consists of seven HUC-10 basins: River Crest Lake – Sulphur River, Cuthand Creek – Sulphur River, Long Lake Slough – Sulphur River, Anderson Creek, Bassett Creek – Sulphur River, Wright Patman Lake – Sulphur River, and Outlet Sulphur River. Figure 1.1 shows the orientation of the Lower Sulphur HUC-8 basin with respect to the counties.

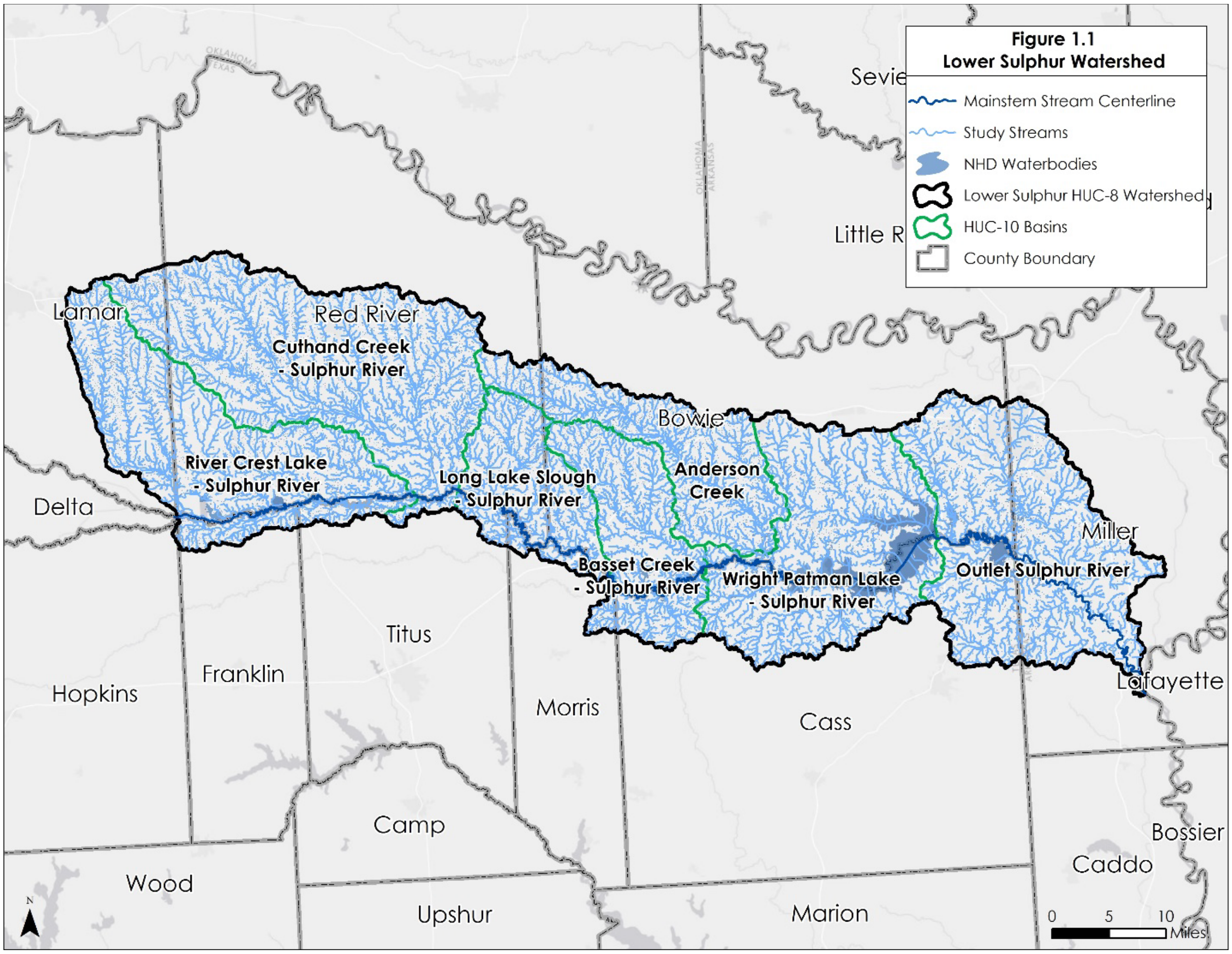

Figure 1.1: Lower Sulphur Watershed

02 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2D hydraulic engineering analysis for the Lower Sulphur 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. The large size of the Lower Sulphur Watershed (1,824 square miles) produced prohibitively long computation runtimes. Therefore, in the 2D HEC-RAS model, the HUC-8 basin was divided into three regions—Lower Sulphur West, Lower Sulphur East (TX), and Lower Sulphur East (AR). This is discussed further in Section 2.2.

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 Lower Sulphur 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 Lower Sulphur 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 Lower Sulphur Watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Lower Sulphur BLE project footprint. Figure 2.1 depicts the datasets identified for leveraged across the project area. FEMA, NOAA, USGS, and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

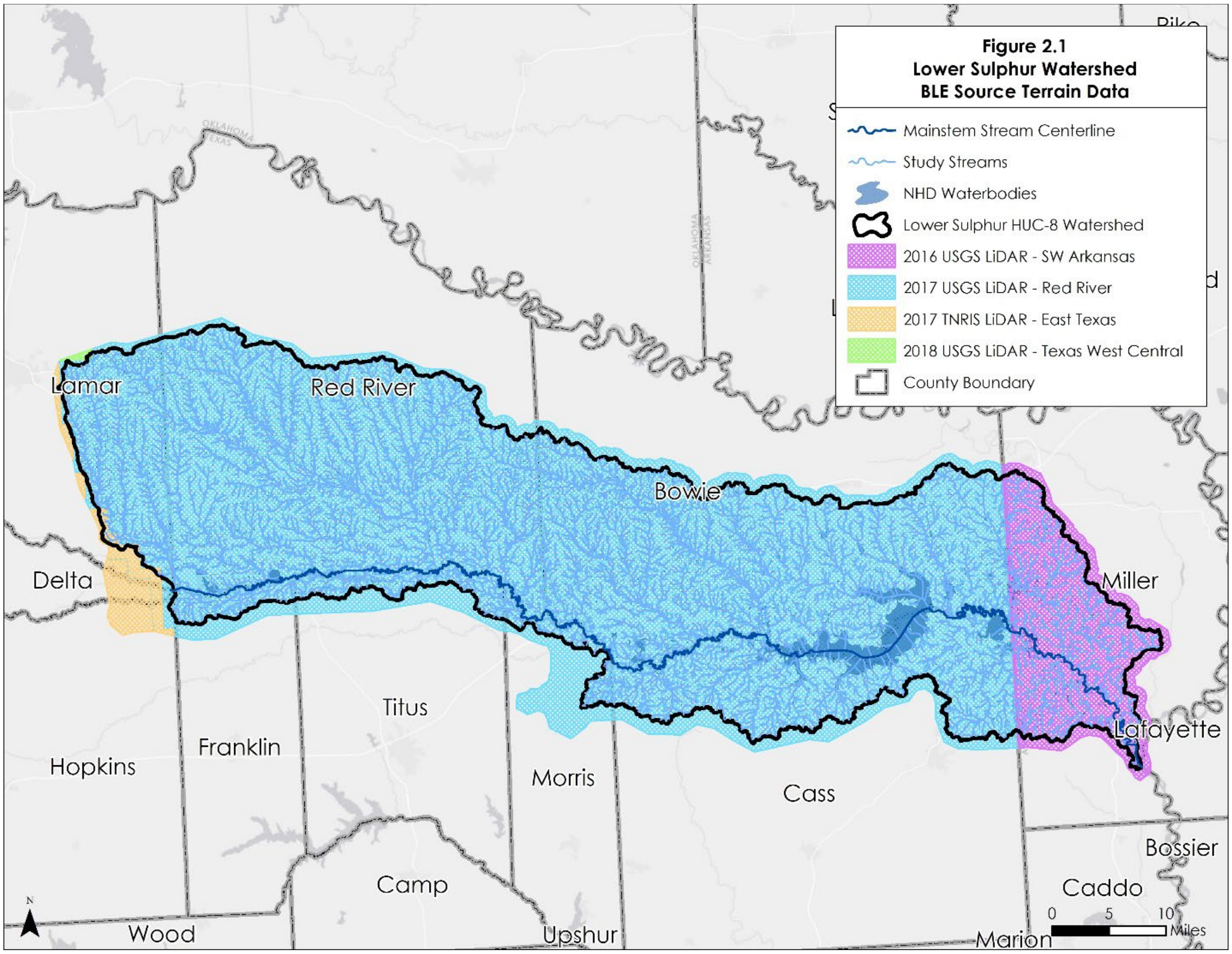

Figure 2.1: Lower Sulphur Watershed BLE Source Terrain Data

2.1.2 Evaluation

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

- Data meet FEMA vertical accuracy standards (Table 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 Lower Sulphur 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 Lower Sulphur Watershed

Year	Description	Data Type	RMSE	Source/Owner
2017	Red River Lidar 2017	Airborne LiDAR	< 10cm NVA	USGS
2017	East Texas Lidar 2017	Airborne LiDAR	10.9cm NVA	TNRIS
2016	SW Arkansas Lidar 2016	Airborne LiDAR	6-19 cm NVA	USGS

2.1.2.1 Lower Sulphur Watershed Source Terrain Data

The source elevation data for the Lower Sulphur Watershed are DEMs derived from USGS and TNRIS LiDAR data. Preprocessed bare-earth hydro-enforced DEMs from the acquiring entity (via TNRIS and USGS) were projected and adjusted as needed into one seamless DEM. Bare-earth LIDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the processed LiDAR returns with hydro-lines and other LiDAR derived break lines enforced. Figure 2.1 depicts the extent of the data defined in Table 2.2. Please see brief descriptions of each LiDAR source is provided below. For more detailed information, the LiDAR project report for each dataset is included in the Terrain submittal.

<u>2016 USGS Ouachita Arkansas LiDAR</u>– The 2016 USGS Ouachita Arkansas LiDAR was acquired from January 2016 through March 2016 with some reflights in April 2017. The measured RMSE was documented as less than 19 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) x 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.

<u>2017 TNRIS Red River LiDAR</u>– 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) x 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.

2017 TNRIS East Texas LiDAR– The 2017 East Texas LiDAR was acquired from December 2016 through February 2017 with limited reflights in April 2017. The measured RMSE was documented as less than 10cm 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) x 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 Lower Sulphur Watershed and contributing drainage areas for the Lower Sulphur BLE modeling efforts. The topographic data for Lower Sulphur Watershed was projected horizontally, as needed, to North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS) Texas N Central in feet (4202-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 Lower Sulphur Watershed BLE analysis were developed using a controlled process, evaluated, and assured by a topographic data development team and were evaluated and assured by the engineering team to meet the quality standards of the project. 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

The quality control after the development process by the topographic data 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 computations.

There were significant differences in the bare earth DEM elevations between Texas and Arkansas. Differences in the elevations can be attributed to the LiDAR being flown during drought or flood events.

This area should be reviewed for future refinement when new LiDAR data is available. Figure 2.2 shows the discrepancies in the terrain at the state boundary.

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

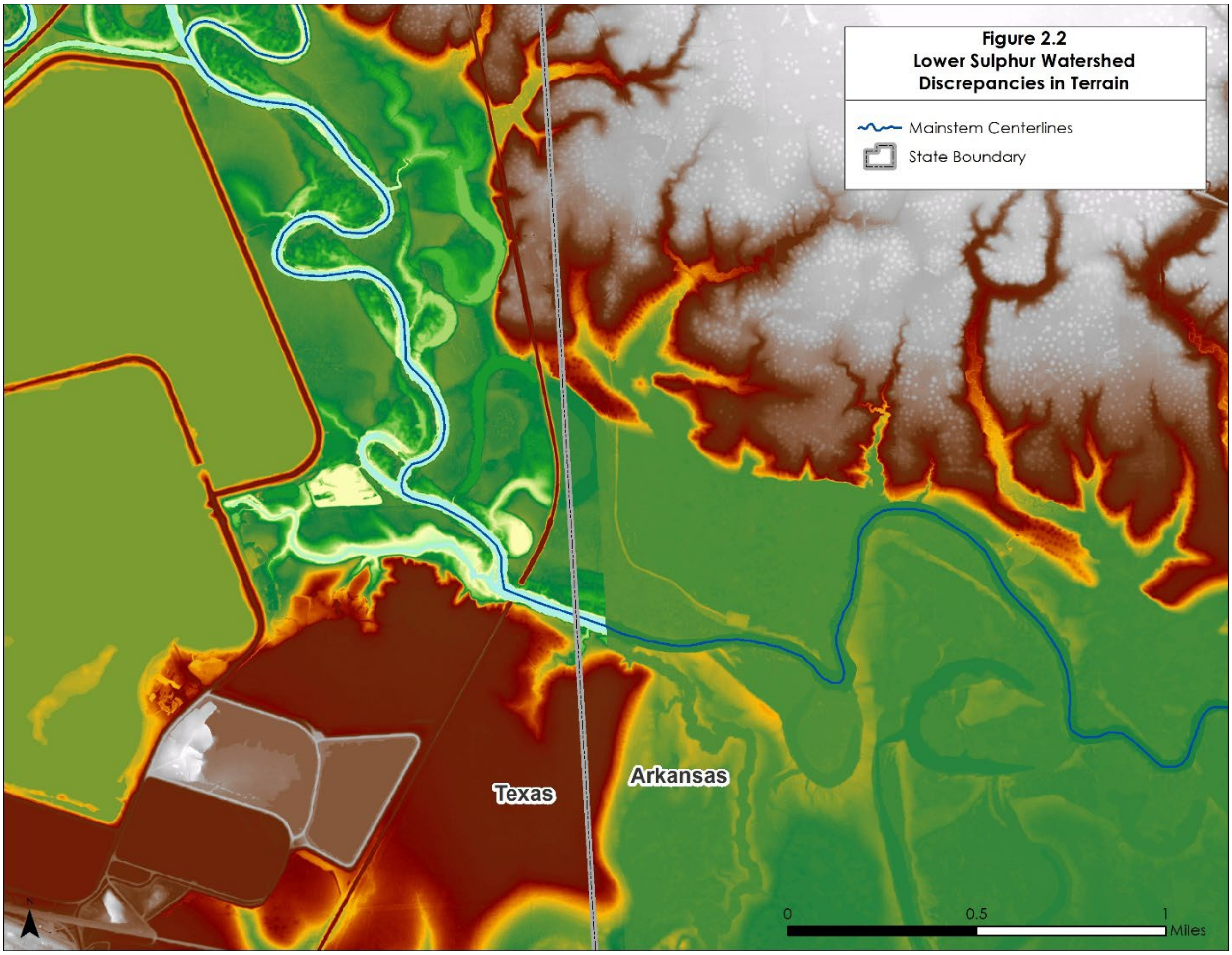

Figure 2.2 : Lower Sulphur Watershed Discrepancies in Terrain

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. As mentioned previously, the Lower Sulphur watershed was divided into three separate models: Lower Sulphur West, Lower Sulphur East (TX), and Lower Sulphur East (AR). This was to facilitate more reasonable model runtimes and address a terrain discrepancy between East Texas and Arkansas. Additionally, the upstream portion of Lower Sulphur West was added to Sulphur Headwaters model to more appropriately model the interactions of the two watersheds and the levee system in the area. The non-accredited levee system follows along the left and right bank of the Sulphur River. Splitting the watersheds along the HUC boundary also caused a split of the levee system which inaccurately represented the flow patterns which would occur in this area. The mesh was adjusted such that the full levee system was modeled within the Sulphur Headwaters model. Figure 2.3 shows the modeling mesh between Sulphur Headwaters and Lower Sulphur with respect to the levee system.

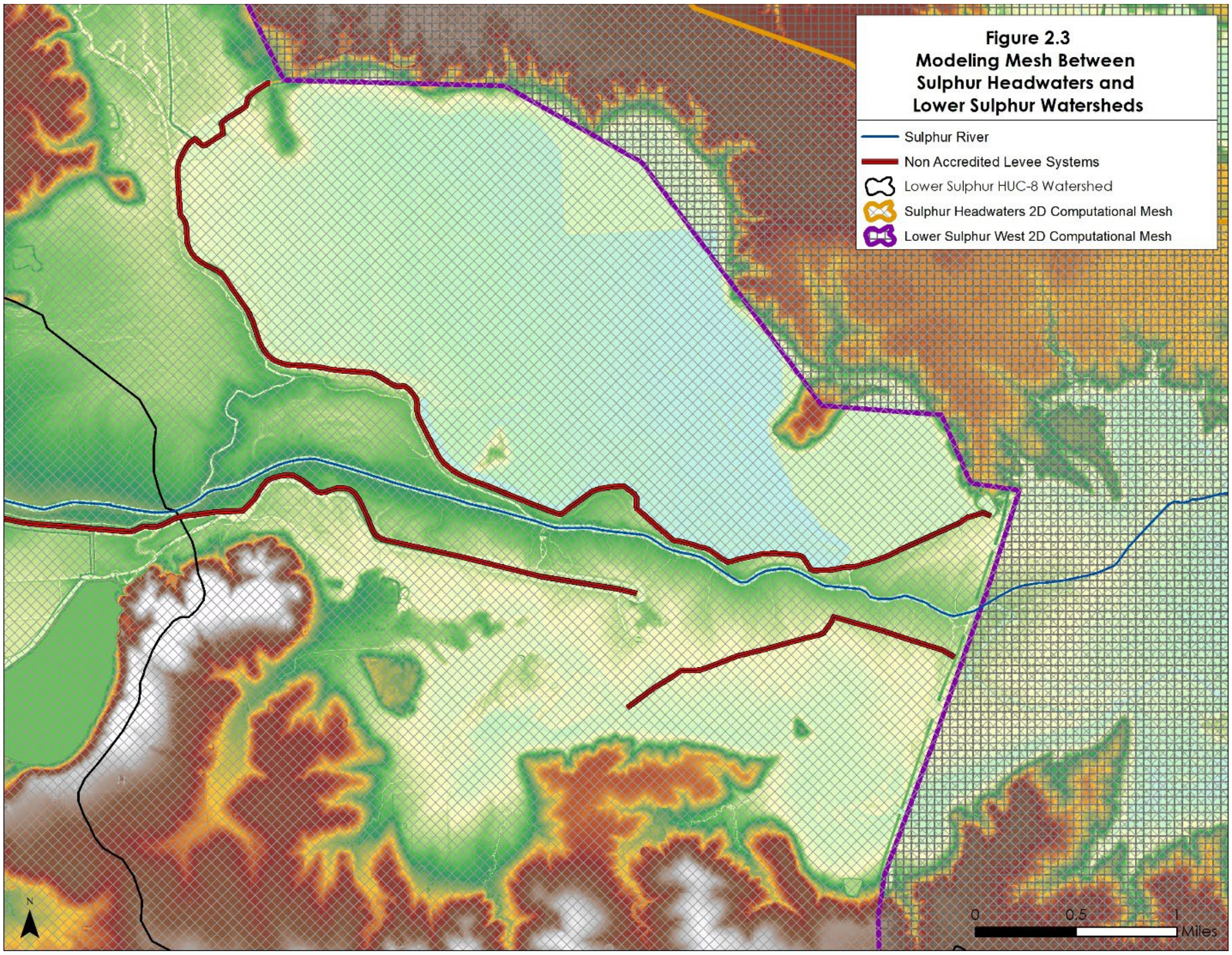

Figure 2.3: Modeling Mesh Between Sulphur Headwaters and Lower Sulphur Watersheds

The original 2D mesh for the three HEC-RAS models was established as evenly spaced cells at 200 feet. A refinement region was added in the Lower Sulphur East Texas model specifically for a portion of the Wright Patman Reservoir which increased the cell mesh size to 600 feet. This cell mesh refinement was due to velocity surcharges closer to the dam. The larger cell size provided more appropriate velocities and stable water surface elevations through the reservoir. The mesh was further refined by placing breaklines along roads, berms, ridges, and other high ground that can impede the flow as well as stream centerlines to allow flow conveyance. To ensure the entire Lower Sulphur Watershed, including adjacent inflows, was represented accurately, 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 due to the 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 Lower Sulphur 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 for the three models consists of 639,205 cells in the Lower Sulphur West model, 752,519 cells in the Lower Sulphur East (TX) model, and 147,290 cells in the Lower Sulphur East (AR) model, with a 200-foot nominal mesh cell size. There are factors that could result in either larger or smaller cell sizes included:

- 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 three HEC-RAS models, 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 Lower Sulphur Watershed, inflow hydrographs from Sulphur Headwaters and White Oak Bayou were used, along with excess precipitation applied to the mesh. Figure 2.4 shows the 2D computational mesh for the Lower Sulphur Watershed, along with USGS peak streamflow gages pertinent to the study area. Figure 2.5 shows the inflow boundary condition location for the Sulphur Headwaters into the Lower Sulphur West model. Figure 2.6 shows the inflow boundary condition locations for the Sulphur West and White Oak Bayou basins into the Lower Sulphur East model. Figure 2.7 shows the inflow boundary condition locations for the Lower Sulphur East Texas model into the Lower Sulphur East Arkansas model. 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.

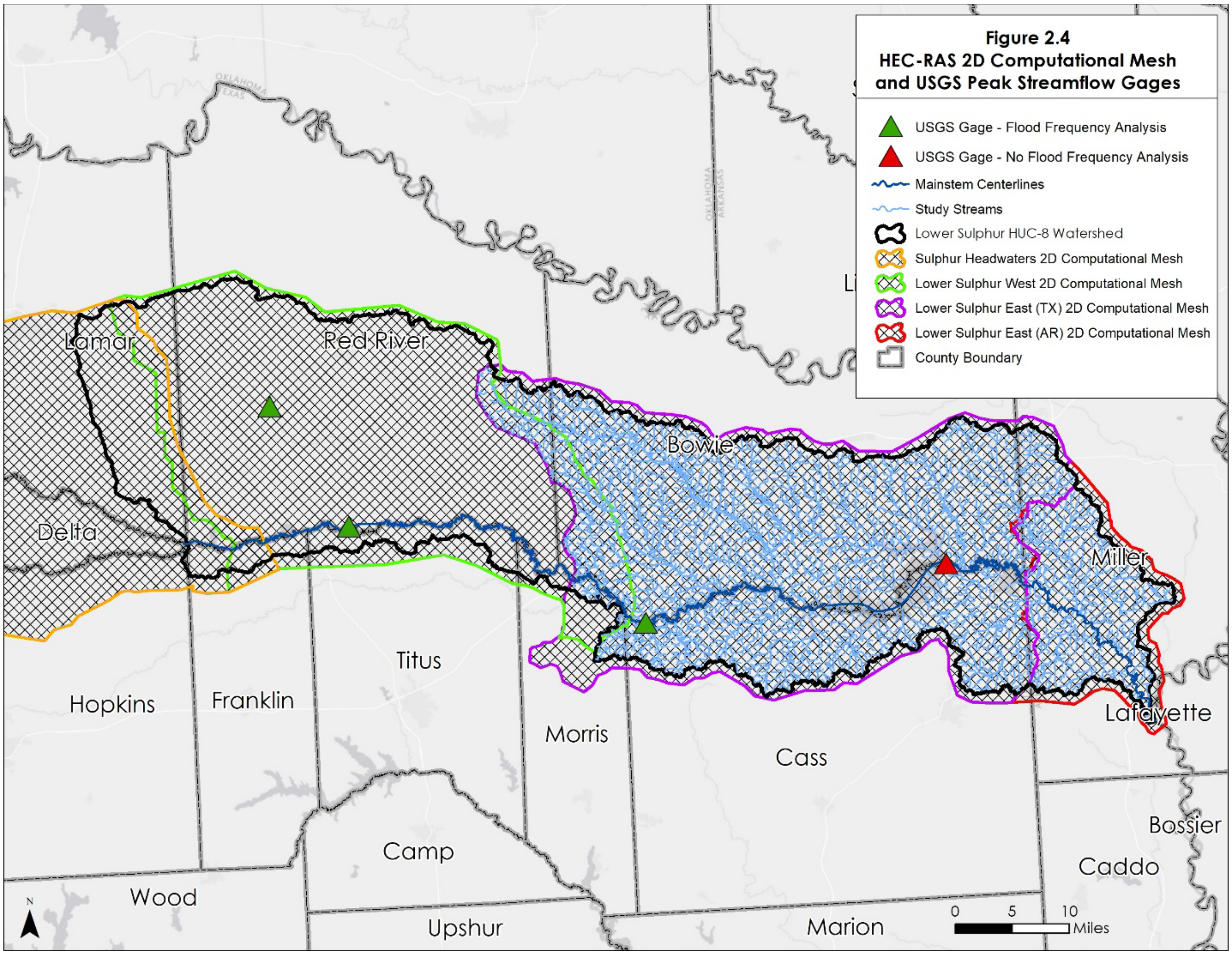

Figure 2.4: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages

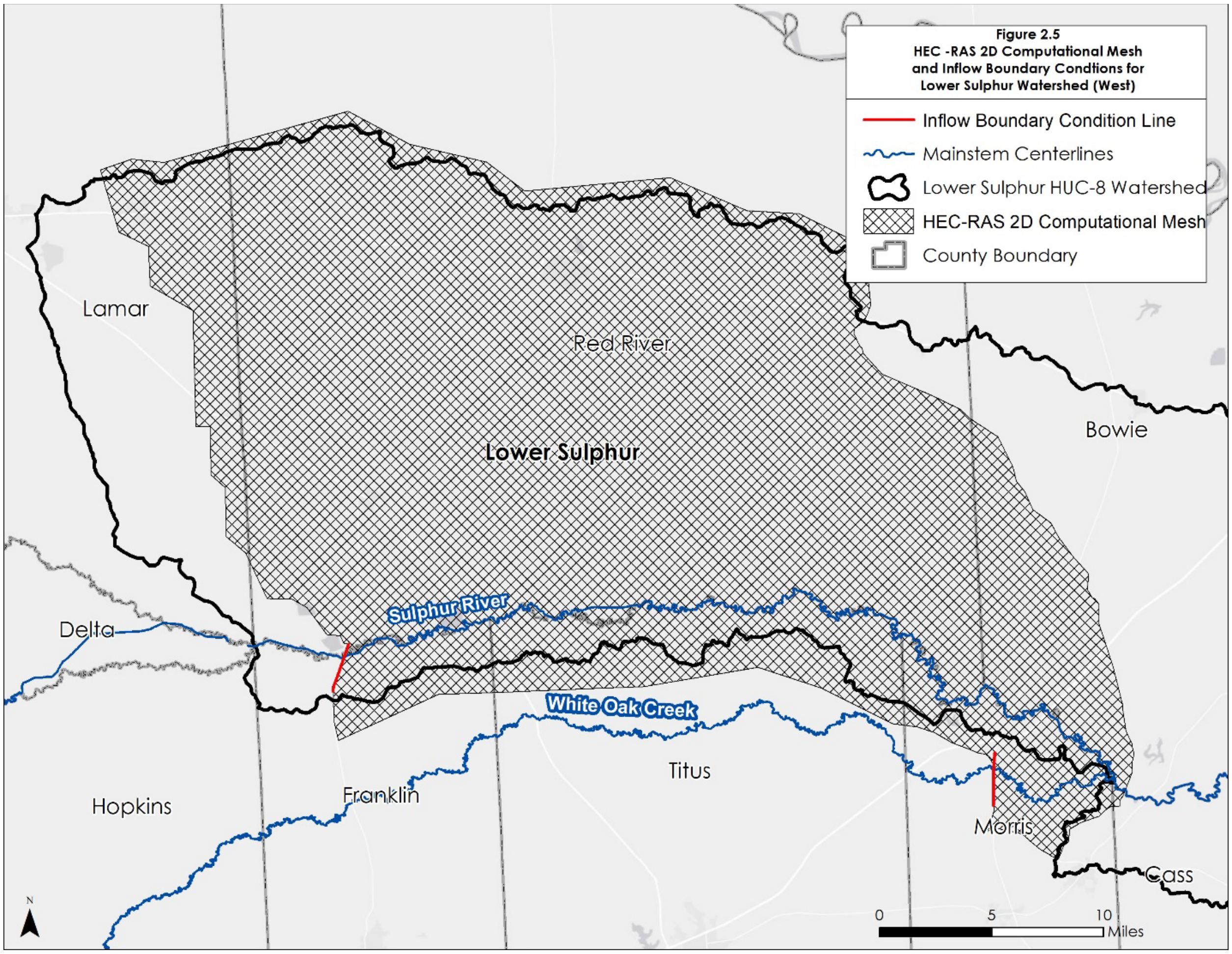

Figure 2.5: HEC-RAS 2D Computational Mesh and Inflow Boundary Conditions for Lower Sulphur Watershed (West)

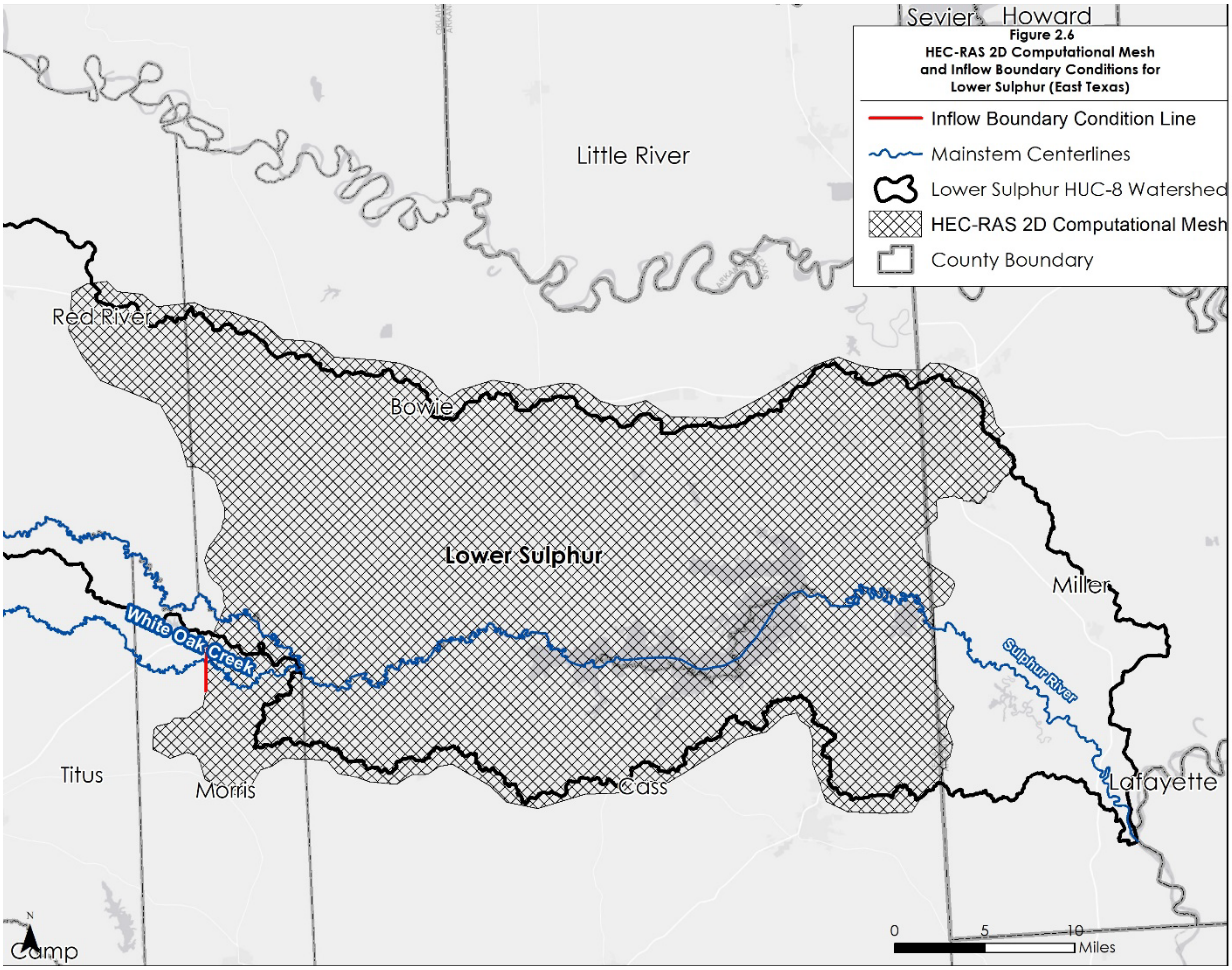

Figure 2.6: HEC-RAS 2D Computational Mesh and Inflow Boundary Conditions for Lower Sulphur (East Texas)

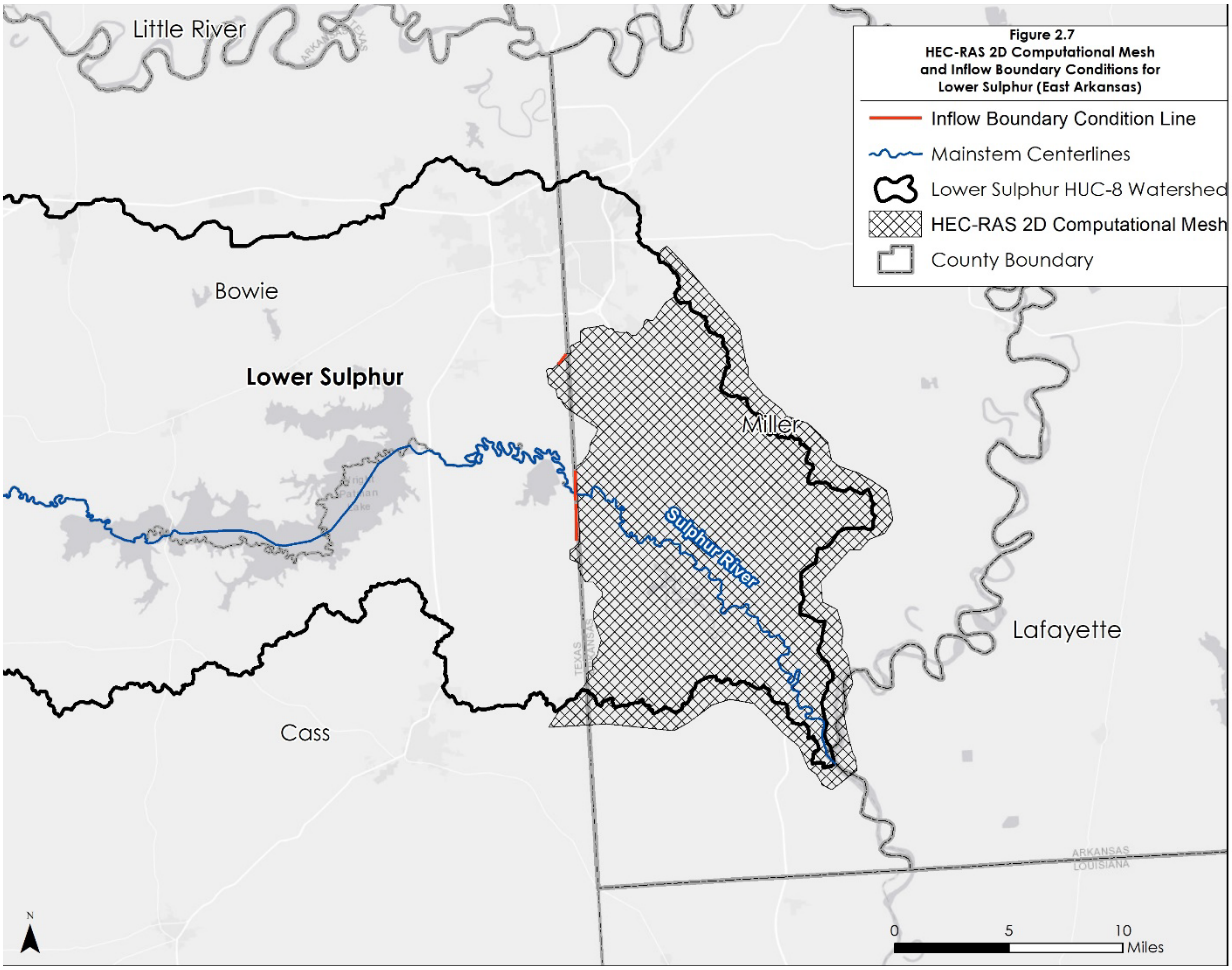

Figure 2.7: HEC-RAS 2D Computational Mesh and Inflow Boundary Conditions for Lower Sulphur (East Arkansas)

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. Due to the large size of the Lower Sulphur Watershed, the HUC-8 area was divided into two HEC-HMS models—Lower Sulphur West, and Lower Sulphur East (applied to both the Lower Sulphur East (TX) and Lower Sulphur East (AR) hydraulic models). 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). 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. Inflow hydrographs from Sulphur Headwaters and White Oak Bayou were used as described in Section 2.2.3.2.

A total of four (4) USGS gages are found within Lower Sulphur Watershed. No peak flow record data was found for the USGS Gage No. 07344200 – Wright Patman Lake near Texarkana, TX and was excluded from the analysis. The other three (3) USGS gages including: 07343200 – Sulphur Rv nr Talco, TX, 0734330 – Cuthand Ck nr Bogata, TX, and 07344000 – Sulphur Rv nr Darden, 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^2)	Period of Record
07343200	Sulphur Rv nr Talco, TX	1,365	1996-2020
07343300	Cuthand Ck nr Bogata, TX	69	1964-1974
07344000	Sulphur Rv nr Darden, TX	2,774	1910-1954

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)
07343200	Sulphur Rv nr Talco, TX	55,220	47,990	63,160
07343300	Cuthand Ck nr Bogata, TX	14,480	11,190	21,430
07344000	Sulphur Rv nr Darden, TX	98,650	85,490	119,400

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 +/- 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)
Lower Sulphur West	72	1,042
Lower Sulphur East	70	1,131

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, 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 depths 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
Lower Sulphur West	10yr	0.69	1.38	2.50	3.17	3.59	4.35	5.20	6.13
	25yr	0.81	1.61	2.93	3.73	4.24	5.17	6.19	7.31
	50yr	0.90	1.79	3.26	4.16	4.75	5.81	6.96	8.23
	100yr	0.99	1.97	3.59	4.61	5.27	6.46	7.76	9.18
	100yr minus	0.78	1.54	2.82	3.65	4.20	5.21	6.32	7.55
	100yr plus	1.20	2.39	4.36	5.56	6.33	7.72	9.21	10.81
	500yr	1.19	2.36	4.36	5.68	6.55	8.13	9.80	11.60
Lower Sulphur East	10yr	0.69	1.35	2.52	3.18	3.61	4.38	5.22	6.15
	25yr	0.80	1.57	2.93	3.74	4.27	5.22	6.26	7.39
	50yr	0.89	1.73	3.25	4.17	4.79	5.89	7.08	8.38
	100yr	0.97	1.89	3.56	4.61	5.32	6.59	7.95	9.43
	100yr minus	0.76	1.49	2.80	3.66	4.24	5.29	6.44	7.69
	100yr plus	1.18	2.30	4.31	5.56	6.40	7.89	9.47	11.16
	500yr	1.17	2.26	4.32	5.70	6.66	8.38	10.20	12.15

Figures 2.8 and 2.9 show the excess precipitation hyetographs applied to the 2D computational mesh.

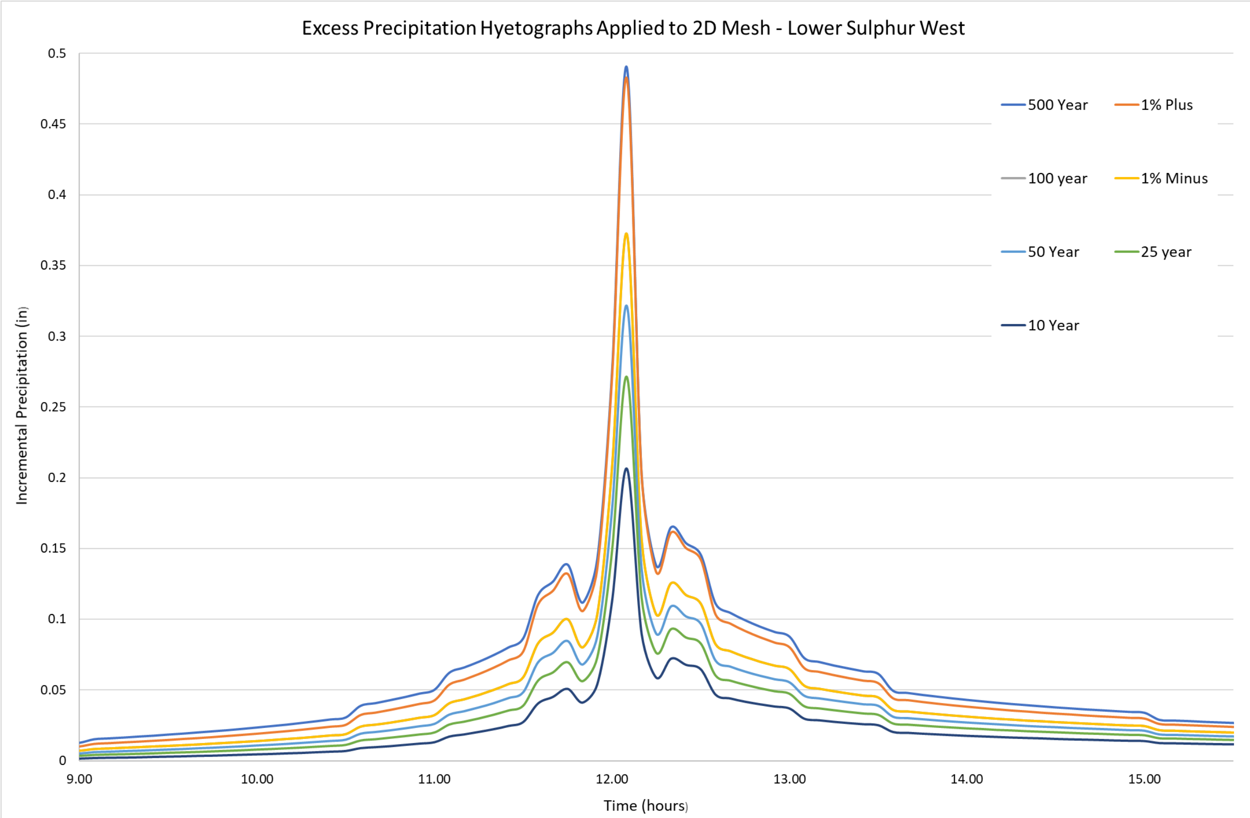

Figure 2.8: Excess Precipitation Hyetographs Applied to the Computational Mesh in the Lower Sulphur West Model

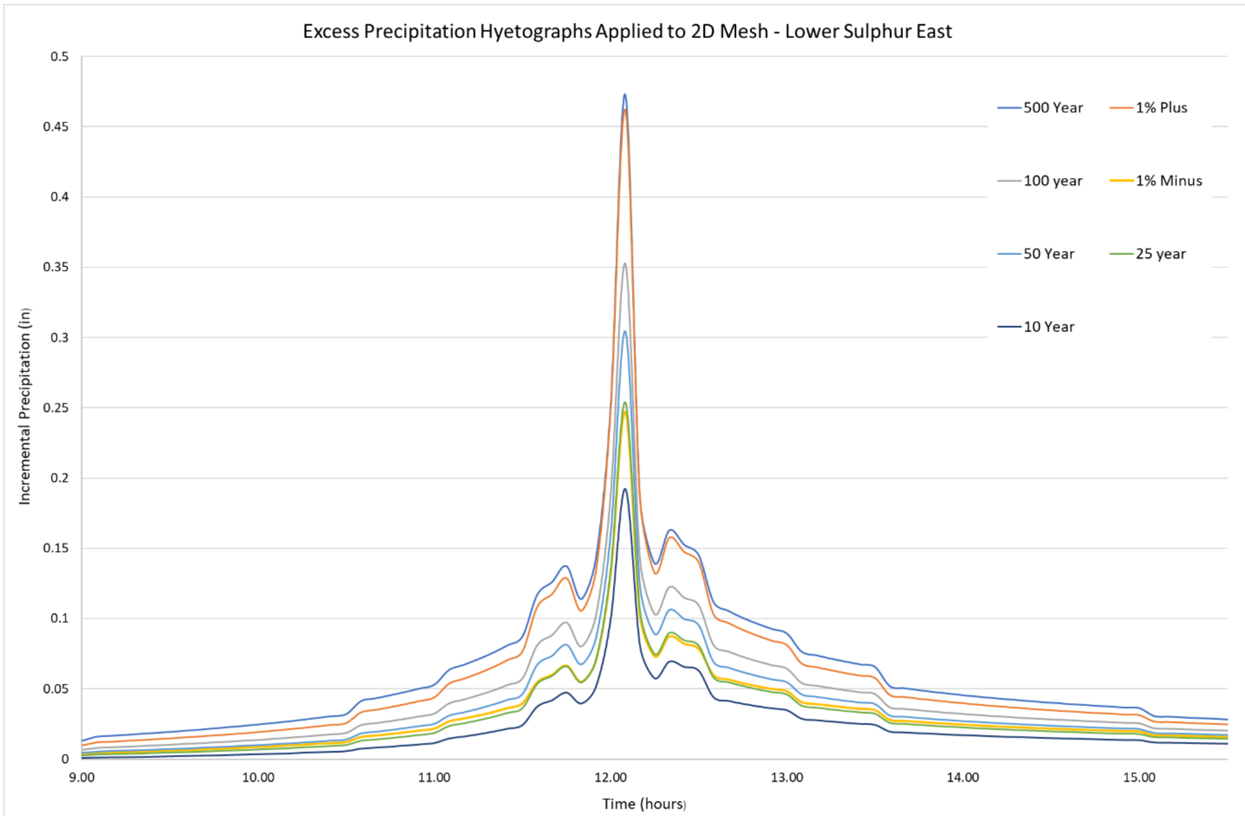

Figure 2.9: Excess Precipitation Hyetographs Applied to the Computational Mesh in the Lower Sulphur East Models

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. Figure 2.10 shows the Sulphur Headwaters contributing inflow hydrograph to Lower Sulphur and Figure 2.11 shows the White Oak Bayou contributing inflow hydrograph.

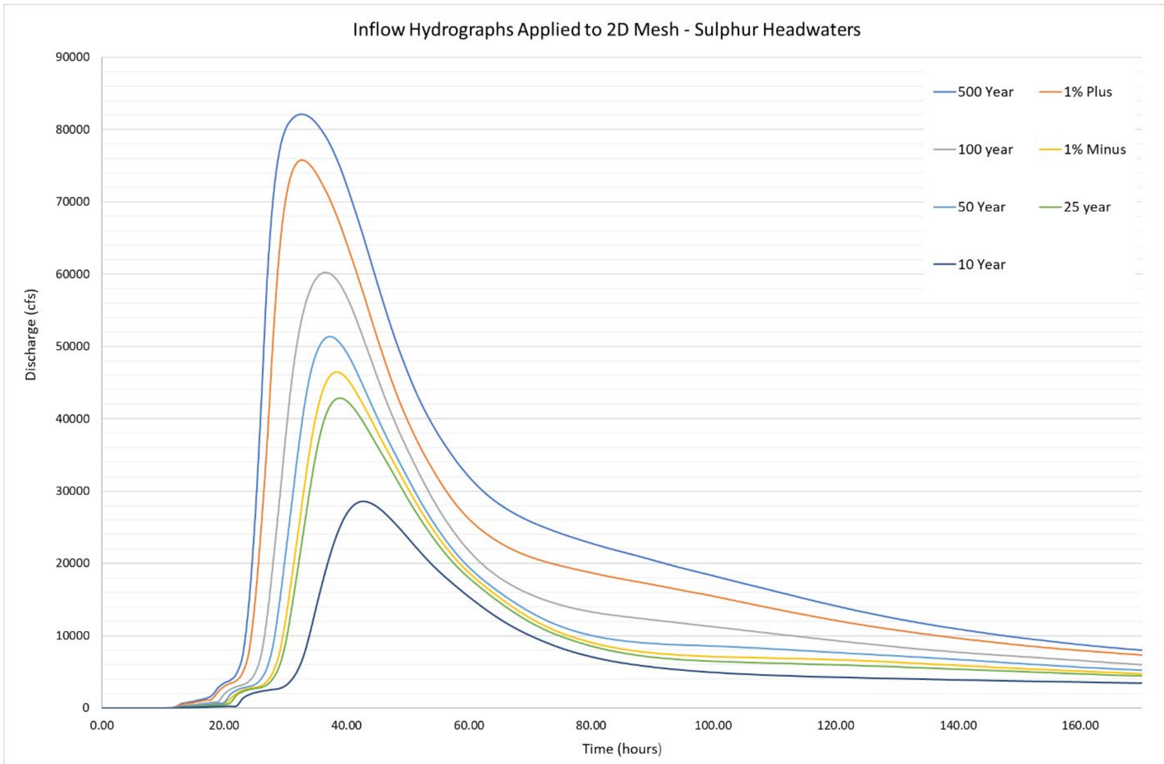

Figure 2.10: Sulphur Headwaters Watershed - Contributing Drainage Area Inflow Hydrographs

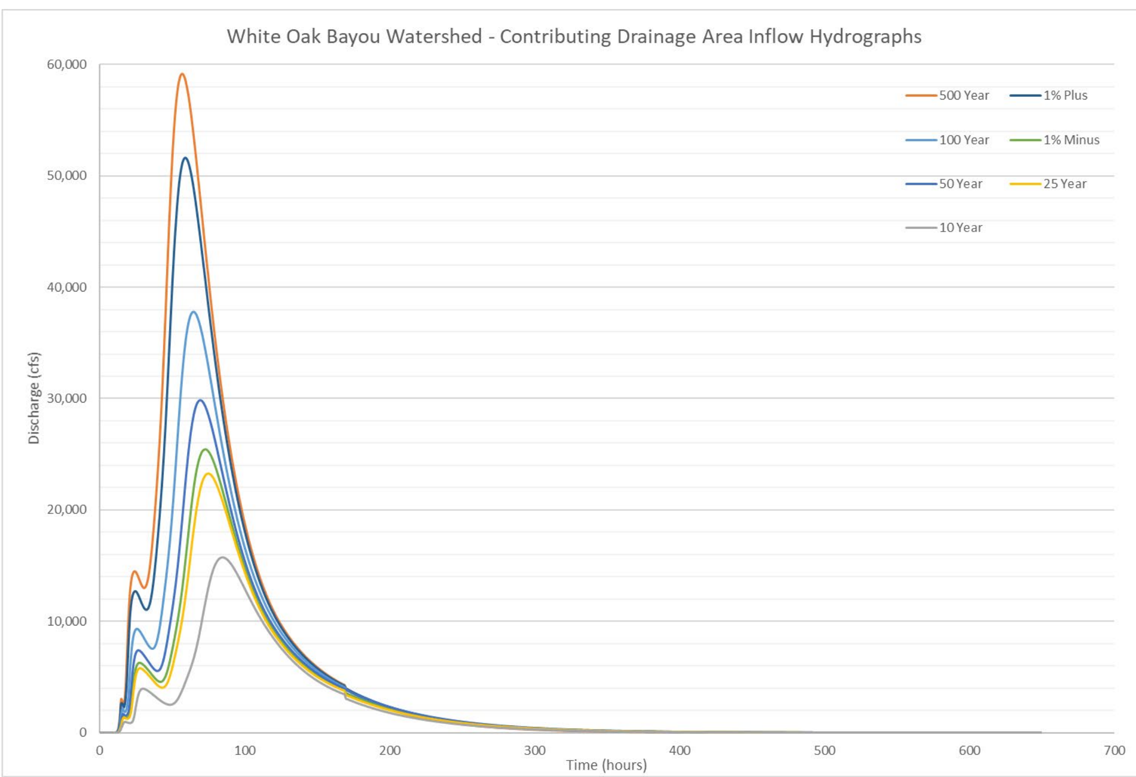

Figure 2.11: White Oak Bayou Watershed – Contributing Drainage Area Inflow Hydrographs

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. Calibration regions were added downstream of the Wright Patman dam to help with stability in the model. 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. The final Manning's n values for developed medium intensity, developed high intensity, barren land, shrub scrub, and emergent herbaceous wetland were updated to more closely reflect current aerial imagery based on regionally accepted values and are thus lower than the HEC-RAS User's Manual range, provided below in Table 2.8.

Table 2.8: NLCD 2019-Manning's N Roughness Matrix

NLCD Classification	Manning's N (West)	Manning's N (East TX)	Manning's N (East AR)	Minimum	Normal	Maximum
Open Water	0.033	0.030	0.030	0.025	0.038	0.050
Developed, Open Space	0.050	0.050	0.050	0.030	0.040	0.050
Developed, Low Intensity	0.070	0.070	0.038	0.060	0.090	0.120
Developed, Medium Intensity	0.100	0.100	0.056	0.080	0.120	0.160
Developed, High Intensity	0.120	0.120	0.075	0.120	0.160	0.200
Barren Land	0.050	0.050	0.025	0.023	0.025	0.030
Deciduous Forest	0.160	0.160	0.100	0.100	0.150	0.200
Evergreen Forest	0.160	0.160	0.100	0.080	0.120	0.160
Mixed Forest	0.160	0.160	0.100	0.080	0.140	0.200
Scrub/Shrub	0.070	0.070	0.035	0.070	0.115	0.160
Grassland/Herbaceous	0.035	0.035	0.025	0.025	0.038	0.050
Pasture/Hay	0.050	0.050	0.030	0.025	0.038	0.050
Cultivated Crops	0.050	0.050	0.025	0.020	0.035	0.050
Woody Wetlands	0.100	0.100	0.080	0.045	0.098	0.150
Emergent Herbaceous Wetland	0.150	0.150	0.075	0.050	0.068	0.085
Main Channel[1]	0.045	0.045	0.025			

[1] Clean, winding, some pools and shoals, some weeds and stones, lower stages, more ineffective slopes and sections

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 <u>Roads</u>

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 is 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 align 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.

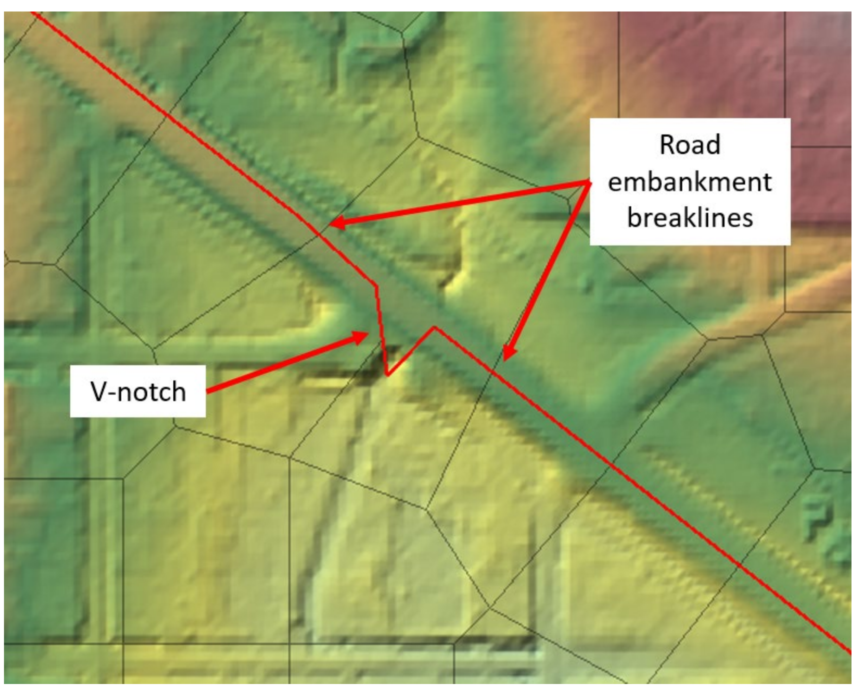

Figure 2.12 : V-Notch Breakline Approach at Bridge Crossing

2.2.4.3 Initial Conditions

Initial conditions were not used in the Lower Sulphur 2D BLE models.

2.2.5 Special Assumptions

Due to the large size of the Lower Sulphur Watershed, it was necessary to split the HUC-8 into an upstream and downstream RAS model (Lower Sulphur East and Lower Sulphur West). The models were split approximately 4,000 ft downstream of the Sulphur River – White Oak Bayou confluence. The Lower Sulphur West model mesh was split at the upstream end approximately 20,000 ft downstream of the HUC boundary with Sulphur Headwaters. This portion of Lower Sulphur West was added to the Sulphur Headwaters model to more appropriately model the interactions of the two watersheds and the levee system in the area. The non-accredited levee system follows along the left and right bank of the Sulphur River. Splitting the watersheds along the HUC boundary also caused a split of the levee system which inaccurately represented the flow patterns which would occur in this area. The mesh was adjusted such that the full levee system was modeled within the Sulphur Headwaters model. The Lower Sulphur East model was further split into two separate models at the state boundary (Lower Sulphur East (TX) and Lower Sulphur East (AR)) due to discrepancies in the terrain between the two state datasets. Figure 2.2 shows the terrain discrepancies at the Stateline within the Lower Sulphur Watershed.

Additionally, there were necessary model differences between the three models such as buffer size and boundary conditions specific to each model area, however, the computational parameters and nominal mesh cell size remained constant between all of the models. Special consideration was made for the land use n-values to remain consistent along model interfaces.

A refinement region was added in the Lower Sulphur East model at a cell spacing of 600 feet within the Wright Patman Lake. The larger cell spacing was added to this region to help stability within the lake and overall model.

Within the Lower Sulphur Watershed is the Wright Patman 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 United States Army Corps of Engineers (USACE).

Wright Patman Dam contains an ogee-crested emergency spillway that is 200 feet wide and a service spillway consisting of two 20-foot-wide gate-controlled conduits. The crest elevation of the emergency spillway is 259.5 ft-msl, and the top of dam is at elevation 286 ft-msl. The invert elevation of the service spillway is 200-ft-msl, and the outlets are controlled by four slide gates, each 10 feet wide by 20 feet tall. To model this structure in HEC-RAS, 2D connector lines were used. The outlet works conduits were modeled as a single outlet using a discharge rating curve, which was developed outside of HEC-RAS. Based on USACE data and to provide model stability, the outlet works was modeled with discharge ramping up to 8,500 cfs by elevation 225.0 ft-msl. The emergency spillway was modeled using the weir equation within HEC-RAS with a weir coefficient of 3.1, representative of the ogee-crested spillway shape. Table 2.9 provides the summary information for the dam. Figure 2.13 shows the discharge rating curve applied for the outlet works 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 USACE to represent the spillway discharges more accurately.

Table 2.9: Lower Sulphur Watershed Dam Summary

Dam Name	ID Number	Source of Information	Owner	County	Outfall Structure Type	Top of Dam Elevation (ft)
Wright Patman Dam	TX00021	USACE	USACE	Cass	Gate-controlled conduit and uncontrolled emergency spillway	286.0

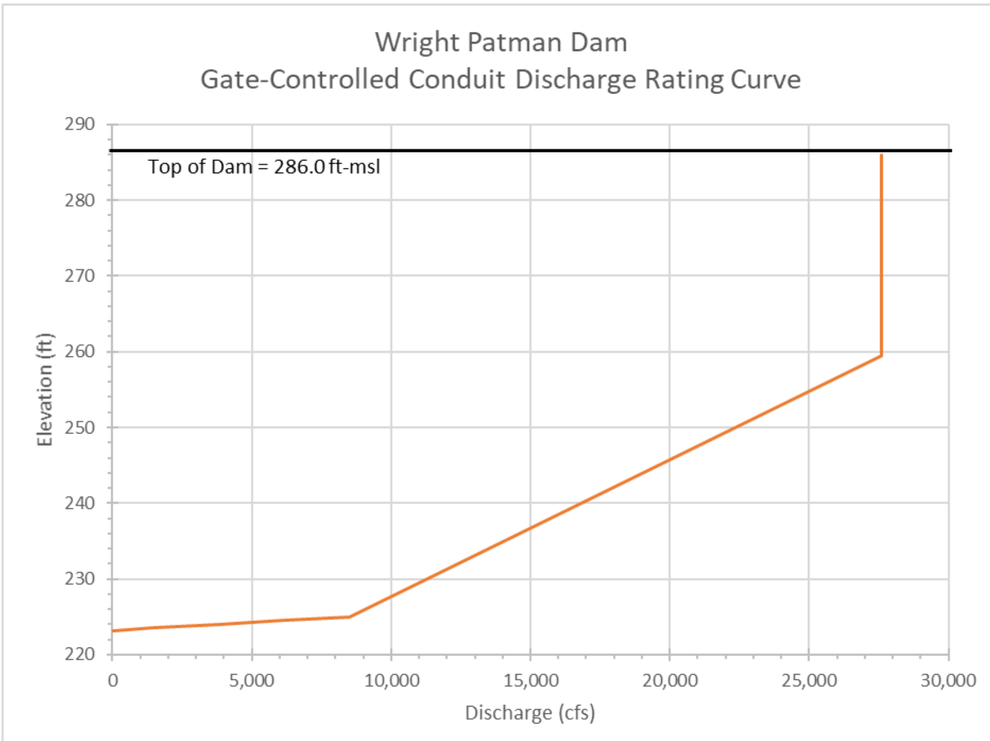

Figure 2.13 : Wright Patman Dam Gate-Controlled Conduit Discharge Rating Curve

2.3 Model Results

The 2D BLE results for the study produced flood risk mapping that compared reasonably well with the effective SFHA in most cases and provides additional estimated flood risk in areas that do not currently have an SFHA mapped. Additionally, the application of rain-on-grid modeling allowed for the identification of localized flood risk beyond the extents of the traditional SFHAs. Table 2.10 shows a comparison of some of the effective BFE data with the model results. The differences from the effective BFEs is largely due land use changes, topographic differences, and the change of rainfall data. 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 as a regulatory product.

Table 2.10: Effective and Model BFE Comparison

Stream	Comparison Point Effective Station	Effective BFE (feet)	Model BFE (feet)	Difference (feet)
Corral Creek	7459	290	289.51	-0.49
Howard Creek	18086	295	292.48	-2.52
Howard Creek	10653	279	277.96	-1.04
Howard Creek	1890	262	261.4	-0.6
South Wagner Creek	12213	305	301.98	-3.02
South Wagner Creek	9030	296	295.19	-0.81
South Wagner Creek	5785	283	282.99	-0.01
Stream WC-2	2002	320	319	-1
Stream WC-1	2735	313	313.03	0.03
Cowhorn Creek	20507	339	338.64	-0.36
Cowhorn Creek	11365	306	305.88	-0.12
Cowhorn Creek	3262	287	286.96	-0.04
Swampoodle Creek East Tributary	1567	315	314.91	-0.09
Swampoodle Creek	9854	301	300.25	-0.75
Swampoodle Creek	765	275	276.01	1.01
Wagner Creek	43397	320	319.66	-0.34
Wagner Creek	28703	302	300.98	-1.02
Wagner Creek	13973	286	285.92	-0.08
Wagner Creek	4514	273	271.8	-1.2

2.3.1 Calibration & Sensitivity Analysis

Known USGS gages within the model area with more than 20-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 2.11. USGS Gage No. 07344000 - Sulphur Rv nr Darden, TX noted a change in "gage height at different site and/or datum." With a change in the gage height and/or datum, the rating curve for the gage changes, resulting in different computed flows. Thus, the validation focused on aligning to water surface elevation instead.

Table 2.11: 1% Annual Chance Reasonability Comparisons

Flooding Source	USGS Gage Used for Verification	**HEC-RAS 6.1** (2D)		Gage Analysis	
		WSEL (ft)	**Discharge (cfs)**	**WSEL (ft)** [1]	**Discharge (cfs)**
Sulphur River	07343200	306.19	55,674	305.88	54,220
Cuthand Creek	07343300	373.89	15,353	374.02	14,480
Sulphur River	07344000	255.0	63,792	255.51	98,650

[1] 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 2.12, Table 2.13, and Table 2.14 summarizes the results of the runs performed at each of the USGS gages. USGS Gage No. 0343200 and USGS Gage No. 0343300 are located within the Lower Sulphur West HEC-RAS model, while USGS Gage No. 07344000 is located within the Lower Sulphur East (TX) HEC-RAS model. Therefore, the parameter settings in Table 2.14 are different than the parameter settings in Table 2.12 and Table 2.13.

Table 2.12: Sensitivity Analysis Results at USGS Gage 07343200

Iteration	Manning's N Zones	Breaklines	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)	
1	Original Land Use	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth		41,856	305.52
2	Land Use with Woody Wetland 0.15, Pasture/Hay 0.025	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth		35,838	305.49
3	Land Use with n-values set to maximum 2	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth		36,843	306.47
4[1]	Land Use with n-values set to match Sulphur Headwaters Watershed	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth		55,674	306.19
					Gage Analysis:		54,220	305.88[2]

[1] Parameters from Iteration 4 were used for the final model
[2] Water surface elevation is approximate based on PeakFQ input data.

Table 2.13: Sensitivity Analysis Results at USGS Gage 07343300

Iteration	Manning's N Zones	Breaklines	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
1	Original Land Use	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	15,747	373.03
2	Land Use with Woody Wetland 0.15, Pasture/Hay 0.025	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	16,920	373.00
3	Land Use with n-values set to maximum	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	13,038	373.33
4[1]	Land Use with n-values set to match Sulphur Headwaters Watershed	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	15,353	373.89
					Gage Analysis:	14,480	374.02[2]

[1] Parameters from Iteration 4 were used for the final model
[2] Water surface elevation is approximate based on PeakFQ input data.

Table 2.14: Sensitivity Analysis Results at USGS Gage 07344000

Iteration	Manning's N Zones	Breaklines	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
1	Original Land Use	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	52,655	253.62
2	Land Use with evergreen forest 0.16	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	56,389	254.01
3	Land Use with n-values set to maximum	Major Roads w/Centerlines Enforced – Simplified with spillway updates	Excess Precipitation	Dry / 1 min	Normal Depth	61,759	255.61
4	Land Use with woody wetland set to minimum and all other n-values set to maximum	Major Roads w/Centerlines Enforced – Simplified with spillway updates	Excess Precipitation	Dry / 1 min	Normal Depth	67,326	253.77
5	Land Use with n-values set to match Lower Sulphur West	Major Roads w/Centerlines Enforced – Simplified with refinement regions incorporated	Excess Precipitation	Dry / 30 sec	Normal Depth	64,337	255
6[1]	Land Use with n-values set to match Lower Sulphur	Major Roads w/Centerlines Enforced – Simplified with refinement regions incorporated	Excess Precipitation	Dry / 30 sec	Stage Hydrograph	63,792	255
					Gage Analysis:	98,650	255.51[2]

[1] Parameters from Iteration 6 were used for the final model.
[2] Water surface elevation is approximate based on PeakFQ input data.

2.4 Challenges

The estimation of the discharge rating curve for the Wright Patman Dam within Lower Sulphur Watershed was a significant challenge. Multiple iterations were performed to stabilize the model and complete 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 operations of this structure.

Due to the size of the Lower Sulphur Watershed, run times were a challenge in this area. The model was divided into three separate models: Lower Sulphur West, Lower Sulphur East (TX), and Lower Sulphur East (AR). This was to facilitate more reasonable model runtimes and address a terrain discrepancy between East Texas and Arkansas. Additionally, the upstream portion of Lower Sulphur West was added to Sulphur Headwaters model to more appropriately model the interactions of the two watersheds and the levee system in the area. The non-accredited levee system follows along the left and right bank of the Sulphur River. Splitting the watersheds along the HUC boundary also caused a split of the levee system which inaccurately represented the flow patterns which would occur in this area. The mesh was adjusted such that the full levee system was modeled within the Sulphur Headwaters model. Figure 2.3 shows the modeling mesh between Sulphur Headwaters and Lower Sulphur with respect to the levee system.

The terrain discrepancy discussed in previous sections provided difficulty in model tie-in due to significant differences in the bare earth DEM elevations between Texas and Arkansas. This area should be reviewed for future refinement when new LiDAR data is available.

Additionally, the Lower Sulphur Watershed discharges into the Red River which has recently been studied by the USACE. This study, which has not been finalized by the USACE, provided revised terrain data within the model that incorporated survey and 1D cross sections which did not align with the best available LiDAR data for this study. Due to the differences in terrain and this study not being released with final floodplain mapping along the Red River, it was not possible to cleanly tie-in the Lower Sulphur Watershed BLE mapping to the Red River USACE study. This tie-in should be reviewed in future BLE maintenance cycles once the USACE study has been finalized with final mapping for the Red River.

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 2.12 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.

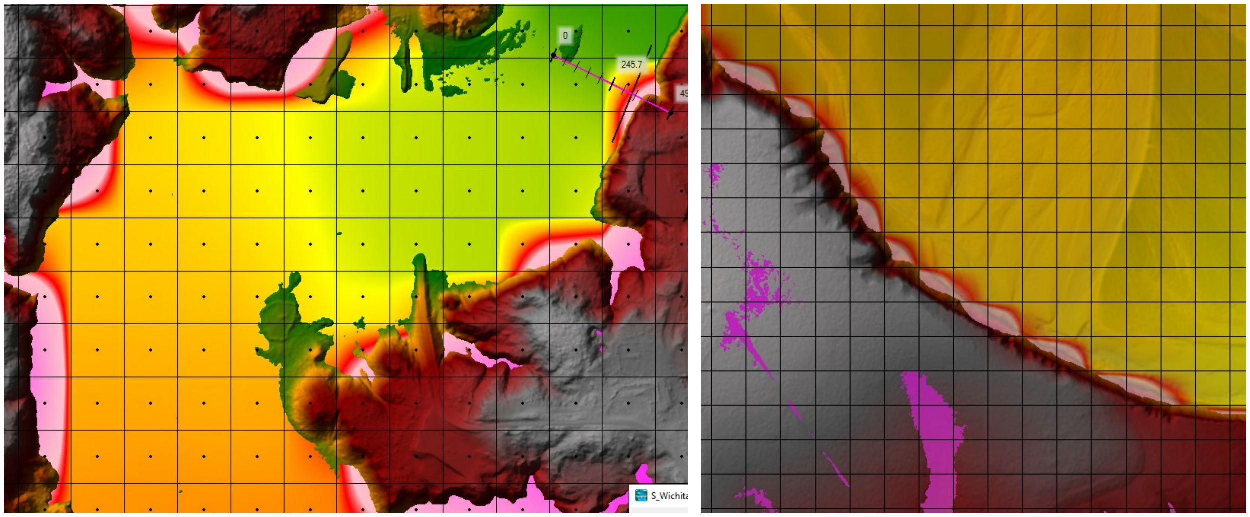

Figure 2.14 : Cupping Examples

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 SFHA 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 Lower Sulphur 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 footprint 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 EBFE_FLD_HAZ_AR.

3.1.4 Mapping Considerations

3.1.4.1 Ponds

Numerous ponds exist throughout the Lower Sulphur 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

Multiple model domains were used to provide full mapping coverage for the Lower Sulphur Watershed. Overlapping regions were provided between models to allow mapping tie-ins to occur between each model domain within plus or minus 0.5 feet, per FEMA requirements. These tie-ins were defined manually by producing a difference raster between model domains to identity an appropriate tie-in location. The final grids were then mosaicked together to produce a seamless depth and water surface elevation grid and flood hazard layer.

A significant tie-in occurs at the downstream side of the White Oak Bayou Watershed. This area is also modeled as part of the Lower Sulphur East (TX) BLE model using an overlapping mesh to determine the appropriate mapping tie-in location and the mapping is incorporated into the White Oak Bayou 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 Lower Sulphur 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 Lower Sulphur 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 known and 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 Lower Sulphur 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 Lower Sulphur 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 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 1,391.5 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 Lower Sulphur Watershed.

Table 3.3: Aggregated Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	183.2
UNVERIFIED	BEING STUDIED	1,208.3

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					
Mulberry Creek-Little Sandy Creek	111403020101	2,058	387	1,671	81.2	FAIL
Little Sandy Creek-Brushy Creek	111403020102	2,767	565	2,202	79.6	FAIL
Brushy Creek-Sulphur River	111403020103	235	164	71	30.2	FAIL
Upper Mustang Creek	111403020104	725	124	601	82.9	FAIL
River Crest Lake-Sulphur River	111403020105	93	27	66	71.0	FAIL
Little Mustang Creek-Sulphur River	111403020106	430	266	164	38.1	FAIL
Whiteoak Creek-Sulphur River	111403020107	526	439	87	16.5	FAIL
Upper Cuthand Creek	111403020201	1,274	178	1,096	86.0	PASS
Scatter Creek	111403020203	103	8	95	92.2	PASS
Pickett Creek-Cuthand Creek	111403020206	111	14	97	87.4	PASS
Kickapoo Creek	111403020207	63	6	57	90.5	PASS
Shawnee Creek-Sulphur River	111403020209	530	245	285	53.8	FAIL
Long Lake Slough	111403020302	1,073	652	421	39.2	FAIL
Boothe Creek-Sulphur River	111403020303	3,239	1,232	2,007	62.0	FAIL
Blythe Creek	111403020401	2,551	568	1,983	77.7	FAIL
Caney Creek-Tuck Branch	111403020402	1,042	234	808	77.5	FAIL
Ward Creek-Bassett Creek	111403020403	3,563	1,078	2,485	69.7	FAIL

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)
Watershed Name	Watershed Number					
Calvert Creek-Sulphur River	111403020404	1,975	556	1,419	71.8	FAIL
Upper Anderson Creek	111403020501	2731	532	2199	80.5	FAIL
Middle Anderson Creek	111403020502	2909	618	2291	78.8	FAIL
Lower Anderson Creek	111403020503	1991	603	1388	69.7	FAIL
Brooks Creek	111403020504	1107	366	741	66.9	FAIL
Thomas Creek-Sulphur River	111403020601	499	200	299	59.9	FAIL
Whatley Creek-Wright Patman Lake	111403020602	1090	355	735	67.4	FAIL
Town of New Boston-Big Creek	111403020603	1904	255	1649	86.6	PASS
Caney Creek-Big Creek	111403020604	1496	327	1169	78.1	FAIL
Brown Creek-Sulphur River	111403020605	3098	1317	1781	57.5	FAIL
Webster Creek-Wright Patman Lake	111403020606	1364	728	636	46.6	FAIL
Elliott Creek-Wright Patman Lake	111403020607	2768	999	1769	63.9	FAIL
Mill Creek-Wright Patman Lake	111403020608	1470	727	743	50.5	FAIL
Akin Creek	111403020701	907	219	688	75.9	FAIL
Cypress Creek-Cypress Slough	111403020702	3028	565	2463	81.3	FAIL
Baker Creek-Sulphur River	111403020703	2416	684	1732	71.7	FAIL
Upper Days Creek	111403020704	201	10	191	95.0	PASS
Middle Days Creek	111403020705	526	83	443	84.2	FAIL
Lower Days Creek	111403020707	32	10	22	68.8	FAIL

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)
Watershed Name	Watershed Number					
Outlet Sulphur River	111403020709	7	1	6	85.7	PASS

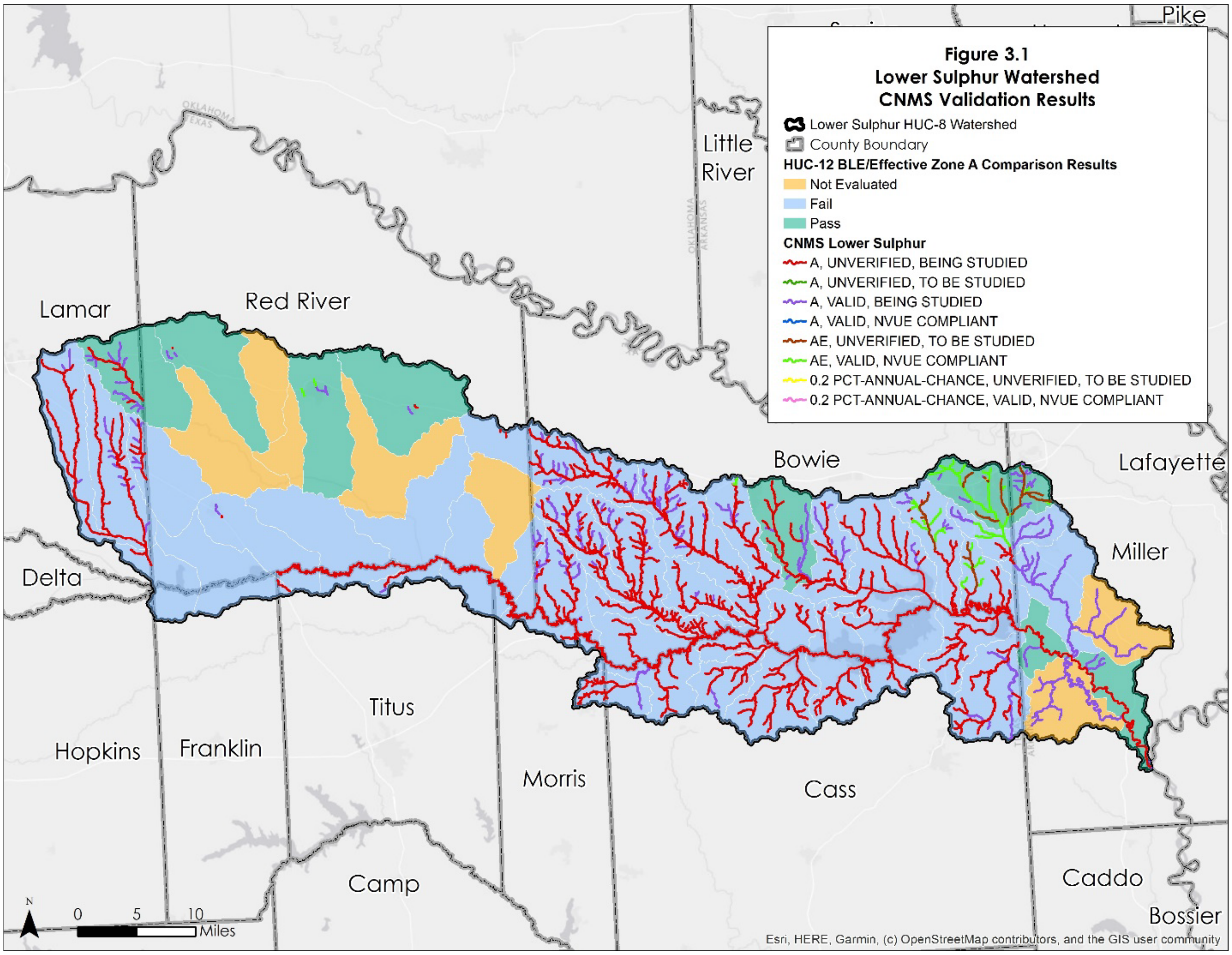

Figure 3.1: Lower Sulphur Watershed CNMS Validation Results

3.3 Flood Risk Analysis

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

Hazus version 5.1 (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 other bodies of water, wetlands, or forests) from the census blocks, changing their shape and reducing their size in these areas. For more information on dasymetric data visit FEMA's Media Library for the Hazus-MH Data Inventories: Dasymetric vs. Homogenous, or Hazus 3.0 Dasymetric Data Overview.

Hazus analysis was performed by count within the project watershed extends for each return period to ensure proper model processing. A summary of results per county for the 100-year scenarios are shown in Table 3.5.

Table 3.5: Hazus 5.1 (SP02) Results for 1-percent-annual-chance (100 year) scenario for Lower Sulphur Watershed, Texas and Arkansas

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Arkansas			
Lafayette	$ -	$ -	$ -
Miller	$174,972,000.00	$2,357,202,000.00	$1,501,620,000.00
Texas			
Bowie	$797,814,000.00	$6,849,372,000.00	$4,671,720,000.00
Cass	$10,793,000.00	$337,040,000.00	$183,896,000.00
Delta	$ -	$ -	$ -
Franklin	$3,553,000.00	$34,807,000.00	$20,528,000.00
Hopkins	$ -	$6,677,000.00	$3,998,000.00
Lamar	$21,586,000.00	$408,232,000.00	$231,827,000.00
Morris	$5,319,000.00	$61,506,000.00	$38,780,000.00
Red River	$56,095,000.00	$891,777,000.00	$561,513,000.00
Titus	$1,437,000.00	$35,151,000.00	$18,235,000.00
Total	**$1,071,569,000.00**	**$10,981,764,000.00**	**$7,232,117,000.00**

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