Sulphur Headwaters 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. 11140301 – Sulphur Headwaters 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 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 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	Sulphur Headwaters Stream Miles
CNMS	2,945

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	210.5
UNVERIFIED	BEING STUDIED	533.9

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 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 Sulphur Headwaters 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, Delta, Hopkins, Hunt, and Fannin Counties, and include the following communities: The Cities of Commerce, Cooper, Cumby, Honey Grove, Paris, Pecan Gap, Reno, Roxton, and Wolfe City, the Towns of Bailey, Ladonia, Neylandville, Tira, and Windom, and the Communities of Gober, Lake Creek, Klondike, and Ben Franklin. The study area consists of four HUC-10 basins: North Sulphur River, North Sulphur River – South Sulphur River, Middle Sulphur River – South Sulphur River, and Spring Creek – South Sulphur River. Figure 1.1 shows the orientation of the Sulphur Headwaters HUC-8 basin with respect to the counties.

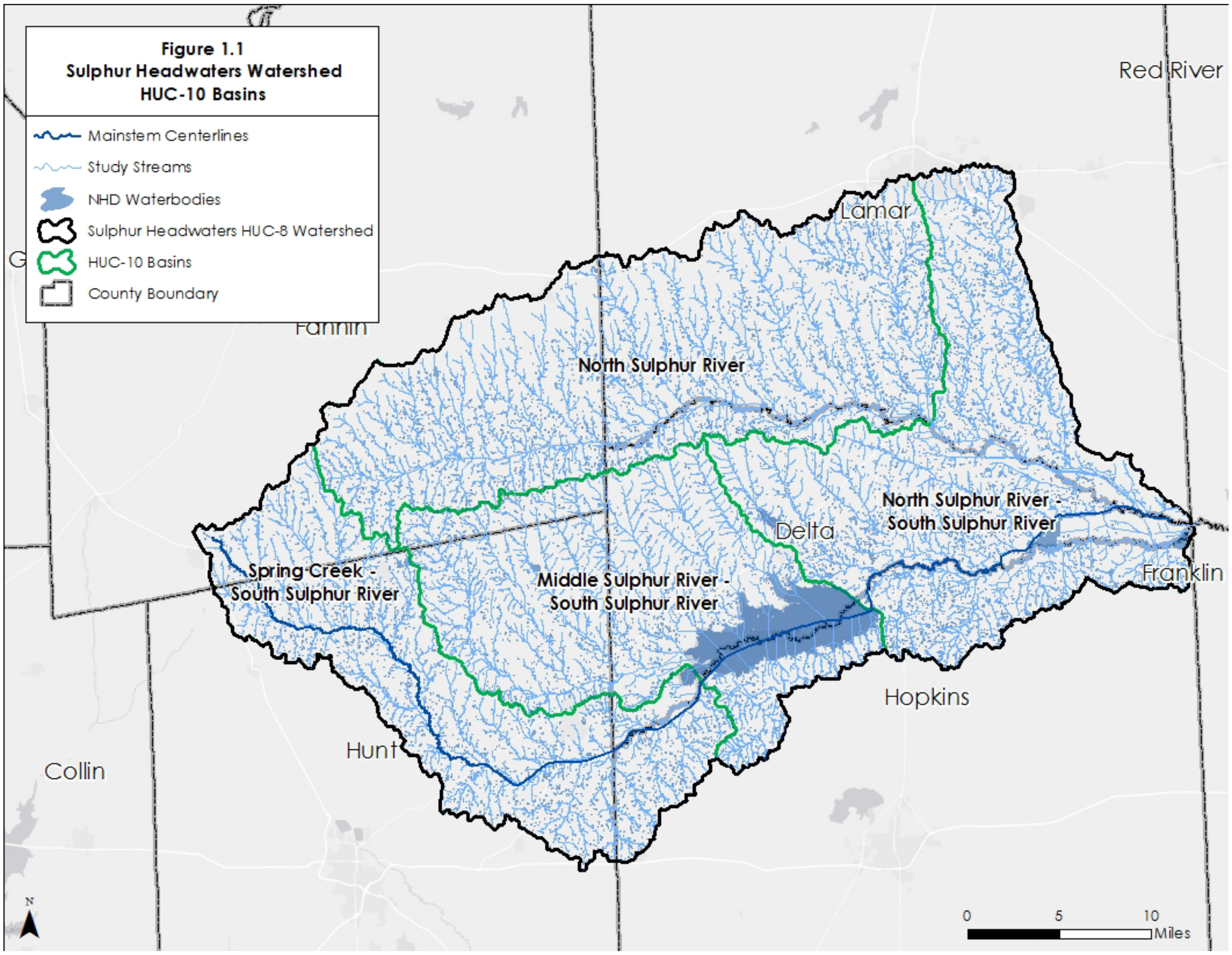

Figure 1.1: Sulphur Headwaters Watershed

02 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2D hydraulic engineering analysis for the Sulphur Headwaters 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 the2D BLE products produced for this watershed.

2.1 Topographic Data

A high-resolution Digital Elevation Model (DEM) is a fundamental component for 2Dengineering analyses by providing a detailed representation of the ground surface for hydraulic routing through the model area. As such, DEMs were developed for the Sulphur Headwaters BLE created by leveraging available high-resolution pre-processed hydro-enforced digital elevation models 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 Sulphur Headwaters 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 Sulphur Headwaters Watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Sulphur Headwaters 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.

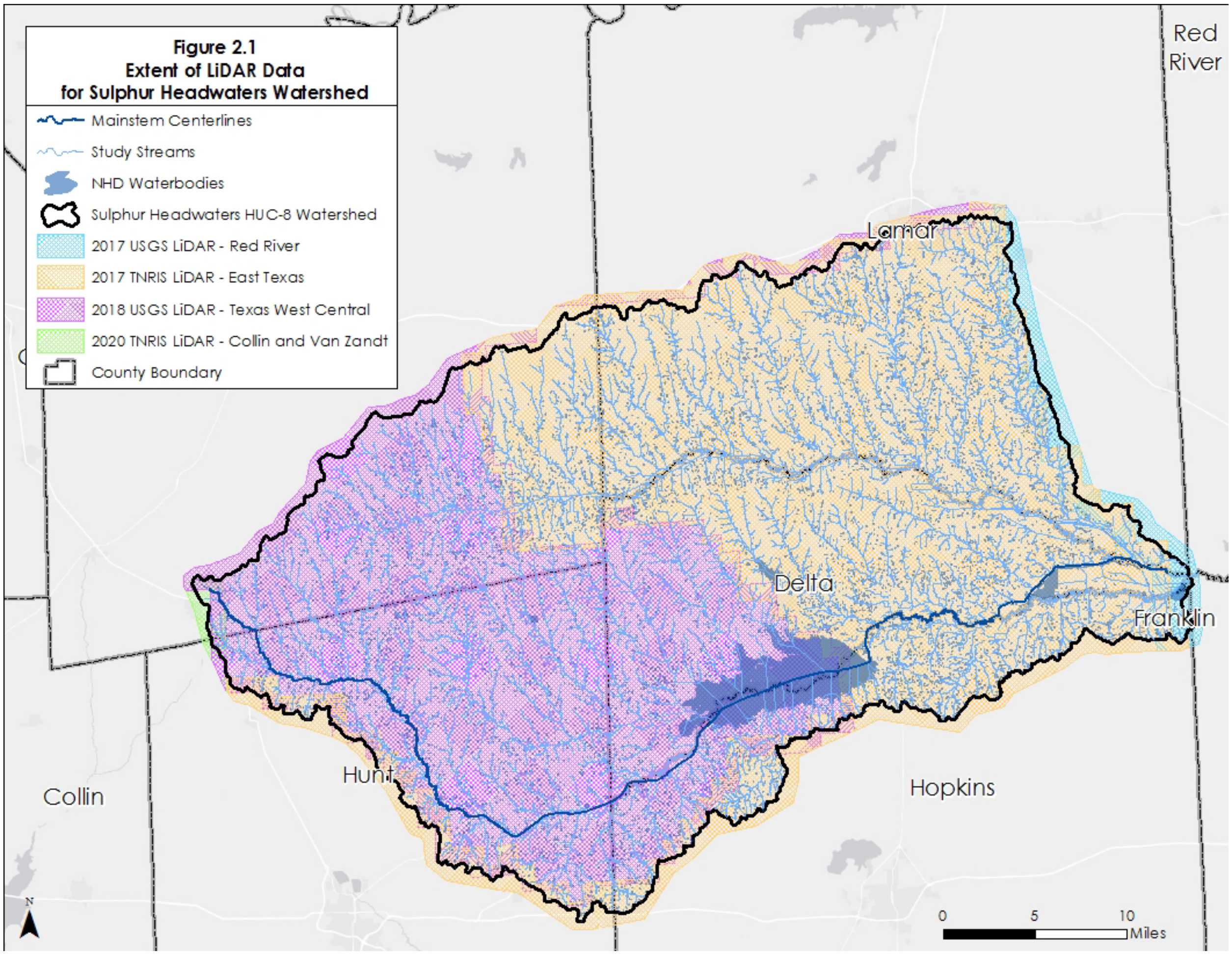

Figure 2.1: Sulphur Headwaters Watershed BLE Source Terrain Data

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 meets 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 Sulphur Headwaters 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 Sulphur Headwaters Watershed

Year	Description	Data Type	RMSE	Source/Owner
2020	StratMap 2020 Colin, Fannin, Vand Zandt	Airborne LiDAR	8.13 cm NVA	TNRIS
2018	Texas West Central Lidar 2018	Airborne LiDAR	9.10 cm NVA	USGS
2017	East Texas Lidar 2017	Airborne LiDAR	< 10.0 cm NVA	TNRIS

2.1.2.1 Sulphur Headwaters Watershed Source Terrain Data

The source elevation data for the Sulphur Headwaters are DEMs derived from 2017, 2018 and 2020 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. 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 Supplemental Data.

<u>2017 TNRIS East Texas LiDAR</u>– 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.

<u>2018 TNRIS West Central TX LiDAR</u>- The 2018 TNRIS LiDAR was acquired in February 2018 through May 2018 (with reflights in November 2018). The Non-Vegetated Vertical Accuracy (NVA) was reported as RMSEz = 9.1 cm. 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>2020 TNRIS Collin and Van Zandt Co. Texas LiDAR</u>– The 2020 TNRIS Collin and Van Zandt County LiDAR was acquired from February to April 2020. The measured RMSE was documented as less than 8.13 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

2.1.3 Data Development Methodology

The source topographic data were processed for an area covering the Sulphur Headwaters Watershed and contributing drainage areas for the Sulphur Headwaters BLE modeling efforts. The topographic data for Sulphur Headwaters 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 Sulphur Headwaters Watershed BLE analysis 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

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 and automated assessments to identify potentially impactful anomalies or slope changes that may adversely impact hydraulic computations.

The final DEM data developed for the Sulphur Headwaters 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 Sulphur Headwaters Watershed, including adjacent inflows, was represented, a 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 the FEMA's requirement to provide mapping through the full extent of the USGS HUC-8 watershed. In addition to this buffer, the mesh boundary was extended into Lower Sulphur to account for the flow spillages across the levees in the lower portion of the watershed.

The HEC-RAS 2D computational mesh was created for Sulphur Headwaters 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 1,051,464 cells with a 200-foot nominal mesh cell size. Factors that 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 1-minute 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 Sulphur Headwaters Watershed, excess precipitation was applied to the mesh and no additional inflows were required to be accounted for. Figure 2.2 shows the 2D computational mesh for the Sulphur Headwaters Watershed, along with USGS peak streamflow gages pertinent to the study area. The development of the 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.

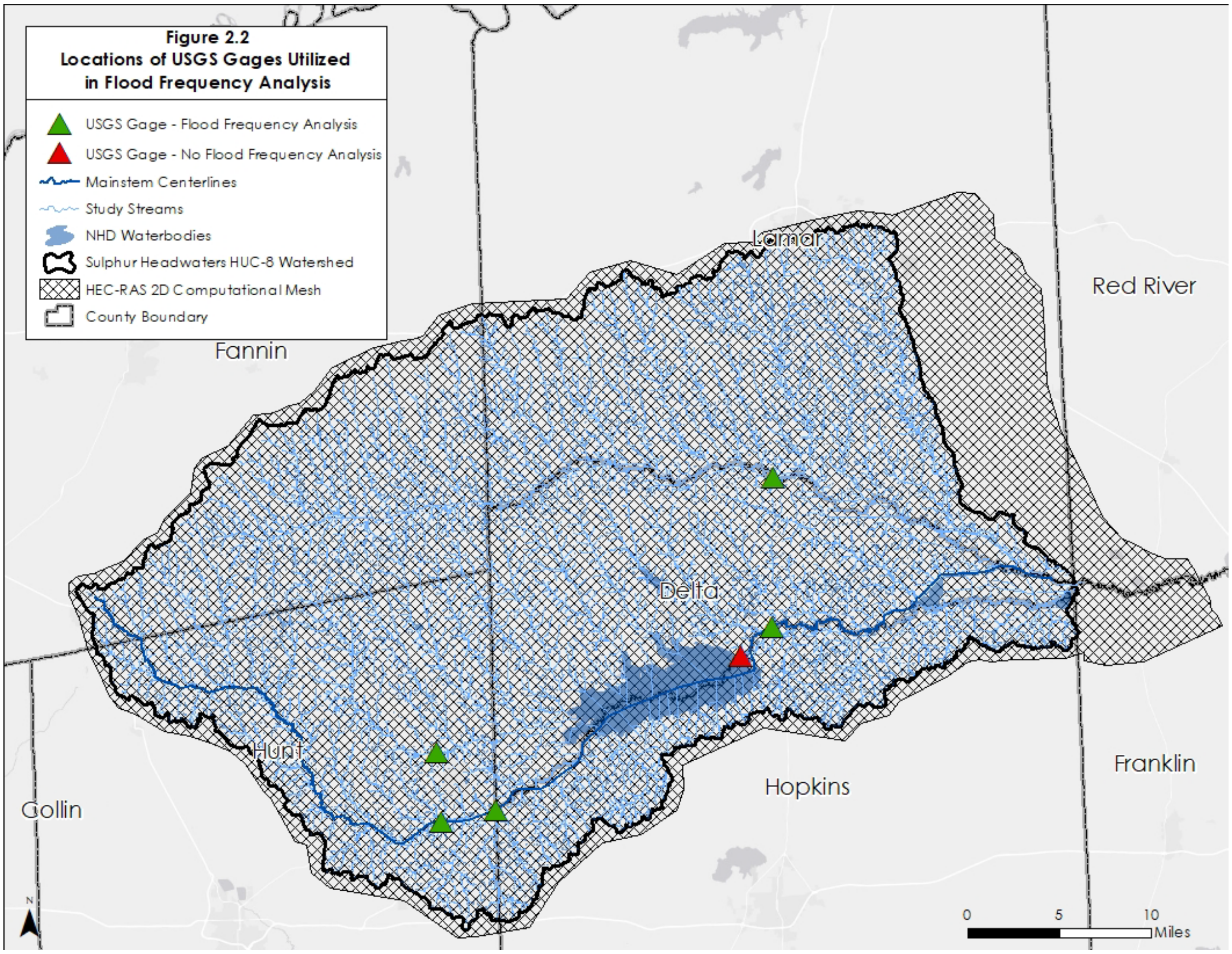

Figure 2.2: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages

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. White Oak Bayou is a headwater basin, so no inflow hydrographs were used.

A total of six (6) USGS gages are found within Sulphur Headwaters Watershed. No peak flow record data was found for the USGS gage No. 07342495 – Jim L. Chapman Lk nr Cooper, TX and was excluded from the analysis. The other five (5) USGS gages including: 07342465 - S Sulphur Rv at Commerce, TX, 07342470 – S Sulphur Rv at SH11 nr Commerce, TX, 07342480 – Middle Sulphur Rv. At Commerce, TX, 07342500 – S Sulphur Rv nr Cooper TX, and 07343000 N Sulphur Rv near Cooper TX had streamflow gage data that was leveraged to estimate peak flows 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
07342465	S Sulphur Rv at Commerce, TX	150	1992-2018
07342470	S Sulphur Rv at SH 11 nr Commerce, TX	189	1980-2020
07342480	Middle Sulphur Rv at Commerce, TX	44	1992-2020
07342500	S Sulphur Rv nr Cooper, TX	527	1943-2020
07343000	N Sulphur Rv nr Cooper, TX	276	1950-2020
07342495	Jim L. Chapman Lk nr Cooper, TX	479	No Data

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 were used for comparison of flow validation within the upper (84% Confidence interval or 1% plus) and lower (16% Confidence interval or 1% minus) confidence intervals are presented in Table 2.4 for the gages 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)
07342465	S Sulphur Rv at Commerce, TX	24,300	20,890	29,470
07342470	S Sulphur Rv at SH 11 nr Commerce, TX	18,950	17,070	22,030
07342480	Middle Sulphur Rv at Commerce, TX	10,920	9,562	12,910
07342500	S Sulphur Rv nr Cooper, TX	11,430	10,240	13,130
07343000	N Sulphur Rv nr Cooper, TX	86,170	80,330	93,460

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)

Basin Description	CN	Tlag (min)
Sulphur Headwaters	70	1220

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 precipitation totals 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
Sulphur Headwaters	10yr	0.70	1.39	2.53	3.22	3.65	4.44	5.32	6.10
	25yr	0.81	1.61	2.95	3.78	4.32	5.30	6.38	7.40
	50yr	0.90	1.78	3.26	4.21	4.84	5.97	7.21	8.46
	100yr	0.98	1.95	3.57	4.65	5.37	6.66	8.06	9.53
	100yr minus	0.77	1.53	2.80	3.69	4.28	5.37	6.57	7.79
	100yr plus	1.19	2.37	4.34	5.61	6.45	7.96	9.50	11.19
	500yr	1.18	2.34	4.34	5.74	6.69	8.41	10.25	12.18

Figure 2.3 show the excess precipitation hyetographs applied to the 2D computational mesh.

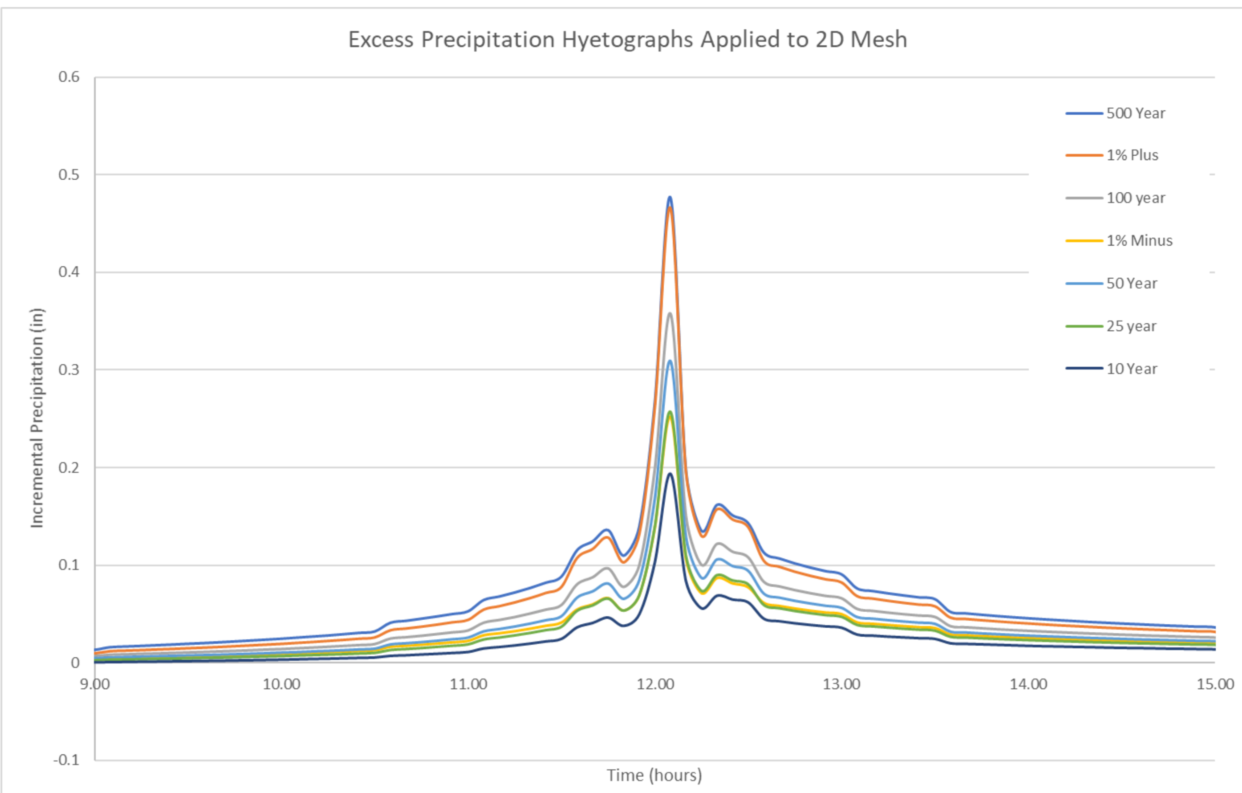

Figure 2.3: Excess Precipitation Hyetographs (post ARF) Applied to the Computational Mesh

2.2.3.2 Rainfall-Runoff Hydrograph Boundary Conditions

Inflow hydrographs were not used in the Sulphur Headwaters 2D BLE model.

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. The final Manning n values for developed low intensity, developed medium intensity, developed high intensity, and shrub scrub 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	Minimum	Normal	Maximum
Open Water	0.030	0.025	0.038	0.050
Developed, Open Space	0.030	0.030	0.040	0.050
Developed, Low Intensity	0.038	0.060	0.090	0.120
Developed, Medium Intensity	0.050	0.080	0.120	0.160
Developed, High Intensity	0.075	0.120	0.160	0.20
Barren Land	0.030	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	0.20
Scrub/Shrub	0.035	0.070	0.115	0.160
Grassland/Herbaceous	0.030	0.025	0.038	0.050
Pasture/Hay	0.030	0.025	0.038	0.050
Cultivated Crops	0.025	0.020	0.035	0.050
Woody Wetlands	0.080	0.045	0.098	0.150
Emergent Herbaceous Wetland	0.075	0.050	0.068	0.085
Main Channel[1]	0.045			

[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 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.

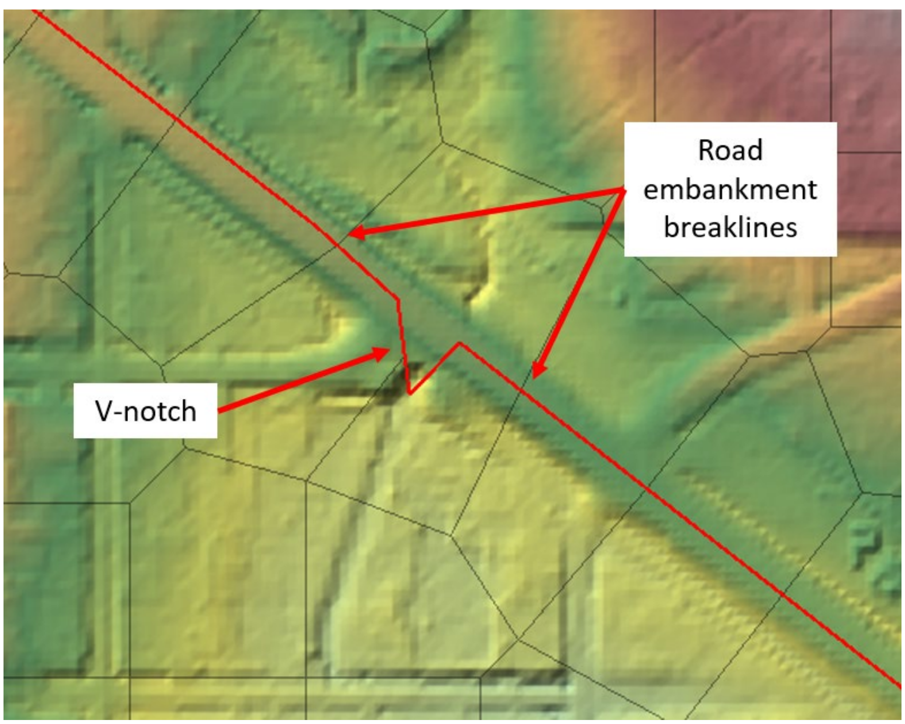

Figure 2.4 : V- Notch Breakline Approach at Bridge Crossing

2.2.4.3 Initial Conditions

Initial conditions were not used in the Sulphur Headwaters 2D BLE model.

2.2.5 Special Assumptions

Within the Sulphur Headwaters watershed is the Jim Chapman 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 United States Army Corps of Engineers (USACE).

Jim Chapman Lake Dam consists of 700-foot-wide ogee-crested spillway at crest elevation 446.2 ft-msl and a gate-controlled conduit measuring 4.45-ft by 10.5-ft with an invert elevation of 394.0 ft-msl. The top of dam is at elevation 464.5 ft-msl. To model this structure in HEC-RAS, 2D connector lines were used. The spillway was modeled using weir equation within HEC-RAS with a weir coefficient of 3.1, representative of the ogee-crested spillway shape. The outlet conduit was modeled using a discharge rating curve developed outside of HEC-RAS. Table 2.9 provides the summary information for the dam. Figure 2.5 shows the discharge-elevation curve used for the outlet structure.

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: Sulphur Headwaters Watershed Dam Summary

Dam Name	ID Number	Source of Information	Owner	County	Outfall Structure Type	Top of Dam Elevation (ft)
Jim Chapman Dam	TX08012	USACE	USACE	Hopkins	Gate-controlled conduit and emergency spillway	464.5

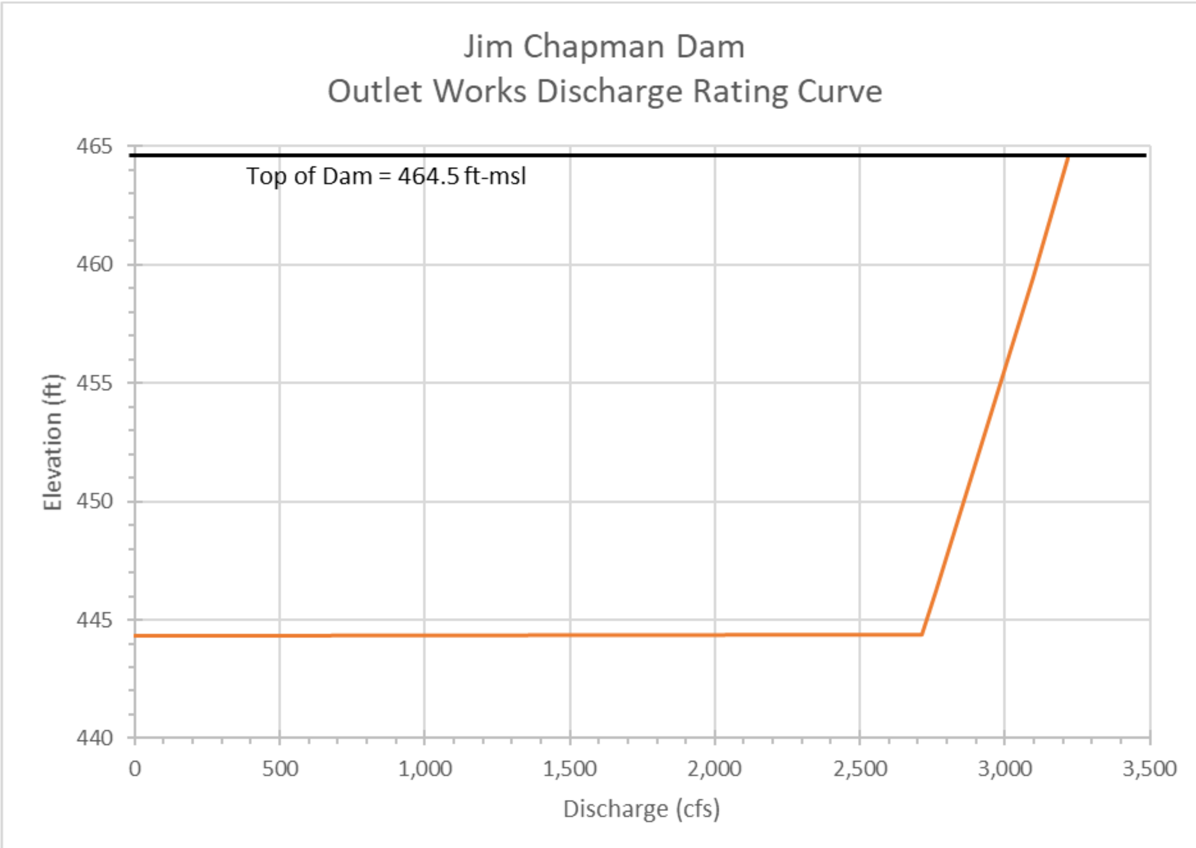

Figure 2.5 : Rating Curve for 2D Connector at Jim Chapman Dam

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 the effective BFE data 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 as a regulatory product.

The effective BFE for Baker Branch Tributary No. 24, Big Sandy Creek Tributary No. 8, Big Sandy Creek Tributary No. 7, and South Sulphur River Tributary are higher than the model BFE. Numerous reasons could exist for this occurrence including changes in analysis methodology, changes in terrain and development and changes in rainfall data used for the study. Baker Branch Tributary No. 10, Big Sandy Creek Tributary No. 6, Big Sandy Creek Tributary No. 4, and Big Sandy Creek Tributary No. 2 effective BFE is lower than model BFE, which is largely due land use changes, topographic differences, and the change of rainfall data. Additionally, the levees may have an impact in the comparison to effective data due to the modeling approach used to analyze the levees.

Table 2.10: Effective and Model BFE Comparison

Stream	Comparison Point Effective Station	Effective BFE (feet)	Model BFE (feet)	Difference (feet)
Cottonwood Branch Tributary No. 11	7649	557.00	556.98	-0.02
Cottonwood Branch Tributary No. 11	2274	526.00	526.38	0.38
Baker Branch	8835	539.00	538.79	-0.21
Baker Branch Tributary No. 24	2350	513.00	512.37	-0.63
Baker Branch Tributary No. 10	1400	546.00	546.72	0.72
Big Sandy Creek	1020	498.00	498.19	0.19
Big Sandy Creek Tributary No. 8	900	554.00	552.80	-1.20
Big Sandy Creek Tributary No. 7	2825	546.00	545.02	-0.98
Big Sandy Creek Tributary No. 6	1925	550.00	551.62	1.62
Big Sandy Creek Tributary No. 4	8700	552.00	553.05	1.05
Big Sandy Creek Tributary No. 3	3615	518.00	518.41	0.41
Big Sandy Creek Tributary No. 2	7457	540.00	543.73	3.73

Stream	Comparison Point Effective Station	Effective BFE (feet)	Model BFE (feet)	Difference (feet)
South Sulphur River Tributary	10000	505.00	502.39	-2.61

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 2.11.

Table 2.11: 1% Annual Chance Reasonability Comparisons

Flooding Source	USGS Gage Used for Verification	**HEC-RAS 6.1** (2D)		Reference	
		WSEL (ft)	**Discharge (cfs)**	**WSEL (ft)** [1]	**Discharge (cfs)**
S Sulphur River	07342465	491.35	25,575	491.26	24,300
S Sulphur River	07342470	477.90	25,024	482.86	18,950
Middle Sulphur River	07342480	489.35	11,372	489.84	10,920
S Sulphur River	07342500	392.10	11,644	392.04	11,430
N Sulphur River	07343000	406.80	89,145	406.98	89,510

[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, Table 2.14, Table 2.15, and Table 2.16 summarizes the results of each run at each of the USGS gages.

Table 2.12: Sensitivity Analysis Results at USGS Gage 07342465

Iteration	Manning's N Zones	Breaklines	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
1	Pasture Hay 0.03	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	22,390	491.66
2	Woody wetlands 0.12, Pasture Hay 0.05, deciduous 0.12	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	19,670	492.23

Iteration	Manning's N Zones	Breaklines	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
3	Woody Wetlands 0.12, deciduous forest 0.12, & Pasture Hay 0.05, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	21,122	491.69
4	Woody Wetlands 0.12, deciduous forest 0.12, & Pasture Hay 0.03, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	22,136	491.63
5	Mesh extended; woody Wetlands 0.12, deciduous forest 0.12, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	22,160	491.86
6	Emergent herbaceous 0.15 with 0.0008 slope; woody Wetlands 0.12, deciduous forest 0.12, grassland herbaceous 0.035, pasture hay 0.05	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	21,161	492.47
7	N values set to maximum	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	18,167	491.87
8[2]	Varying N values	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	25,575	491.35
					Gage Analysis:	24,300	491.26[1]

[1] Water surface elevation is approximate based on PeakFQ input data.

[2] Parameters from Iteration 8 were used for the final model.

Table 2.13: Sensitivity Analysis Results at USGS Gage 07342470

Iteration	Manning's N Zones	Breaklines	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
1	Pasture Hay 0.03	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	19,397	477.94
2	Woody wetlands 0.12, Pasture Hay 0.05, deciduous 0.12	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	17,143	478.06
3	Woody Wetlands 0.12, deciduous forest 0.12, & Pasture Hay 0.05, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	18,844	478.47
4	Woody Wetlands 0.12, deciduous forest 0.12, & Pasture Hay 0.03, grassland her 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	21,320	478.35
5	Mesh extended; woody Wetlands 0.12, Deciduous Forest 0.12, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	21,337	478.26
6	Emergent herbaceous 0.15 with 0.0008 slope; woody Wetlands 0.12, Deciduous Forest 0.12, grassland herbaceous 0.035, pasture hay 0.05	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	20,340	478.3
7	N values set to maximum	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	17,355	478.13
8[2]	Varying N values	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	25,024	477.9
					Gage Analysis:	18,950	482.86[1]

[1] Water surface elevation is approximate based on PeakFQ input data.
[2] Parameters from Iteration 8 were used for the final model.

Table 2.14: Sensitivity Analysis Results at USGS Gage 07342480

Iteration	Manning's N Zones	Breaklines	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
1	Pasture Hay 0.03	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	-	489.12
2	Woody wetlands 0.12, Pasture Hay 0.05, Deciduous 0.12	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	-	489.29
3	Woody Wetlands 0.12, Deciduous Forest 0.12, & Pasture Hay 0.05, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	9,969	489.34
4	Woody Wetlands 0.12, Deciduous Forest 0.12, & Pasture Hay 0.03, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	10,347	489.37
5	Mesh extended; woody Wetlands 0.12, Deciduous Forest 0.12, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	10,349	489.37
6	Emergent herbaceous 0.15 with 0.0008 slope; woody Wetlands 0.12, Deciduous Forest 0.12, grassland herbaceous 0.035, pasture hay 0.05	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	9,970	489.34
7	N values set to maximum	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	8,482	489.3
8[2]	Varying N values	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	11,372	489.35
					Gage Analysis:	10,920	489.84[1]

[1] Water surface elevation is approximate based on PeakFQ input data.
[2] Parameters from Iteration 8 were used for the final model.

Table 2.15: Sensitivity Analysis Results at USGS Gage 07342500

Iteration	Manning's N Zones	Breaklines	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
1	Pasture Hay 0.03	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	10,830	392.54
2	Woody wetlands 0.12, Pasture Hay 0.05, deciduous 0.12	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	-	392.78
3	Woody Wetlands 0.12, deciduous forest 0.12, & Pasture Hay 0.05, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	10,320	392.89
4	Woody Wetlands 0.12, deciduous forest 0.12, & Pasture Hay 0.03, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	10,696	392.95
5	Mesh extended; woody Wetlands 0.12, deciduous forest 0.12, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	11,872	393.22
6	Emergent herbaceous 0.15 with 0.0008 slope; woody Wetlands 0.12, deciduous forest 0.12, grassland herbaceous 0.035, pasture hay 0.05	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	5,116	393.22
7	N values set to maximum	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	10,381	392.81
8[2]	Varying N values	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	11,644	392.1
					Gage Analysis:	11,430	392.04[1]

[1] Water surface elevation is approximate based on PeakFQ input data.
[2] Parameters from Iteration 8 were used for the final model.

Table 2.16: Sensitivity Analysis Results at USGS Gage 07343000

Iteration	Manning's N Zones	Breaklines	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
1	Pasture Hay 0.03	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	70,732	407.01
2	Woody wetlands 0.12, Pasture Hay 0.05, deciduous 0.12	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 3 min	Normal Depth	64,362	407.77
3	Woody Wetlands 0.12, deciduous forest 0.12, & Pasture Hay 0.05, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	68,654	407.38
4	Woody Wetlands 0.12, deciduous forest 0.12, & Pasture Hay 0.03, grassland her 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	75,194	407.2
5	Mesh extended; woody Wetlands 0.12, deciduous forest 0.12, grassland herbaceous 0.035	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	73,394	407.21
6	Emergent herbaceous 0.15 with 0.0008 slope; woody Wetlands 0.12, deciduous forest 0.12, grassland herbaceous 0.035, pasture hay 0.05	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	68,944	407.94
7	N values set to maximum	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	67,825	407.29
8[2]	Varying N values	Major Roads w/Centerlines Enforced - Simplified	Excess Precipitation	Dry / 1 min	Normal Depth	89,145	406.8
					Gage Analysis:	89,510	406.98[1]

[1] Water surface elevation is approximate based on PeakFQ input data.

[2] Parameters from Iteration 8 were used for the final model.

2.4 Challenges

The estimation of the discharge rating curve for the Jim Chapman Dam within Sulphur Headwaters was another 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 gate operations of this structure.

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.

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 2.6 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.

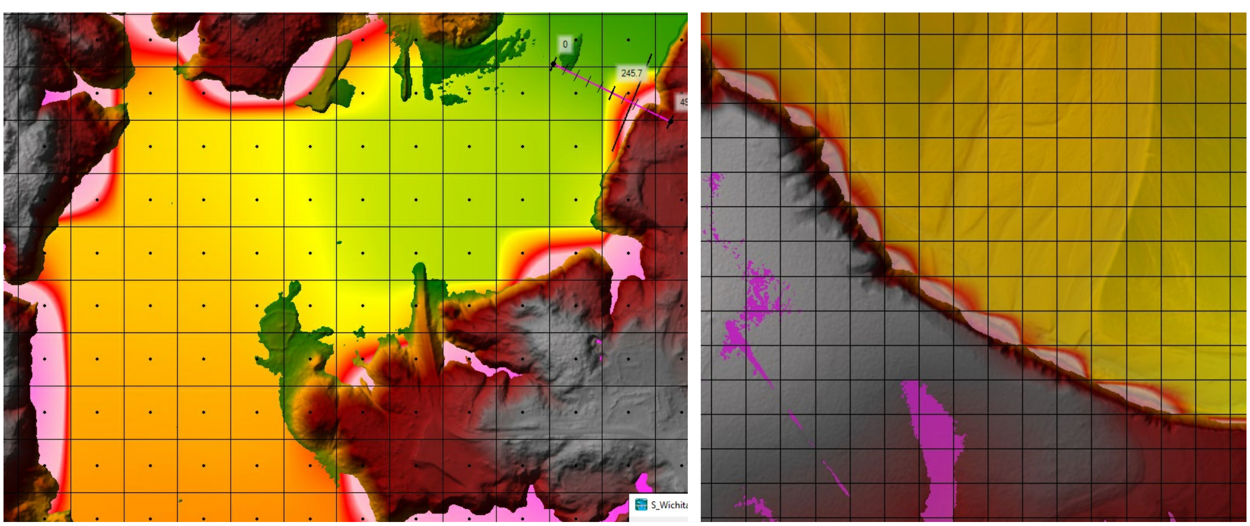

Figure 2.6: Cupping Examples

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 meshes. 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 Sulphur Headwaters 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 EBFE_FLD_HAZ_AR.

3.1.4 Mapping Considerations

3.1.4.1 Ponds

Numerous ponds exist through the Sulphur Headwaters 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-feet FEMA requirement. A significant tie-in occurs downstream of the Sulphur Headwaters Watershed with the Lower Sulphur Watershed. This portion of the Lower Sulphur West model was included in both the Lower Sulphur model and the Sulphur Headwaters model using an overlapping mesh to determine an appropriate tie-in location. The Sulphur Headwaters results replaced mapping in a portion of the Lower Sulphur Watershed.

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 Sulphur Headwaters 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 Sulphur Headwaters 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 Sulphur Headwaters 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 Sulphur Headwaters 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 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 744.4 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 White Oak Bayou Watershed.

Table 3.3: Aggregated Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	210.5
UNVERIFIED	BEING STUDIED	533.9

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					
Hickory Creek-South Sulphur River	111403010101	2,121	359	1,762	83.1	FAIL
Loring Creek-Spring Creek	111403010102	1,493	290	1,203	80.6	FAIL
Honey Creek-South Sulphur River	111403010103	1,613	334	1,279	79.3	FAIL
Rays Creek-South Sulphur River	111403010104	1,711	511	1,200	70.1	FAIL
Dunbar Creek-South Sulphur River	111403010105	1,495	338	1,157	77.4	FAIL
City of Commerce-South Sulphur River	111403010106	1,018	197	821	80.6	FAIL
Middle Sulphur River	111403010201	2,263	557	1,706	75.4	FAIL
Willow Oak Creek	111403010202	878	161	717	81.7	FAIL
Pecan Creek-Middle Sulphur River	111403010203	1,117	196	921	82.5	FAIL
Barnett Creek-Middle Sulphur River	111403010204	360	132	228	63.3	FAIL
West Fork Jernigan Creek	111403010205	151	41	110	72.8	FAIL
Cooper Lake	111403010208	1,339	257	1,082	80.8	FAIL
Pot Creek-North Sulphur River	111403010301	1,836	384	1,452	79.1	FAIL
Bralley Pool Creek-North Sulphur River	111403010302	2,218	624	1,594	71.9	FAIL
Baker Creek	111403010303	697	130	567	81.3	FAIL
Wafer Creek-North Sulphur River	111403010304	1,539	245	1,294	84.1	FAIL
Rowdy Creek-North Sulphur River	111403010305	1,298	185	1,113	85.7	PASS

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)
Watershed Name	Watershed Number					
Maxwell Creek-North Sulphur River	111403010306	1,289	191	1,098	85.2	PASS
Auds Creek	111403010307	2,331	302	2,029	87.0	PASS
Mallory Creek-North Sulphur River	111403010308	1,376	177	1,199	87.1	PASS
Big Creek-South Sulphur River	111403010401	104	26	78	75.0	FAIL
Brushy Creek-South Sulphur River	111403010402	405	56	349	86.2	PASS
Morgan Creek-South Sulphur River	111403010403	658	87	571	86.8	PASS
Big Sandy Creek	111403010405	1,918	435	1,483	77.3	FAIL
Hickory Creek-North Sulphur River	111403010406	1,250	391	859	68.7	FAIL
North Sulphur River-South Sulphur River	111403010407	918	383	535	58.3	FAIL

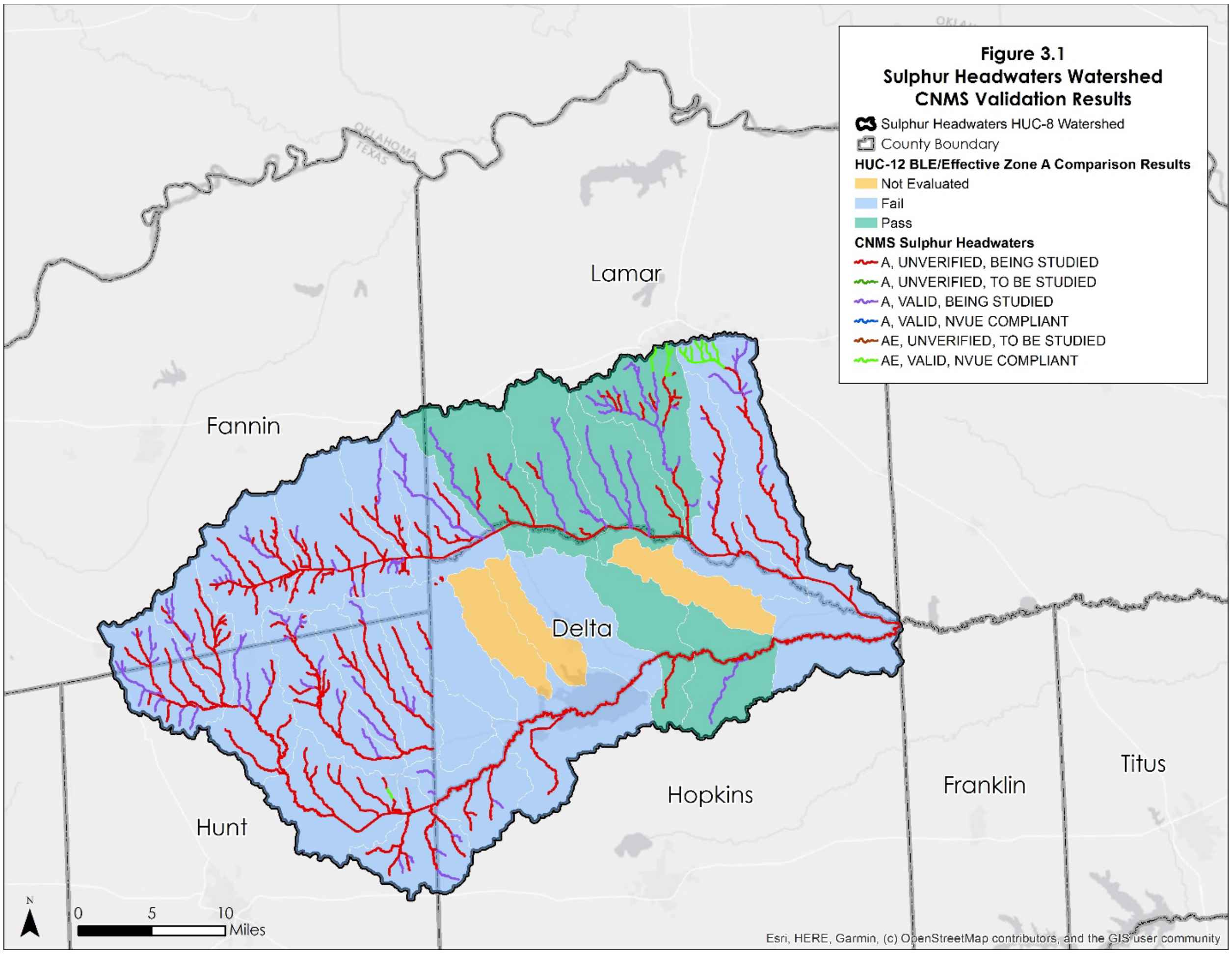

Figure 3.1: Sulphur Headwaters Watershed CNMS Validation Results

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 parish within the project watershed extends for each return period to ensure proper model processing. A summary of results per parish for the 100-year scenarios are shown in Table 3.5.

Table 3.5: Hazus 5.1 (SP02) Results for 1-percent-ACE Scenario for Sulphur Headwaters Watershed, Texas

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Delta	$30,680,000.00	$476,578,000.00	$294,388,000.00
Fannin	$9,459,000.00	$438,357,000.00	$256,471,000.00
Franklin	$0, No Loss	$1,787,000.00	$939,000.00
Hopkins	$4,915,000.00	$190,592,000.00	$99,737,000.00
Hunt	$50,201,000.00	$1,340,372,000.00	$825,392,000.00
Lamar	$104,771,000.00	$2,632,296,000.00	$1,823,599,000.00
Total	**$200,026,000.00**	**$5,079,982,000.00**	**$3,300,526,000.00**

04 References

1. Chow, Ven T. "Development of Uniform Flow and It Formulas." *Open Channel Hydraulics*. Caldwell, NJ: Blackburn, 1959. 109-113. Print.
2. City of Dallas, "Drainage Design Manual." September 2019 (https://dallascityhall.com/departments/public-works/DCH%20Documents/Public%20Works/pdf/Drainage%20Design%20Manual_091019.pdf).
3. FEMA, "Coordinated Needs Management Strategy (CNMS) Technical Reference", November 2021 (https://www.fema.gov/sites/default/files/documents/fema_CNMS-technical-reference_112021.pdf).
4. FEMA, 'Data Capture Technical Reference", November 2021, (https://www.fema.gov/sites/default/files/documents/fema_data-capture-technical-reference_112021.pdf).
5. FEMA, "Flood Risk Database Technical Reference", February 2018 (https://www.fema.gov/sites/default/files/2020-02/Flood_Risk_Database_Technical_Reference_Feb_2018.pdf).
6. FEMA, "Guidance for Flood Risk Analysis and Mapping – Base Level Engineering (BLE) Analyses and Mapping", February 2018. (https://www.fema.gov/media-library-data/1526489690918-2862bece100f28564c4167aaf4b2378b/Base_Level_Engineering_Guidance_Feb_2018.pdf).
7. NOAA, "NOAA Atlas 14 Precipitation-Frequency Atlas of the United States", 2013. Volume 9, Version 2.0. (https://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume9.pdf).
8. U.S. Army Corps of Engineers, Hydrologic Engineering Center. (March 2019). HEC-RAS River Analysis System, Version 5.0.7 Davis, California.
9. USGS, "Estimating Magnitude and Frequency of Floods Using PeakFQ Program: USGS Fact Sheet", 2006.
10. USGS, "Estimating Magnitude and Frequency of Floods Using PeakFQ Program: USGS Fact Sheet", 2006.
11. USGS. Multi-Resolution Land Characteristics Consortium. *National Land Cover Database 2019*. (https://www.mrlc.gov/data/nlcd-2019-land-cover-conus).