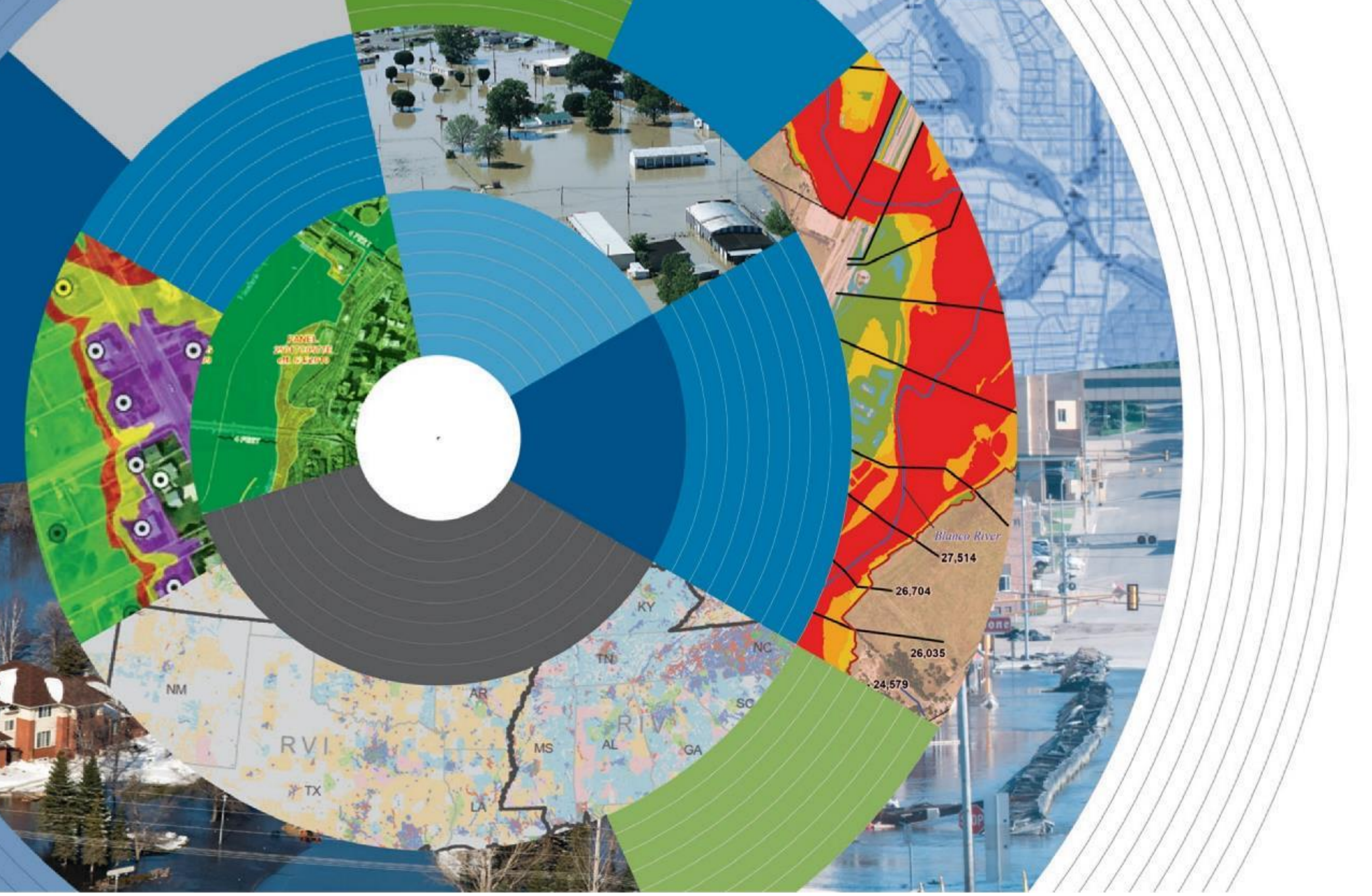

2D Base Level Engineering Report

Upper Beaver Watershed (HUC 8 11100101)

FEMA

April 22, 2024

Version 1.0

Report Prepared for:

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Revision History

Version Number	Version Date	Summary of Changes	Author
1.0	April 2024	Deliverable to FEMA Region VI	Compass PTS JV

Table of Contents

List of Figures

List of Tables

Executive Summary

FEMA Region 6 contracted Compass to complete a Base Level Engineering (BLE) analysis for the Upper Beaver Hydrologic Unit Code 8 (HUC 8) Watershed in Oklahoma, Texas and New Mexico to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHAs). The BLE process involves using the best available data and incorporating automated techniques with traditional model development procedures to produce regulatory-quality flood hazard boundaries for the 1-percent annual chance event and estimate 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 in the respective sections throughout this report.

Flood discharges for this study were calibrated using the United States Geological Survey (USGS) regression equations. Regression equation discharges were obtained using the USGS Streamstats online application for locations in New Mexico, and Oklahoma. Texas regression equations were used per USGS Scientific Investigations Report 2009-5087. A gage analysis was performed however these results were not used in the calibration of this study due to insufficient records.

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) program version 6.3.1 was used to compute water surface elevations and peak flows using 2D analysis.

The stream mile network that was validated for this watershed was compiled using FEMA's Community Needs Management Strategy (CNMS) inventory. CNMS is an inventory of flood hazard studies and flood hazard mapping needs for areas where a study is needed. This data is helpful for community officials in analyzing and depicting flood hazards to enhance the understanding of flood risks. Communities may use this information to make informed decisions on their planning and flood mitigation efforts. Table 1 lists the Zone A stream miles associated with this validation analysis.

Table 1: Summary of Stream Miles

Source	Stream Miles
Current Inventory – CNMS (S_Studies_Ln)	84.7
New Study Streams – CNMS (S_Unmapped_Ln) Informed by NHD 1:100	0.0
Total (BLE) Stream Miles	**84.7**

The full inventory of Zone A studies in the watershed were classified in CNMS. Total miles validated in CNMS are summarized in Table 2 and illustrated in Figure 1 below. There aren't any Zone A studies in the Upper Beaver Watershed due to lack of previously effective data.

Table 2: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment/Total (miles)
VALID	BEING STUDIED	0	4.7
UNVERIFIED	BEING STUDIED	84.7	80

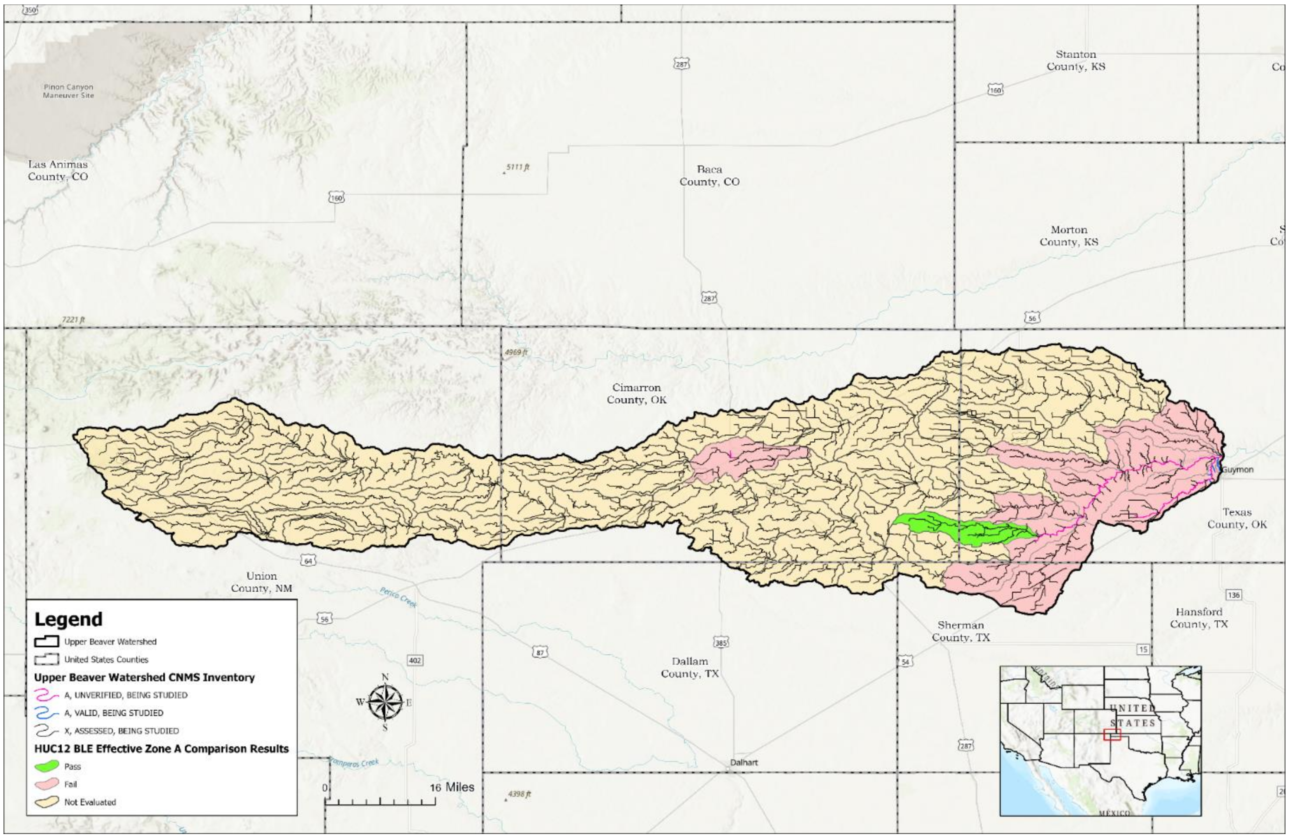

Figure 1: Upper Beaver – HUC 8 CNMS Validation Results

2D Base Level Engineering (BLE) Methodology

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 traditional 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 Upper Beaver Watershed BLE documented here was designed to use 2-dimensional (2D) modeling efforts with enhancements and calibration to develop products intended to be transitioned into regulatory data development workflows.

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 Coordinated Needs Management Strategy (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 Identification (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 large volume of data resulting from a BLE 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.

In an effort to increase and enhance the flood risk products in Oklahoma, Texas and New Mexico, FEMA Region VI contracted the Compass PTS JV to perform a BLE analysis for the Upper Beaver Watershed. This report documents the BLE process, products, and results for this watershed. Figure 2 depicts the Upper Beaver Watershed footprint.

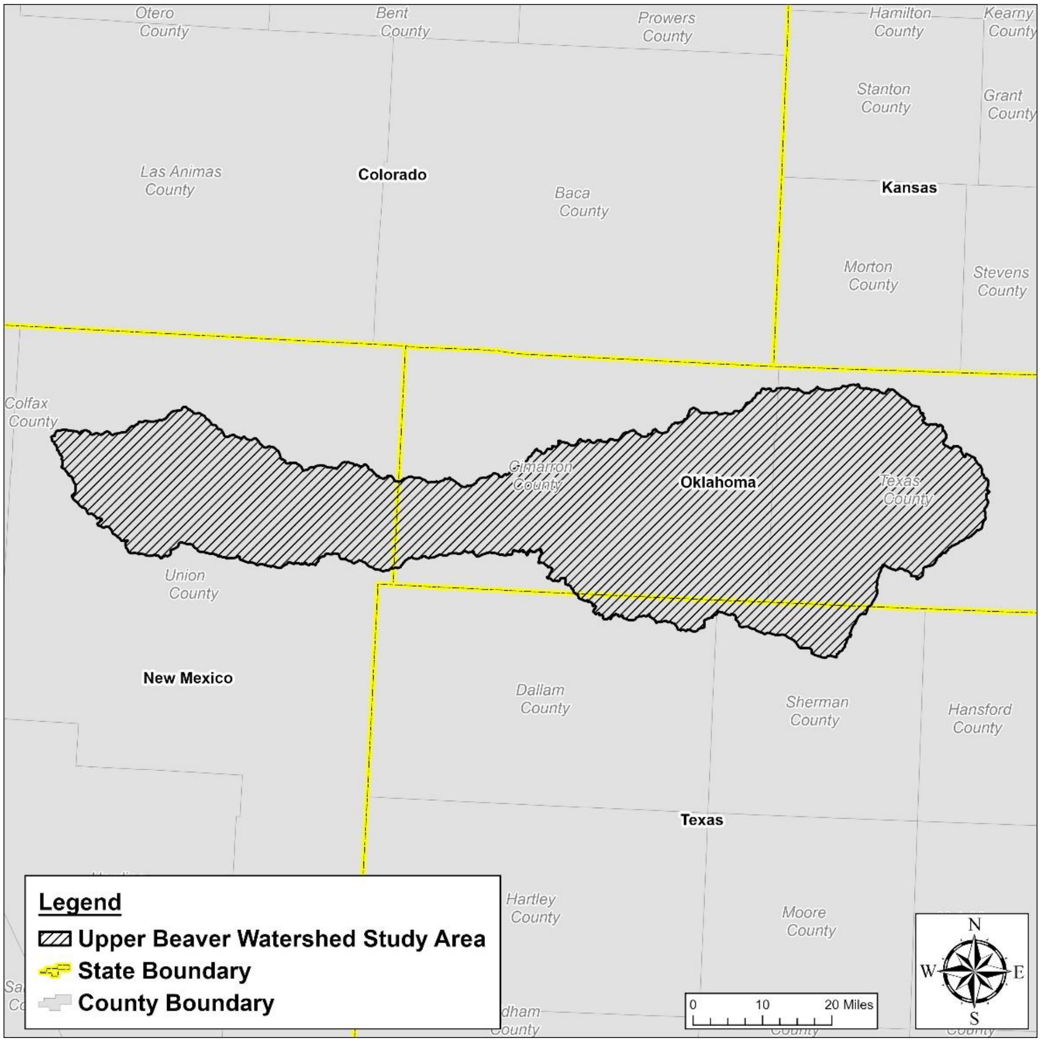

Figure 2: Upper Beaver Watershed

The BLE assessment prepared Zone A analyses for approximately 2,714 miles of stream reaches within the Upper Beaver Watershed. The selection and extent of stream reaches studied was based upon the number of stream miles with minimum drainage area of one square mile AND the number of effective Zone A stream miles. Study reaches were extended above this one square mile threshold as appropriate to ensure all effective Zone A floodplain received an updated analysis. The following sections will summarize the BLE process and will discuss the results along with their recommended use.

Topographic Data

A high-resolution Digital Elevation Model (DEM) is a fundamental component for 2D engineering analyses by providing a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the Upper Beaver BLE project by leveraging available high-resolution gridded elevation data derived from Light Detection and Ranging (Lidar) collections throughout the watershed within New Mexico, Oklahoma and Texas. The 10-foot DEM developed to support the 2D BLE modeling and analysis, within the Upper Beaver 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 below. 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 Upper Beaver Watershed.

Inventory

An inventory of existing topographic data was conducted for the Upper Beaver BLE project footprint. Figure 3 depicts the datasets identified for leveraged across the project area. FEMA, National Oceanic Atmospheric Administration (NOAA), USGS, and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

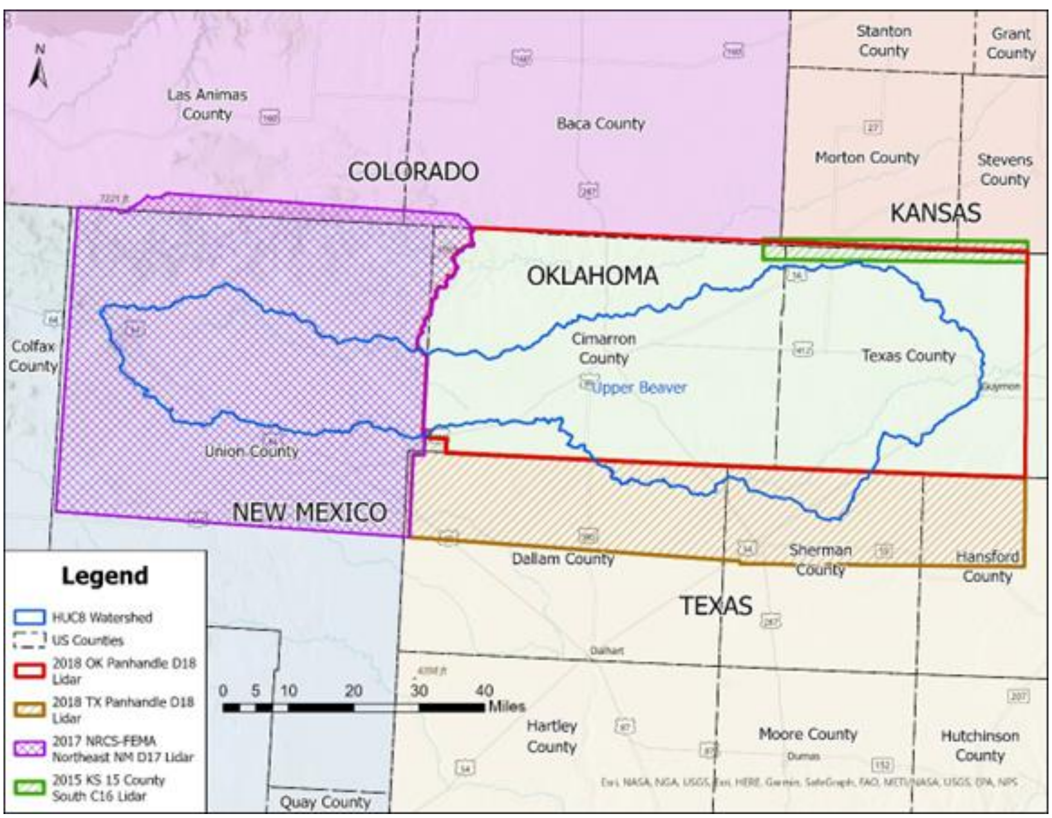

Figure 3. Available Topographic Source Data for Upper Beaver HUC 8 Watershed

Evaluation

The initial step in developing terrain data for the Upper Beaver Watershed included gathering data. Five Lidar datasets were identified to be leveraged for the watershed. These datasets were assessed based on accuracy, age of acquisition, and coverage area. Detailed descriptions of the data follows in the next section. The following table lists the prioritization of these datasets.

Table 3: LiDAR Data Sources

Priority	Source	Collection Date	Vertical Accuracy	Horizontal Accuracy	Point Spacing	Vertical Datum	Horizontal Datum
1	2018 TX Panhandle D18 Lidar	February 9, 2018 - May 20, 2018	7.2 cm RMSEz	Not Provided	0.7 m	NAVD88, GEOID 12B	NAD83 (2011)
2	2018 OK Panhandle D18 Lidar	January 8, 2019 - March 7, 2019	11.8 cm; UTM 13 8.8 cm; UTM14 RMSEz	+/- 36.0 cm	0.71 m	NAVD88, GEOID 12B	NAD83 (2011)
3	2017 NRCS FEMA Northeast NM D17 Lidar	November 20, 2017 - February 11, 2018	9.8 cm	Not Provided	0.7 m	NAVD88, GEOID 12B	NAD83 (2011)
4	2015 KS 15 County South C16 Lidar	November 24, 2015	6.0 cm RMSEz	12.99 cm RMSEr	0.64 m	NAVD88 GEOID 12A	NAD83 HARN

RMSEr =root mean square error horizontal; RMSEz =root mean square error vertical;
NRCS=Natural Resources Conservation Service; HARN=High Accuracy Reference Network
NAVD=North American Vertical Datum of 1988; NAD83=North American Datum of 1983;
Lidar=Light Detection and Ranging; m=meters; cm=centimeters

Upper Beaver Source Terrain Data

2018 TX Panhandle D18 Lidar

The 2018 TX Panhandle D18 Lidar project task order was issued by the U.S. Geological Survey National Geospatial Technical Operations Center (USGS-NGTOC). This task order called for the acquisition and processing of Quality Level 2 (QL2) data over one area of interest covering approximately 34,005 square miles across 38 partial and full counties in the Texas Panhandle and Red River regions in northern Texas and western Oklahoma. Data for this task order was acquired and produced to meet USGS Lidar Base Specification v1.2 standards and the American Society of Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0).

Lidar data was collected from February 9, 2018 through May 20, 2018 by Woolpert. The data was horizontally referenced to NAD83 (2011) Universal Transverse Mercator (UTM) Zones 13 and 14, meters. Vertical datum was North American Vertical Datum of 1988 (NAVD88) (GEOID12B) with elevations in meters. The 1-meter bare-earth DEMs were acquired from the National Map Download (https://apps.nationalmap.gov/downloader/).

This project required that the calculated NVA of the DEM dataset was required to meet 19.6 cm at a 95 percent confidence level using a Root Mean Square Error (RMSEz) target value of 10 cm x 1.9600. VVA was required to meet 0.294 cm at the 95th percentile error. Testing was assessed and reported using guidelines developed by the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS). The bare-earth DEM NVA measured 0.072 meters using an RMSEz of 0.037 meters x 1.9600 using 619 checkpoints. VVA of the bare-earth DEM tested 0.218 meters at the 95th percentile using 423 checkpoints.

2018 OK Panhandle D18 Lidar

The 2018 OK Panhandle 2018 D18 task order was issued by the USGS NGTOC and called for the acquisition and processing of QL2 Lidar data over three areas of interest covering approximately 7,176 square miles across the Oklahoma Panhandle region. The data fully covers Beaver, Cimarron, Ottawa, and Texas Counties and partially covers Cleveland and Oklahoma Counties. Data for this task order was acquired and produced to meet USGS Lidar Base Specification v1.3 standards and the ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0).

Lidar data was collected from January 8, 2019 through March 7, 2019 by Woolpert. The data collected during Oklahoma Panhandle (Block 1) was horizontally referenced to NAD83 (2011) UTM Zone 13, meters. Vertical datum was NAVD88 (GEOID12B) with elevations in meters. The data collected during Oklahoma Panhandle (Block 2) and Oklahoma City (Block 1) was horizontally referenced to NAD83 (2011) UTM Zone 14, meters. Vertical datum was NAVD88 (GEOID12B) with elevations in meters. The 1-meter bare-earth DEMs were acquired from the National Map Download (https://apps.nationalmap.gov/downloader/).

For the Oklahoma Panhandle and Oklahoma City AOIs, the data sets were produced to meet ASPRS "Positional Accuracy Standards for Digital Geospatial Data" (2014) for a 14.7 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 36.0 cm at a 95 percent confidence level.

AccuracyZ has been tested to meet 19.6 cm or better NVA at 95 percent confidence level using RMSEz x 1.9600 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines. The bare-earth DEM NVA was tested using 168 checkpoints to be the following:

- UTM Zone 13 (OK Panhandle Block 1): 0.116 meters, RMSEz of 0.059 meters x 1.9600; 43 checkpoints
- UTM Zone 14 (OK Panhandle Block 2): 0.092 meters, RMSEz of 0.047 meters x 1.9600; 125 checkpoints

2017 NRCS-FEMA Northeast NM D17 Lidar

The Lidar portion of the Natural Resources Conservation Service (NRCS) FEMA Northeast 2017 D17 task order issued by the USGS-NGTOC called for the acquisition and processing of QL2 data over New Mexico and Colorado NRCS. Data for this task order was acquired and produced to meet USGS Lidar Base Specification v1.2 standards and the ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0). The project area consists of approximately 15,038 square miles over portions of Northeast New Mexico, Southeast Colorado, and a small portion of Western Oklahoma.

Lidar was collected from November 20, 2017 through February 11, 2018 by Woolpert while rivers were at or below normal levels. The spatial reference system for this project was UTM Zone 13 North. The horizontal datum was referenced to NAD83 (2011) meters with vertical datum referenced to NAVD88 meters, GEOID12B. The 1-meter bare-earth DEMs were acquired from the National Map Download (https://apps.nationalmap.gov/downloader/).

This data set was produced to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10-cm RMSEz Vertical Accuracy Class. The NVA of the bare-earth DEM was tested to be 0.098 meters RMSEz of 0.050 meters x 1.9600 using 366 checkpoints. The VVA was tested as 0.141 meters at the 95th percentile using 262 checkpoints.

2015 KS 15 County South C16 Lidar

The 2015 Kansas 15 County South C16 Lidar-derived DEM data covers the entire 2,633 square mile Area of Interest intended for this project task. Atlantic acquired the Lidar in seven flight missions completed on November 24, 2015.

The horizontal datum was referenced to NAD83 (HARN) UTM Zone 14, meters. Vertical datum was referenced to NAVD88 (GEOID12A) with units in meters. The 1-meter bare-earth DEMs were acquired from the National Map Download (https://apps.nationalmap.gov/downloader/).

Vertical Accuracy of the point cloud and bare-earth Lidar data was assessed and reported in accordance with the ASPRS Positional Accuracy Standards for Digital Geospatial Data. This data set was required to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10.0 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy of the bare-earth was found to be RMSEz equal to 5.9 cm, equating to +/- 11.7 cm at 95 percent confidence level. The NVA of the bare-earth DEM was tested at 6.0 cm RMSEz. The actual VVA accuracy was found to be +/-23.3 cm at the 95th percentile.

The ASPRS Positional Accuracy Standards for Digital Geospatial Data for horizontal errors specify that the expected radial horizontal positional error should be RMSEr equal to 12.99cm.

Data Processing and DEM Quality Assurance/Quality Control (QA/QC)

The source 1-meter bare earth DEMs from the Lidar datasets used were compiled in order of vertical accuracy into a mosaic dataset using ArcPro. The mosaics were projected to NAD83 State Plane Oklahoma North FIPS 3501 Feet US horizontal projection. Elevation units were converted from meters to feet with vertical datum in NAVD88. From this mosaic, a seamless 1-meter bare-earth DEM was exported. The mosaic 1-meter DEM were clipped to work areas with a 10,000 foot buffer. Figure 4 shows the final DEM for the Upper Beaver HUC 8 Watershed.

A qualitative visual inspection of the composite DEM was performed to ensure no voids and/or artifacts were present. The qualitative visual inspection of the composite DEM also utilized hillshades derived from the 1-meter mosaic DEM. Raster outliers were also generated for locations with high slope or change in elevation. No indications of unusual or non-terrestrial features or data gaps were observed in the composite DEM, assuring the surface files used for hydrologic and hydraulic analyses and floodplain mapping activities are sufficient for BLE analysis. The DEM surface model was affirmed to be suitable for hydraulic takeoffs and supporting other hydraulic analyses.

Stream centerlines were created using ArcHydro tools. Cutlines were created at culvert and dam locations and were used to recondition the DEM to ensure flow contribution to correct drainage basins. A visual QC was performed to ensure proper stream alignment through dams and culverts and to ensure the streamlines represented the stream bed channel correctly. Manual adjustment was applied where necessary as well as ensuring the stream did not jump a channel bank and flow into a neighboring stream. These final streams will be used for BLE modeling and mapping. Streams as breaklines will be provided within the Hydraulics submittal.

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

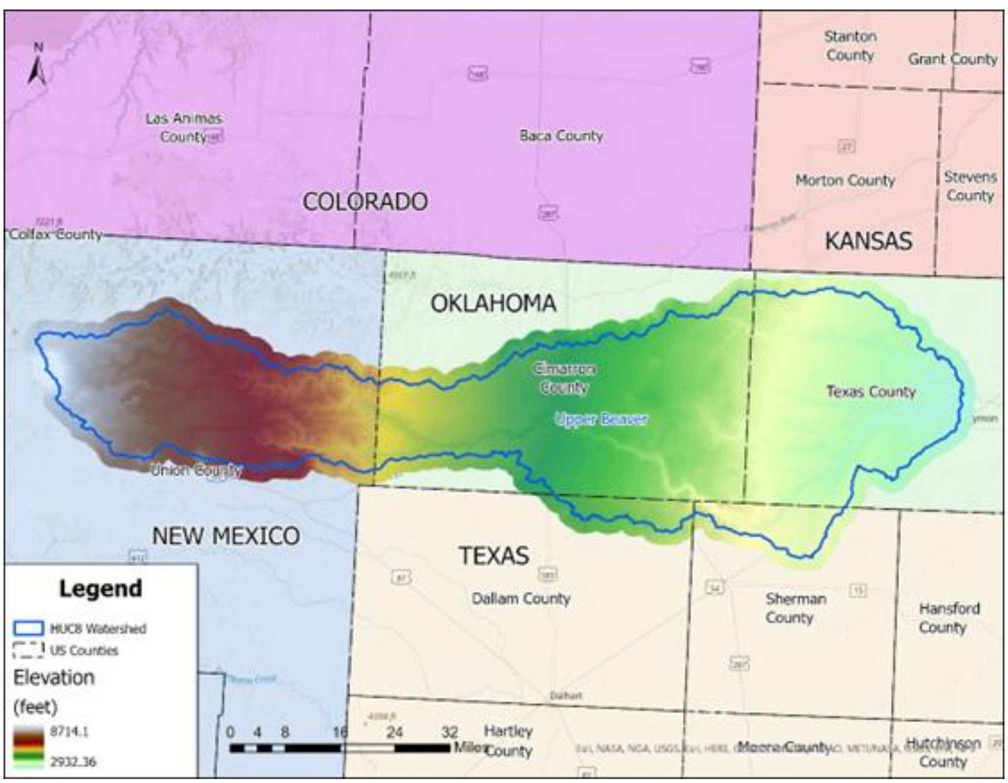

Figure 4: Final 1-meter DEM for Upper Beaver HUC 8 Watershed

2D BLE Parameters

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. HEC-RAS version 6.3.1 was used for this project. The Upper Beaver HUC 8 Watershed covers an area of 2,742 square miles. To accurately model the area and provide a sufficient level of hydraulic and hydrologic detail, the HUC 8 was split into six modeling areas (Upper Beaver 1-6) based on HUC 10 watersheds as shown in Figure 5.

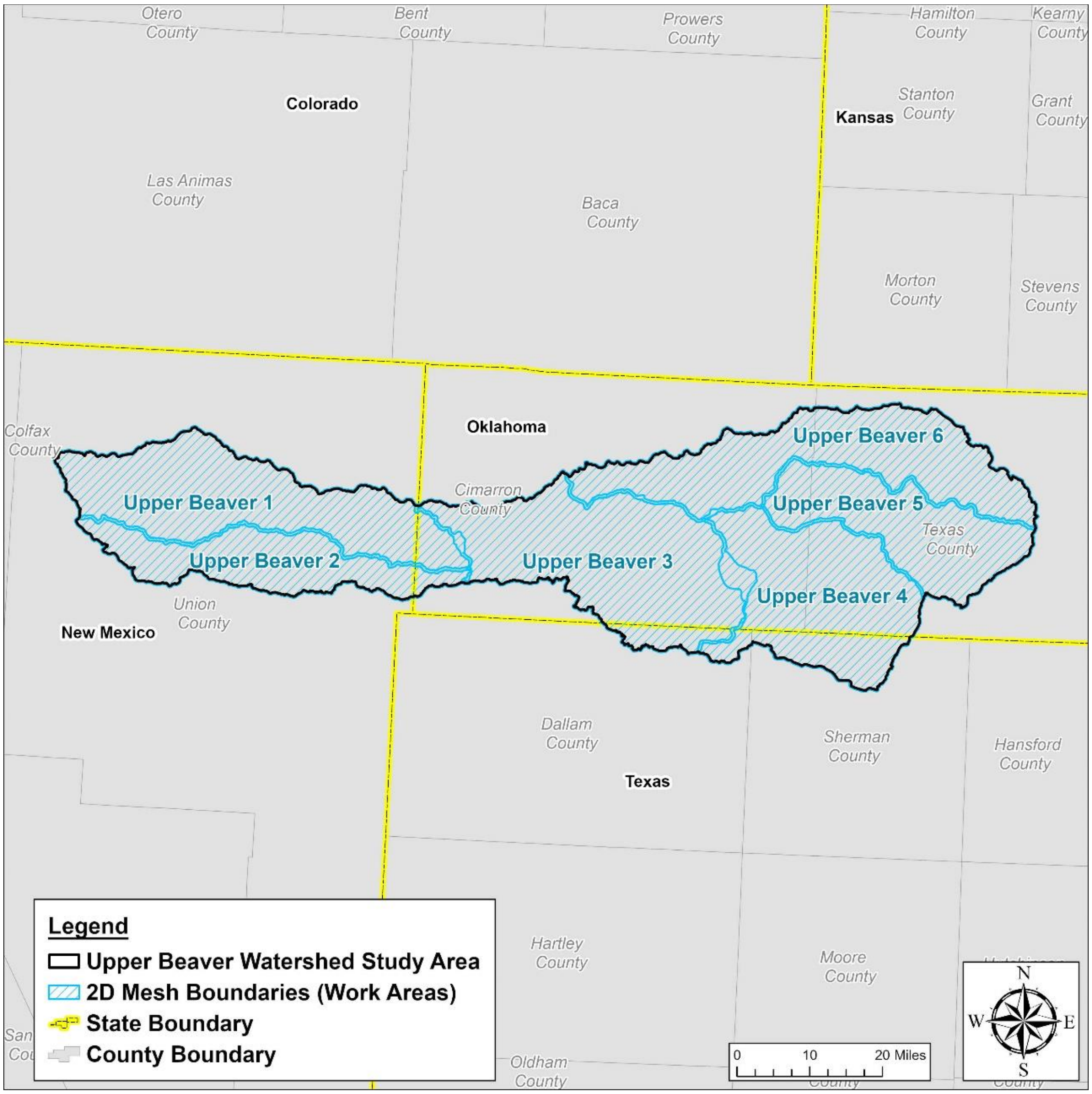

Figure 5: HEC-RAS 2D BLE Model Areas

2D Computational Mesh and Settings

The HEC-RAS 6.3.1 2D computational mesh was created for each model area using RAS Mapper and supplemented with ArcGIS toolsets, which reduced the need for manual edits to mesh cells within HEC-RAS 6.3.1 that resulted in error generation. Each individual model's 2D mesh nominal cell size is 200 feet, with additional refinement to include 100-foot cells within scoped stream areas and 50-foot cells within community boundaries. To ensure smooth mapping and tie-ins, a 1,000-foot buffer was added to each modeling area's boundary.

The HEC-RAS 6.3.1 model was run with the Diffusion Wave (simplified Full Momentum) equations. An adaptive 1-minute time step was used to allow the model to lower the time step, as necessary, to keep the maximum Courant Number under 1.5 for the duration of the simulation. The time step was set to reach 120 seconds as the maximum and 7.5 seconds as the minimum. Table 4 shows a summary of the methodology and settings used for this 2D BLE study.

Table 4: Summary of 2D Computational Settings

Model Settings	BLE Methodology Used
Equation	Diffusion Wave Equation (DWE) - Simplified Full Momentum
Initial Conditions	Start Completely Dry
Initial Time Step	1 Minute
Adaptive Time Step	Range from 7.5 to 120 seconds based on maximum Courant number of 1.5
Nominal Mesh	• 200-FT x 200-FT cell size • 4-sided (nominal)
Mesh Refinement	• 1-square mile streams and roads/rails, 100-FT cell size • Communities and roads/rails/streams within boundaries, 50-FT cell size • Additional refinement along transportation features and dams

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 computation times. The 2D mesh for the model was set as evenly spaced cells at 200 feet. The mesh was further refined by placing breaklines along roads, berms, ridges, and other high ground that can influence the flow. Table 5 lists the specific work areas and 2D cell counts used to cover the project footprint and facilitate proper water surface elevation (WSEL) tie-ins.

Table 5: Work Area Cell Count

Work Area	Area (mi^2)	Cell Count
Upper Beaver 1	520	445,079
Upper Beaver 2	291	256,852
Upper Beaver 3	583	591,753
Upper Beaver 4	487	443,586
Upper Beaver 5	344	352,862
Upper Beaver 6	508	489,532

Model and Boundary Condition Setup

Using HEC-RAS rain-on-grid modeling requires establishing a 2D computational mesh boundary. For this project, precipitation was applied to the mesh and losses were calculated within HEC-RAS using the Soil

Conservation Service (SCS) Curve Number (CN) method. RAS 6.3.1 2D modeling has multiple options to define boundary and initial conditions. Based on the characteristics of the studied watershed, the options for boundary conditions are listed in Table 6 below:

Table 6: HEC-RAS Boundary Condition Options

Boundary Condition	Type	Used (Yes/No)
External	Flow Hydrograph	Yes
	Stage Hydrograph	No
	Normal Depth	Yes
	Rating Curve	No
Internal	Flow Hydrograph	No
	Precipitation	No
Global	Precipitation	Yes
	Evapotranspiration	No
	Wind	No

Outflow boundary conditions (from the computational 2D mesh) were utilized along basin boundaries using normal depths. Unique outflow boundaries were established for obvious riverine outflows, while the remaining boundaries were defined as continuous boundaries to allow drainage from adjacent basins to leave the model area freely. Normal depth was used for all non-unique outflow boundary conditions using approximate energy grade-line slopes estimated from the Lidar terrain data. Figure 6 shows the mesh of each model area along with the gages in this study area.

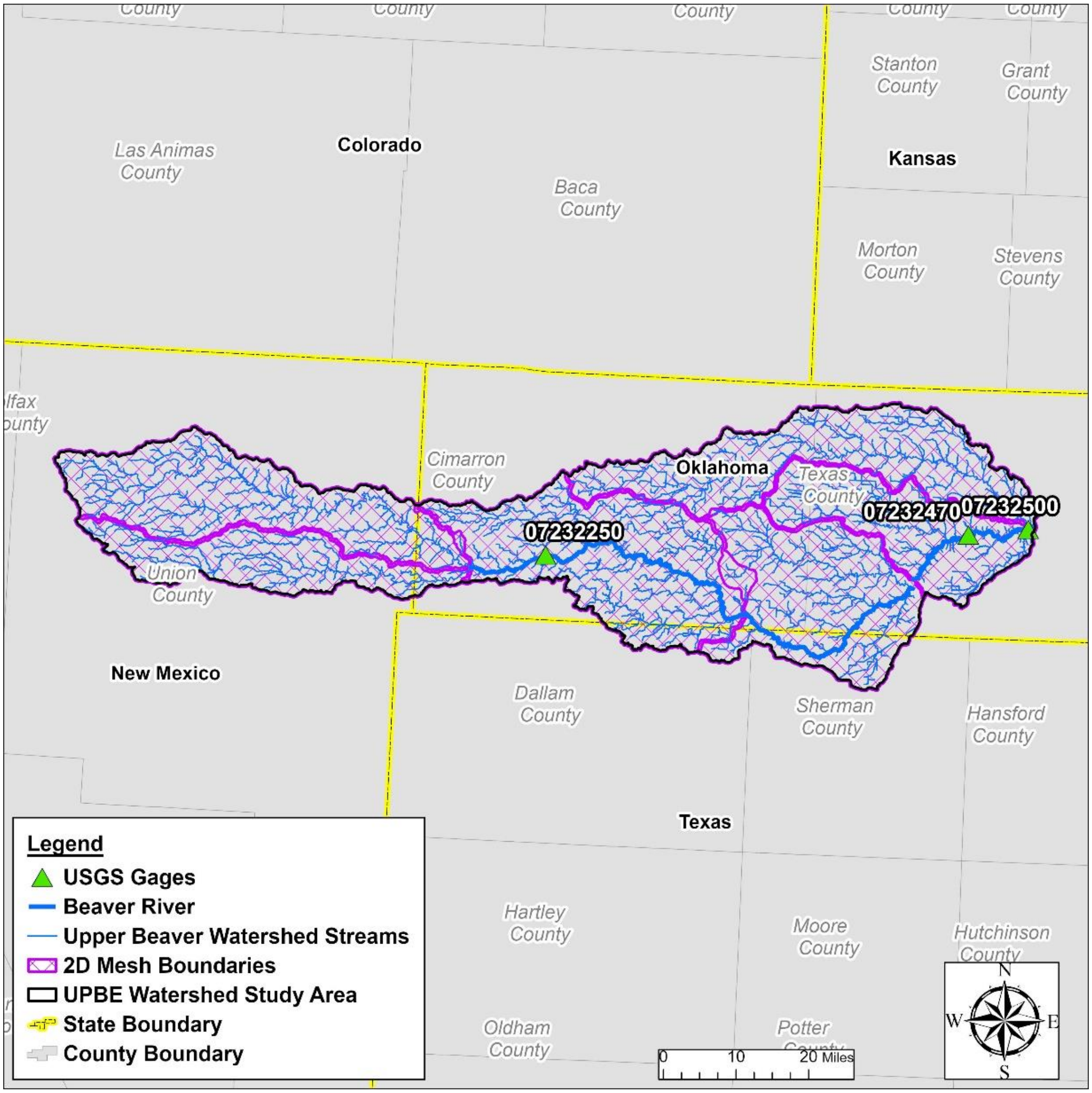

Figure 6: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages

Hydrology

A series of tasks were undertaken to gain insights into the study area's hydrological characteristics. These tasks encompassed acquiring datasets, including Land Use and Land Cover (LULC) data, soil data, and precipitation data; generating essential Hierarchical Data Format (HDF) RAS layers within the HEC-RAS software for infiltration, soils, and LULC; developing lookup tables for Manning's n and Curve Number; converting gridded precipitation data from ASCII to DSS format for compatibility; reviewing local studies equations for Area Reduction Factor (ARF) computation; and performing gage analysis to interpret hydrological data from USGS gages for calibration. These tasks collectively contributed to a thorough exploration of the hydrological aspects of the study area within the framework of 2D rain-on-grid modeling using HEC-RAS.

Precipitation frequency estimates for the study were acquired from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 data server, which is accessible at (https://hdsc.nws.noaa.gov/pfds/pfds_gis.html). The geographical focus of the study pertains to the Upper Beaver region across New Mexico, Oklahoma, and Texas. The watershed falls within three different regions (semiarid southwest area, Midwestern states and Texas) of the aforementioned data server. Upper Beaver 1 and Upper Beaver 2 models predominantly align with the semiarid southwest area as defined in Volume 1. Upper Beaver 3-6 align with Midwestern and Texas rainfall patterns that were used as defined in Volume 8 and Volume 11 respectively. The data retrieval process involved obtaining spatial grids in the ASC file format from each of these two regions, which depict 24-hour precipitation depths for various return periods, including 10-year, 25-year, 50-year, 100-year, and 500-year events. Furthermore, 1% plus, and 1% minus precipitation was calculated from upper and lower confidence limits for the 1% annual chance precipitation frequency estimate, as described later in this report. Since Upper Beaver spans over multiple regions, the three grids were merged together and used as one grid file in order to cover the entire watershed. To transform the gridded precipitation data and generate rasters at 6-minute intervals, Python programming was utilized. For Upper Beaver 1 and 2, the study areas falls under the Southwest 3 (SW-3) temporal distributions, which was applied to the gridded data. This process yielded a total of 240 individual rasters, each representing a specific time distribution of precipitation data. To incorporate these rasters into the DSS format, a specialized tool, developed by the US Army Corps of Engineering, Vortex was employed. Vortex seamlessly integrated these 6-minute interval rasters into the DSS file generated by HEC-DSSVue. Subsequently, this precipitation file in DSS format was used in the HEC-RAS model, employing the rain-on-mesh technique to simulate the runoff process. The same process to create the DSS file was used for Upper Beaver 3-6 models but using the Midwest 2 (MSE2) temporal distribution instead.

The validation of flows was conducted using USGS Streamstats Batch Processor v506 and well established USGS gages. This batch processing tool employs aerial regression equations to determine the peak discharges corresponding to the calibration points. There are three USGS stream gages in the Upper Beaver HUC 8 watershed. A summary of the characteristics for the gages is listed in the Table 7:

Table 7: USGS Peak Streamflow Gages with the Upper Beaver HUC 8 Watershed

Gage ID	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
07232500	Beaver River near Guymon, OK	2,139	1937-1993
07232470	Beaver River near Goodwell, OK	2,281	2002-2003
07232250	Beaver River near Felt, OK	879	1981-2002

Gage 07232470 was not utilized in this study due to the minimal years of record. In addition, Gage 07232500 was not utilized due to outdated records that were more than 30 years ago. For Gage 07232250, half of the records available had gage height recorded below the minimum recordable elevation. These observations expanded the confidence interval and result in higher discharges generated by PeakFQ. Based off the results of the gage analysis, it was decided not to use this gage for calibration. The data recorded for Gage 07232250 was also more than 20 years old.

Since no gages were used to validate model results, multiple StreamStats locations were used to calibrate and compare with throughout the entire Upper Beaver Watershed.

Rain-on-Mesh (RoM) Precipitation for 2D Computational Mesh

HEC-RAS version 6.3.1 was used to apply a spatially varied 24-hour design storm hyetograph input to the pluvial model plans for each exceedance probability. The spatially varied 24-hour precipitation grids from NOAA Atlas 14 (NOAA, 2018) for the states of New Mexico, Oklahoma, and Texas were spliced into incremental 6-minute grids to apply a set of time-series grids for the 24-hour period following the specified rainfall distribution. These 6-minute splices were then combined using HEC-DSS Vue version 3.2.3 to create a gridded dataset allowing for incremental spatial rainfall input to the HEC-RAS model. A regionally appropriate ARF was applied to each model area's plans globally which was then applied to the gridded rainfall input.

Depending on the model, the NRCS Nested Distribution developed for either the Southwest Region or Midwest Region, as shown in Figure 7, was used for defining storm distributions of the spatially varied rainfall input. The nested distribution approach allows for smaller duration rainfall events to be nested within the greater 24-hour duration storm event for every recurrent interval. This is important to represent hydrology in smaller sub-basins within each model, where the controlling duration is often shorter and more intense than larger basins.

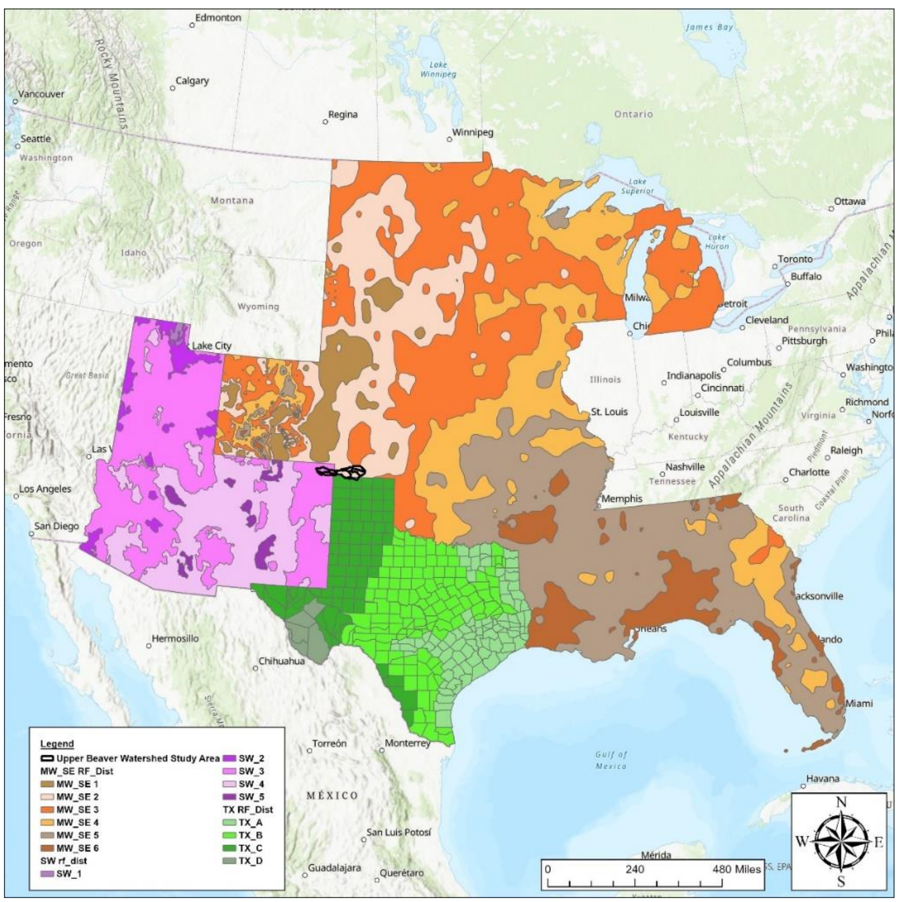

Figure 7: NRCS Nested Distribution Zones – Southwest, Midwest, and Texas

Figure 8 shows an example of spatially varied precipitation depths after the application of the ARF at the scalar (cell) level. These precipitation depths represent the total accumulated rainfall in the RAS model during the 24-hour design storm period at that physical location.

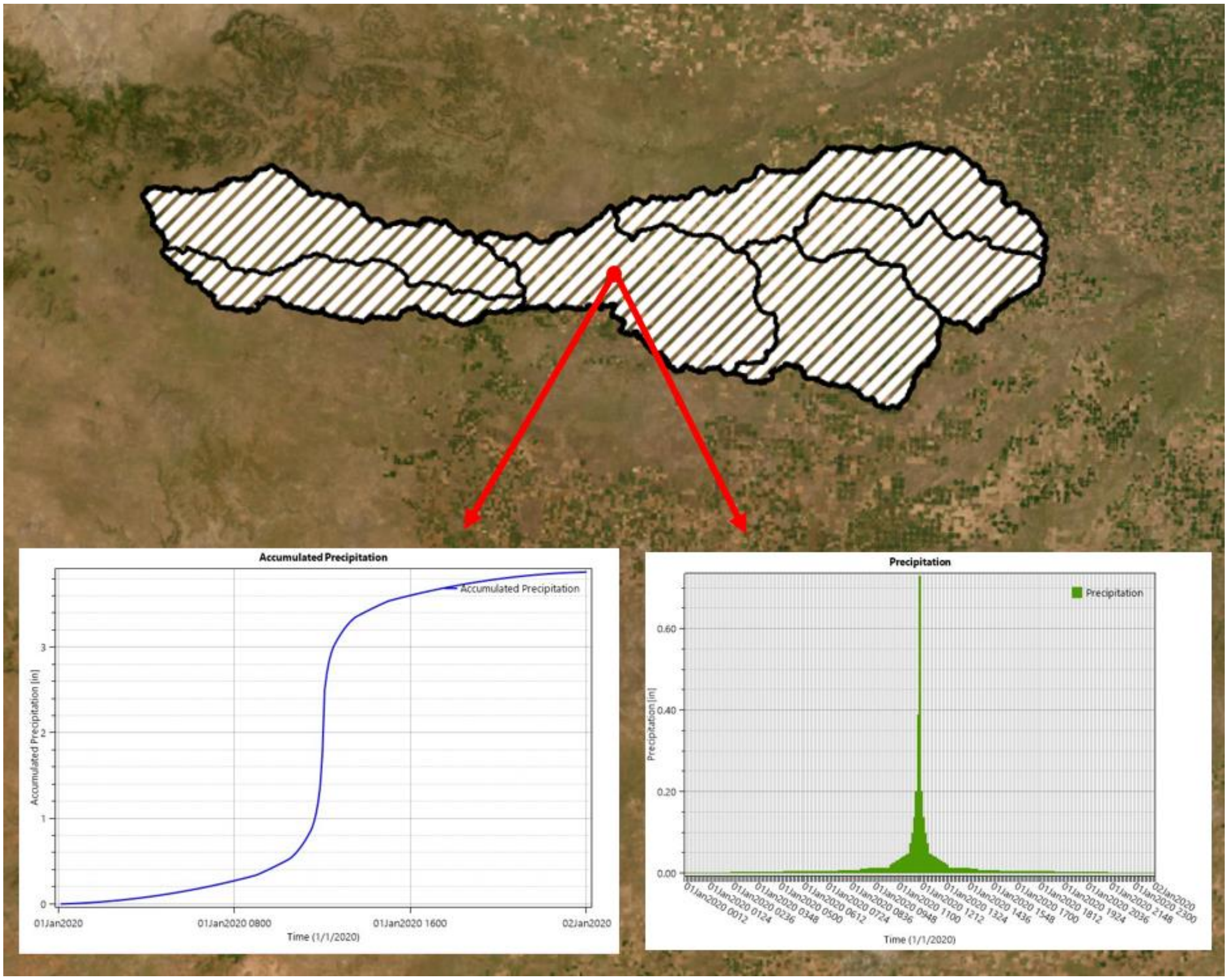

Figure 8: Spatially Varied Precipitation Example

1% (plus/minus) Annual Chance Gridded Precipitation Data

In addition to recurrence interval precipitation estimates, NOAA Atlas 14 provides 90% confidence intervals of reported precipitation values.

For a 2D watershed model, the 1% plus (upper 84-percent confidence limit) is to be based on the precipitation data since the flows are implicitly calculated in the model at every cell. The recommended approach to prepare the 1% plus precipitation totals using available data from NOAA is described below. This process assumes the log of the precipitation uncertainty is normally distributed and uses the quantile function to transform the 90% confidence intervals into the 1% plus and minus precipitation values.

- Given precipitation values (lower 90%, median, and upper 90%) from NOAA.

- Calculate μ (natural log of medial rainfall)
  - $\mu = \ln(Precip_{median})$

- Calculate σ_{max} $(the\ \max\ natural\ \log\ of\ the\ standard\ deviation\ of\ data)$
  - $\sigma_{lower} = \frac{[\mu - ln(Precip_{lower\ 90\%})]}{1.645}$
  - $\sigma_{upper} = \frac{[ln(Precip_{upper\ 90\%}) - \mu]}{1.645}$
  - $\sigma_{max} = \max(\sigma_{lower}, \sigma_{upper})$

- Calculate the 1-percent plus and minus precipitation values:
  - $Precip_{1\%\ Plus} = exp[\mu + \sigma_{max} * \sqrt{2} * erfinv(2 * 0.84 - 1)]$

    $= \exp(\mu + \sigma_{max} * 0.994)$

  - $Precip_{1\%\ Minus} = exp[\mu + \sigma_{max} * \sqrt{2} * erf(2 * 0.16 - 1)]$

    $= exp(\mu + \sigma_{max} * -0.994)$

*Note: $erfinv$ is the inverse error function also denoted as erf^{-1}

Areal Reduction Factor (ARF)

An ARF is a description of the relationship between the point maximum observed depth of precipitation in a storm pattern and the average depth of precipitation over a larger area. Generally, ARFs decrease as storm area increase.

$$ARF = \frac{Average\ Precipitation\ within\ the\ Area}{Maximum\ Precipiation\ within\ the\ Area}$$

The most common ARF method is one developed by the National Weather Service (formerly known as the Weather Bureau). In practice, areal reduction methods are applied to the depth value derived from those relations. Per FEMA Guidance, the selected ARF methodology must be documented. Area reduction methods should come from NOAA Atlases, Regional Climate Centers, or State and Local Agencies responsible for flood control. For the Upper Beaver Watershed 2D BLE study, ARF was determined through the utilization of the formula outlined in the regional extreme rainfall study conducted by the Colorado Department of Natural Resources, specifically within the Division of Water Resources. Comprehensive report detailing this study can be accessed here: (https://damfailures.org/wp-content/uploads/2020/10/3.-CO-NM-REPs-Summary-Report_Volume-III-Task-2_Final-July-2019.pdf).
This report includes regression equations for ARF calculations within Macro Regions (East, West, and Rio Grande) and across three distinct storm types, namely Local Storms (LS), Mesoscale Storms with

Embedded Convection (MEC), and Mid-Latitude Cyclones (MLC). These equations are applicable at key time durations of 2 hours (LS), 6 hours (MEC), and 48 hours (MLC). In the analysis, the equation corresponding to the MLC storm type within the East Macro Region (Bold in Table 8) was selected for the ARF calculation. This choice was made since storm type considers a 48-hour storm duration, aligning with the time under consideration in the BLE study, whereas the other two storm types mentioned in the report encompass storm durations of less than 24 hours. The provided equations for all storm types are given in Table 8.

Table 8: Area Reduction Factor Calculations within Macro Region

Macro Region	Storm type	Watershed size (mi^2)	Equation used where y=ARF; x=Log10(watershed area, mi^2)
East	**MLC**	**1 - 1000**	**$y = -0.013257x^5 + 0.108832x^4 - 0.300585x^3 + 0.265403x^2 - 0.076466x + 1.000694$**
East	MEC	1 - 500	$y = -0.009114x^5 + 0.078659x^4 - 0.228760x^3 + 0.198464x^2 - 0.072290x + 1.000464$
East	LS	1 - 200	$y = -0.019265x^5 + 0.146755x^4 - 0.371625x^3 + 0.278722x^2 - 0.092194x + 1.000226$
West	MLC	1 - 500	$y = -0.014771x^5 + 0.121212x^4 - 0.334808x^3 + 0.296515x^2 - 0.085609x + 1.000792$
West	MEC	1 - 200	y = 0.010574x3 - 0.088460x2 + 0.020526x + 0.998281
West	LS	1 - 100	$y = 0.013351x^4 - 0.058832x^3 - 0.013985x^2 + 0.000290x + 0.997799$
Rio	MLC	1 - 500	$y = -0.012973x^5 + 0.106852x^4 - 0.295968x^3 + 0.261726x^2 - 0.075402x + 1.000672$
Rio	MEC	1 - 500	$y = -0.008558x^5 + 0.071635x^4 - 0.200460x^3 + 0.156794x^2 - 0.047929x + 1.000196$
Rio	LS	1 - 200	$y = -0.018704x^5 + 0.129375x^4 - 0.282599x^3 + 0.131023x^2 - 0.030251x + 0.998530$

The final ARF applied to all events for each modeled area and resulted from numerous iterations while trying to find a best fit match with the best available hydrologic data sources available. A summary of the final modeled ARF values is provided in Table 9.

Table 9: Final Modeled ARF Values

Work Area	Area (mi^2)	ARF
Upper Beaver 1	520	0.69
Upper Beaver 2	291	0.73
Upper Beaver 3	583	0.68
Upper Beaver 4	487	0.69
Upper Beaver 5	344	0.72
Upper Beaver 6	508	0.69

Excess Precipitation for 2D Computational Mesh

Excess precipitation and infiltration losses are determined in HEC-RAS 6.3.1 using the NRCS Curve Number (CN) Loss Method. HEC-RAS calculates a separate curve number for each 2D cell based on a combination of land use and soils datasets. This will vary the excess precipitation throughout the 2D model domain to represent varied geography within the larger model area. Initial curve numbers were computed by intersecting the National Land Cover Dataset (NLCD) 2019 and NRCS soils data based on the matrix presented in Table 10.

Table 10: Land Use Soils-CN Matrix

Land Use Grid Code	Land Cover Description	Hydrologic Soil Group							No Data
		A	B	C	D	AD	BD	CD	
11	Open Water	99	99	99	99	99	99	99	99
12	Perennial Ice/Snow	99	99	99	99	99	99	99	99
21	Developed Open Space	49	69	79	84	84	84	84	84
22	Developed Low Intensity	61	75	83	87	87	87	87	87
23	Developed Medium Intensity	81	88	91	93	93	93	93	93
24	Developed High Intensity	89	92	94	95	95	95	95	95
31	Barren Land	49	69	79	84	84	84	84	84
41	Deciduous Forest	30	48	57	63	63	63	63	63
42	Evergreen Forest	35	58	73	80	80	80	80	80
43	Mixed Forest	36	60	73	79	79	79	79	79
52	Shrub Scrub	35	56	70	77	77	77	77	77
71	Herbaceous	55	71	81	89	89	89	89	89
81	Hay Pasture	49	69	79	84	84	84	84	84
82	Cultivated Crops	63	73	80	83	83	83	83	83
90	Woody Wetlands	72	80	87	93	93	93	93	93
95	Emergent Herbaceous Wetlands	72	80	87	93	93	93	93	93
0	No Data	61	74	82	86	86	86	86	86

Boundary Condition Setup

A spatially varied precipitation input was applied to each model 2D mesh as a meteorological variable for the inflow boundary condition. Models that have contributing drainage from upstream areas used inflow hydrograph boundary conditions. These inflow hydrographs are the results of the upstream 2D model to ensure continuity between models. The HEC-RAS models include a 1,000-foot buffer around each model boundary with further buffer distances at flow transition locations to increase the overlap between models. Including model boundary buffers helps to improve hydraulic routing and model tie-ins. The summary of the boundary conditions is shown in Table 11.

Table 11: Summary of Boundary Conditions

Hydrologic Feature	Boundary Condition Type	Note
Riverine Inflow	Flow Hydrograph	Developed from upstream 2D H&H modeling
Riverine Outflow	Normal Depth	Energy grade slope estimated from terrain
Rain-on-Mesh (RoM) Precipitation Input	Meteorological Data Precipitation	Spatially varied DSS gridded dataset developed from NOAA Atlas 14
Precipitation Overflow	Normal Depth	Allows for rainfall in buffer area to exit model

Outflow Boundary Conditions

Outflow boundary conditions were used along model boundaries. Unique outflow boundaries were established for obvious riverine outflows that flow into the downstream Middle Beaver HUC 8. The remaining boundaries were defined as continuous boundaries to allow drainage to adjacent basins to leave the model area freely. Normal depth was used for all non-unique outflow boundary conditions using approximate energy grade-line slopes estimated from the Lidar terrain data.

Inflow Hydrograph Boundary Conditions

A coupled pluvial fluvial approach was used in this project. The upstream modelers were tasked with furnishing the inflow hydrograph data for the designated work area and maintained seamless coordination with the downstream modeler. This inflow hydrograph serves as the basis for capturing all contributing drainage area upstream of the models. All the inflow hydrographs across the Upper Beaver work areas are depicted in the subsequent figures. Middle Beaver HUC 8 receives the inflow hydrographs from Upper Beaver 5 and Upper Beaver 6 models.

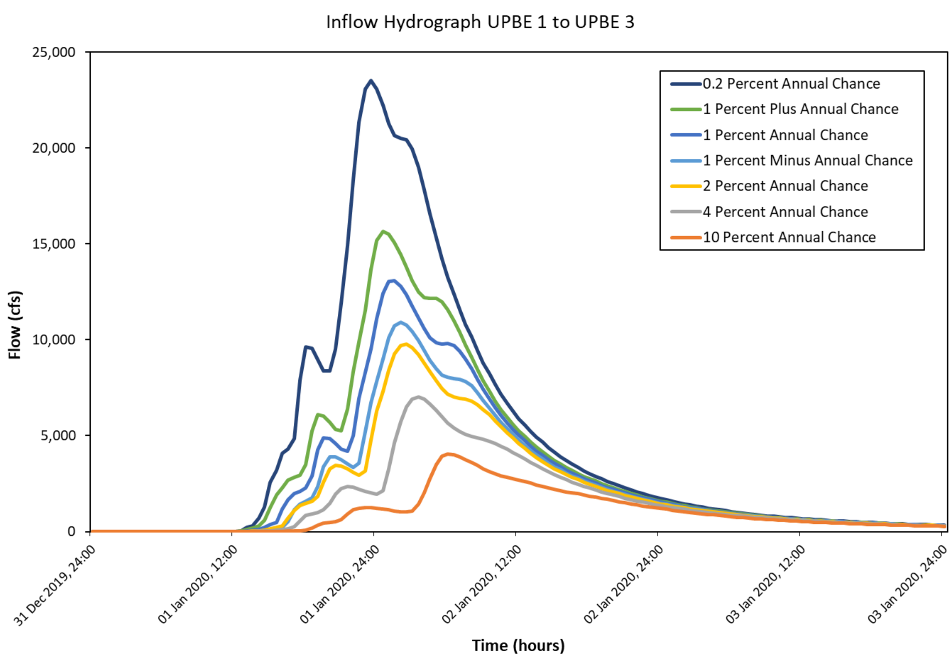

Figure 9: Inflow Hydrograph from Upper Beaver 1 to Upper Beaver 3

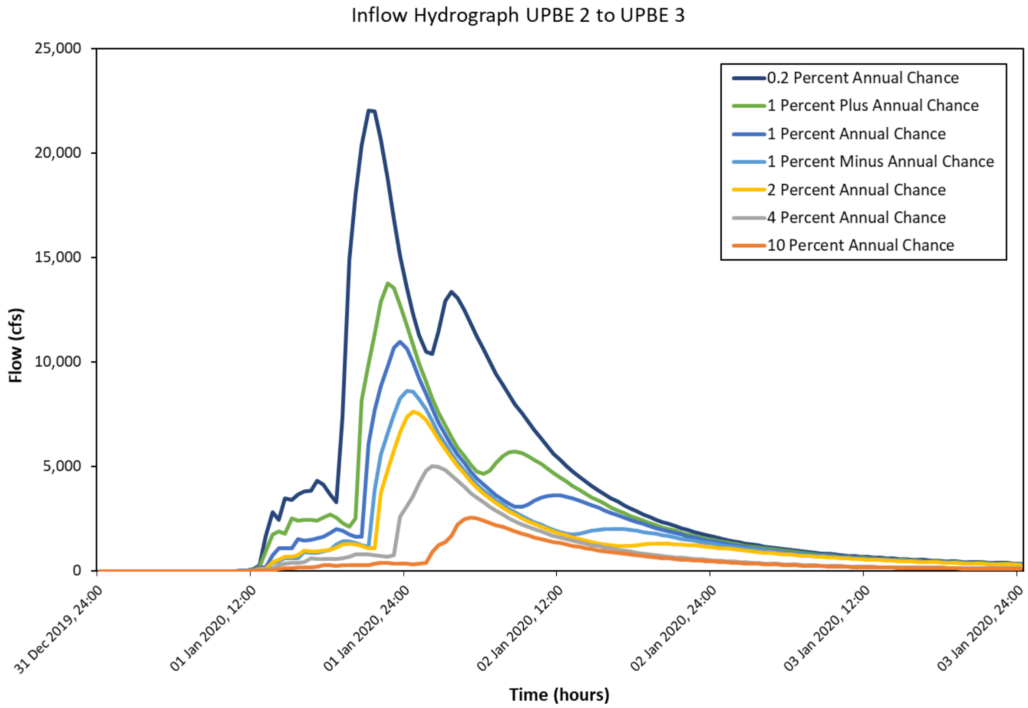

Figure 10: Inflow Hydrograph from Upper Beaver 2 to Upper Beaver 3

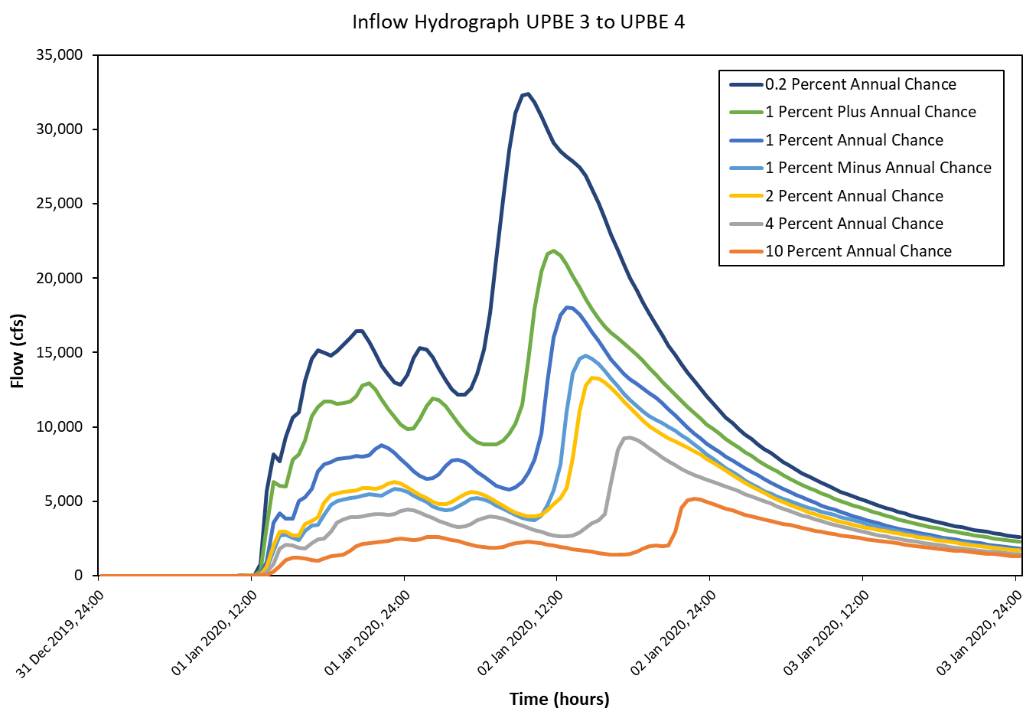

Figure 11: Inflow Hydrograph from Upper Beaver 3 to Upper Beaver 4

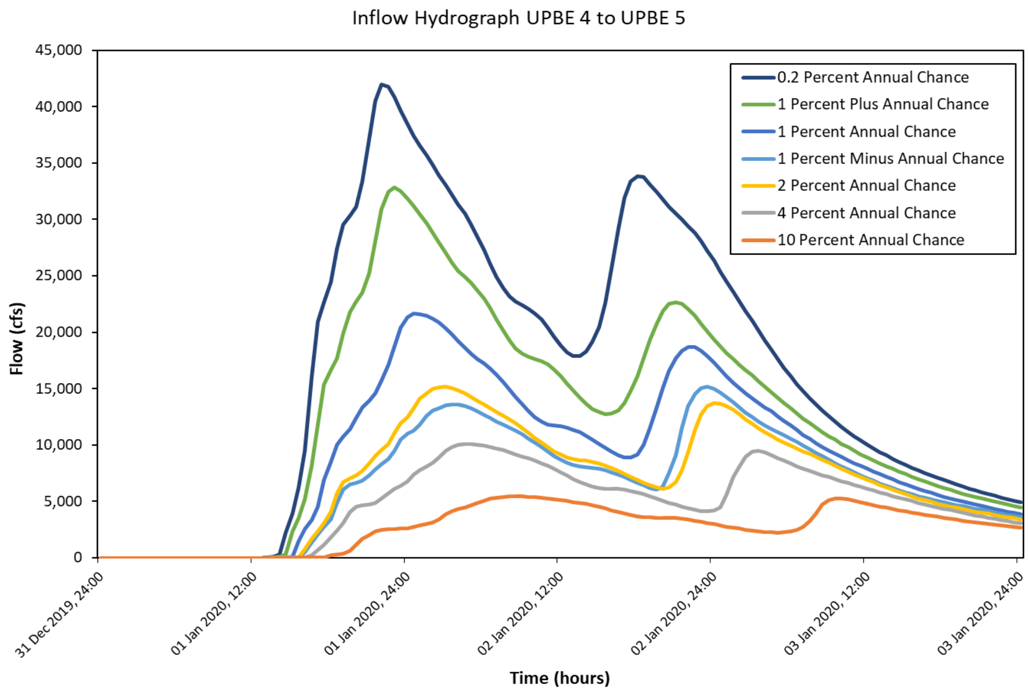

Figure 12: Inflow Hydrograph from Upper Beaver 4 to Upper Beaver 5

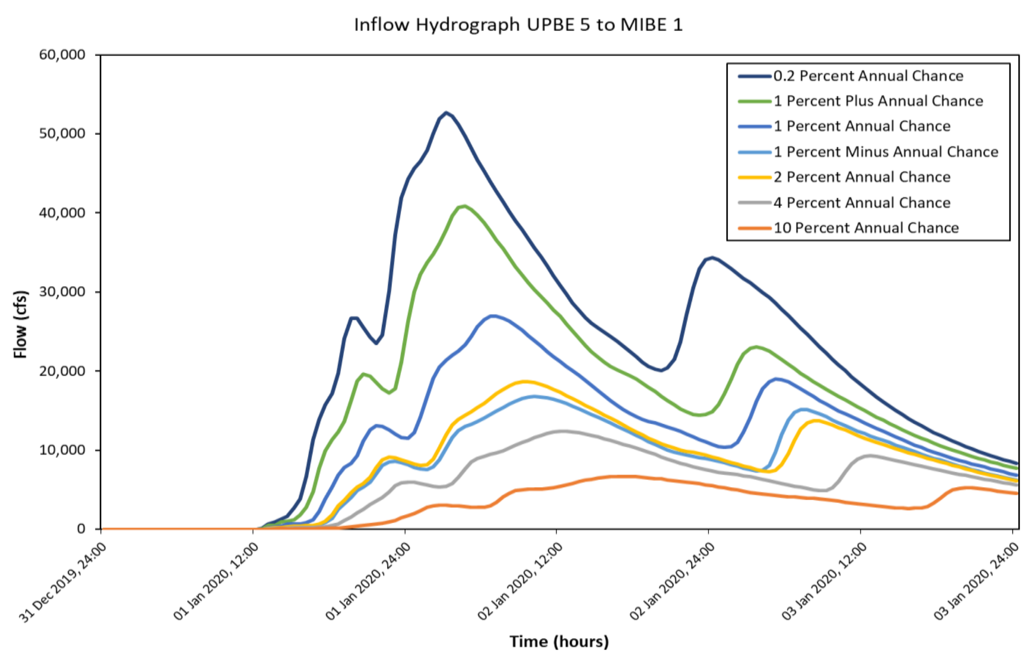

Figure 13: Inflow Hydrograph from Upper Beaver 5 to Middle Beaver 1

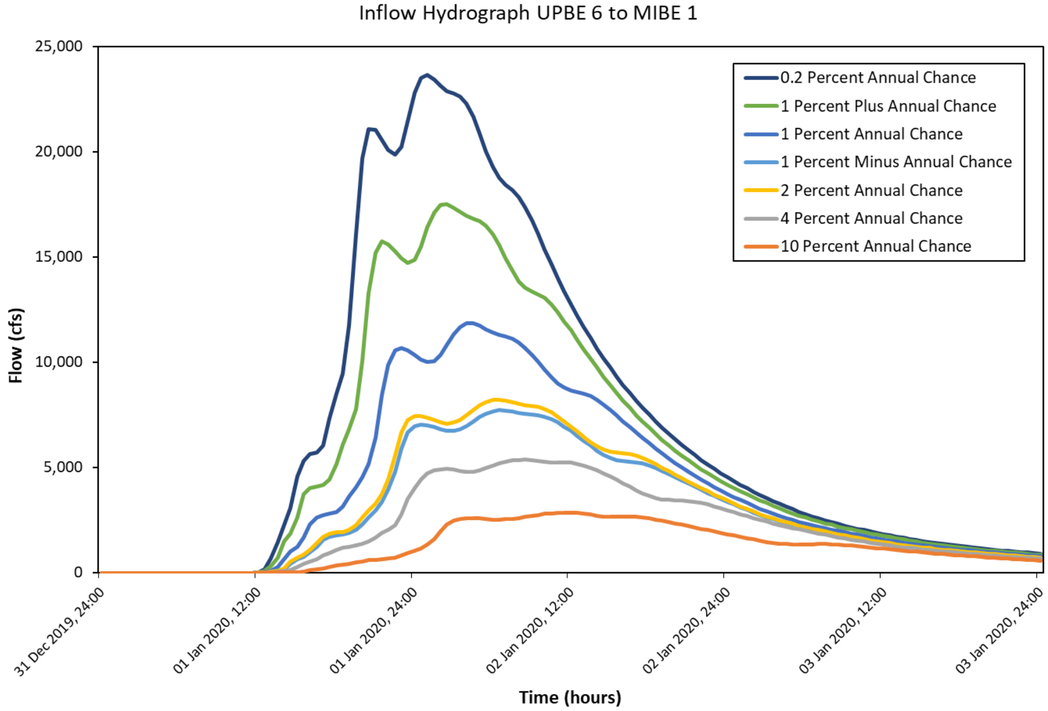

Figure 14: Inflow Hydrograph from Upper Beaver 6 to Middle Beaver 1

Hydraulics

This section describes the remaining hydraulic modeling considerations, including implementation of Manning's n roughness, breaklines, refinement regions, and hydraulic structures within the 2D computational mesh. The modeling methodology is discussed in the following sub-sections.

Roughness Coefficients

Manning's (n) roughness coverage was developed for the 2D computational mesh using typical roughness values for given NLCD land classifications. Two different sets of Manning's n values were used for areas within the channel and all other areas outside of the channels of the stream network. This allows for the model to accurately represent deep, swift flow within the channel and shallow overland flow outside of the channel areas.

Table 12 shows a typical land use roughness matrix used in defining the roughness coverage for the study area for areas both inside and outside of the channel.

Table 12: NLCD 2019 Manning's n Roughness Matrix

NLCD Classification	Within Channel	Outside Channel	Source
Open Water	0.040	0.040	Chow 1959
Developed, Open Space	0.035	0.050	Calenda, et al. 2005
Developed, Low Intensity	0.035	0.080	Calenda, et al. 2005
Developed, Medium Intensity	0.035	0.100	Calenda, et al. 2005
Developed, High Intensity	0.040	0.150	Calenda, et al. 2005
Barren Land	0.030	0.040	Chow 1959
Deciduous Forest	0.060	0.160	Chow 1959
Evergreen Forest	0.060	0.160	Chow 1959
Mixed Forest	0.060	0.160	Chow 1959
Scrub/Shrub	0.040	0.100	Chow 1959
Grassland/Herbaceous	0.040	0.060	Chow 1959
Pasture/Hay	0.040	0.060	Chow 1959
Cultivated Crops	0.040	0.060	Chow 1959
Woody Wetlands	0.050	0.120	Chow 1959
Emergent Herbaceous Wetland	0.045	0.070	Chow 1959

Breaklines

Breaklines aligned grid cell faces and were used within the 2D mesh area to define prominent features, including road embankments and hydraulic structures. Road embankment features were delineated in GIS and imported into HEC-RAS as breaklines to contain water where appropriate. Significant bridge/culvert crossings that were not processed out of the terrain data were modeled by adding a v-notch in the breakline at the road embankment to allow water to be routed through the embankment without creating artificial backwater. An example of the v-notch approach is shown in Figure 15.

County, interstate, farm-to-market, state-recognized, and U.S. roads were incorporated for road breaklines that were acquired from the New Mexico Department of Transportation, Oklahoma Department of Transportation, and the Texas Department of Transportation.

According to the 2018 National Inventory of Dams, all publicly owned dams were modeled with breaklines to provide protection. This method allows water to flow out of the spillway if it reaches that elevation. Private dams were not modeled as showing protection to lessen the burden on private dam owners to maintain their dams to sustain the regulatory products created because of this study.

Breaklines were also used along all the stream centerlines of streams draining greater than one square mile of drainage area. Each stream centerline was enforced with 100-foot cell spacing to align cells along the streamline and capture more detail along the one square mile stream network.

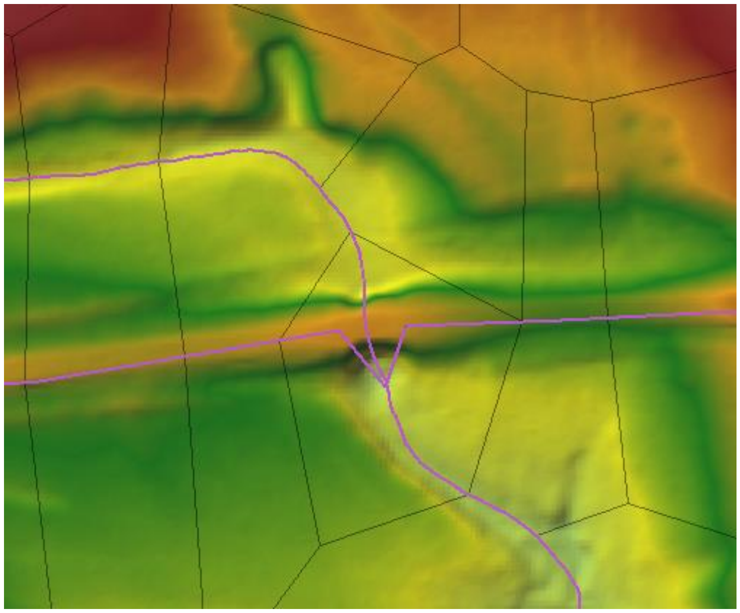

Figure 15: V-Notch Approach at Embankment Crossing

Refinement Regions

Refinement regions were created for each community within the model. The population center boundary was used to determine the shape of the refinement region. The regions were assigned a cell spacing of 50-feet by 50-feet. This finer cell spacing allows for more hydraulic calculations and mapping detail near areas where there are likely to be more structures. The figure below shows a community contained within the Upper Beaver Watershed that was modeled with refinement region.

Figure 16: Communities with 2D Mesh Refinement

Model Results

The 2D BLE results for the study provide additional estimated SFHA in areas that do not currently have a SFHA mapped. While the results provide context for flood risk communication as part of the Discovery process and are scalable, the results require further analysis to be used for regulatory purposes. The validity of the 2D BLE results should be verified through community work map meetings before being applied to a regulatory product.

Of the three USGS gages found in the Upper Beaver Watershed, none had sufficient years of data or recent data to rely on. As a result, several locations along the model mainstem and tributaries were selected throughout each model area to compare model flows with the published USGS regional regression equations. These locations utilized StreamStats for their 1% estimated flow and compared against the model results for the 1% event. Results of the flow comparisons are presented in Table 13. The calibration range for Beaver River mainstem was estimated using New Mexico and Oklahoma regression equations and flows were found to be different. Because of this the modeled flows were found to be higher than the expected range. To calibrate more accurately to Oklahoma estimates, the inflows used for Upper Beaver 3 used a multiplier of 0.46, which is the ratio of the difference in flow estimates between the two regression equations. This resulted in calibrated mainstem flows for Upper Beaver 3 and the remaining models downstream.

Table 13: Model Calibration Results

Work Area	Calibration Location	Drainage Area (mi^2)	Lower Limit (cfs)	Q1% (cfs)	Upper Limit (cfs)	2D Model Flow (cfs)
Upper Beaver 1	Reference Line 1	19.4	1,447	2,390	3,947	2,350
	Reference Line 2	18.8	1,877	3,100	5,120	4,042
	Reference Line 3	57.0	2,949	4,870	8,043	7,895
	Reference Line 4	29.5	2,264	3,740	6,177	5,922
	Reference Line 7	19.5	2,101	3,470	5,731	3,626
	Reference Line 10	77.7	4,765	7,870	12,998	8,043
	Reference Line 11	14.4	3,936	6,500	10,735	4,243
	Reference Line 12	216.0	9,022	14,900	24,609	16,609
	Reference Line 13	329.0	11,504	19,000	31,380	25,531
	Reference Line 14	408.0	13,018	21,500	35,509	26,829
	Reference Line 15	22.1	2,234	3,690	6,094	2,973
	Reference Line 16	22.5	1,544	2,550	4,212	3,075
	Reference Line 17	501.9	6,418	10,600	17,507	28,401
Upper Beaver 2	Reference Line 1	16.6	939	1,550	2,560	1,047
	Reference Line 2	11.7	799	1,320	2,180	1,493
	Reference Line 3	8.6	642	1,060	1,751	1,054
	Reference Line 4	40.0	1,829	3,020	4,988	2,906
	Reference Line 5	43.8	1,756	2,900	4,790	3,418
	Reference Line 6	29.7	2,083	3,440	5,681	4,668
	Reference Line 7	4.1	866	1,430	2,362	874
	Reference Line 12	23.0	1,962	3,240	5,351	2,838
	Reference Line 13	12.2	1,653	2,730	4,509	1,723
	Reference Line 14	43.7	3,027	5,000	8,258	4,043
	Reference Line 15	268.0	5,068	8,370	13,824	10,951
Upper Beaver 3	Reference Line 1	13.7	1,635	2,700	4,459	1,736
	Reference Line 2	13.7	1,641	2,710	4,476	2,075
	Reference Line 4	14.5	1,671	2,760	4,558	3,137
	Reference Line 5	799.2	7,690	12,700	20,975	17,537
	Reference Line 6	824.6	7,750	12,800	21,140	17,616
	Reference Line 8	863.0	7,932	13,100	21,636	17,727
	Reference Line 10	886.0	7,992	13,200	21,801	17,788
	Reference Line 13	13.0	1,605	2,650	4,377	2,368
	Reference Line 14	944.0	8,174	13,500	22,296	18,051
	Reference Line 18	15.4	1,714	2,830	4,674	1,955
	Reference Line 19	2.6	872	1,440	2,378	919

Table 13 contd.: Model Calibration Results

Work Area	Calibration Location	Drainage Area (mi^2)	Lower Limit (cfs)	Q1% (cfs)	Upper Limit (cfs)	2D Model Flow (cfs)
Upper Beaver 4	Reference Line 1	9.7	1,435	2,370	3,914	1,535
	Reference Line 2	27.2	2,125	3,510	5,797	3,165
	Reference Line 5	950.0	8,174	13,500	22,296	17,933
	Reference Line 6	106.4	3,566	5,890	9,273	8,365
	Reference Line 9	1089.3	8,659	14,300	23,618	17,544
	Reference Line 10	173.8	4,299	7,100	11,726	11,079
	Reference Line 13	20.0	1,889	3,120	5,153	2,720
	Reference Line 15	45.1	2,573	4,250	7,019	2,715
	Reference Line 16	23.7	2,016	3,330	5,500	2,495
	Reference Line 17	1315.0	9,264	15,300	25,269	21,632
	Reference Line 18	15.1	1,701	2,810	4,641	1,796
Upper Beaver 5	Reference Line 1	27.0	2,119	3,500	5,781	2,229
	Reference Line 6	14.0	1,665	2,750	4,542	1,806
	Reference Line 7	12.0	1,514	2,560	4,129	1,516
	Reference Line 8	85.0	3,270	5,400	8,919	4,121
	Reference Line 9	13.0	1,623	2,680	4,426	2,292
	Reference Line 10	1331.0	9,324	15,400	25,434	21,660
	Reference Line 14	1613.0	10,051	16,600	27,416	26,968
	Reference Line 15	140.0	3,966	6,550	10,818	6,176
	Reference Line 18	47.0	2,604	4,300	7,102	2,752
	Reference Line 19	12.2	1,568	2,590	4,278	1,585
Upper Beaver 6	Reference Line 3	7.0	1,265	2,090	3,452	1,511
	Reference Line 4	21.35	1,931	3,190	5,269	2,521
	Reference Line 5	51.0	2,694	4,450	7,350	3,999
	Reference Line 6	25.4	2,071	3,420	5,648	2,514
	Reference Line 7	93.5	3,397	5,610	9,265	5,620
	Reference Line 8	142.9	3,990	6,590	10,884	7,164
	Reference Line 9	12.1	1,562	2,580	4,261	1,724
	Reference Line 11	196.4	4,505	7,440	12,288	8,444
	Reference Line 12	28.1	2,149	3,550	5,863	2,373
	Reference Line 13	47.9	2,634	4,350	7,184	3,073
	Reference Line 14	295.8	5,262	8,690	14,352	11,677
	Reference Line 16	324.3	5,449	9,000	14,864	11,840

Floodplain Mapping

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.

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 1% SFHA and 0.2% shaded X polygons.

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 Upper Beaver BLE project, floodplain mapping delineation was completed using connected raster cells at the extent of the CNMS mapped and unmapped features in the project footprint with raster depths greater than 0.5 foot. 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% 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. 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. Mapping polygons were cleaned against the criteria of being larger than 2 acres. For example, if flooding polygons were disconnected from a flooding source and less than 2 acres, the polygon was removed from the SFHA. Flood polygons less than 2 acres that intersected a flooding source were assessed individually. These edits adhere to traditional and approved floodplain mapping approaches.

In addition to the SFHA, all other flooding associated with the 1% and 0.2% raw results were retained as "on the shelf" data that may be leveraged for future needs and analysis.

Flood Hazard Area Layer

Special Flood Hazard Areas, as noted above, were developed to the extent of the CNMS features or up to 1 square mile drainage area and effective zone A study locations. The Regional CNMS database, National Flood Hazard Layer, and paper inventory was used as reference data to ensure the extent of the BLE results represents appropriate flooding extent.

The 0.2% 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.

CNMS Validation

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

The inventory of Zone A studies (84.7 miles) in the Upper Beaver Watershed were classified in CNMS with validation status of "UNVERIFIED" (80.0 miles) or "VALID" (4.7 miles), and with status type of "BEING STUDIED." The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial assessment checks A1-A3 were evaluated for the CNMS inventory of Zone A studies.

Initial Assessment A1 – Significant Topography Update Check

This check involves determining whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. For effective Zone A studies within Texas County and Cimarron County, lower quality topographic sources were used in the effective studies and the topographic sources used in this BLE study are considered significant improvements. Therefore, the streams fail this check.

Initial Assessment A2 – Check for Significant Hydrology Changes

This check involves first determining if regression equations were used for the effective study. Next, it must be determined 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 annual chance flow.

For streams in Texas County, regression equations from USGS Fact Sheet 008-01 were used. These equations were published in 2001 and new equations were published in 2015 for rural areas in the Oklahoma panhandle. Therefore, all streams in Texas County fail this check. All other effective Zone A studies in this watershed did not use regression and automatically pass this check.

Initial Assessment A3 – Check for Significant Development

This check involves using the National Urban Change Indicator (NUCI) dataset to assess increased urbanization in the watershed of the Zone A study. If the percentage of urban area within the HUC 12 watershed containing the effective Zone A study is 15% or more, and has increased by 50% or more since the effective analysis, the study would fail this check. Although the NUCI data provide year-to-year changes in urbanization, the NLCD also is needed to establish a baseline of urban land cover for this analysis. The check for significant development in this watershed was completed by evaluating percentage of urban change at the HUC 12 level.

All effective Zone A studies within the watershed are classified as rural and, therefore, pass this check.

All of the initial assessment results are shown in Table 14.

Table 14: Zone A Initial Assessment Results

Assessment Check	Pass/Fail	Notes
A1- Topography	Fail	LiDAR sources available are considered significant improvements from the effective zone A topographic sources
A2 – Hydrology	Pass/Fail	Regression equations were not used / New equations that create a significant change in BFE are now available
A3 – Development	Pass	Watershed does not meet urban threshold

Validation Check A4 – Check for 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.

Effective Zone A study within Cimarron County is not supported by technical data and fails this check. All other Zone A studies within this watershed are model-backed studies and, therefore, pass this check.

Validation Check A5 – Comparison of BLE and Effective Zone A

The effective Zone A comparison was performed at the full extent of the Upper Beaver 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 Floodplain Boundary 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 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 plus half of the contour interval of the USGS quad and the DEM minimum value is greater than or equal to the 1% minus minimum value minus half of the of the contour interval of the USGS quad. 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.

Validation Results

84.7 total miles of available CNMS features representing effective Zone A studies were categorized as VALID – BEING STUDIED or UNVERIFIED – BEING STUDIED. Total miles in each of these categories are summarized in Table 15 and illustrated in Figure 17 below. Table 16 summarizes the validation results based on the individual HUC 12 watersheds within the Upper Beaver Watershed.

Table 15: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment/Total Miles
VALID	BEING STUDIED	0	4.7
UNVERIFIED	BEING STUDIED	84.7	80

Table 16: BLE Comparison Results

HUC 12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	HUC 12 ID						
Upper Beaver	All Streams	7,552	1,624	5,928	78%	Fail	
111001010403 Unnamed Tributary	111001010403	174	51	123	71%	Fail	16.8
111001010803 Unnamed Tributary	111001010803	41	2	39	95%	Pass	2.4
111001010804-Town of Texhoma	111001010804	82	30	52	63%	Fail	18.3
111001010805-Beaver River	111001010805	969	204	765	79%	Fail	11.2
111001011207-Beaver River	111001011207	1,255	245	1,010	80%	Fail	11.6
111001011209-Beaver River	111001011209	1,031	334	697	68%	Fail	17.5
Confluence of Tepee Creek-Beaver River	111001011206	1,392	291	1,101	79%	Fail	12.6
Dry Sand Creek	111001011208	2,272	357	1,915	84%	Fail	12.7
Little Golf Creek	111001011104	67	11	56	84%	Fail	8.2
Lower Golf Creek	111001011105	107	57	50	47%	Fail	26.6
Lower Sand Creek	111001010705	130	36	94	72%	Fail	13.8
Lower Tepee Creek	111001011205	32	6	26	81%	Fail	9.4

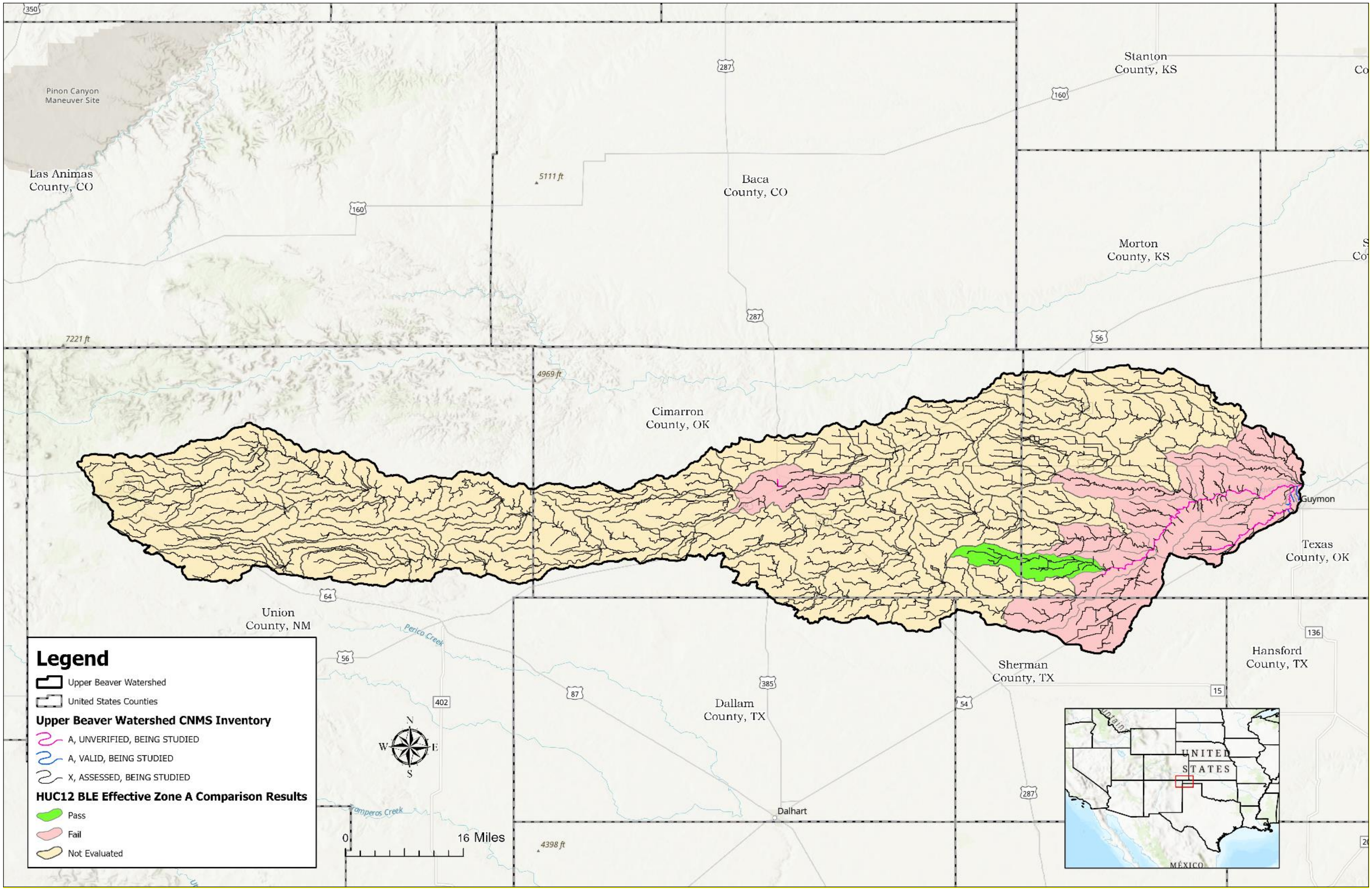

Figure 17: Upper Beaver Watershed CNMS Validation Results

An overall risk for each HUC 12 watershed was calculated using the National Flood Risk Percentages Dataset and its proportional area. The weighted risk was multiplied by the percentage of points in the watershed that failed the CNMS comparison to effective to determine the priority score. Figure 18 below shows the range of the Upper Beaver HUC 12 priority scores which can be used to initiate discussions during the Discovery phase. Lower Golf Creek HUC 12 was determined to have the highest priority score and the most need while 111001010803 Unnamed Tributary HUC 12 has the lowest score.

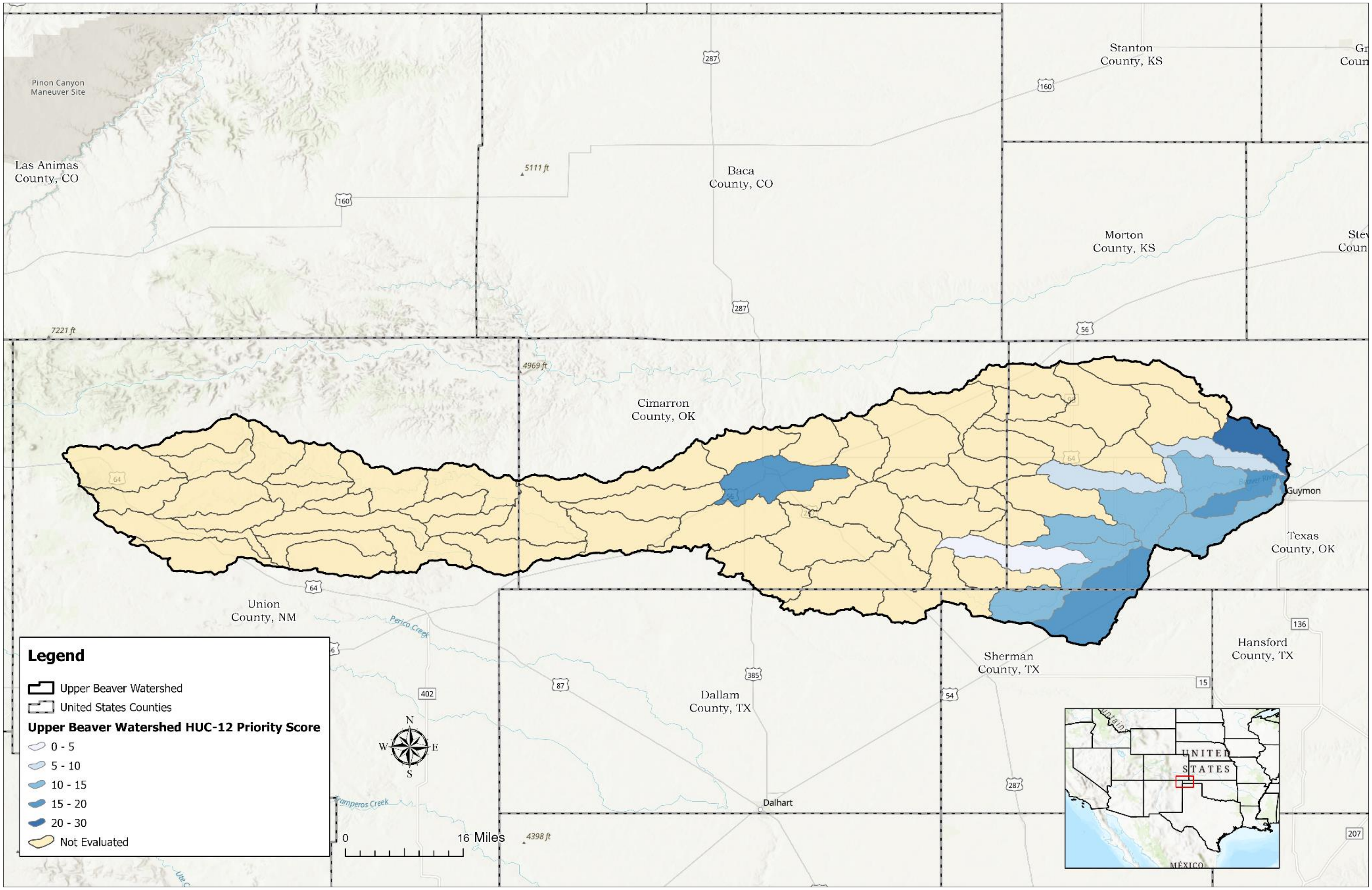

Figure 18: Ranking of Upper Beaver Watershed HUC 12s

Flood Risk Assessment

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 6.0 was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that the Hazus version used utilizes 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 county within the project watershed extents for the 1-percent annual chance scenario and are shown in Table 17.

Table 17: Hazus 6.0 Results for 1-percent-annual-chance (100 year) scenario for Upper Beaver Watershed, New Mexico, Texas and Oklahoma

County	Full Replacement - Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Cimarron, OK	$27,013,000	$482,130,000	$367,274,000
Dallam, TX	$60,000	$12,940,000	$10,344,000
Sherman, TX	$243,000	$97,316,000	$64,539,000
Texas, OK	$10,421,000	$1,691,741,000	$1,300,446,000
Union, NM	$79,000	$83,353,000	$56,852,000
Total	**$37,816,000**	**$2,367,480,000**	**$1,799,455,000**

Quality Assurance & Quality Control

The 2D BLE results were independently assured to meet quality standards of the project. Standard checklists complying with FEMA standards were used to review hydrology and hydraulics results, the resulting flood hazard area delineations and CNMS dataset. Quality Assurance (QA) during the data development process includes, but is not limited to the following Quality Control (QC) checks:

- Hydrologic QC – included checks for curve number calculation, input precipitation, flood events, areal reduction factor and human error.
- Hydraulic QC – included checks for HEC-RAS geometry, breaklines placement, v-notch placement to ensure water conveyance at crossings, refinement regions, roughness coefficients, boundary/initial conditions, timestep and mapping outputs.

- Mapping – included checks for spot checking flood inundation accuracies based on floodplain mapping criteria, ensuring flood extents from higher frequency events did not exceed lower frequency extents due to GIS smoothing algorithms, and topological overlap and cluster tolerance errors were resolved.
- CNMS – Included review of the A1-A5 analysis for all effective approximate reaches in the HUC, geometry updates to newly studied reaches added as Zone X, and removal of scoped areas which lie outside of the final BLE footprint.

Deliverables

All information, data, and files for the Upper Beaver Watershed BLE process were uploaded to the FEMA Mapping Information Platform (MIP). Items included with this deliverable include:

- Base Level Engineering Summary Report
- Certificate of Compliance and Completeness forms
- Hydraulic and Hydrologic Models (HEC-RAS and HEC-HMS, respectively)
- Spatial Files (EBFE File Geodatabase and metadata)
- Supplemental Data (CNMS and Hazus)

Considerations & Challenges

The main challenges during the duration of the modeling effort of the Upper Beaver 2D BLE study were:

- Calibrating the mainstem of all models in Upper Beaver HUC 8. The two most upstream models, Upper Beaver 1 and Upper Beaver 2, both predominantly lie in New Mexico, but have a small portion near the outlet of the models in Oklahoma. This initially caused issues in the mainstem calibration since the StreamStats flows that were estimated in Oklahoma at the outlet were significantly lower than the flows estimated upstream in New Mexico. The regression equations used in New Mexico and Oklahoma were compared and showed extreme differences in the 1-percent-annual-chance estimate at the same location.
- Despite the inflows from Upper Beaver 1 and Upper Beaver 2 being adjusted, most models experienced mainstem flows that were exceeding the upper limit at the outlet locations. Multiple calibration methods were used to try to decrease mainstem flows throughout the model while keeping flows along tributaries high enough to stay within range too. Mainstem flows were able to be adjusted enough to be considered calibrated but remain on the upper end of that range.
- In this project, the modeling covers rural areas where the terrain exhibits streamline without a clear flow path. Cases of gaps in the floodplain were resolved by setting a smaller cell size along the location where gaps occurred. The original cell size at these locations was 100 feet x 100 feet, and was reduced to 25-feet x 25-feet cells.
- Structures have not been added to the BLE model despite evidence of cross structures which allow the streams to convey water through numerous structures. An estimated structure opening was

modeled however, 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.

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.

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Appendix A – Exhibits – Base Level Engineering Results