Blackwater Draw Watershed, Texas 2D Base Level Engineering and Mapping Methods and Results

Texas Water Development Board Contract No. 1800012224, Task Order 11
Texas MAS (MAST) No. 4

August 2022

Prepared for:

Texas Water Development Board
Attn: Manuel Razo, GISP, CFM
1700 N. Congress Avenue
Austin, Texas 78701

Prepared By:

AECOM Technical Services
13640 Briarwick Drive, Suite 200
Austin, TX 78729
aecom.com

Document History

DOCUMENT LOCATION

K:/FY2022/22-06-0047S/

REVISION HISTORY

Version Number	Version Date	Summary Changes	Team/Author
1.0	August 2022	Deliverable to TWDB	AECOM
2.0	August 2022	Final Deliverable to TWDB	AECOM

APPROVALS

This document requires the approval of the following persons:

Role	Name	Phone	Title (CLIN/RMC)	Review Date	Approved Date
Project Manager	Sean Sutton	512.457.7745	Project Manager	August 11, 2022	August 31, 2022

CLIENT DISTRIBUTION

Name	Title/Organization	Location
Manuel Razo	Contract Manager, TWDB	Austin, Texas

Table of Contents

List of Figures

List of Tables

1. Introduction

Base Level Engineering (BLE) provides technically credible flood data for various geographies - community, county, watershed and/or state level. BLE data can be shared with Federal, State, local and tribal governments, this data sharing provides stakeholders at all levels the necessary data to make informed decisions to reduce future flood losses. Without the mapping of flood prone areas, there can be a lack of information to effectively communicate flood risk to community officials, citizens, and businesses.

BLE is a riverine hydrologic and hydraulic modeling approach that builds on lessons learned to produce a baseline understanding of flood risk to communities, produced to support the assessment and maintenance of the national flood hazard inventory. Engineering models are created during a BLE assessment, producing information that meets the mapping Standards for Flood Risk Projects (FEMA Policy Memo FP 204-078-1) to produce Zone A (1-percent-annual-chance flood) information. BLE data is intended to represent the base level of investment needed for all flood study efforts FEMA will undertake. The Black Water Draw watershed BLE documented here was designed to use two-dimensional (2D) modeling techniques with enhancements and calibration to develop products that can be communicated and shared with stakeholders, and transitioned into FEMA regulatory data development workflows.

The intent of BLE is to provide communities technically credible flood hazard information in a cost efficient and timely manner. Additionally, BLE provides communities a chance to review draft modeling information, reflecting the potential changes in risk within their community. Providing additional flood risk datasets, like water surface elevation (WSEL) grids and flood depth grids, delivers alternative information that reinforces the variability of flood risk within a designated floodplain and supports historic community requests for a source to determine a Base Flood Elevation in Zone A areas.

For floodplain management purposes, BLE data may be used as best available information in areas that are designated as Zone A floodplain. It may also be used to regulate development in areas where no Special Flood Hazard Area (SFHA) has been mapped before. Communities may adopt BLE data to support local regulations, which facilitates use of the data in local floodplain management activities, including in the post disaster environment where a need for updated and/or enhanced flood hazard information may be necessary.

BLE provides information to communities who are currently unmapped and provides a digital entry to communities that are currently un-modernized. BLE acts as a measuring tool to allow FEMA to assess the current Zone A inventory identified as unknown or unverified in FEMA's Coordinated Needs Management Strategy (CNMS), which FEMA is required to evaluate once every five years, as described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e). 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. Another important goal of the BLE process is scalability of the results, meaning that the model produced during the BLE assessment may be refined to produce a more enhanced model with additional manual correction and on the ground survey. If BLE modeling exists, FEMA will recommend that it be used as the base model for any detailed studies performed in those areas.

BLE practices leverage high-resolution topography that meets or exceeds the United States Geological Survey (USGS) 3-D Elevation Program (3DEP) standards and often applies flood engineering at a large scale as opposed to targeting stream reaches within a watershed. BLE can be conducted at any scale, commonly for larger areas (Hydrologic Unit Code (HUC)-8 watershed) but may be produced at the county or local level too. It is encouraged to do BLE for wider areas in order to build on efficiencies in modeling and ensure cost efficiency. Using current technologies, multiple watersheds or watersheds with large land areas can be analyzed at a more efficient rate to produce water-surface elevations and site-specific hazard data replacing outdated flood studies shown in existing Flood Insurance Rate Maps (FIRMs). All flood prone areas within a watershed will have an engineering model calculating multiple flood recurrence intervals and defining floodplains with elevation grids using high-resolution topography.

Per standard identification SID #84 and #133, BLE will include all recurrence intervals (0.2-percent, 1-percent, 1-percent plus, 1-percent minus, 2-percent, 4-percent, and 10-percent-annual-chance floods). As such, hydrologic and hydraulic analysis should be performed to determine the expected WSELs for each of the seven recurrence intervals previously identified.

The Blackwater Draw watershed 2D BLE project was scoped as described in the Texas Water Development Board (TWDB) Task Order 11. In an effort to increase and enhance the flood risk products in Texas, the study was contracted through the TWDB's Cooperative Technical Partner (CTP) program to AECOM Technical Services, Inc. This report documents the BLE process, products, and results for this watershed. Figure 1 depicts the Blackwater Draw watershed footprint.

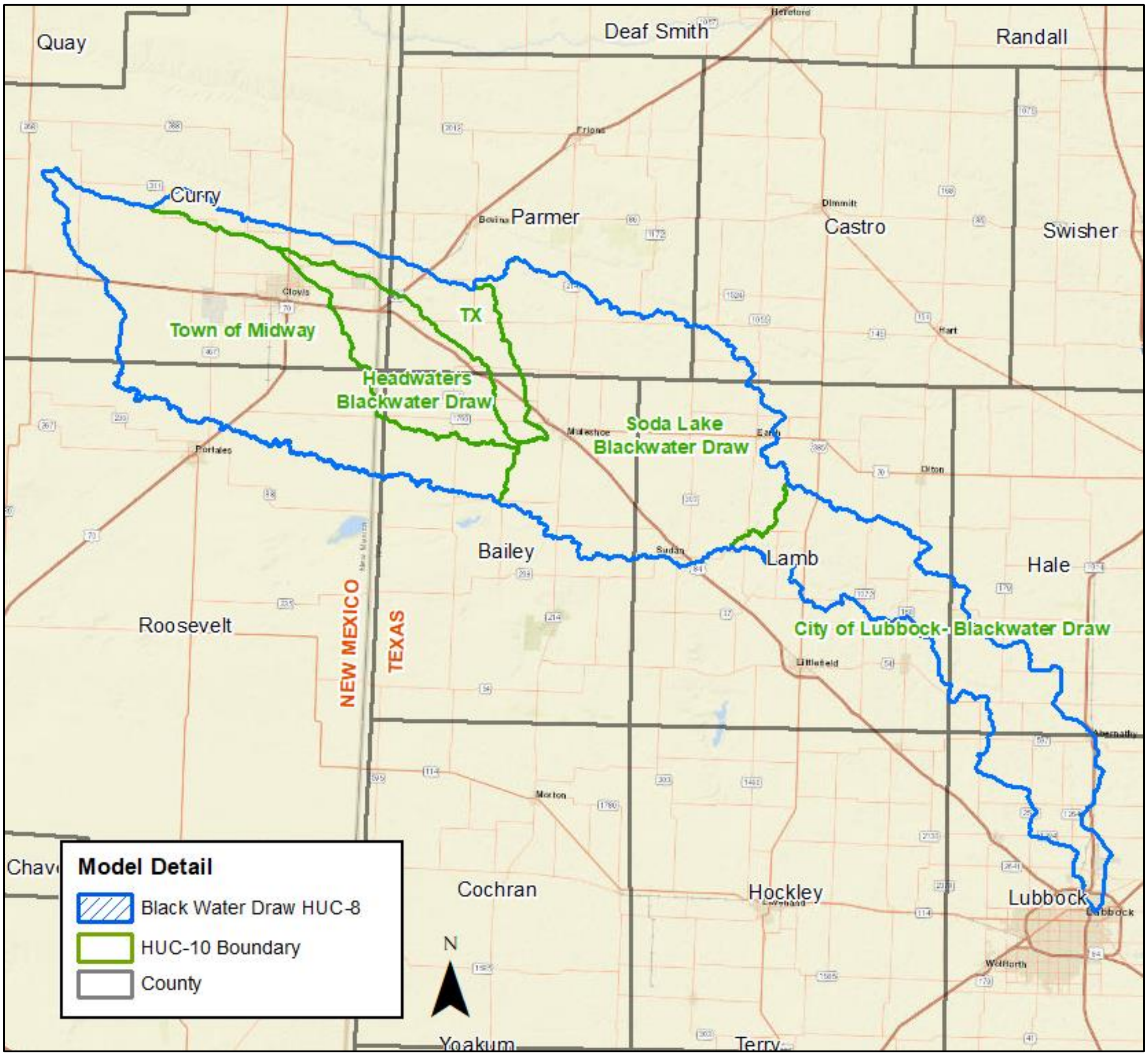


Figure 1: Blackwater Draw Watershed

2. 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2D hydraulic engineering analysis for the Blackwater Draw watershed. Inputs such as elevation data, hydrology from rain-on-grid and inflow hydrographs, and hydraulic analyses and variables are defined herein. HEC-RAS 6.1 rain-on-grid utility was applied in the production of the 2D BLE products produced for this watershed.

2.1 Topographic Data

A high resolution Digital Elevation Model (DEM) is a fundamental component for 2D engineering analyses by providing a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the Black Water Draw BLE project by leveraging available high resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the State of Texas. The 1 meter DEM developed to support the 2D BLE modeling and analysis, within the Blackwater Draw 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 Geographic Information Systems (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 Section 2.1.2. 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 Blackwater Draw watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Blackwater Draw BLE watershed footprint. Figure 2 depicts the datasets identified and leveraged across the project area. FEMA, National Oceanic and Atmospheric Administration (NOAA), USGS, Texas Natural Resources Information System (TNRIS) and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

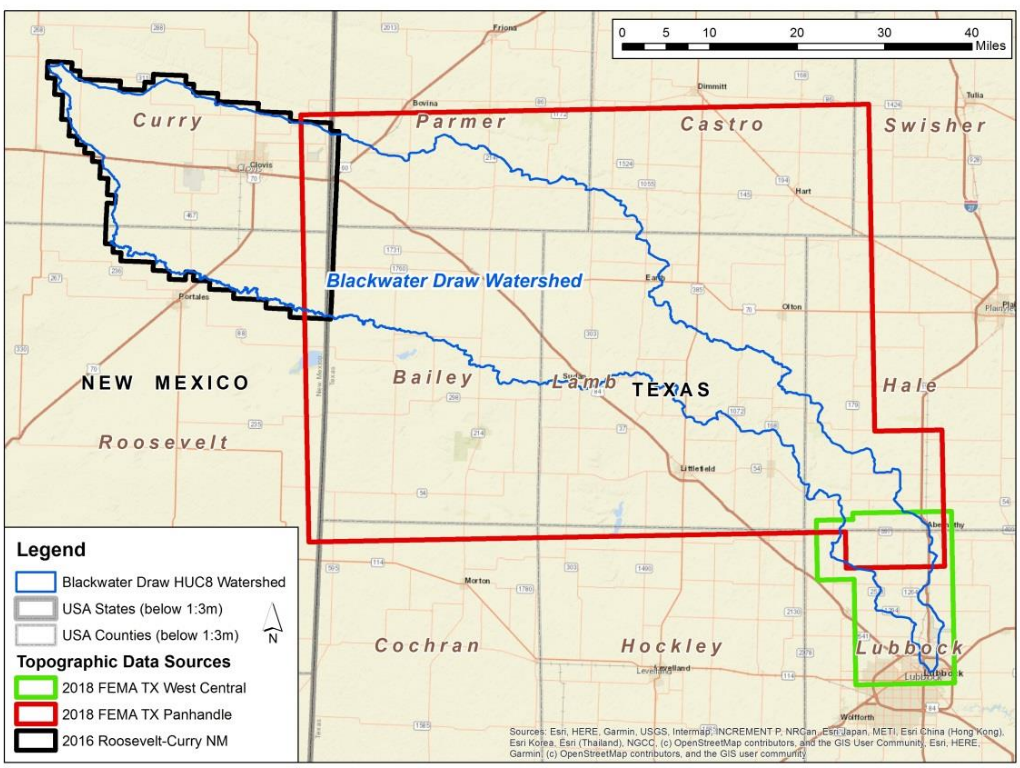


Figure 2: Blackwater Draw Watershed BLE Source Terrain Data

2.1.2 Evaluation

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

- Data meet FEMA vertical accuracy standards (Table 1)
- Date of origination
- Data density and coverage

Table 1 depicts the Risk MAP SID #43 vertical accuracy requirements based on flood risk and terrain slope within the floodplain being mapped.

Table 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 depicts the complete list of source elevation data and attributes leveraged for the Blackwater Draw watershed. All datasets used for hydraulic analyses and mapping meet the highest specification level defined in Table 1. The following datasets were evaluated and prioritized as best available:

Table 2: LiDAR Topographic Data Available for the Black Water Draw Watershed

Year	Description	Source/Owner	Accuracy[1]	Approximate Footprint (Sq. Mi.i)[2]
2018	2018 FEMA Texas West Central	USGS/FEMA	9.1 cm	110.0
2017	2018 FEMA Texas Panhandle	USGS/FEMA	7.2 cm	1,100.2
2017	2016 Roosevelt and Curry, New Mexico	TNRIS/TWDB	11.9 cm	478.1

[1]RMSEz reported at the 95% confidence level

[2]Size of LiDAR DEM footprint utilized for BLE study

2.1.2.1 Blackwater Draw Watershed Source Terrain Data

The source elevation data for the Blackwater Draw watershed are DEMs derived from the 2018 FEMA Texas West Central; the 2018 FEMA Texas Panhandle; and the 2016 Roosevelt and Curry, New Mexico LiDAR. Only points classified as "ground" points (i.e., bare earth) were imported from the LiDAR and used for development of the project DEMs. Bare-earth LiDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the raw laser returns. Figure 2 depicts the extent of the data defined in Table 2.

2018 FEMA Texas West Central

This USGS LiDAR project covers portions of Hale and Lubbock Counties, Texas within the Blackwater Draw HUC8 study area. The USGS awarded this project to support the FEMA Risk MAP program. The acquisition was conducted from February 1, 2018 through May 27, 2018. Reflights were collected on November 5, 2018. Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all lidar products, breakline production, DEM production, and quality assurance. The source 1-meter bare earth DEM data was in Universal Transverse Mercator (UTM) Zone 13N, North American Datum of 1983 (NAD83) (2011), meters with elevations in North American Vertical Datum of 1988 (NAVD88) (GEOID12B), meters. For the Texas West Central QL2 Lidar Project, the tested RMSEz of the classified lidar data for checkpoints in non-vegetated terrain equaled 4.7 cm compared with the 10 cm specification; and the Non-vegetated Vertical Accuracy (NVA) of the classified lidar data computed using RMSEz x 1.9600 was equal to 9.1 cm, compared with the 19.6 cm specification. Using NSSDA methodology, the horizontal accuracy at the 95 percent confidence level was reported as 61.4 cm (target was 100 cm).

2018 FEMA Texas Panhandle

This USGS LiDAR project covers Bailey, Castro, Hale, Lamb, Lubbock, and Parmer Counties, Texas within the Blackwater Draw HUC8 study area. The task order for this LiDAR project was issued by the USGS's National Geospatial Technical Operations Center (NGTOC) for the acquisition and processing of QL2 data in the Texas Panhandle and Red River regions in northern Texas and western Oklahoma. The acquisition was conducted from the winter of 2017 through April 20, 2018. Woolpert was responsible for LAS classification, all lidar products, breakline production, DEM production, and quality assurance. The source 1-meter bare earth DEM data was in UTM Zone 13N, NAD83 (2011), meters with elevations in NAVD88 (GEOID12B), meters. The NVA of the DEM computed using RMSEz x 1.9600 was equal to 7.2 cm, compared with the 19.6 cm specification.

2016 Roosevelt and Curry, New Mexico

This USGS LiDAR project covers Curry and Roosevelt Counties, New Mexico within the Blackwater Draw HUC8 study area. Digital Aerial Solutions, LLC was tasked to collect and process this lidar-derived elevation dataset. The acquisition was conducted from September 30, 2015 and was completed on October 15, 2015. The source bare earth 1-meter DEM data was in UTM Zone 15N, NAD83, meters with elevations in NAVD88 (GEOID12B), meters. The NVA of the DEM, computed using RMSEz x 1.9600, was equal to 11.9 cm, compared with the 19.6 cm specification.

2.1.3 Data Processing

ArcGIS software was utilized in order to create a digital surface model for the Blackwater Draw HUC-8 watershed project area. The LiDAR datasets were added to a mosaic dataset and prioritized by date with the most recent dataset taking the first priority. If two datasets are from the same year or flown at similar dates, the accuracy was reviewed to determine the priority. The mosaic dataset was exported to make a seamless bare earth 1-meter DEM for mapping and modeling according to the model area extents, including a 1,000 foot buffer.

The exported DEM was reviewed through automated quality control (QC) to check for anomalies and outlier locations based on slope and cells that exceed z value differences from surrounding cells. Visual review was also performed to check for ground differences at the extents of the datasets for differences in ground values.

2.1.4 DEM QA/QC

DEMs developed for use in the Blackwater Draw watershed BLE analysis were developed and independently assured to meet quality standards of the project. The data were developed using a controlled process, were evaluated and assured by a topographic data development team, and were evaluated and assured by the engineering team. Quality assurance (QA) 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 QC after the development process by the DEM development team included visual observations using hillshade, contouring, color rendering, and/or other visual aids to review and identify potential impactful anomalies within the DEM surface. This QC step included, but was 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

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

The final DEM data developed for the Blackwater Draw watershed is 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

HEC-RAS 6.1 (RAS6) rain-on-grid utility was applied in the Texas 2D BLE products workflow. The following sections describe the engineering methods and model inputs used.

2.2.1 2D Computational Mesh and Settings

Due to the size of the Blackwater Draw watershed (approximately 1,688 sqmi, 1,145 sqmi in Texas) and presence of highly populated and urbanized areas, and to account for computation and modeling limitations, the Texas portion of the Blackwater Draw watershed HUC-8 was split into 2 separate HEC-RAS geometries as shown in Figure 3. The HUC-8 was split into modeling areas as Blackwater Draw 1 and Blackwater Draw 2. Minor adjustments have been made to HUC-10 boundaries to improve modeling efficiency. The most downstream ends of both the Yellowhouse Draw and Black Water Draw HUC-8 watersheds, near the confluence of the three watersheds, were modeled as a part of the upstream end of the North Fork Double Mountain Fork Brazos (NFDMFB) 2D BLE model. This was done to move the model area tie in away (upstream) from the large confluence area and allow for easier tie in of the mapping of all three HUC-8 watersheds. After the modeling and mapping processes were completed for the three watersheds, with the upstream limits of the NFDMFB_1 model tied in with the Yellowhouse Draw and Black Water Draw models at this location upstream of the confluence, the spatial data containing the mapping products was split and merged such that all mapped products delivered adhere to the original HUC-8 boundaries. Therefore, users should note that while the mapped floodplains and other datasets will be consistent with the original HUC-8 watershed boundaries, the modeling footprints will represent the edits to the boundaries described above.

The RAS6 watershed boundaries were created for the Blackwater Draw model areas using ArcGIS toolsets, which reduce the need for manual edits to mesh cells within RAS6 that result in error generation.The Blackwater Draw 1 and Blackwater Draw 2 2D meshes contain 1,388,599 and 724,673 cells, respectively, consisting of 200 foot cells, with the exception of 100 foot along the 1 square mile streams and 50 foot cells within community boundaries using refinement regions. Within community boundaries the streamlines were also extended to the 0.5 square mile extent and assigned 50 foot cell spacing in order to be more detailed. Internal connections were used to extract flow readings for regression locations throughout the model. 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 for the duration of the simulation. The time step was allowed to reach 240 seconds for a maximum and 7.50 seconds for the minimum. The RAS6 model was run with Diffusion Wave (simplified Full Momentum) equations.

2.2.2 Model and Boundary Condition Setup

Using RAS6 rain-on-grid modeling requires a 2D computational mesh boundary and often requires defining inflow boundary conditions and application of excess precipitation. Excess precipitation was applied to the 2D mesh as a precipitation boundary condition. The process to determine the excess precipitation to be applied is outlined in the hydrology section. Figure 3 depicts the Blackwater Draw 1 and Blackwater Draw 2 model boundaries and the flow transition points between models. There were no USGS stream gages used in the calibration of the Blackwater Draw models.

The Blackwater Draw HUC8 extends across the border with New Mexico, therefore the Blackwater Draw 1 model area was clipped to the state boundary. Because of this, inflows from existing New Mexico BLE models were extracted using profile lines and applied as inflow hydrographs to the Blackwater Draw 1 work area. Additionally, since the Blackwater Draw HUC-8 was split into two work areas, the outflow from the Blackwater Draw 1 model along the Blackwater Draw River was used as an inflow hydrograph for the Blackwater Draw 2 work area. This hydrograph was extracted from the Blackwater Draw 1 model using a 2D connection, and then placed as a flow hydrograph external boundary condition for the Blackwater Draw 2 model.

Outflow boundary conditions (from the computational 2D mesh) were used along model boundaries. Outflow boundaries were established as normal depth using approximate energy grade-line slope estimated from the LiDAR data. This allowed the boundary conditions defined as continuous boundaries to allow drainage to leave the model area freely to adjacent basins.

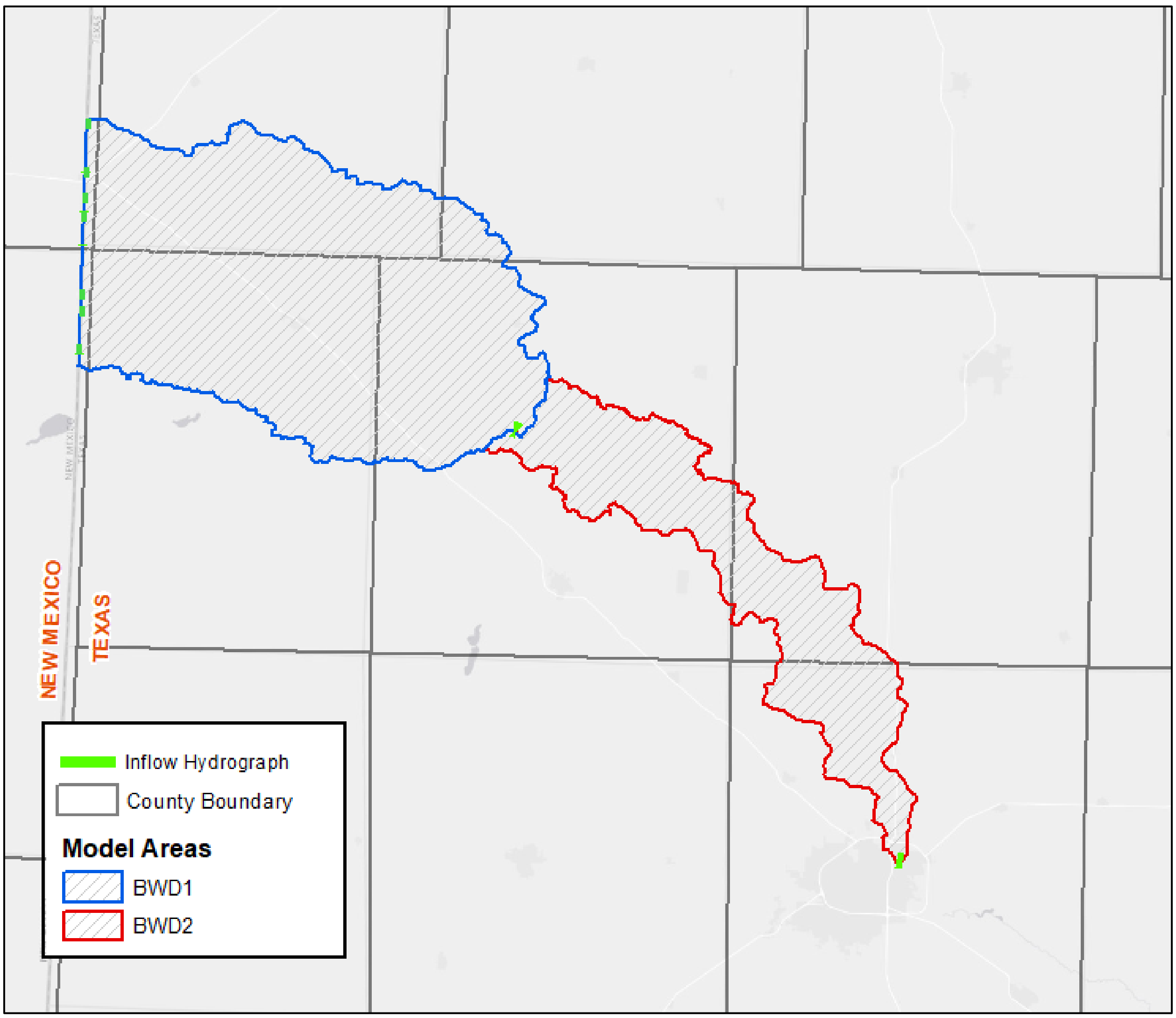


Figure 3: RAS6 2D Computational Mesh and Boundary Conditions

2.2.3 Hydrology

Precipitation frequency data (NOAA, 2018) was 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), and appropriate values for all sub-basin elements were determined considering spatial variation and a representative total for both the Blackwater Draw 1 and Blackwater Draw 2 model areas. Excess precipitation for the 2D meshes were developed as described in Section 2.2.3.1

2.2.3.1 Excess Precipitation for 2D Computational Mesh

HEC-HMS version 4.8 was used to apply the Soil Conservation Service (SCS) Curve Number (CN) method to calculate losses and define excess precipitation for this watershed. Temporal distributions of point rainfall totals were defined using 24-hour, frequency-based 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. An areal reduction as per Technical Paper 40 (TP-40) was used in HEC-HMS on all recurrence interval total precipitation depths in order to determine the effective precipitation for the sub-basin representing 2D mesh.

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-percent plus and minus events are defined to be one standard deviation above and below the 1-percent event. It should be noted that the standard errors for the 1-percent rainfall depth were based on the depth used post-areal reduction. The estimated 1-percent plus and minus rainfall depths are shown, alongside the other events, in Table 5 later in this section.

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 3.

Table 3: Land Use(LU)-Soils-CN Matrix for Defining Initial Curve Number

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

In addition to rainfall, the 1-percent plus and minus event estimates were further refined by adjustment of their respective CNs. A CN can be considered a parameter, exhibiting variability that follows some frequency distribution. While Antecedent Runoff Condition (ARC) II CNs were used for a 1-percent event, the range between ARC I and ARC III for the ARC II CN was assumed to correspond to an 80% confidence interval of the ARC II CN. The CN loss method assumes a maximum potential retention parameter, S, is inversely related to a CN by S = 1000 / CN – 10; this relationship is based on a median value of S determined from plotting a large number of observations.

Chapter 5 of the NRCS National Engineering Handbook (NEH) Part 630 provides an example of computing a CN for a watershed based on annual peak gage observations. The example involves computing a CN and corresponding S value for each event, then taking the logarithms of the S values. Further, the logarithm of S is assumed to vary normally, and the mean of the logarithms corresponds to the arithmetic median. Therefore, 10% (S10) and 90% (S90) extremes of lognormally distributed S values can be assumed to correspond to ARC III and ARC I condition CN values, respectively. This range represents an 80% confidence interval, corresponding to +/- 1.282 standard deviations from the mean. The following procedure was used to estimate one standard deviation of a given CN (in fact, one standard deviation of the logarithm of S) for the purposes of modeling 1-percent plus and minus events. First, ARC III (corresponding to S10) and ARC I (corresponding to S90) CN values can be estimated from a 1-percent CN (ARC II) by:

$$\mathrm{CNI} = 4.2 * \mathrm{CNII} / (10 - 0.058 * \mathrm{CNII})$$

$$\mathrm{CNIII} = 23 * \mathrm{CNII} / (10 + 0.13 * \mathrm{CNII})$$

Next, S90 and S10 can be computed by:

$$\mathrm{S10} = 1000 / \mathrm{CNIII} - 10$$

$$\mathrm{S90} = 1000 / \mathrm{CNI} - 10$$

The following relationship can then be used to compute one standard deviation of the logarithm of S:

$$\log(\mathrm{S10}) = \mathrm{mean}(\log(\mathrm{S})) + 1.282\ \mathrm{std.dev.}(\log(\mathrm{S}))$$

$$\log(\mathrm{S90}) = \mathrm{mean}(\log(\mathrm{S})) - 1.282\ \mathrm{std.dev.}(\log(\mathrm{S}))$$

$$1\ \mathrm{std.dev.}(\log \mathrm{S}) = (\log \mathrm{S10} - \log \mathrm{S90}) / 1.282$$

Therefore, 1-percent plus and minus S values can be estimated by:

$$\log \mathrm{SPlus} = \log \mathrm{S} + [1\ \mathrm{std.dev.}(\log \mathrm{S})]$$

$$\log \mathrm{SMinus} = \log \mathrm{S} - [1\ \mathrm{std.dev.}(\log \mathrm{S})]$$

Finally, 1-percent plus and minus CNs can be computed by:

$$\mathrm{CNPlus} = 1000 / (\mathrm{SPlus} + 10)$$

$$\mathrm{CNMinus} = 1000 / (\mathrm{SMinus} + 10)$$

Since the 1-percent plus and minus events represent plus and minus one standard deviation of a 1-percent event, CNs used in a rainfall-runoff simulation for modeling 1-percent plus and minus events were developed, as described above. A single basin was used in HEC-HMS for simulation to estimate excess precipitation.

The table below shows the curve numbers computer for the model.

Table 4: Rainfall-Runoff Curve Numbers

Sub-basin Description	CN (initial)	CN (verified)	CN 1-percent Minus	CN 1-percent Plus
Blackwater Draw 1	61.3	80.0	67.3	88.6
Blackwater Draw 2	65.6	70.6	54.6	81.9

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including CNs for defining rainfall losses. No routing was considered in the rainfall-runoff modeling. Frequency-based storm with 50%

storm centering were used for-defining temporal distributions of point rainfall totals. Table 5 provides the precipitation totals applied to the model including areal reduction factor (ARF).

Table 5: Precipitation Totals estimated in HEC-HMS (post ARF)

Percent Annual Chance Precipitation Depths (in.)							
Sub-Basin Description	**1-percent**	**0.2-percent**	**2-percent**	**4-percent**	**10-percent**	**1-percent Plus**	**1-percent Minus**
Blackwater Draw 1	6.04	7.86	5.32	4.65	3.81	6.39	5.69
Blackwater Draw 2	6.34	8.28	5.59	4.87	3.97	7.53	5.15

Table 6 shows the excess precipitation totals determined from the HMS model. These values are a factor of the average CN and precipitation depths for each model area. Note that CNs were modified during the calibration process and the excess precipitation depths were recalculated to install confidence in the final model results.

Table 6: Total Excess Precipitation Applied to 2D Mesh

Percent Annual Chance Precipitation Depths (in.)							
Sub-Basin Description	**1-percent**	**0.2-percent**	**2-percent**	**4-percent**	**10-percent**	**1-percent Plus**	**1-percent Minus**
Blackwater Draw 1	0.47	0.66	0.40	0.33	0.24	0.62	0.27
Blackwater Draw 2	0.36	0.58	0.28	0.21	0.14	0.64	0.08

Figure 4 and Figure 5 show the excess precipitation hyetograph used for Blackwater Draw. CN and precipitation depth are the two factors used by the HMS model to determine the magnitude of the excess precipitation event. The excess precipitation hyetograph is calculated in 6-minute increments. All models in this study have excess hyetograph shapes that closely resemble this one, but with varying maximum excess precipitation values.

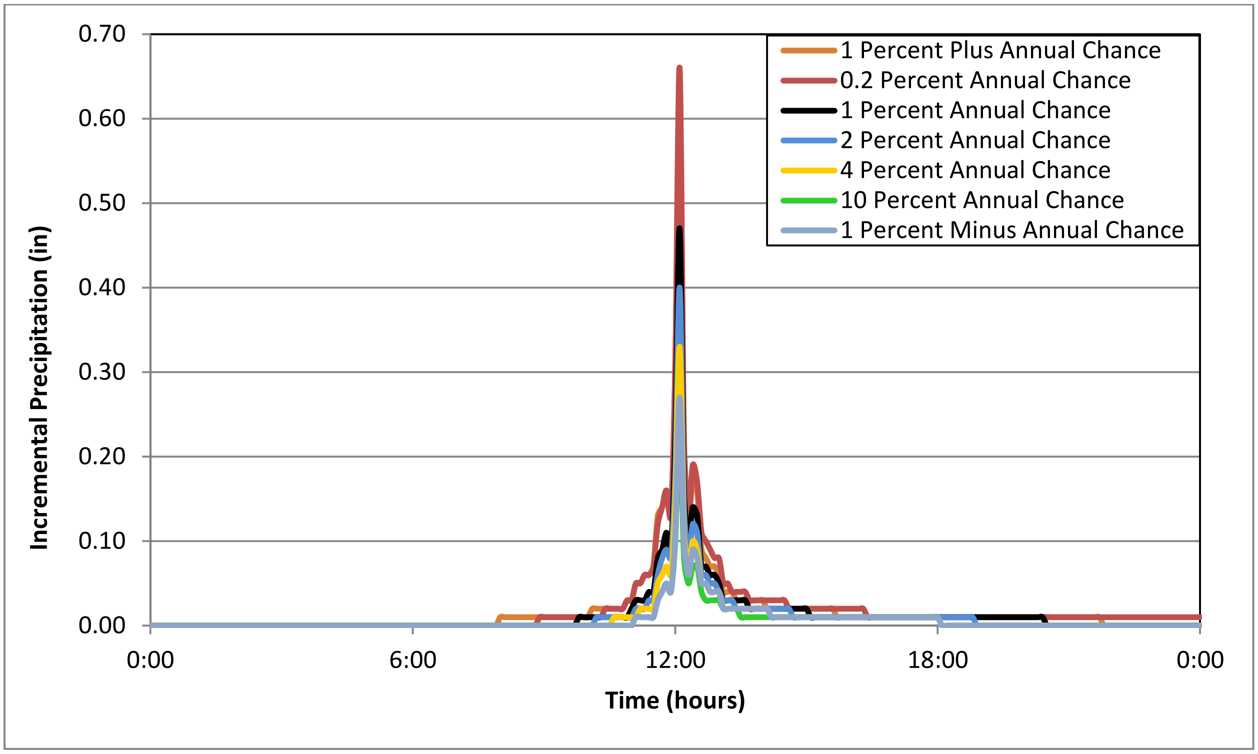


Figure 4: Excess Precipitation Hyetograph Applied to 2D Mesh – Black Water Draw 1

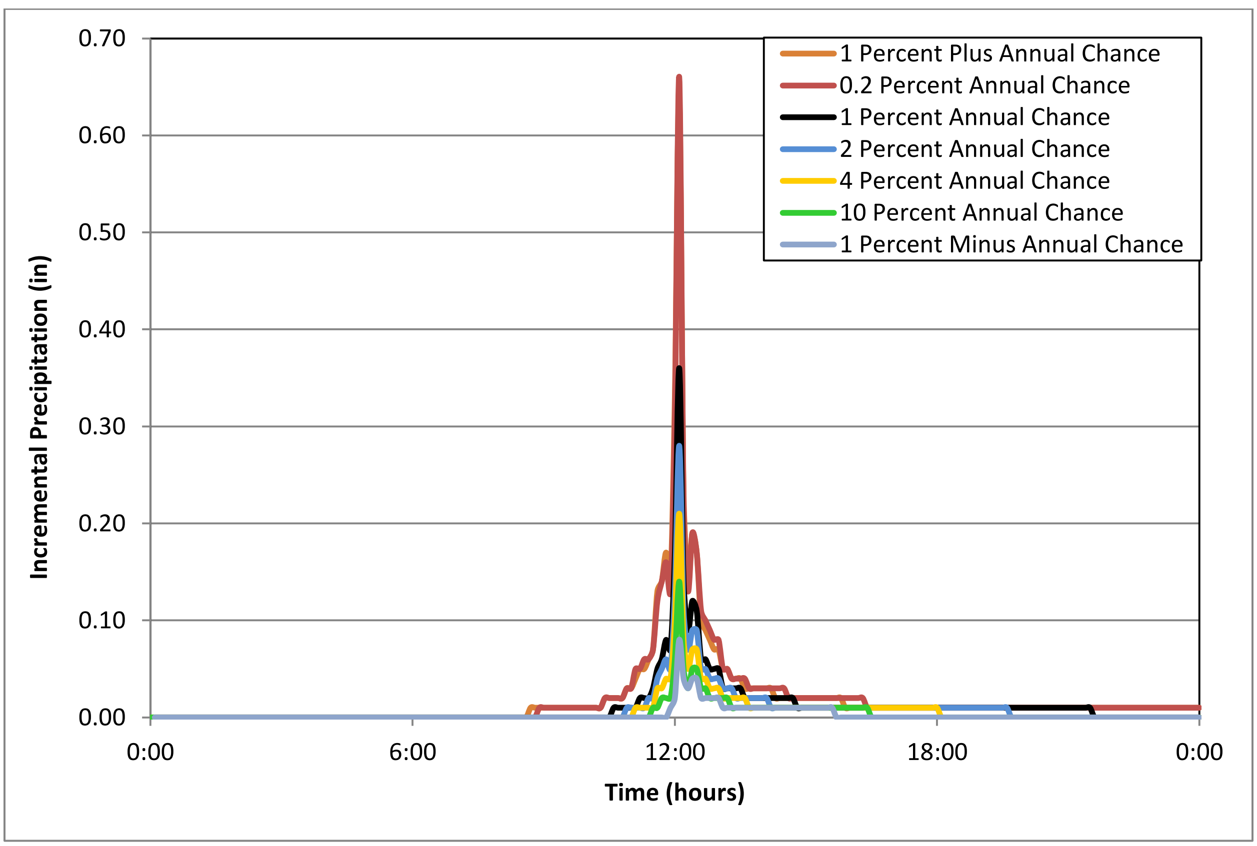


Figure 5: Excess Precipitation Hyetograph Applied to 2D Mesh – Black Water Draw 2

2.2.3.2 Inflow Hydrograph Boundary Conditions

Because the Blackwater Draw HUC8 borders New Mexico, outflow hydrographs were extracted from the existing New Mexico BLE models along the border to apply as inflows to Blackwater Draw 1. Additionally, flow from the Blackwater Draw River in the Blackwater Draw 1 model was used as an inflow into the Blackwater Draw 2 model. The inflow hydrograph was derived by utilizing the results of the HEC-RAS model for Blackwater Draw 1 directly upstream. By using upstream model results as inflow hydrographs to the downstream model, this allows the two separate HEC-RAS models to act as one continuous model of the larger Blackwater Draw watershed area. The inflow hydrograph was extracted from the Blackwater Draw 1 model using a 2D connection. The inflow hydrograph applied to Blackwater Draw 2 RAS model is represented in Figure 6.

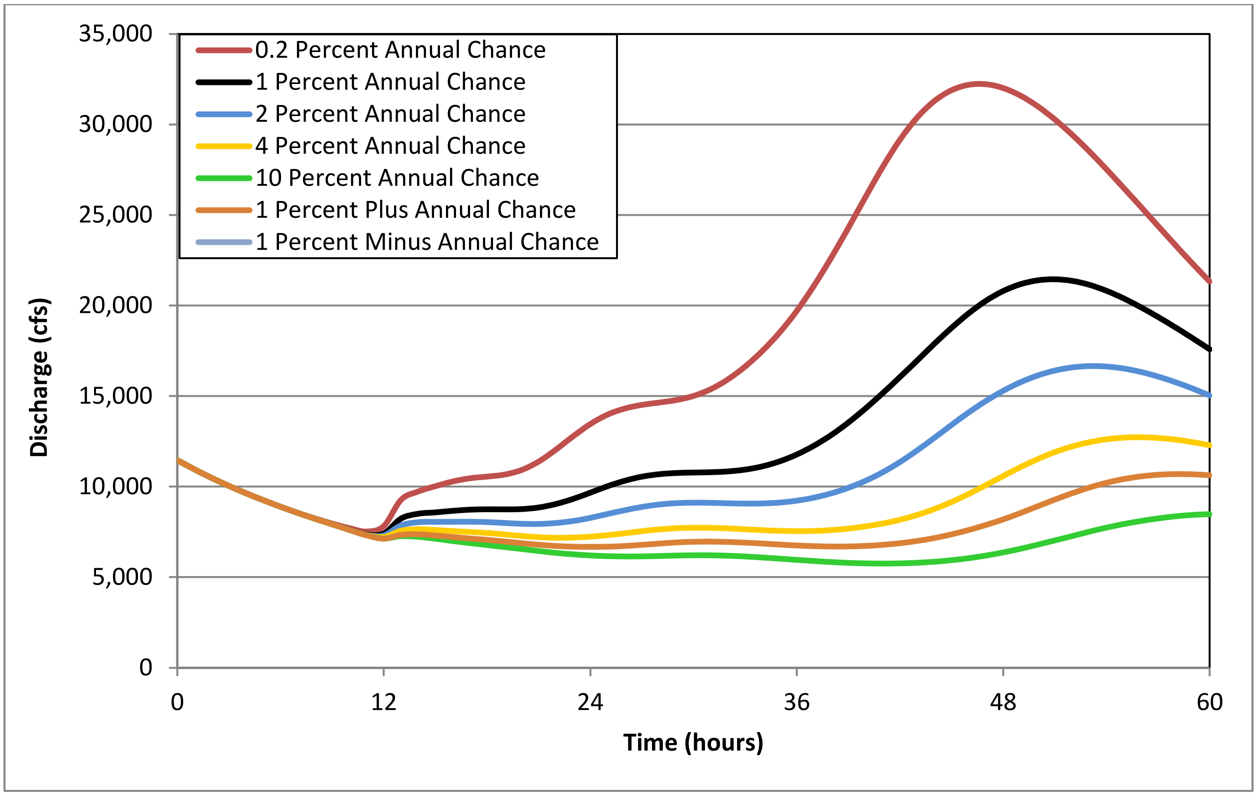


Figure 6: Inflow Hydrograph for Blackwater Draw 2

In order to achieve a seamless flood hazard result at a transition location (locations where flow is exchanged between 2D model areas), the water surface elevation (WSE) and inundation tie-ins between models must be made as close as possible. A 1,000 feet buffer was applied to each model work area for the mesh boundary. This is done so that the inflow boundary condition of the downstream model and the normal depth outlet boundary condition of the upstream model are far enough away from the work area transition location that they do not impact the WSE tie-ins between models in an undesired way. To make this overlap work without double accounting for rainfall, an internal 2D connection is placed in the upstream model at the exact same location as the inflow boundary condition for the downstream model. Approximately halfway between the model overlap is the actual model area boundaries where the mapped floodplain products switch from the upstream model results to the downstream model results. This transition location is the targeted area to have the water surface elevation and inundation tie-in as closely as possible.

2.2.3.3 Restart File

Due to the playas and natural depression in the terrain, a restart file was used to establish initial conditions for the Blackwater Draw 1 simulation. Many of the playas are holding back water from flowing along natural riverine pathways. The restart file was essentially used to fill the playas before the start of the simulations. One restart file was used for all plans. The excess precipitation hyetograph that was input into the resart file is shown in the figure below.

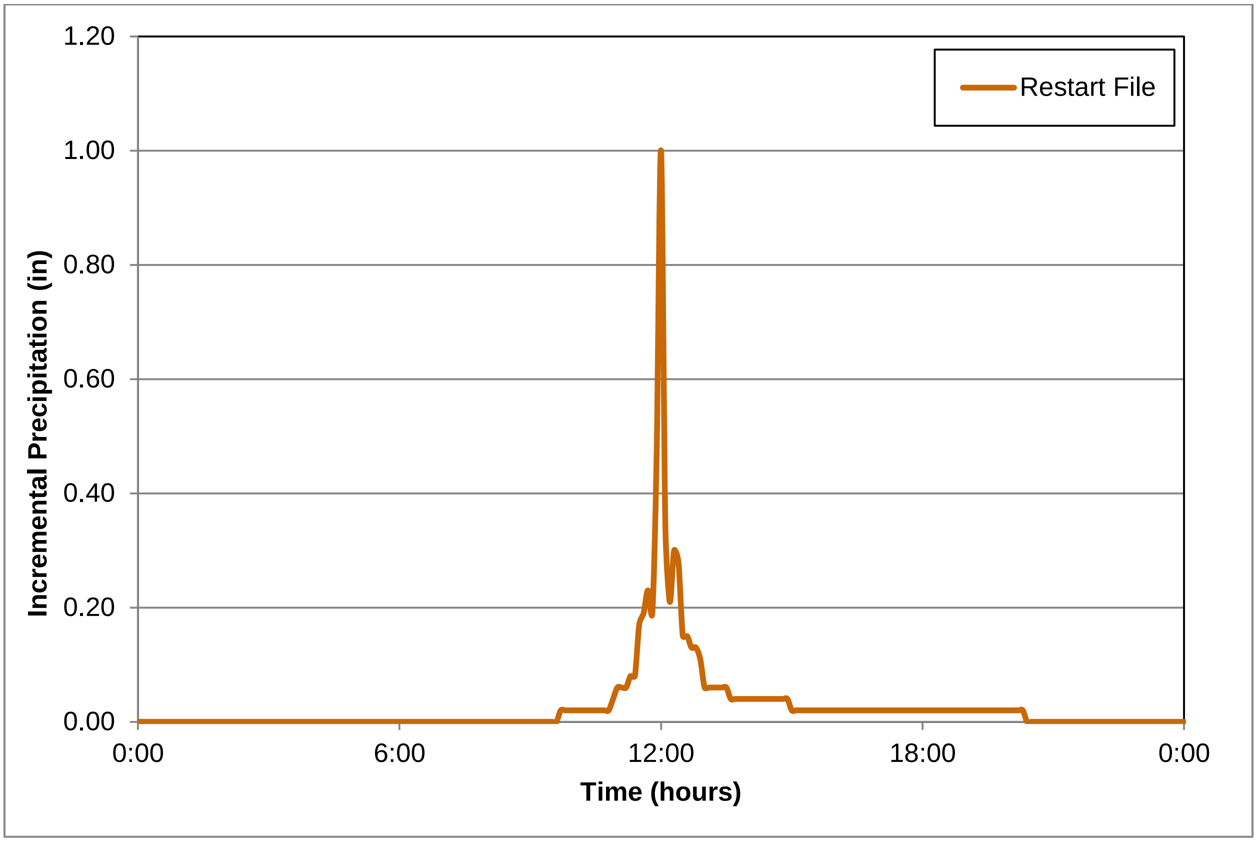


Figure 7: Restart File Used in Blackwater Draw 1

2.2.4 Hydraulics

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

2.2.4.1 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. The channel layers were created using a 100 foot buffer. This allows for the model to accurately represent deep, swift flow within the channel and shallow overland flow outside of the channel areas. The table below shows a typical landuse-roughness matrix used in defining the roughness coverage for the study area for areas both inside and outside of the channel. In the HEC-RAS model Channel n values are listed as land classification – Channel, and Overbank bank n values are listed as land classification – Base.

Table 7: NLCD 2016 Manning's n Roughness Matrix

NLCD Classification	Channel		Overbank	
	N Value	Source	N Value	Source
Open Water	0.03	Chow, 1959	0.03	Chow 1959
Developed, Open Space	0.035	Chow, 1959	0.04	NRCS KS Dam Breach, 2016
Developed, Low Intensity	0.035	Chow, 1959	0.08	NRCS KS Dam Breach, 2016
Developed, Medium Intensity	0.035	Chow, 1959	0.1	NRCS KS Dam Breach, 2016

Table 7, continued: NLCD 2016 Manning's n Roughness Matrix

NLCD Classification	Channel		Overbank	
	N Value	Source	N Value	Source
Developed, High Intensity	0.035	Chow, 1959	0.15	NRCS KS Dam Breach, 2016
Barren Land	0.03	Chow, 1959	0.03	NRCS KS Dam Breach, 2016
Deciduous Forest	0.05	Chow, 1959	0.16	NRCS KS Dam Breach, 2016
Evergreen Forest	0.05	Chow, 1959	0.16	NRCS KS Dam Breach, 2016
Mixed Forest	0.05	Chow, 1959	0.15	NRCS KS Dam Breach, 2016
Scrub/Shrub	0.04	Chow, 1959	0.1	NRCS KS Dam Breach, 2016
Grassland/Herbaceous	0.04	Chow, 1959	0.15	HCFCD modeling Guidelines, 2018
Pasture/Hay	0.04	Chow, 1959	0.15	HCFCD modeling Guidelines, 2018
Cultivated Crops	0.04	Chow, 1959	0.1	HCFCD modeling Guidelines, 2018
Woody Wetlands	0.04	Chow, 1959	0.12	NRCS KS Dam Breach, 2016
Emergent Herbaceous Wetland	0.04	Chow, 1959	0.07	NRCS KS Dam Breach, 2016

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. Road embankment features were delineated in GIS and imported into RAS5 as breaklines to contain water where appropriate. Similarly, significant bridge/culvert crossings that were not processed out of the terrain data were modeled by v-notch breaklines adjacent to the road embankment to align grid cells around the embankment and allow water to be routed through the embankment without creating artificial backwater. An example of the v-notch breakline approach is shown in Figure 8.

County, interstate, common name, state recognized, and U.S. roads were incorporated for road breaklines from the U.S. Census Bureau TIGER/Line road layer.

A breakline is added to represent Palmetto dam which is at the downstream end of the Blackwater Draw HUC-8. Private dams were not modeled as showing protection. This is to lessen the burden on private dam owners to maintain their dams in order to sustain the regulatory products that could be created in the future as a result of this study. The study area does not include any FEMA accredited levees.

Breaklines were also used along all the stream centerlines of streams draining greater than one square mile of drainage area, and 0.5 square miles of drainage area within densely populated areas. Each streamline was topo-derived and the stream centerline was enforced with 100 feet cell spacing in order to align cells along the stream line and capture more detail along the one square mile stream network. Streamline alignment was also hand checked with the terrain by the modeler to ensure accuracy. Stream names were referenced from other sources such as NFHL and NHD datasets. In the HEC-RAS model, streams that passed through densely populated regions were enforced as breaklines using 50ft cell spacing.

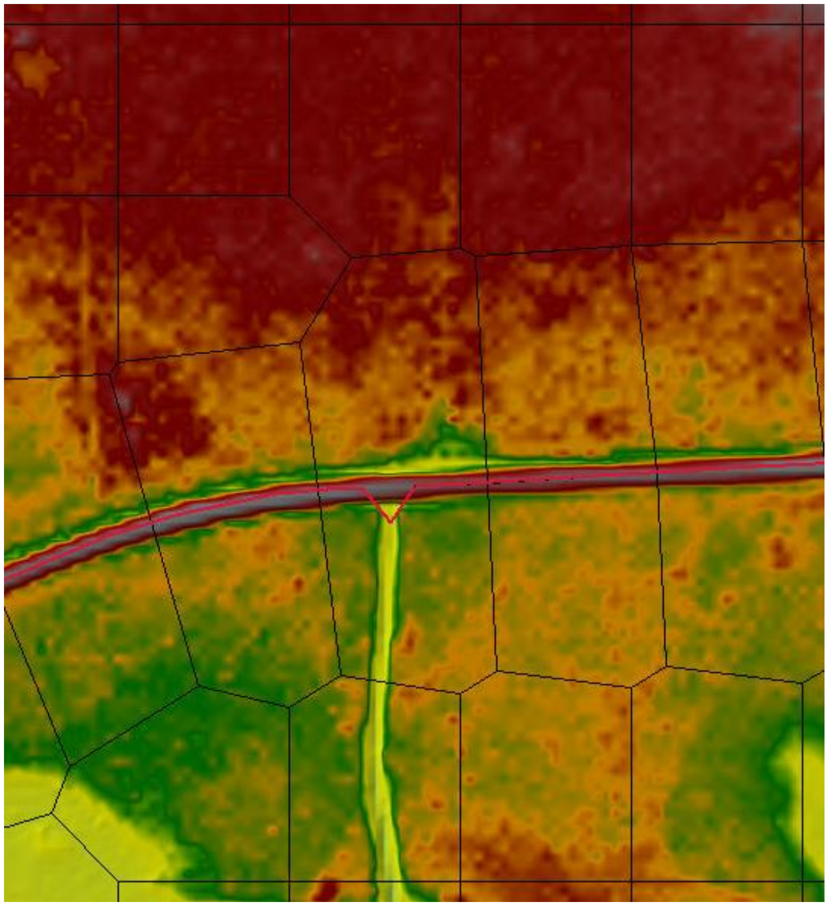


Figure 8: V-notch Breakline Approach at Bridge Crossing

2.2.4.3 Refinement Regions

Refinement regions were created for each community within the model. The political 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. Table 8 shows the communities contained within Blackwater Draw watershed that were modeled with refinement regions as well as the square mileage of the refinement region.

Table 8: Communities with 2D Mesh Refinement

Community Name	Area (mi^2)
Farwell	1.2
Sudan	1.3
Earth	1.8
Muleshoe	5.0
New Deal	0.5
Abernathy	1.8
Lubbock	17.6

2.2.5 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 during the data development process includes, but is not limited to the following QC checks:

- Hydrological QC – included checks for curve number calculation, input precipitation, flood events, areal reduction factor and human error.
- Hydraulic QC – included checks for RAS geometry, breakline 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 described in section 4.1.2, 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.

3. Results

The 2D BLE results for the study produced flood hazard area that compared reasonably well with effective SFHA in most cases, and provides additional estimated flood hazard risk area where not previously mapped. The HEC-RAS peak (max) results were exported for mapping and both HEC-RAS models were run with a hydrograph output interval of 30 minutes, mapping output interval of 1 hour and the detailed output interval of 1 hour.The Blackwater Draw watershed is sufficient to facilitate FEMA regulatory processes while also providing the best available information for planning purposes. The 2D BLE results should be verified through community work map meetings as part of the regulatory workflow.

3.1 Calibration

There are no USGS gages within the Blackwater Draw work area that were acceptable for use in calibration. In order to verify the model results, a regression analysis was completed for eleven points, five in Blackwater Draw 1 and six in Blackwater Draw 2. Due to the playas throughout the model, the main river running through the model, the Blackwater Draw River, was calibrated. Points outside of the river system were checked and showed that a significant amount of water is not exiting the playas. The discharge from HEC-RAS model were calibrated to the regression flows, however due to the limitations and scope of this study, extensive efforts were not feasibile. Therefore, model flows were accepted although they are a slightly different from the regression flows.

Table 9: Calibration Results

Model	Location	Method Used in Original Study	Reference			HEC-RAS 6.1 (2D) (cfs)
			Lower Limit (cfs)	1-percent (cfs)	Upper Limit (cfs)	
BWD 1	S_01	Regression	5,223	10,421	20,792	12,980
BWD 1	S_02	Regression	7,386	14,737	29,405	16,023
BWD 1	S_04	Regression	10,207	20,365	40,633	19,974
BWD 1	S_05	Regression	10,035	20,023	39,951	16,426
BWD 1	Outflow BWD2	Regression	16,794	33,509	66,859	21,449
BWD 2	Regression 2	Regression	4,164	8,309	16,578	19,461
BWD 2	Regression 3	Regression	5,603	11,179	22,305	19,340

Table 9, continued: Calibration Results

Model	Location	Method Used in Original Study	Reference			HEC-RAS 6.1 (2D) (cfs)
			Lower Limit (cfs)	1-percent (cfs)	Upper Limit (cfs)	
BWD 2	Regression 4	Regression	8,218	16,396	32,715	19,170
BWD 2	Regression 5	Regression	10,360	20,671	41,244	19,172
BWD 2	Regression 6	Regression	10,144	20,239	40,383	19,102

Figure 9 shows the final results of the calibration locations compared to modeled flows throughout the Blackwater Draw watershed along with error bars created using the difference between 1-percent and 1-percent plus discharges and 1-percent and 1-percent minus discharge as minimum and maximum values. Eleven comparisons were made with varying drainage areas to ensure the calibration of excess precipitation for different points over the entire watershed area. This large collection of calibration points provides confidence in results throughout the entire watershed.

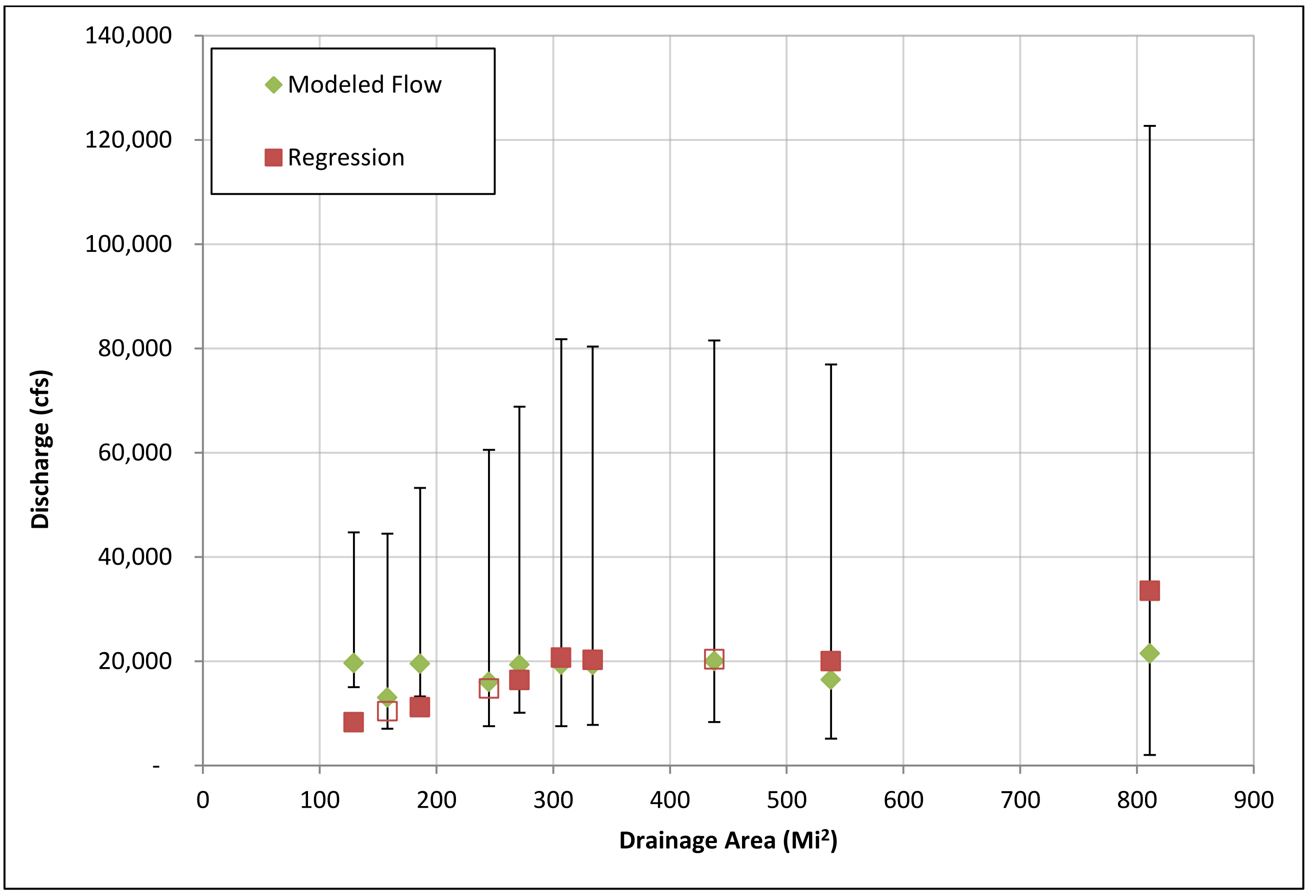


Figure 9: Calibration Comparison

3.2 Challenges

A considerable challenge for the Blackwater Draw watershed was the size of the HUC8 basin. In order to create this model without creating runtime or cell number issues, it was decided that the watershed would be split into two working models. The outflow from the upstream model containing the Blackwater Draw River was then used as an inflow boundary condition to the downstream model. The Blackwater Draw watershed contains the Millen Lake Dam and the Rita Blanca Dam. Due to the project scope, structure outlet data was not included in this analysis, and the outlets were modeled using V-notches. The HUC-8 also included portions of Lubbock, a large urbanized area.

Yellow House Draw and Black Water Draw HUC-8s are adjacent to each other, and even the shared watershed boundary area is extremely flat and consists of several playas that retain water. Because of this, many areas of shallow pluvial flow or playa storage straddle the boundary between the modeled areas of the two HUC8s. While these areas are numerous, their impact to downstream flood flows is minimal as they do not convey, but rather retain, much of the flow that reaches these locations. This creates a challenge for edge matching these small flooded areas since minor differences in excess precipitation and other coarsely-defined model parameters (such as CN or even n-value) used for the two watersheds can lead to discrepancies in mapping extent. While many of these areas along the shared boundaries do edge match reasonably well, extensive efforts using modeing and/or mapping techniques is not feasible for a BLE analysis, and is limited to checking for similar WSEs across the HUCs (which was verified), so that the primary focus for achieving good tie in between model areas and HUC8 watersheds remains along primary flood channels. Some lessons learned can be carried forward for future BLE modeling in flat areas like these, such as coordination of model parameters with adjacent model teams, if feasible, intentional delineation of model domain areas in an attempt to keep entire ponded or shallow flow areas on one side of the model divide, and more detailed focus on areas of interest during future modeling efforts.

Within the watershed, there are several populated areas, agricultural fields, and playas that appear to be trapping water which prevents runoff from reaching the channel in the model. Various v-notches were applied to represent cross culverts and improve conveyance. Further detail and study of the flow patterns and likely runoff conveyance would be recommended as part of a future study if more detailed flood risk information was needed in these areas. In addition, several breaklines and refinement regions increased the total number of cells and thereby increasing the model runtime.

The complex hydrology in the area also presented a challenge. The large number of playas in the Blackwater Draw watershed coupled with the lack of gage data and effective data presented a challenge for calibrating; as did the approximate study (BLE) done for the upstream contributing areas in New Mexico. In future more detailed studies, a more in-depth analysis of the hydrology in the area is recommended. .

3.3 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.

Point source Atlas 14 rainfall was used in the analysis, and due to the large size of the modeled area (the entire HUC-8 watershed), the point rainfall used has a tendency to vary more widely from the actual point rainfall data at any specific location within the watershed. For detailed modeling and further improvements, smaller-sized modeled areas are recommended, which will result in smaller rainfall and CN variability. In addition, future versions of HEC-RAS are anticipated to include the capability to utilize spatially varying rainfall, which may result in additional improvements in the reasonability in some of these aspects. The hydraulic model can further be improved by using a smaller cell size than 200 foot along with adding structural and survey data for each crossing.

4. Floodplain Mapping and Effective Zone A Validation

The following sections provide a synopsis of how raw modeled depths were translated into SFHA. In addition to developing a new SFHA, the BLE model data was leveraged to validate the effective Zone A studies within the project footprint.

4.1 Special Flood Hazard Area

4.1.1 Model Outputs

The HEC acknowledged RAS Mapper may not render water surface elevation values and/or delineate inundation extent appropriately for direct use in FEMA regulatory mapping products. To maintain a high level of consistency between modeling results and final mapping, minimal map clean up was performed while maintaining identification of both fluvial and pluvial flood risk as reflected by the models. Additional processing may be required to make the mapping products FEMA compliant.

4.1.2 Methodology

The sloping render mode plots water surface elevation (WSE) by interpolating the WSE between the 2D cell faces, producing a more continuous flood inundation extent. Depth rasters from the sloping render mode were exported for the 10-percent, 1-percent, and 0.2-percent flood events with a tolerance of 0.333333 feet because the Blackwater Draw watershed is in an area categorized as 'High Plains' per TWDB guidelines. To reduce the extent of disconnected flood areas, raster grid processing is used to filter and remove disconnected, small, or shallow areas of flooding by processing through the 'Mapping Threshold Matrix' shown in Table 10.

Table 10: Mapping Threshold Matrix

Area (acres)	Average Depth (feet)
< 0.33	-
0.33 – 0.5	< 0.5

Polygon outputs from the 'Mapping Threshold Matrix' also fill in minor areas of high ground (islands) that are less than 0.33 acre. The outputs are then modified through a simplication and smoothing process to reduce unnecessary/erroneous vertices, remove rough edges and reduce the size and complexity of the raw floodplain polygons for the 1-percent, and 0.2-percent flood events. For the Blackwater Draw watershed, the polygon outputs were simplified by retaining critical points at a 5 foot tolerance. The simplified polygon outputs were then smoothed utilizing the PAEK algorithm and the tolerance was set to 25 feet. The 10-percent flood event polygons are not modified through the simplification and smoothing process and are delivered in the rasterized polygon shape.

Due to topographic differences within a lake footprint, these areas sometimes appear partially mapped in the flood extents from the model results. Lakes and reservoirs larger than 40 acres are reviewed to ensure full inundation on the 1-percent, and 0.2-percent polygon extents. If necessary, lake boundaries were copied into the flood event polygons to make sure they are fully mapped.

Once the final polygon flood extents are complete, it is necessary to merge the 10-percent boundaries into the 1-percent and the 1-percent extents into the 0.2-percent extents. This step ensures that the extents of the 10-percent floodplain is smaller than the 1-percent floodplain, and the 1-percent is smaller than the extents of the 0.2-percent floodplain.

4.1.3 BLE Flood Hazard Layer

BLE database format FLD_HAZ_AR feature classes were developed and attributed with Zone A and Shaded Zone X features. The BLE FLD_HAZ_AR feature class was tested for topological errors described in the FIRM Database Technical Reference and all errors were fixed for data integrity and BLE schema agreement. The 10-percent boundaries have been included in the BLE TENPCT_FP feature class.

4.1.4 Water Surface and Depth Grids

Once the final floodplain polygons were created, it is required that the depth and WSEL grids match the full extents of the flood inundation polygons. Because of the processing of the floodplain polygon boundaries through the above mentioned steps, there are areas in the model produced raster grids that no longer match the polygons. Final grids are interpolated for areas filled in with surrounding cell values and then clipped to the polygon extents to create the final water surface and depth grids for the 1-percent and 0.2-percent flood events.

4.1.5 Additional 1-Percent Features

The BLE results for this study produced a SFHA that compares favorably with the effective SFHA. These boundaries provide an estimated SFHA in areas that have not been previously studied and therefore do not currently have an SFHA mapped. These results provide context for flood risk communication as part of the Discovery process, and should be verified through community work map meetings before being applied to a regulatory product.

A map showing the BLE results is included as Appendix A BLE Map.

4.2 Validation of Effective Zone A SFHA

The inventory of Zone A studies (258.59 miles) in the Blackwater Draw Watershed were classified in CNMS with validation status of "UNVERIFIED" (258.59 miles) or "VALID" (0.0 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.

4.2.1 Intial 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 the study area within Blackwater Draw Watershed, LIDAR sources were not used for the effective study. New LiDAR sources are now available in this area and are considered significant improvements from the effective zone A topographic sources. Therefore, reaches within this study area fail this check.

4.2.2 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 all Zone A streams within Blackwater Draw Watershed, regression equations were not known to be used for any effective studies and, therefore, pass this assessment check.

4.2.3 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 studies in the Blackwater Draw HUC-8 are in rural watersheds and, therefore, pass this check.

All of the initial assessment results are shown in Table 11.

Table 11: Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Fail	Effective Study did not utilize LiDAR source and LiDAR is now available
A2 – Hydrology	Pass	Regression equations not used in effective study
A3 – Development	Pass	Watershed does not meet urban threshold

4.2.4 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. All streams in Blackwater Draw HUC-8 are not known to be model-backed and fail this check.

4.2.5 Validation Check A5 – Comparison of BLE and Effective Zone A

The BLE /effective Zone A comparison method leverages the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach uses the 1-percent plus and 1-percent minus flood profiles and horizontal and vertical tolerances described in FEMA's Automated Engineering guidance document dated May 2016. For the comparison of BLE and effective Zone A in the Texas study area, the following vertical and horizontal tolerances were used to conduct the modified FBS procedure. One point was placed every 200 feet along the floodplain boundaries for comparison.

- Vertical Tolerance: +/- 2.5 - 5 feet (one-half contour interval of effective topographic source).
- Horizontal Tolerance: +/- 75 feet (standard horizontal tolerance for BLE comparison testing).

Comparison results for thse streams were grouped at the HUC-12 level and are summarized in Table 12 to better understand the general health of the HUC-12 watershed, but the validation check was performed at the stream level. Streams where the percentage of passing FBS sample points is greater than or equal to 85% are marked as "Pass", otherwise marked as "Fail".

Table 12: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Blackwater Draw Watershed	All Streams	7,698	2,460	5,238	68%	Fail	
120500020504-Blackwater Draw	120500020504	1,120	330	790	71%	Fail	7.4
120500020505-Blackwater Draw	120500020505	1,578	517	1,061	67%	Fail	8.2
120500020506	120500020506	1,210	276	934	77%	Fail	5.7
Lubbock International Airport-Blackwater Draw	120500020508	1,297	294	1,003	77%	Fail	12.3
Spring Lake-Blackwater Draw	120500020407	529	312	217	41%	Fail	14.7
Town of Abernathy-Blackwater Draw	120500020507	1,643	568	1,075	65%	Fail	9.3
Town of Earth-Blackwater Draw	120500020410	191	126	65	34%	Fail	16.5
Town of Muleshoe-Blackwater Draw	120500020401	130	37	93	72%	Fail	10.6

4.2.6 Validation Results

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Black Water Draw watershed has been updated as summarized in Table 13 and illustrated in Figure 10.

Table 13: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	0.0
UNVERIFIED	BEING STUDIED	258.59

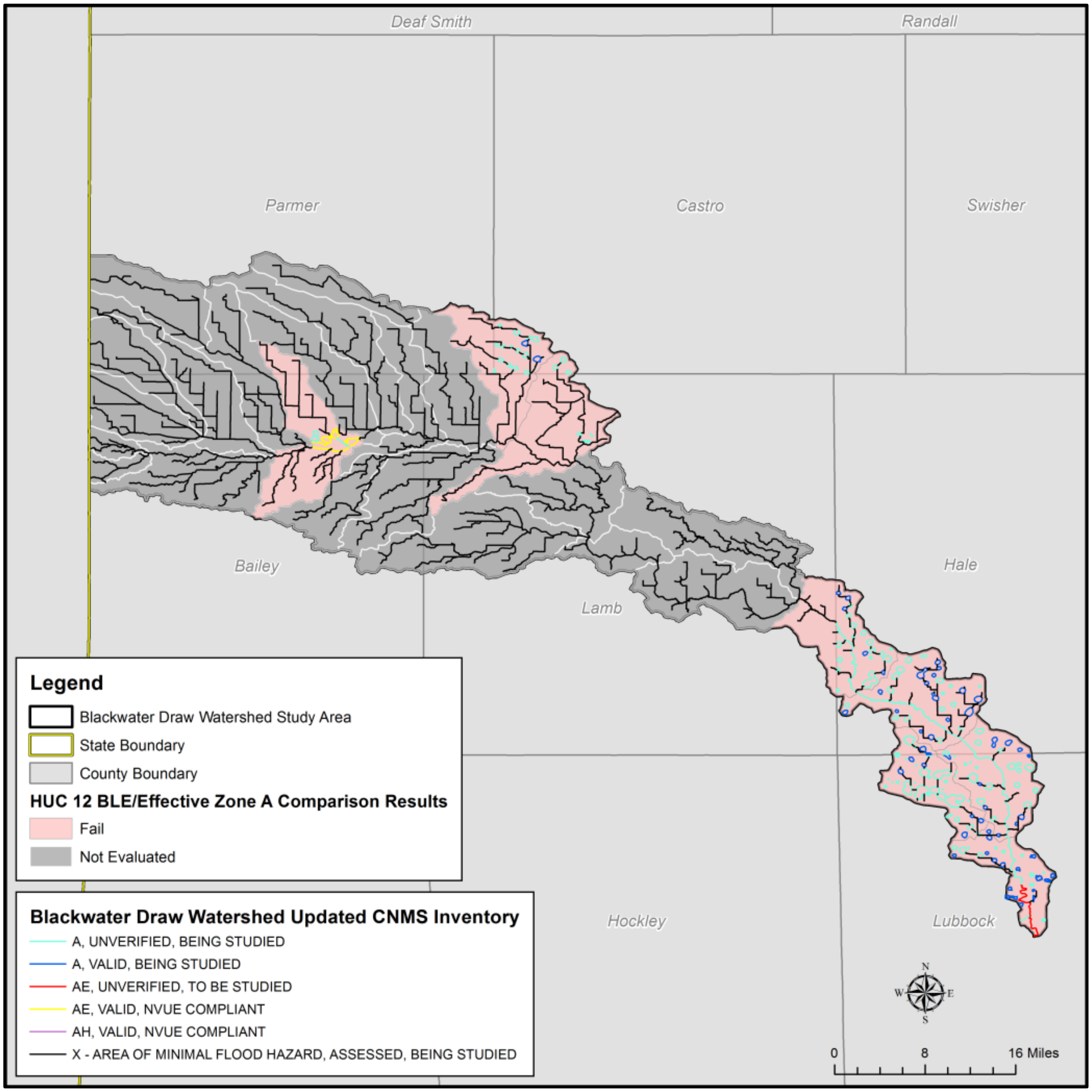


Figure 10: Blackwater Draw Watershed CNMS Validation Results

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 11 below shows the range of the HUC-12 priority scores which can be used to initiate discussions during the Discovery phase.

Spring Lake – Blackwater Draw HUC-12 was determined to have the highest priority score and the most need while HUC 12 – 120500020506 had the lowest score.

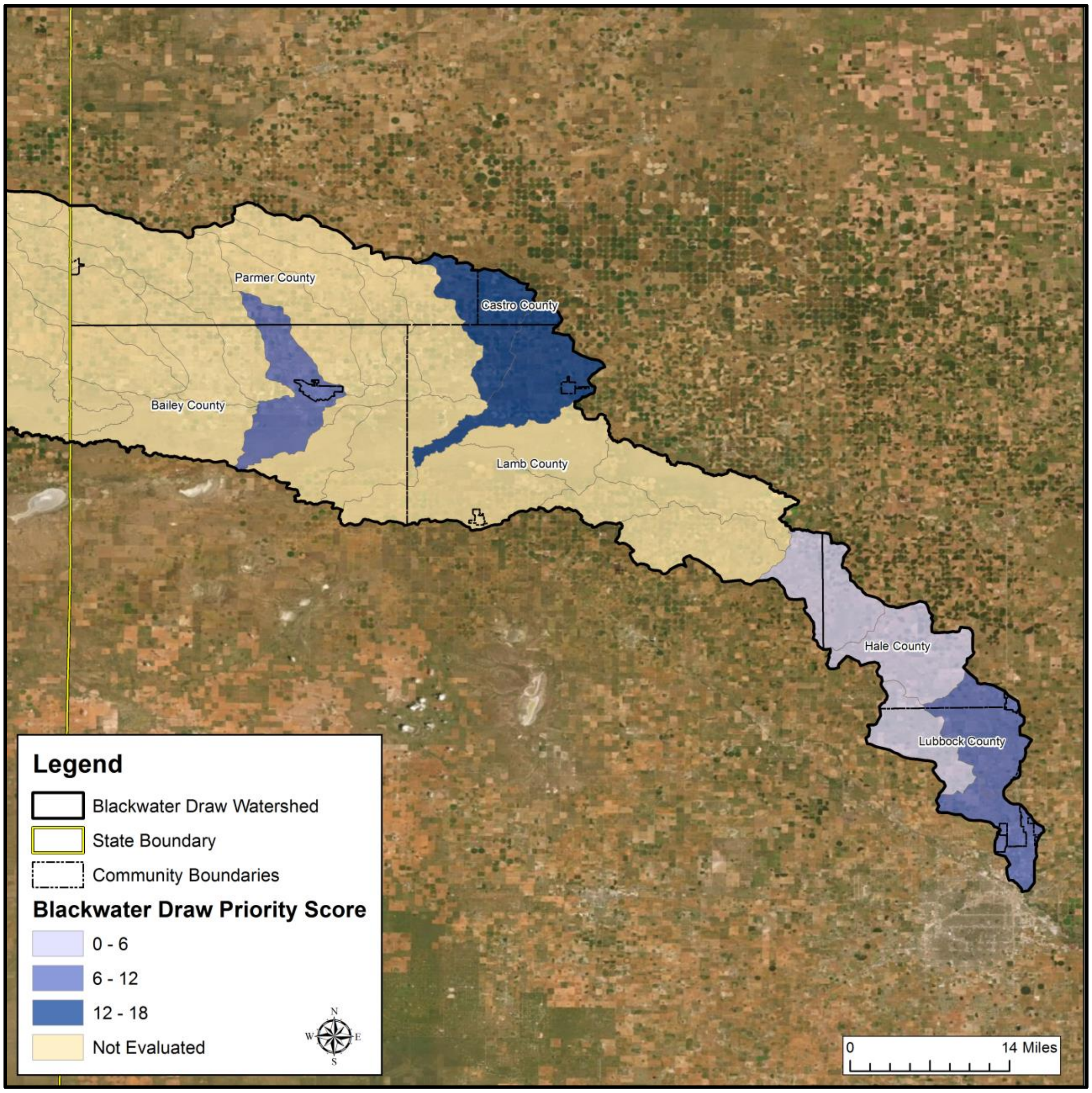


Figure 11: Ranking of Blackwater Draw Watershed HUC-12s

4.3 Flood Risk Analysis

A flood risk analysis was performed for this project. The updated 1-percent annual chance and 0.2-percent annual chance depth grids were 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 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 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 watershed extents for each return period to ensure proper model processing. A summary of results for counties within the watershed for the 1-percent annual chance scenarios are shown in Table 14. Totals only reflect data for those census tracts/blocks included in the user's study region and will reflect the entire county only if all of the census blocks for that county/state were selected at the time of study region creation.

Table 14: Hazus 5.1 Results for 1-Percent-Annual-Chance (100 year) Scenario

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Bailey	$139,679,000	$579,822,000	$406,791,000
Castro	$176,000	$5,866,000	$2,928,000
Hale	$3,468,000	$155,909,000	$93,594,000
Lamb	$23,918,000	$249,153,000	$157,236,000
Lubbock	$78,231,000	$545,219,000	$402,025,000
Parmer	$15,197,000	$231,489,000	$150,652,000
Total	**$260,669,000**	**$1,767,458,000**	**$1,213,226,000**

5. References

Earth Data Analysis Center, *Base Level Engineering Analysis Techincal Support Data Notebook (TSDN) for Curry and Roosevelt County*, New Mexico, June 2018

FEMA, *Lubbock County Flood Insuance Study*, Texas, February 2017

Harris County Flood Control District – TX, *Two Dimensional Modeling Guidelines*, July 2018

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, *Completion of the 2016 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing*, v. 81, no. 5, p. 345-354

National Oceanic and Atmospheric Administration. NOAA Atlas 14, Volume 11 Version 2.0 Texas, *Precipitation-Frequency Atlas of the United States*. Silver Spring, Maryland, 2018.

Painter, C.C., Heimann, D.C., and Lanning-Rush, J.L., 2017, *Methods for estimating annual exceedance-probability streamflows for streams in Kansas based on data through water year 2015 (ver. 1.1, September 2017):* U.S. Geological Survey Scientific Investigations Report 2017–5063, 20 p., https://doi.org/10.3133/sir20175063.

USACE, *HEC-RAS 2D Modeling User's Manual*, February 2016

USACE, *HEC-RAS Hydraulic Reference Manual*, February 2016

United States Department of Agriculture, *Chapter 5 of the NRCS National Engineering Handbook Part 630. Amended* May 2012.

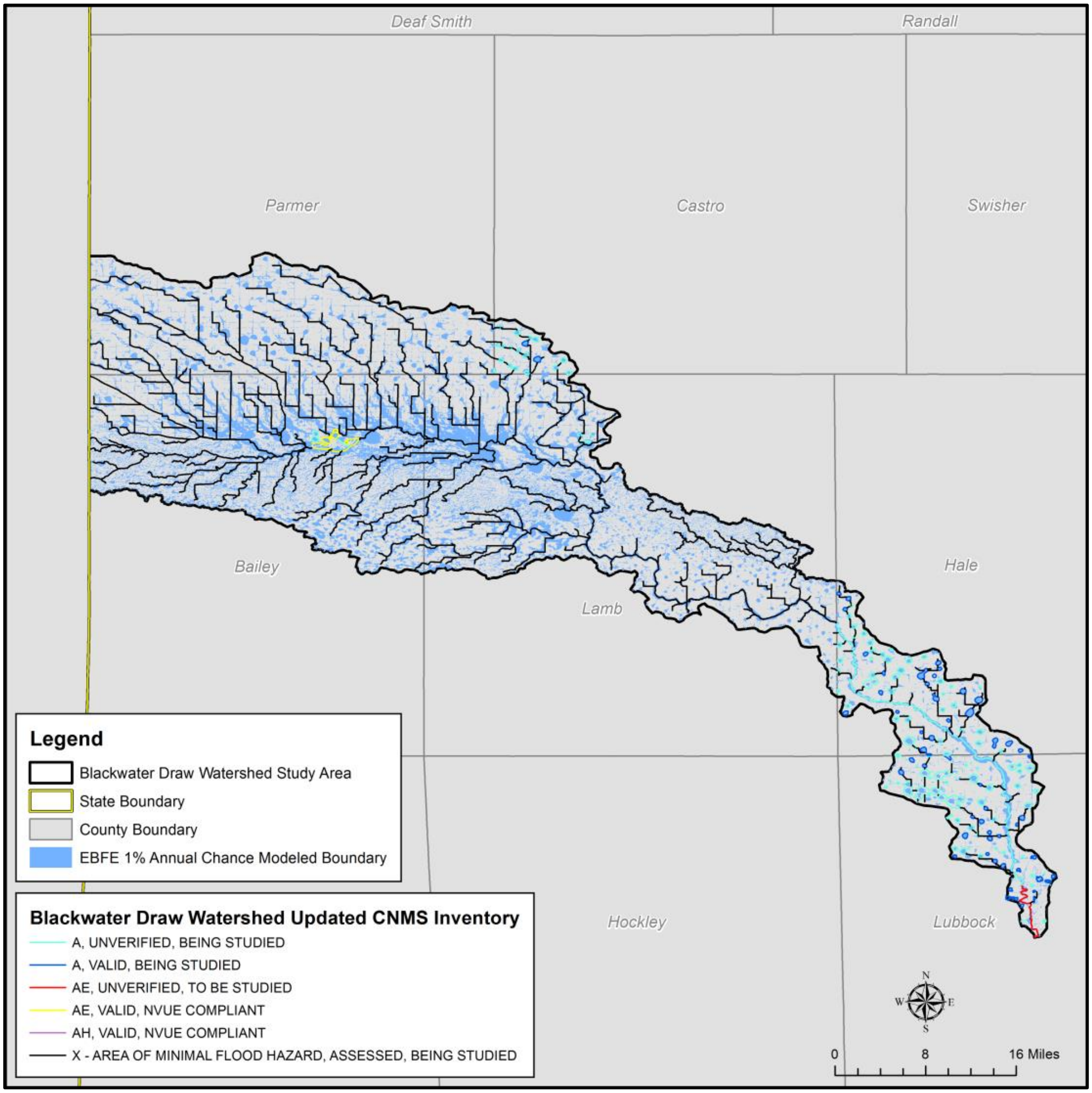
USDA, NRCS, *Manning's n Values for Various Land Covers To Use for Dam Breach Analysis in Kansas*, 2016

USDA, NRCS, *NOAA Atlas 14 rainfall for Midwest and Southeast states,* 2015.

USDA, NRCS, Part 630 National Engineering Handbook, Chapter 5 Streamflow Data, March 2020

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

Appendix A BLE Map



aecom.com