



2D Base Level Engineering Report

Lower Wolf Watershed (HUC 8 11100203)



FEMA

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Executive Summary

FEMA Region 6 contracted Compass to complete a Base Level Engineering (BLE) analysis for the Lower Wolf Hydrologic Unit Code 8 (HUC 8) Watershed in Texas and Oklahoma 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 both the United States Geological Survey (USGS) regression equations and gage analysis, where stream gages with sufficient record exist. Regression equation discharges were obtained using the USGS StreamStats online application for locations in Oklahoma.

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) program version 6.10 was used to compute water surface elevations 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)	1,554
New Study Streams – CNMS (S_Unmapped_Ln) Informed by NHD 1:100	336.2
Total (BLE) Stream Miles	1,890.2

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.

Table 2: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment/Total Miles
VALID	BEING STUDIED	0	22.2
UNVERIFIED	BEING STUDIED	51.7	29.5

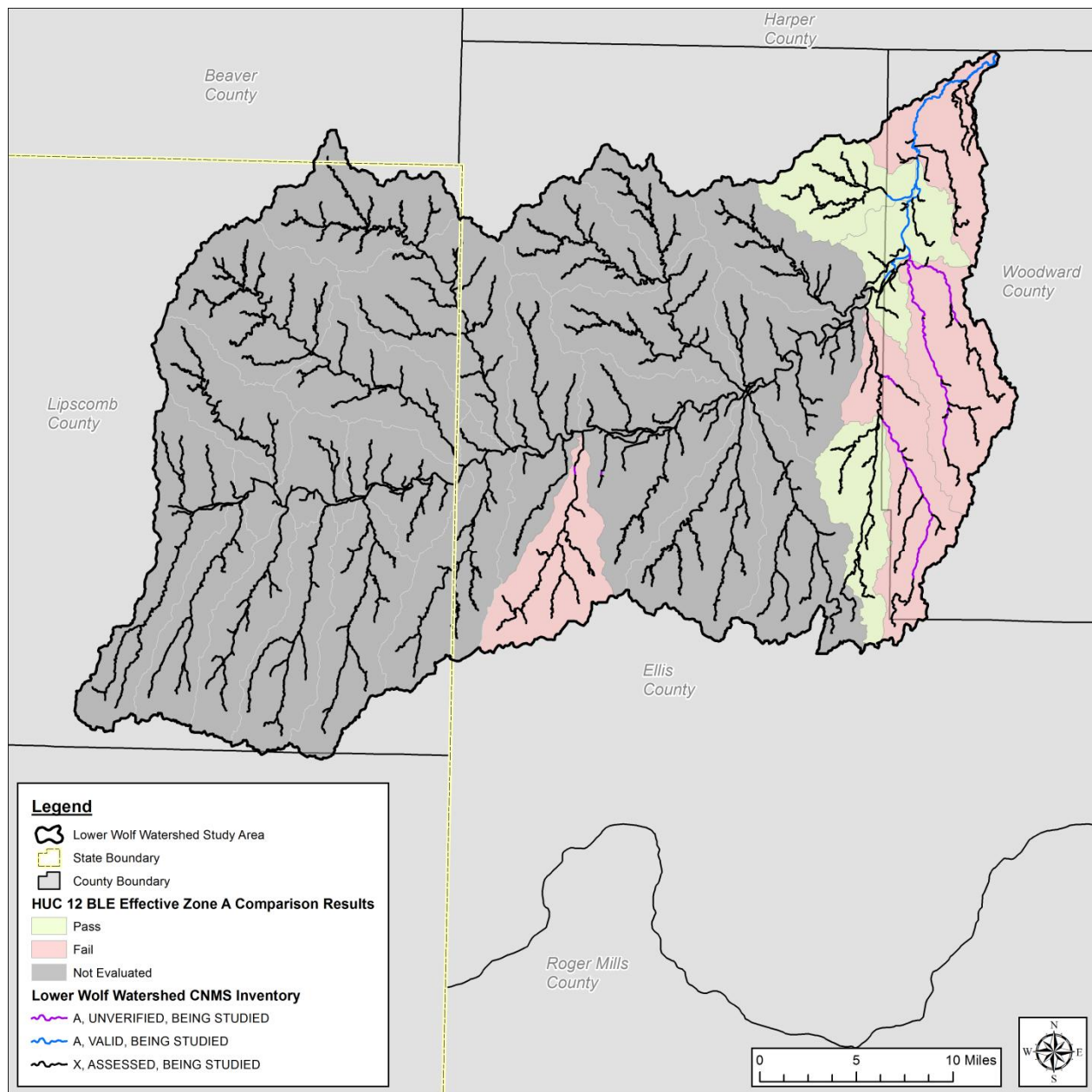


Figure 1: Lower Wolf - CNMS Validation Results

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 formerly known as First Order Approximation (FOA), now labeled 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 automated techniques to produce estimates of flood hazard boundaries for multiple recurrence intervals. The Lower Wolf Watershed BLE study 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 which 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 should 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 Texas and Oklahoma, FEMA Region VI contracted the Compass PTS JV to perform a BLE analysis for the Lower Wolf Watershed. This report documents the BLE process, products, and results for this watershed. Figure 2 depicts the Lower Wolf Watershed footprint.

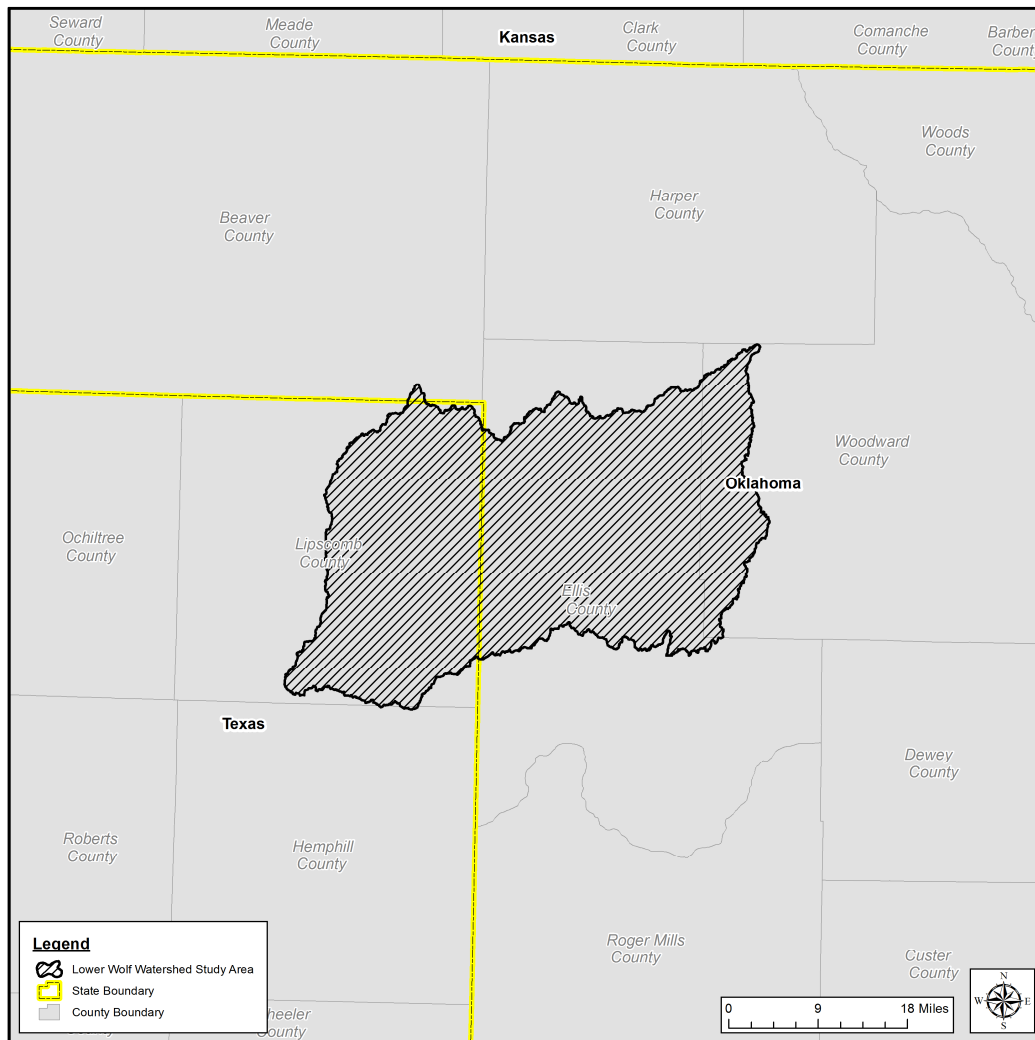


Figure 2: Lower Wolf – 2D BLE Model Domains Index

The BLE assessment prepared Zone A analyses for approximately 1,900 miles of stream reaches within the Lower Wolf Watershed with a minimum drainage area tolerance of one square mile. 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 Lower Wolf BLE project by leveraging available high-resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the entire States of Oklahoma and Texas. The 10-foot DEM developed to support the 2D BLE modeling and analysis, within the Lower Wolf 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 Lower Wolf Watershed.

Inventory

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

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
- Date of origination
- Data density and coverage

Table 3 depicts the Risk MAP SID #42 vertical accuracy requirements based on flood risk and terrain slope within the floodplain being mapped.

Table 3: 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 4 depicts the complete list of source elevation data and attributes leveraged for the Lower Wolf Watershed BLE project. All datasets used for hydraulic analyses and mapping meet the highest specification level defined. Further explanation of the datasets can be referenced below.

Table 4: LiDAR Data Sources

Description	Year	Accuracy	Source/ Contact	Approximate Footprint (mi ²)
Oklahoma – Panhandle, OKC, Moore & Ottawa County LiDAR	2018	11.6 cm	USGS	3
FEMA Texas Panhandle LiDAR	2018	4.3 cm	FEMA	896
FEMA Region 6 OK – Woodward LiDAR	2017	4.7 cm	FEMA	784

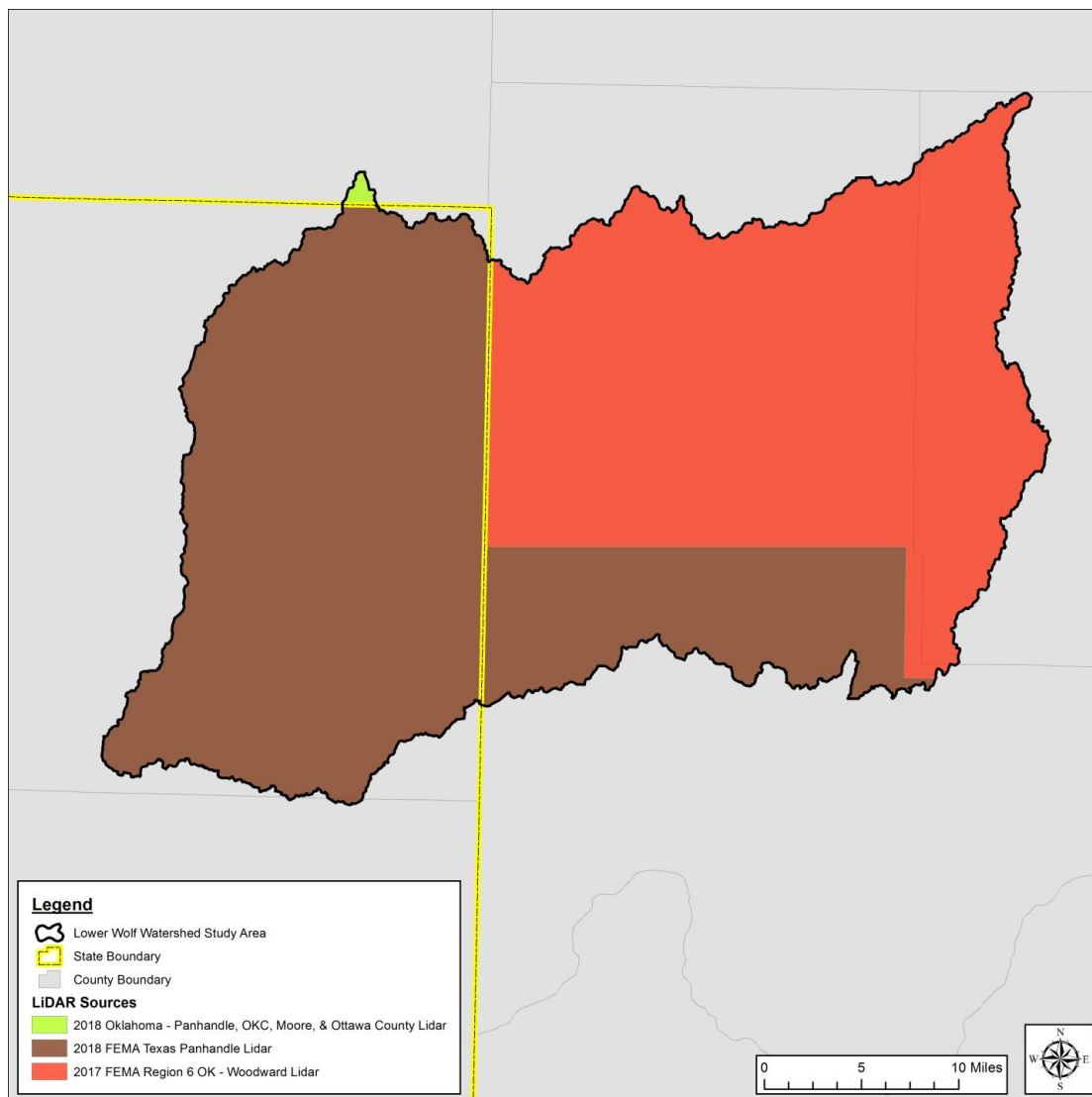


Figure 3: Extent of LiDAR Data

Lower Wolf Watershed Source Terrain Data

The source elevation data for the Lower Wolf Watershed are DEMs derived from the 2018 Oklahoma – Panhandle, OKC, Moore, & Ottawa County LiDAR dataset; the 2018 FEMA Texas Panhandle LiDAR dataset; and the 2017 FEMA Region 6 OK – Woodward LiDAR dataset. 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 3 depicts the extent of the data defined in Table 4. The 2018 Oklahoma – Panhandle, OKC, Moore, & Ottawa County LiDAR was collected with a nominal pulse spacing of 0.71 meters. The dataset was compiled to meet a 19.6 cm vertical accuracy at 95% confidence level ($RMSE * 1.96$). The 2018 FEMA Texas Panhandle LiDAR was collected with a nominal pulse spacing of 0.7 meters. The data was compiled to meet 19.6 cm vertical accuracy at 95% confidence level ($RMSE * 1.96$). The 2017 FEMA Region 6 OK – Woodward LiDAR was collected with a nominal pulse spacing of 0.35 meters and was compiled to meet 19.6 cm vertical accuracy at 95% confidence level ($RMSE * 1.96$).

Data Development Methodology

The source topographic data were processed for an area covering the Lower Wolf Watershed and contributing drainage areas for the Lower Wolf BLE modeling efforts. The topographic data for Lower Wolf Watershed was projected horizontally, as needed, to North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS) Oklahoma North in feet (3501-SPC83). All topographic data were adjusted vertically, as needed, to North American Vertical Datum of 1988 (NAVD88) in feet. Compass used a combination of ArcGIS and other software tools to apply any vertical datum shifts and/or any horizontal projection transformations to the topographic data.

DEM Quality Assurance/Quality Control (QA/QC)

DEMs developed for use in the Lower Wolf 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. 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 were not limited to the following QC checks:

- Seamless Data Check to ensure no voids along the edges and between the prioritized datasets

- NoData Value Check to ensure no null values
- Manual Elevation Check using hillshade rasters to find erroneous elevation issues
- Unit Consistency Check
- Legacy Cell Value Anomalies

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 calculations.

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

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 6.10 was used for this project. This HUC 8, as shown in Figure 4 was split into two modeling areas based on HUC 10 watersheds (City of Shattuck Wolf Creek and Fort Supply Lake Wolf Creek). Note that the Fort Supply Lake Wolf Creek model terminates at the Fort Supply Reservoir dam. Results from the Town of Fort Supply – Beaver River model were included in the digital data delivered with this watershed however, modeling data and parameters are included in the Lower Beaver HUC 8 BLE report/study.

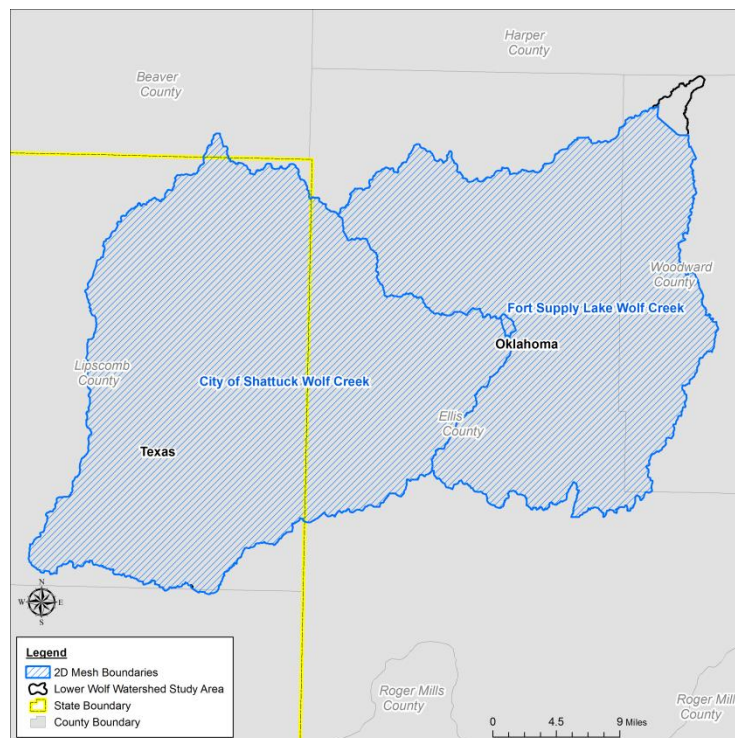


Figure 4: HEC-RAS 2D BLE Model Areas

2D Computational Mesh and Settings

The HEC-RAS 2D computational mesh defines the extents of the 2D flow and can affect the accuracy of the 2D calculations. A denser mesh may provide more accurate results, but it can dramatically increase computation times. The 2D mesh for the models 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. To ensure the smooth mapping and tie ins, a 500-foot to 1,000-foot buffer was added to the HUC boundary.

The HEC-RAS 2D computational meshes were created for the Lower Wolf models based on HUC boundaries using ArcGIS toolsets, such as smoothing and simplification routines; ultimately, significantly reducing the need for manual edits to mesh cells within HEC-RAS that happen to generate errors. The 2D mesh count for each work area is outline below in Table 5, with a 200-foot nominal mesh cell size for all;

there are factors that could result in either larger or smaller cell sizes including proximity to the edge of the 2D mesh or the presence of breaklines. An adaptive time step based on a maximum Courant of 1 and minimum Courant of 0.4 was used in the HEC-RAS model, applying the Diffusion Wave (simplified Full Momentum) equations.

Table 5: Work Area Cell Count

Work Area	Cell Count
City of Shattuck – Wolf Creek	579,117
Fort Supply Lake – Wolf Creek	367,090

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.

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 5 shows the mesh of each model area along with the gages in this study area.

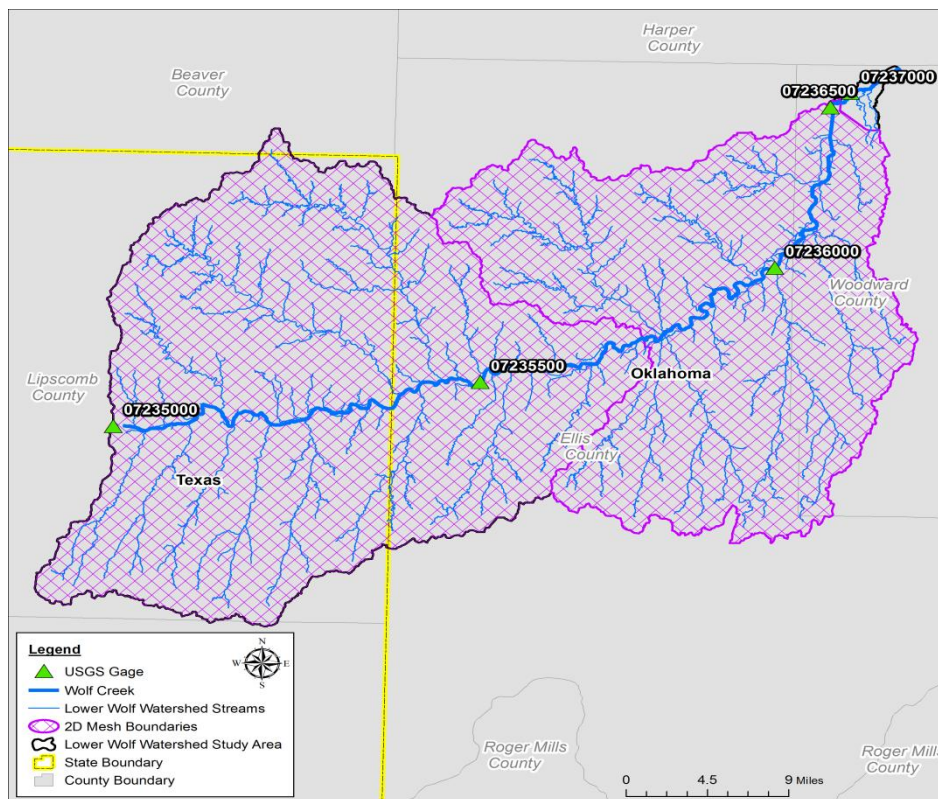


Figure 5: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages

Hydrology

Precipitation data for this study were referenced from NOAA's Precipitation Frequency Data Server (PFDS), and appropriate values for all sub-basin elements were determined considering spatial variation. USGS streamflow gage data were leveraged to develop the inflow hydrograph for the City of Shattuck – Wolf Creek model (USGS gage 07235000) and to estimate peak flows for downstream gages within each work area for calibration purposes.

The gages utilized for this study are presented in Table 6. Gages 07235500 and 07236500 were not utilized in this study due to the minimal years of record and the published drainage area discrepancies from the upstream and downstream gages, respectively.

Table 6: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (mi ²)	Period of Record
07235000	Wolf Creek at Lipscomb, TX	475	1938 - 2021
07236000	Wolf Creek near Fargo, OK	1,386	1943 - 1976
07237000	Wolf Creek near Fort Supply, OK	1,498	1938 - 1993

Annual chance peak flows were calculated at each gage using USGS Bulletin 17C methodology. The 84% confidence interval was used to determine the 1% plus and minus chance events. Calculated discharges for the 1%, 1% plus, and 1% minus events are presented in Table 7 for each gage utilized in this study.

Table 7: USGS Peak Streamflow Gage Analysis Results

Gage ID	Flooding Source and Location	1% Peak Q (cfs)	1%- Peak Q (cfs)	1%+ Peak Q (cfs)
07235000	Wolf Creek at Lipscomb, TX	27,700	15,390	135,700
07236000	Wolf Creek near Fargo, OK	51,300	30,831	71,769
07237000	Wolf Creek near Fort Supply, OK	3,310	2,026	6,079

Excess Precipitation for 2D Computational Mesh

Precipitation frequency data published in NOAA Atlas 14, Volume 9 Version 2.0 (NOAA, 2013) were used for this study. These data were obtained from NOAA's PFDS (<http://hdsc.nws.noaa.gov/hdsc/pfds/index.html>). The 10%, 4%, 2%, 1%, and 0.2% annual chance 24-hour precipitation depths for all sub-basin elements were determined by area-weighted intersection of gridded PFDS data with sub-basins.

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

The SCS CN method was used to calculate losses and define excess precipitation for these watersheds. Curve numbers were computed by intersecting the National Land Cover Dataset (NLCD) 2019 coverage and Natural Resources Conservation Service (NRCS) soils data based on land cover and soils matrices.

During the calibration of the model, curve numbers were adjusted to achieve flows that are closer to regression equation and flood frequency analysis estimates. Initial CNs for this study are provided in Table 8.

Table 8: Land Use-Soils-CN Matrix for Computing Initial Curve Numbers

LU_GridCode	NLCD Land Use Description	Hydrologic Soil Group			
		A	B	C	D
11	Open Water	96.6	96.6	96.6	96.6
21	Developed Open Space	38.9	59.6	71.1	77.2
22	Developed Low Intensity	50.9	66.4	75.9	80.9
23	Developed Medium Intensity	73.5	82.2	86.0	88.6
24	Developed High Intensity	83.4	87.3	89.9	91.2
31	Barren Land	38.9	59.6	71.1	77.2
41	Deciduous Forest	22.2	37.9	46.8	53.0
42	Evergreen Forest	26.3	47.8	64.1	72.3
43	Mixed Forest	27.1	49.8	64.1	71.1
52	Shrub Scrub	26.3	45.7	60.7	68.7
71	Herbaceous	44.7	61.8	73.5	83.4
81	Hay Pasture	38.9	59.6	71.1	77.2
82	Cultivated Crops	53.0	64.1	72.3	75.9
90	Woody Wetlands	62.9	72.3	80.9	88.6
95	Emergent Herbaceous Wetlands	62.9	72.3	80.9	88.6

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including CNs for defining rainfall losses. The precipitation was applied using a set of nested frequency distributions published by the NRCS based on Atlas 14 statistical data; all work areas were within the MSE3 and TX C temporal regions. Table 9 provides the precipitation totals used for determining excess precipitation.

Table 9: Precipitation Totals for HEC-RAS 2D Computational Mesh (post ARF)

Sub-basin Description	Percent Annual Chance (PAC) Precipitation Total (in)						
	10	4	2	1	0.2	1% Minus	1% Plus
City of Shattuck – Wolf Creek	4.12	5.02	5.74	6.50	8.51	5.42	7.80
Fort Supply Lake – Wolf Creek	4.25	5.18	5.96	6.78	8.91	5.75	7.99

Figure 6 and Figure 7 shows the hyetographs applied to the 2D computational mesh for each model.

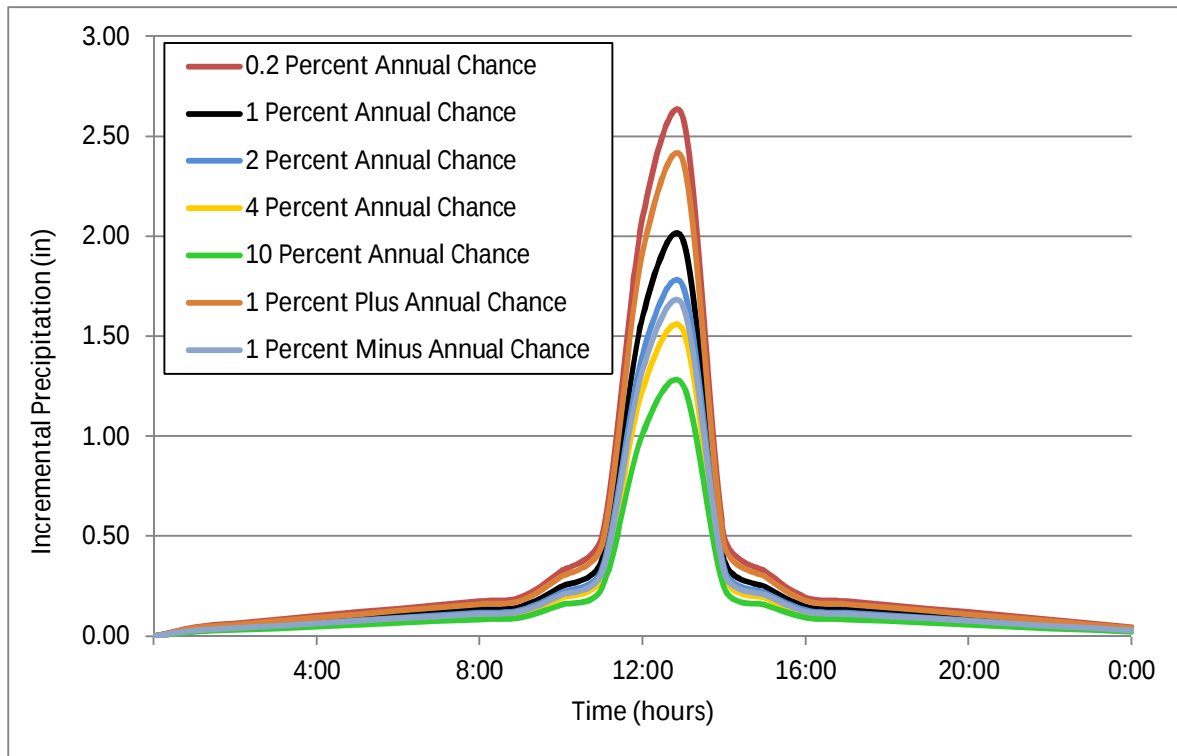


Figure 6: Precipitation Hyetographs applied to the Computational Mesh in City of Shattuck – Wolf Creek

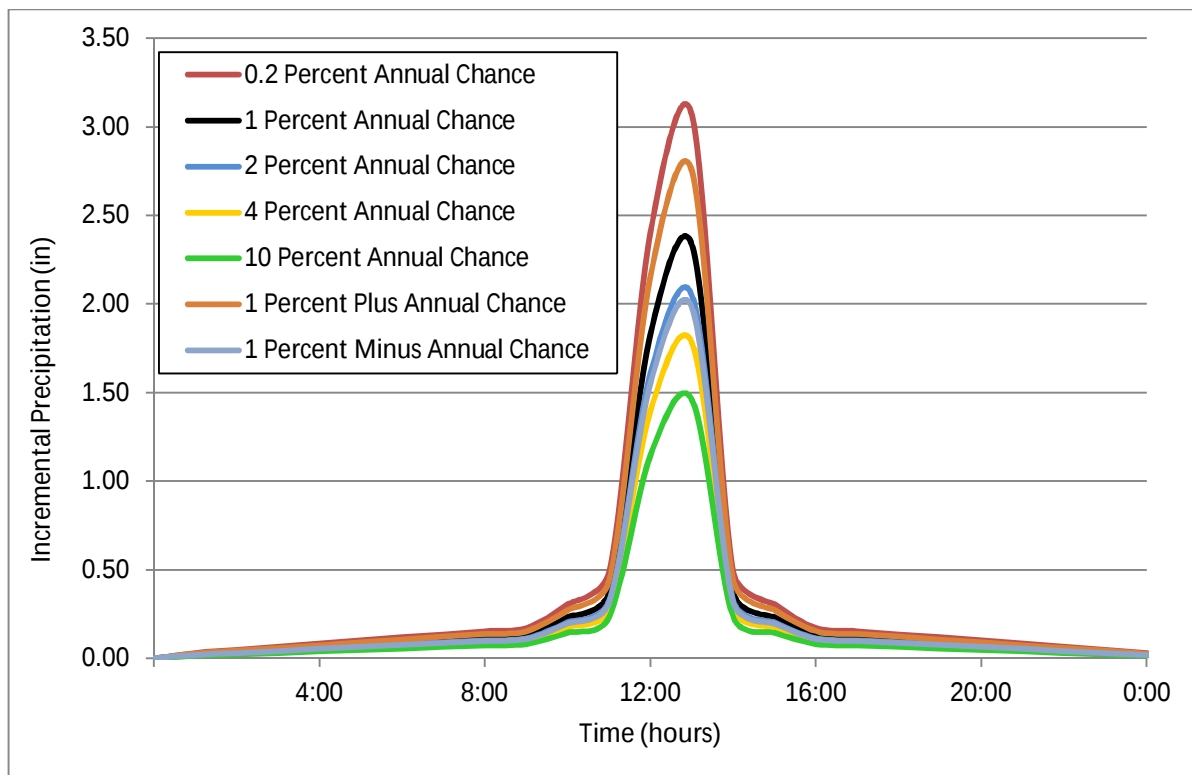


Figure 7: Precipitation Hyetographs applied to the Computational Mesh in Fort Supply – Wolf Creek

Hydrograph Boundary Conditions

The City of Shattuck – Wolf Creek model utilized an inflow flow hydrograph (Figure 8), developed from USGS gage data (USGS gage 07235000), that was used as a boundary condition to the 2D computational mesh.

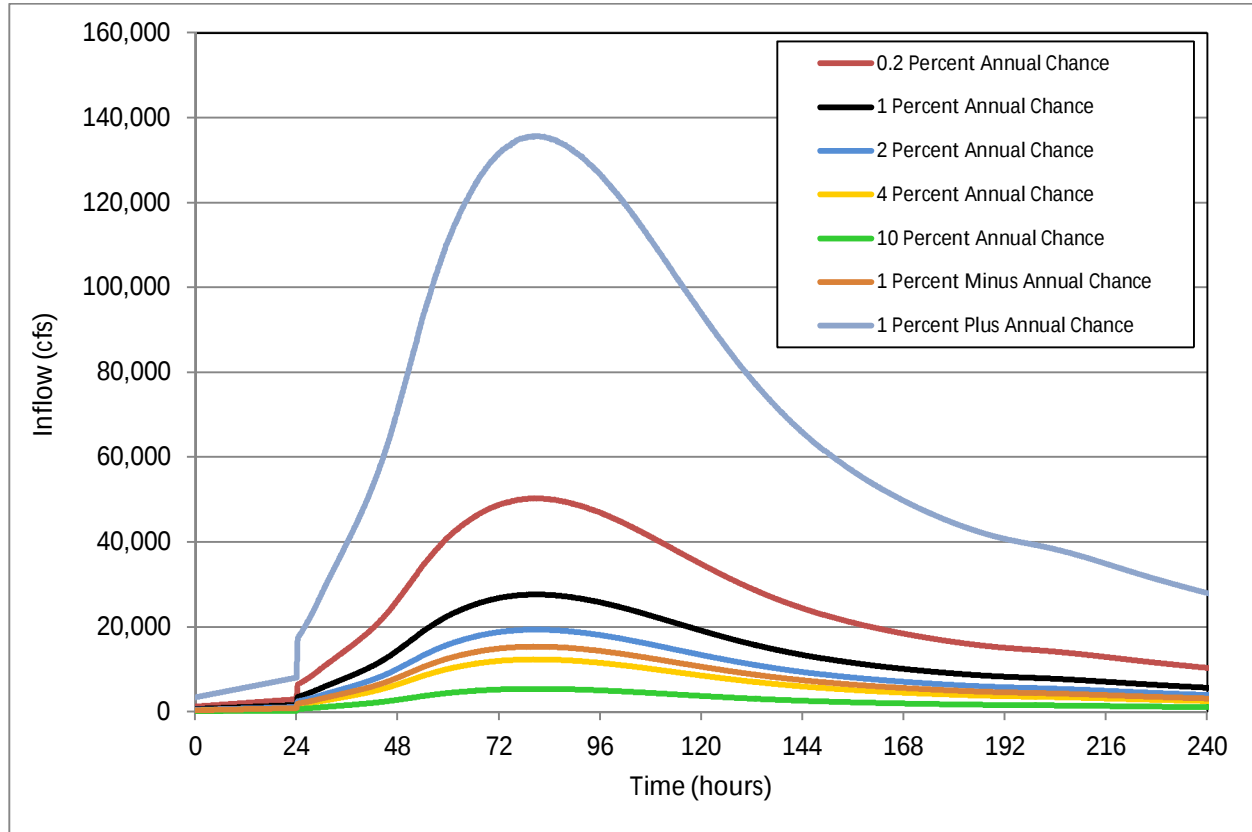


Figure 8: City of Shattuck – Wolf Creek Inflow Flow Hydrograph

The Fort Supply Lake – Wolf Creek model utilized a stage hydrograph from the City of Shattuck – Wolf Creek model as shown in Figure 9.

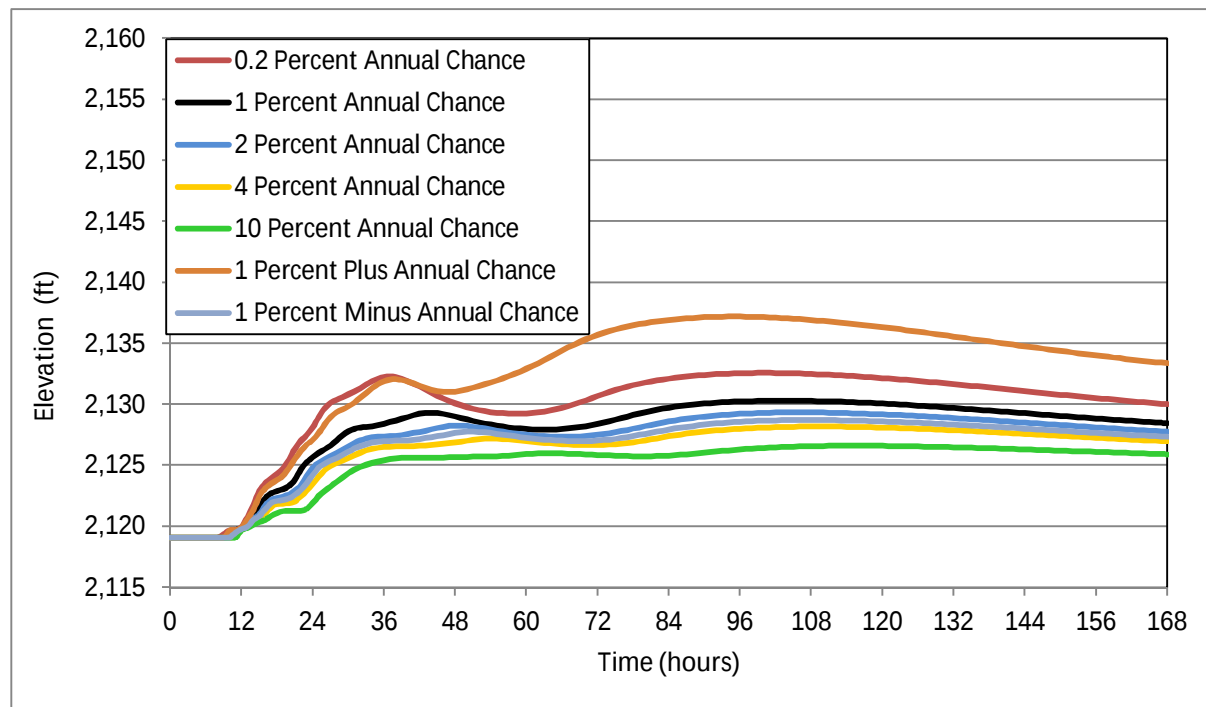


Figure 9: Fort Supply Lake – Wolf Creek Stage Hydrograph

Hydraulics

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

Roughness Coefficients

A Manning's n roughness coverage was developed for the 2D computational mesh using typical values for roughness for given NLCD land classifications. A buffer zone was created around each stream centerline to create a main channel roughness zone. The channel roughness zone was given a channel Manning's n value that is dependent on the NLCD Classification to ensure the channel 2D cells have appropriate conveyance. The table below shows a typical land use-roughness matrix used in defining the roughness coverage for the study area.

Table 10: NLCD 2019 – Manning's N Roughness Matrix

NLCD Classification	Overland Manning's N	Channel Manning's N	Normal	Source
Open Water	0.03	0.03	0.03	Ven Te Chow 1959
Developed, Open Space	0.04	0.035	0.04	2D User's Manual, 2016
Developed, Low Intensity	0.1	0.035	0.1	2D User's Manual, 2016
Developed, Medium Intensity	0.08	0.035	0.08	2D User's Manual, 2016
Developed, High Intensity	0.15	0.035	0.15	2D User's Manual, 2016
Barren Land	0.03	0.03	0.03	Ven Te Chow 1959
Deciduous Forest	0.16	0.05	0.16	Ven Te Chow 1959
Evergreen Forest	0.16	0.05	0.16	Ven Te Chow 1959
Mixed Forest	0.15	0.05	0.15	Ven Te Chow 1959
Scrub/Shrub	0.1	0.04	0.1	Ven Te Chow 1959
Grassland/Herbaceous	0.035	0.04	0.035	Ven Te Chow 1959
Pasture/Hay	0.03	0.04	0.03	Ven Te Chow 1959
Cultivated Crops	0.035	0.04	0.035	Ven Te Chow 1959
Woody Wetlands	0.16	0.04	0.16	Ven Te Chow 1959
Emergent Herbaceous Wetland	0.07	0.04	0.07	Ven Te Chow 1959

Breaklines

Breaklines align grid cell faces and were used within the 2D mesh area to define prominent features including, road embankments and hydraulic structures as well as stream centerlines. Road embankments were identified in ArcGIS and imported into HEC-RAS as breaklines to ensure that water was not routed past roads until it was deep enough to overtop the road. Similarly, bridge/culvert crossings that were not processed out of the terrain data were modeled by adjusting breaklines adjacent to the road embankment to align grid cells around the embankment and allow water to be routed across the embankment without creating artificial backwater.

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. These were then used to identify points where streams intersect road embankments and v-notch breaklines were added to ensure flow was passing the embankments in a way that was reflective of the culverts or bridges similar to the process for highways as outlined above, but only being implemented at the streams.

The stream centerlines were input as breaklines to ensure cells lined up perpendicularly to the stream and to capture stream conveyance.

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.

Three USGS gages within the model areas had more than 10 years of flow record and were used for calibration and validation of the 1% annual chance event. Peak flows within the model were compared with a Bulletin 17C analysis of the gage data using PeakFQ. Several other locations were selected throughout each model area to compare model flows with the published USGS regional regression equations. At certain calibration locations where the upstream drainage area was significantly developed, adjustments were made to the regression equation estimates based on urbanization. Final results of the flow comparisons are presented in Table 11. Given that Gage 07236000 has only 16 years of published discharges within its period of record, its calibration results were not analyzed but are included in the table below.

Table 11: Model Calibration Results

Work Area	Calibration Location	Drainage Area (mi ²)	Lower Limit (cfs)	Q1% (cfs)	Upper Limit (cfs)	2D Model flow (cfs)
City of Shattuck – Wolf Creek	USGS Gage 07235000	475	15,390	27,700	135,700	24,263
	StreamStats CS_WC_1	94.4	3,384	5,630	7,876	3,718
	StreamStats CS_WC_2	15.7	1,713	2,850	3,987	1,977
	StreamStats CS_WC_3	40.1	2,446	4,070	5,694	3,253
	StreamStats CS_WC_4	29.3	2,170	3,610	5,050	2,219
	StreamStats CS_WC_5	24.6	2,031	3,380	4,729	2,175
Fort Supply Lake – Wolf Creek	USGS Gage 07236000	1,386	30,831	51,300	71,769	26,121
	USGS Gage 07237000	1,498	2,026	3,310	6,079	2,327
	StreamStats FS_WC_1	627	19,340	32,180	45,020	26,083
	StreamStats FS_WC_2	43.4	2,518	4,190	5,862	4,322
	StreamStats FS_WC_3	23.1	1,983	3,300	4,617	3,132
	StreamStats FS_WC_4	23.3	1,989	3,310	4,631	3,218
	StreamStats FS_WC_5	89.8	3,318	5,520	7,722	5,348

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 Lower Wolf 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 feet. 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 two 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.

Methodology in Texas

Floodplain outputs in the portions of the watershed in Texas were produced to match the methodology developed by the Texas Water Development Board (TWDB). This was done in order to produce outputs at the upstream edge of the watershed that matched the neighboring watershed that is entirely within Texas and is concurrently being studied. TWDB uses a size and depth matrix for determining floodplain outputs that are included in the final deliverable as seen in Table 12. Simplification, smoothing and "holes" were filled in, similar to the methodology in the Oklahoma portions of the watershed.

Table 12: Texas Water Development Board Mapping Threshold Matrix

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

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 were used as reference data to ensure 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 Lower Wolf Watershed.

The inventory of Zone A studies (51.7 miles) in the Lower Wolf Watershed were classified in CNMS with validation status of “UNVERIFIED” (29.2 miles) or “VALID” (22.2 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. All effective Zone A studies within this watershed did not use LiDAR data. The LiDAR sources utilized in this BLE study are considered significant improvements from the effective zone A topographic sources. Therefore, all reaches 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.

All effective Zone A studies in Woodward County used 1997 regression equations. New equations were published in 2019 that would create a significant change in Base Flood Elevation (BFE), causing all streams in the county to fail this check. The effective Zone A studies in Ellis County did not use regression and, therefore, 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 13.

Table 13: A1-A3 Validation Results

Assessment Checks	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 regression equations published that would impact the BFE
A3 – Development	Pass	Watershed does not meet urban threshold.

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 effective Zone A studies in Woodward County are model-backed studies and pass this check. All effective Zone A studies in Ellis County are not supported by technical data and, therefore, fail 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 Lower Wolf 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 Standards (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 BFE. The minimum value of the 1% minus raster, and the maximum value of the 1% plus raster are also extracted. These 1% plus maximum and 1% minus minimum values are products of the new 2D BLE study and act as the vertical tolerance. The test point passes if the DEM maximum value is less than or equal to the 1% plus maximum value and the DEM minimum value is greater than or equal to the 1% minus minimum value. This can be visualized as a short 75-foot radius cylinder, with a height of 1% plus maximum – 1% minus minimum. This test verifies that at least one point from the ground surface (i.e. proxy BFE) falls both vertically and horizontally within this range.

Validation Results

All 51.7 total miles of available CNMS features representing the 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 14 and illustrated in Figure 10 below. Table 15 summarizes the validation results based on the individual HUC 12 watersheds within the Lower Wolf Watershed.

Table 14: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment/Total Miles
VALID	BEING STUDIED	0	22.2
UNVERIFIED	BEING STUDIED	51.7	29.5

Table 15: BLE Comparison Results

HUC 12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	HUC 12 ID						
Lower Wolf	All Streams	2,871	1,121	1,750	61%	Fail	
Eightmile Creek	111002030508	118	4	114	96.6%	Pass	0.8
Lower Boggy Creek	111002030505	726	435	291	40.1%	Fail	15.0
Lower Fort Supply Lake-Wolf Creek	111002030510	562	86	476	84.7%	Fail	3.8
Rock Creek	111002030404	41	17	24	58.5%	Fail	37.3
Turkey Creek	111002030507	1,098	558	540	49.2%	Fail	12.7
Upper Boggy Creek	111002030504	1	0	1	100%	Pass	0 ¹
Upper Fort Supply Lake-Wolf Creek	111002030509	325	21	304	93.5%	Pass	1.6

¹Priority Score calculation is 0 due to one test point within the HUC 12 boundary. Upper Boggy Creek is not being considered in summary text below.

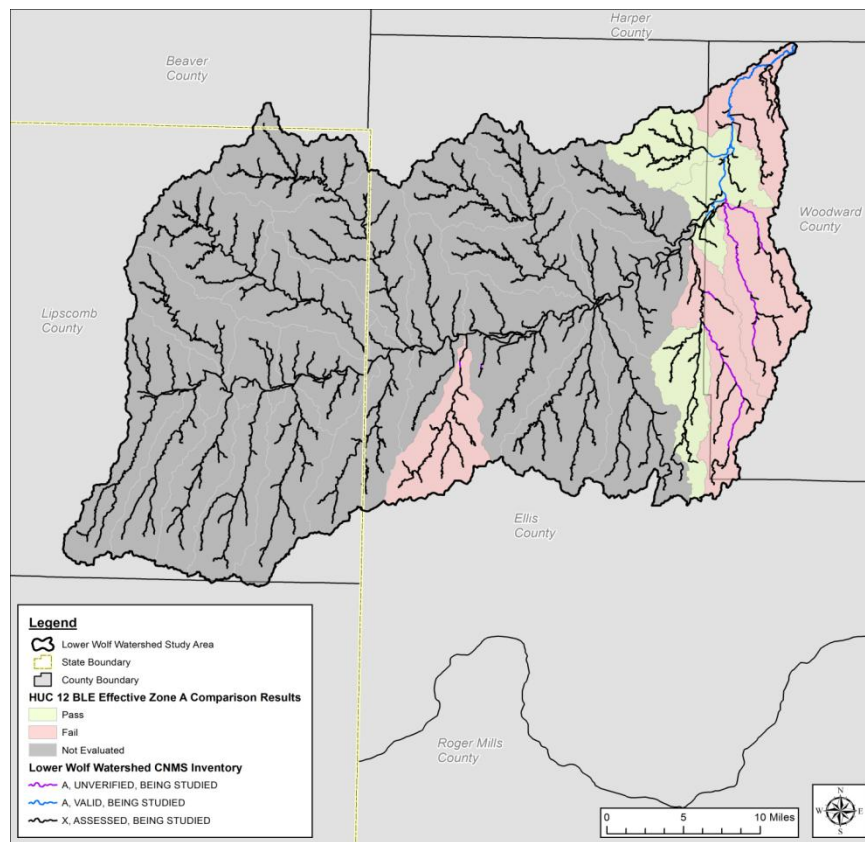


Figure 10: CNMS Validation Results

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 Lower Wolf HUC 12 priority scores which can be used to initiate discussions during the Discovery phase. Rock Creek HUC 12 was determined to have the highest priority score and the most need while Eightmile Creek HUC 12 has the lowest score.

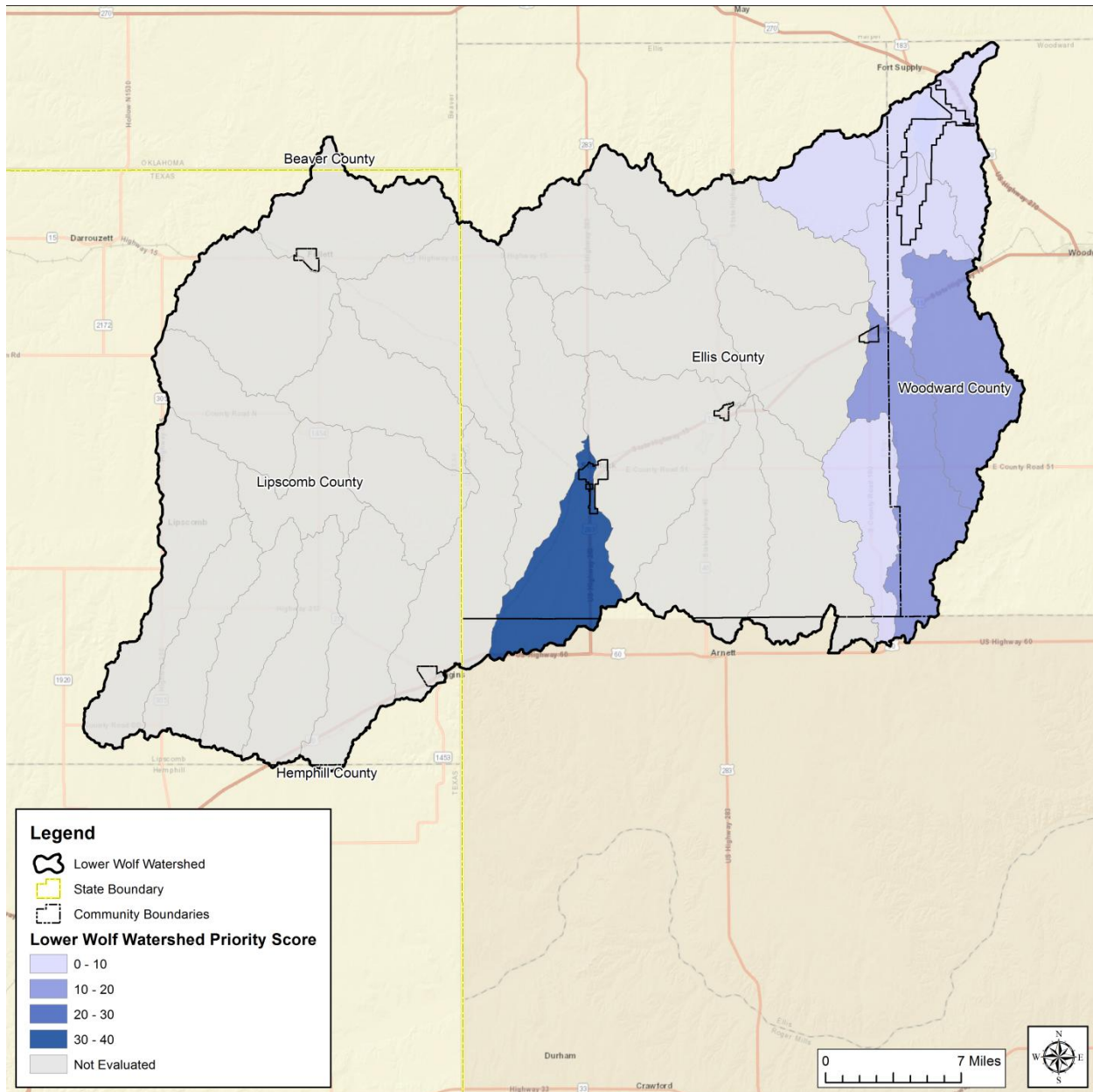


Figure 11: Ranking of Lower Wolf Watershed HUC 12s

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 6.1 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 and extends for each return period to ensure proper model processing. A summary of results per county for the 1-percent annual chance scenario are shown in Table 16.

Table 16: Hazus 6.1 Results for 1-percent-annual-chance scenario for Lower Wolf Watershed, Oklahoma/Texas

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Beaver, OK	\$0	\$591,000	\$295,000
Ellis, OK	\$19,691,000	\$621,674,000	\$471,387,000
Hemphill, TX	\$0	\$838,000	\$1,257,000
Lipscomb, TX	\$7,495,000	\$402,701,000	\$303,077,000
Woodward, OK	\$3,443,000	\$105,090,000	\$56,666,000
Total	\$30,629,000	\$1,130,894,000	\$832,682,000

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 during the data development process includes, but is not limited to the following 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, 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, 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 Lower Wolf 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

Major challenges included a lack of peak streamflow records at the outlet, though sufficient data was available to provide confidence in the results. Streamstats data was used in addition to USGS gage data for the parts of the model within Oklahoma to increase confidence in model results. Flow reducers were utilized in the Fort Supply Lake Wolf Creek model to replicate the losses seen in the gage analysis. These losses could be associated with the known subterranean landscapes in this region.

Another major challenge included incorporating portions of the upstream HUC 8. This was resolved by developing a set of inflow hydrographs using the gage data located at the upstream end of the mainstem in the City of Shattuck model. The tie-in between the City of Shattuck and Fort Supply Lake Wolf Creek models posed a challenge because of the wide shallow floodplain with multiple branches. This issue was resolved by moving the 2D connection line further upstream of the original model area boundary to be further away from a large contributing stream in the Fort Supply Lake Wolf Creek model. The 2D connection line was also drawn with some minor bends to better conform to the uneven terrain and water surface elevations across the floodplain.

The tie-in at the downstream end was a challenge due to the large dam at the Fort Supply Reservoir. The dam is sufficiently large to capture the entirety of the flow on most profiles and the majority of the flow on the 0.2-percent annual chance and the 1-percent annual chance plus. By moving the tie-in location upstream of the model boundary to be located on the crest of the dam spillway, the downstream model (the Town of Fort Supply – Beaver River model) was better able to capture the conditions downstream of the dam.

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

