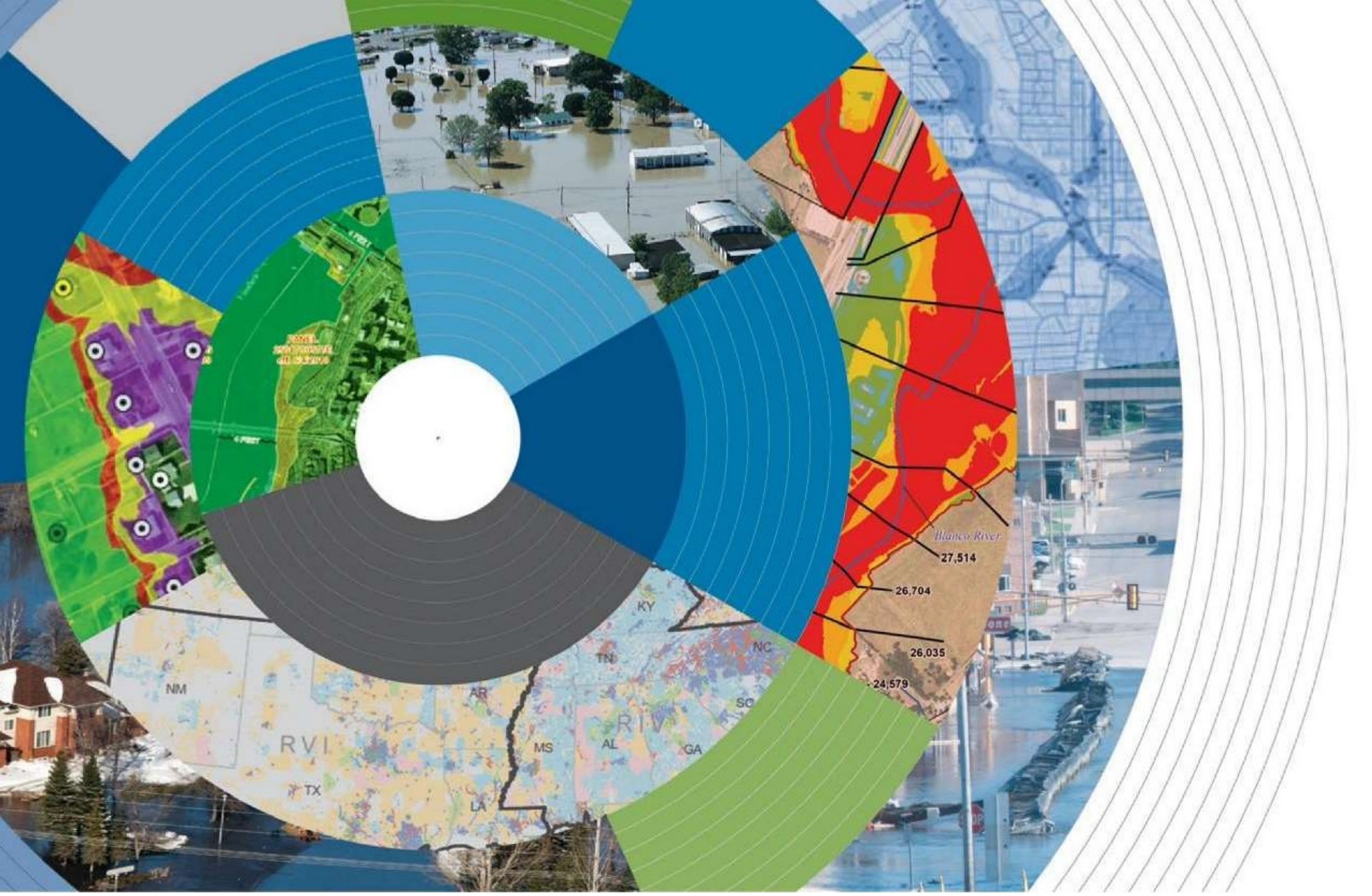

2D Base Level Engineering Report

Lower Beaver Watershed (HUC8 11100201)

FEMA

September 5, 2023

Version 1.0

Report Prepared for:

FEMA (Federal Emergency Management Agency)

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Executive Summary

FEMA Region 6 contracted Compass to complete a Base Level Engineering (BLE) analysis for Lower Beaver 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)	1,726.5
New Study Streams – CNMS (S_Unmapped_Ln) Informed by NHD 1:100	766.2
Total (BLE) Stream Miles	**2,492.7**

The full inventory of Zone A studies in the watershed were classified in CNMS. Total miles validated in CNMS are summarized in Table 2 and illustrated in Figure 1 below.

Table 2: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment/Total Miles
VALID	BEING STUDIED	0	0
UNVERIFIED	BEING STUDIED	7.7	7.7

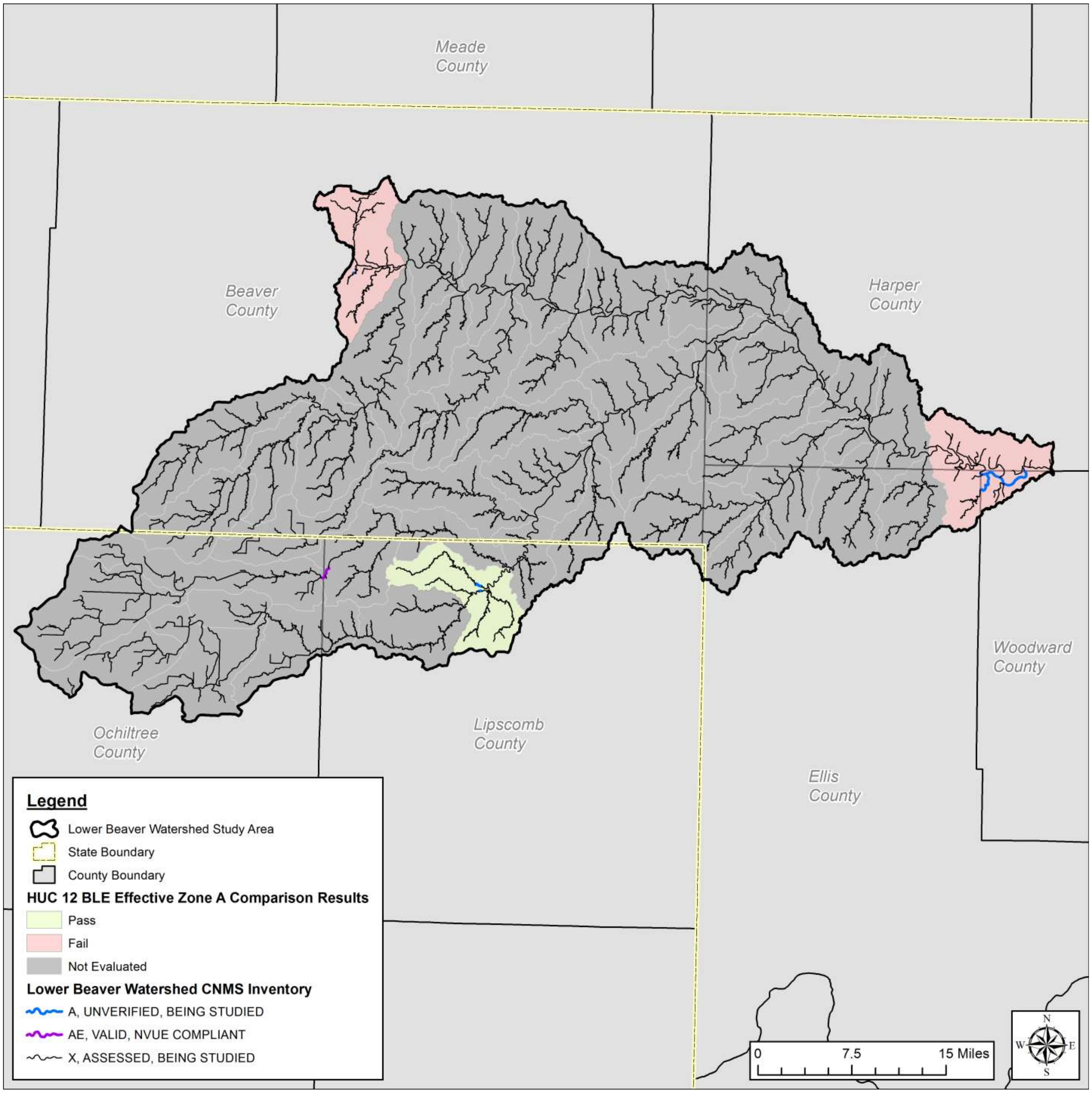

Figure 1: Lower Beaver - CNMS Validation Results

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

As described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e), once every five years, FEMA must evaluate whether the information on Flood Insurance Rate Maps (FIRMs) reflects the current risks in flood prone areas. FEMA makes this determination of flood hazard data validity by examining flood study attributes and change characteristics, as specified in the Validation Checklist of the Coordinated Needs Management Strategy (CNMS) Technical Reference. The CNMS Validation Checklist provides a series of critical and secondary checks to determine the validity of flood hazard areas studied by detailed methods (e.g., Zone AE, AH, or AO). While the critical and secondary elements in CNMS provide a comprehensive method of evaluating the validity of Zone AE studies, a cost-effective approach for evaluating Zone A studies has been lacking.

In addition to the need for Zone A validation guidance, FEMA standards require flood risk data to be provided in the early stages of a Flood Risk Project. FEMA Program Standard Identification (SID) #29 requires that during Discovery, data must be identified that illustrates potential changes in flood elevation and mapping 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 Beaver Watershed. This report documents the BLE process, products, and results for this watershed. Figure 2 depicts the Lower Beaver Watershed footprint.

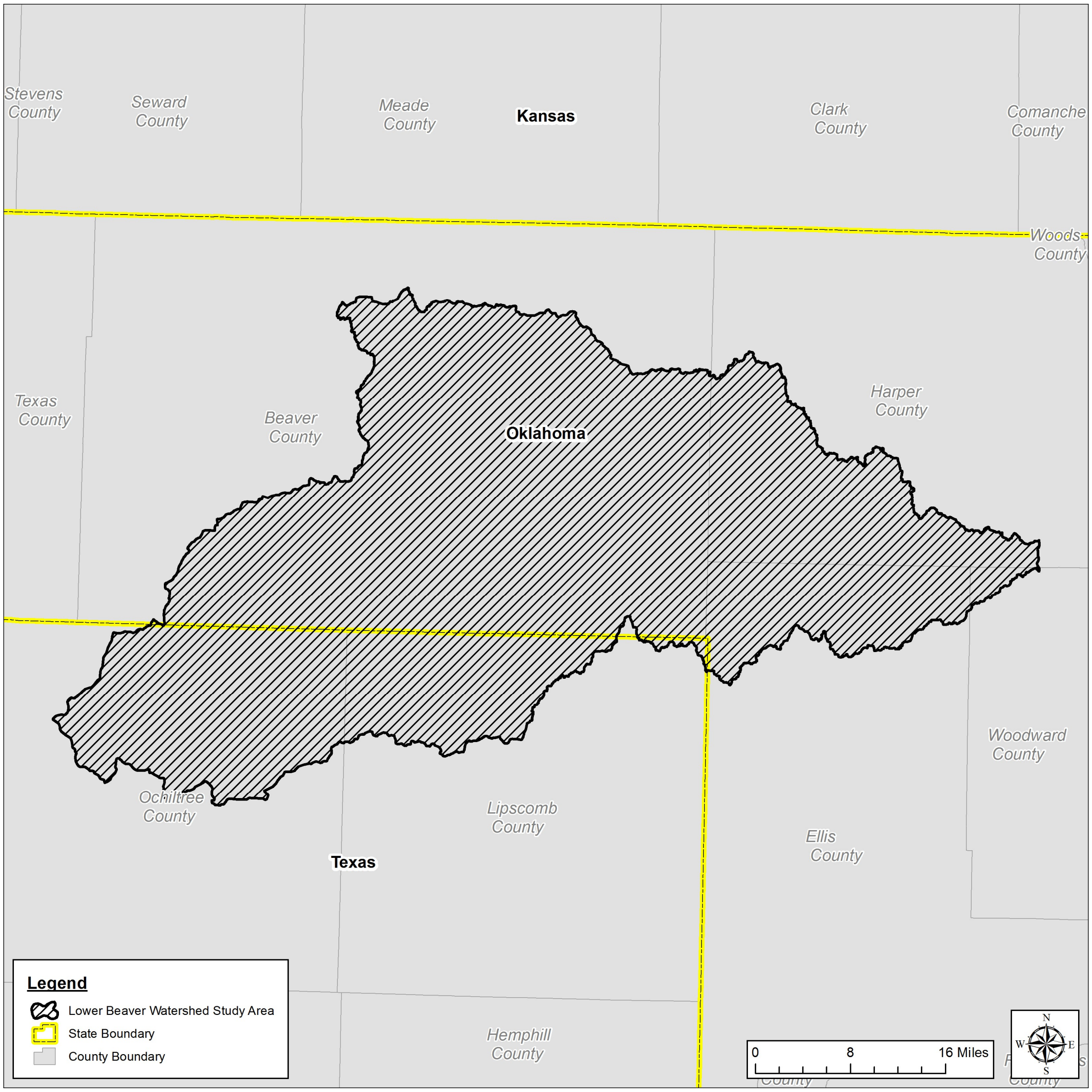

Figure 2: Lower Beaver HUC 8

The BLE assessment prepared Zone A analyses for approximately 1,765 miles of stream reaches within the Lower Beaver 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 Beaver 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 Beaver Watershed, was executed using the following steps:

1. Available elevation data for the project area were inventoried and collected.
2. Leveraged elevation data were evaluated and prioritized based on source vertical accuracy, year of collection and resolution.
3. Seamless DEMs were processed using GIS.
4. Quality was assured using quantitative and qualitative assessment.

Documentation regarding leveraged data including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables and text below. All vertical accuracy specifications were obtained from the metadata or survey reports provided with the leverage datasets. All available metadata, survey reports, and other leverage documentation are included in the FEMA Data Capture Technical Reference compliant submittal content for the Lower Beaver Watershed.

Inventory

An inventory of existing topographic data was conducted for the Lower Beaver 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 baed 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 Beaver 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	927.1
FEMA Texas Panhandle LiDAR	2018	4.3 cm	FEMA	450.4
FEMA Region 6 OK – Woodward LiDAR	2017	4.7 cm	FEMA	403.1
Lower Cimarron - Eagle Chief QL2 Lidar	2016	2.6 cm	FEMA	0.2

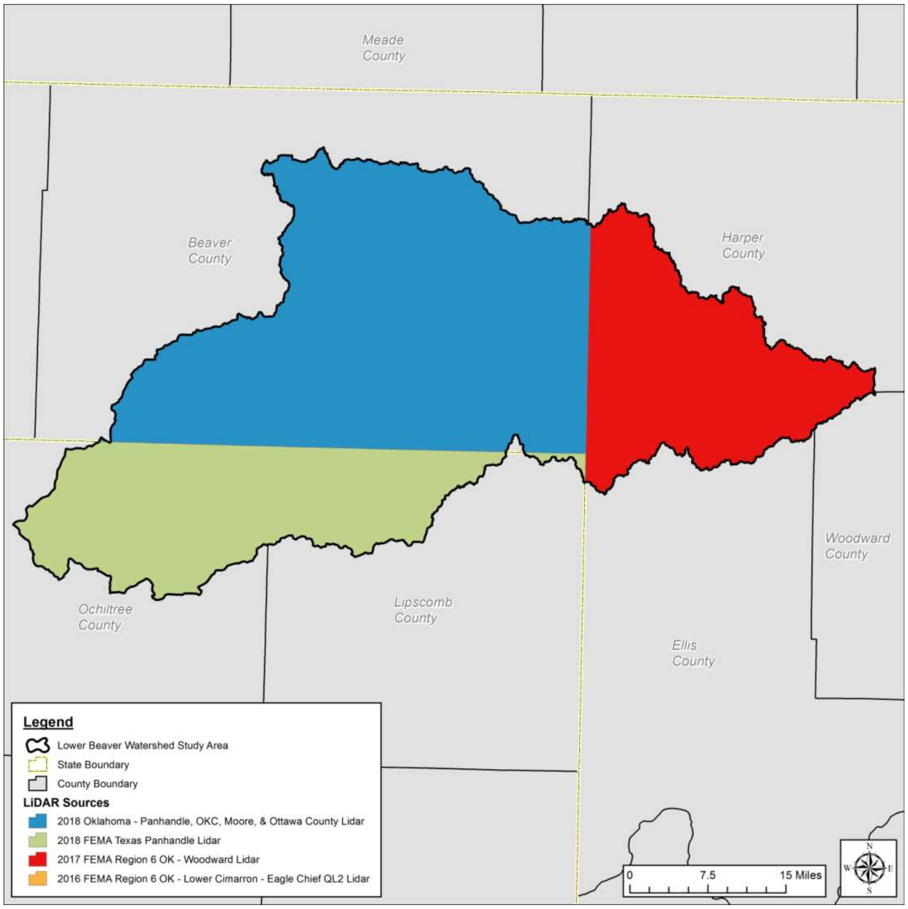

Figure 3: Extent of LiDAR Data

Lower Beaver Watershed Source Terrain Data

The source elevation data for the Lower Beaver Watershed are DEMs derived from the 2018 Oklahoma – Panhandle, OKC, Moore, & Ottawa County LiDAR dataset; the 2018 FEMA Texas Panhandle LiDAR dataset; the 2017 FEMA Region 6 OK – Woodward LiDAR dataset; and the 2016 Lower Cimarron - Eagle Chief QL2 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. The data was compiled to meet 19.6 cm vertical accuracy at 95% confidence level (RMSE * 1.96). The 2016 Lower Cimarron – Eagle Chief QL2 LiDAR was collected with a nominal pulse spacing of 0.69 meters. The data was compiled to meet a 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 Beaver Watershed and contributing drainage areas for the Lower Beaver BLE modeling efforts. The topographic data for Lower Beaver 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 Beaver 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 Beaver Watershed are assured to meet FEMA standards and present a representative surface developed from leveraged elevation data for the purposes of this BLE project.

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 6.1.0 was used for this project. This HUC 8, as shown in Figure 4 was split into three modeling areas based on HUC 10 watersheds (Upper Kiowa Creek, Town of Rosston – Beaver River and Town of Fort Supply – Beaver River). Note that the Town of Fort Supply – Beaver River results were included in the Lower Wolf HUC 8 deliverable as 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 the Lower Wolf HUC 8 watershed.

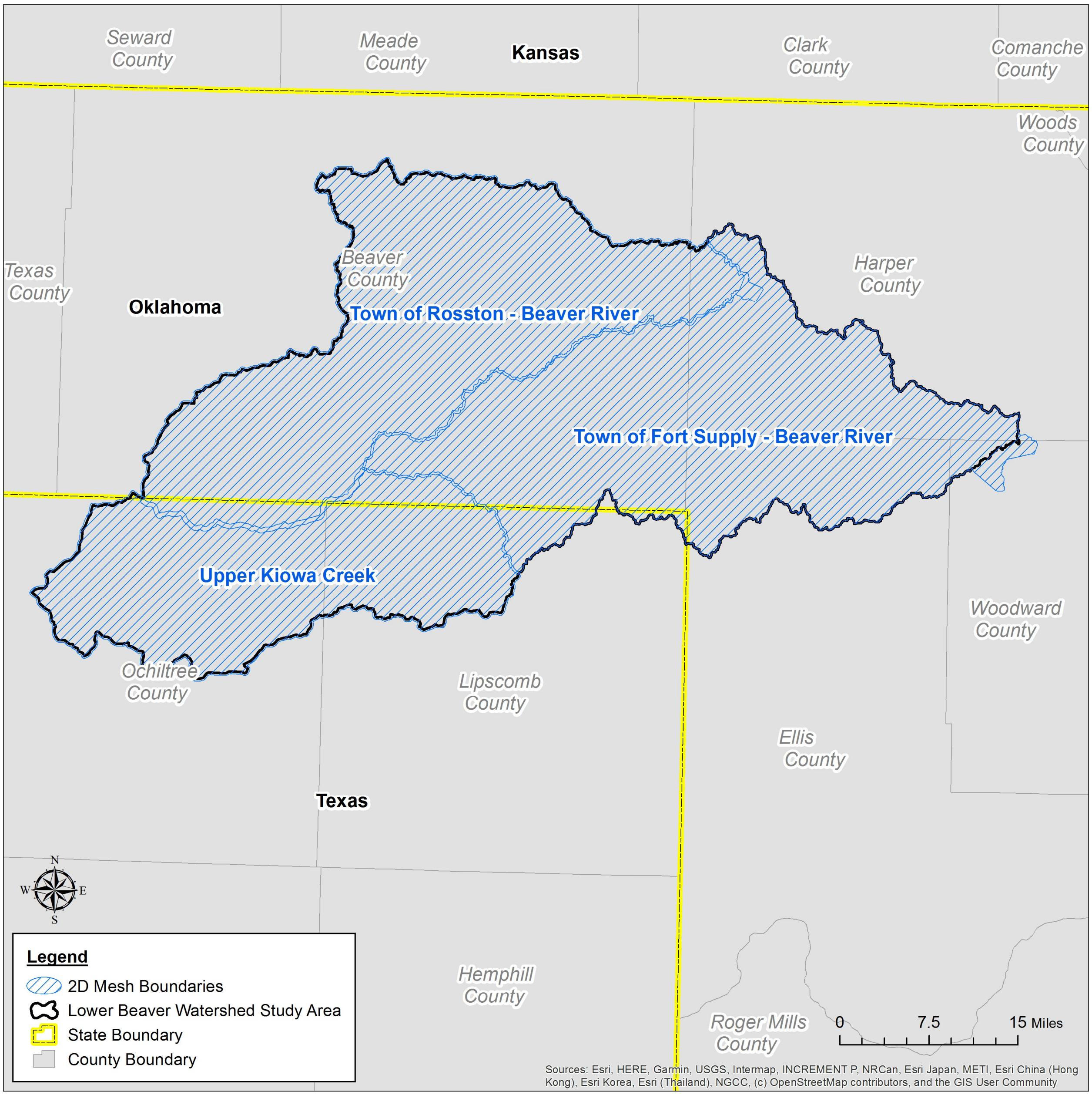

Figure 4: HEC-RAS 2D BLE Model Areas

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 Beaver 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
Town of Fort Supply – Beaver River	586,958
Town of Rosston – Beaver River	620,262
Upper Kiowa Creek	395,249

Model and Boundary Condition Setup

Using HEC-RAS rain-on-grid modeling requires establishing a 2D computational mesh boundary. For this project, precipation 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.

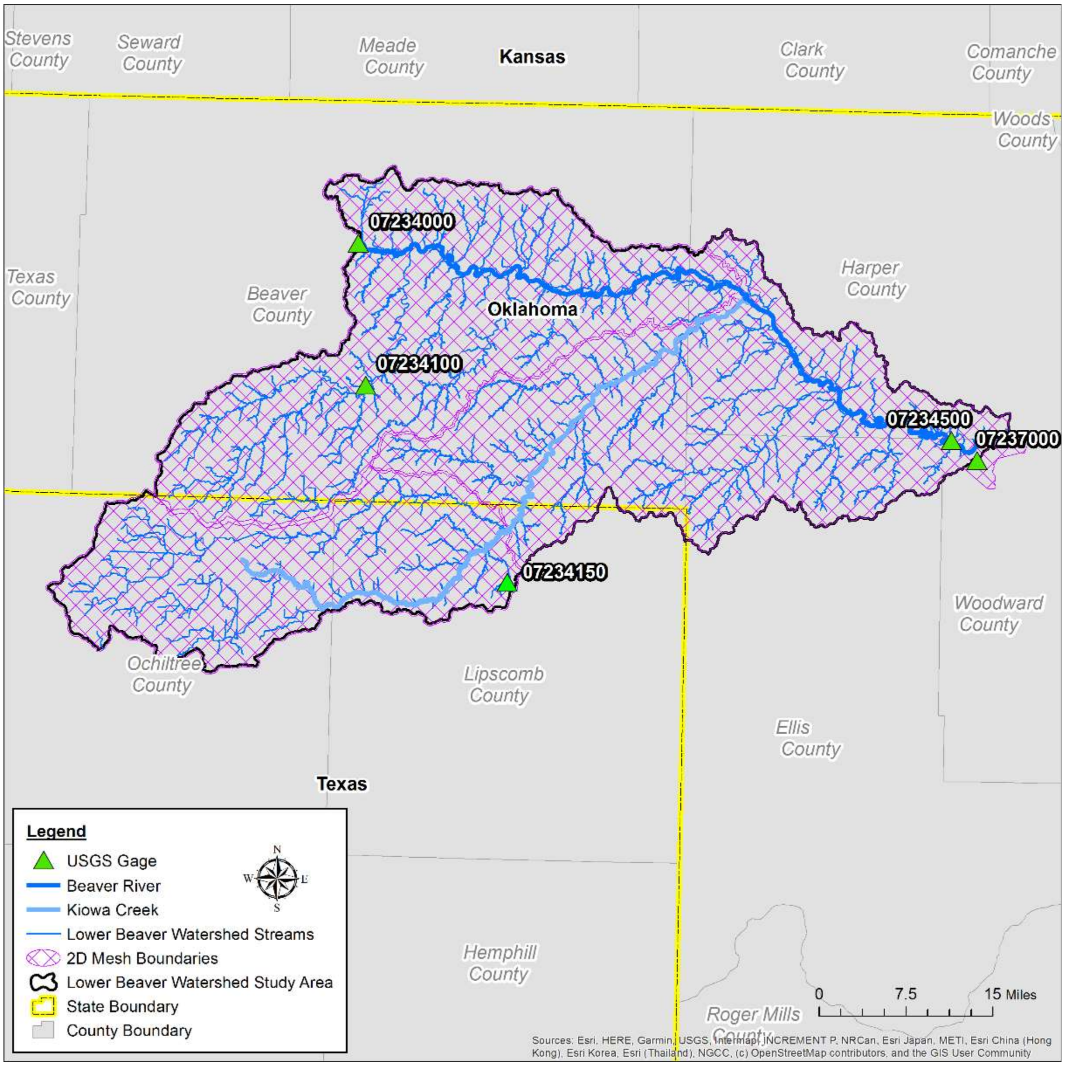

Figure 5: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages

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 Town of Rosston – Beaver River model (USGS gage 07234000) 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 07234500 was not utilized in this study due to the minimal years of record.

Table 6: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
07234000	Beaver River at Beaver, OK	4,986	1979 – 2021
07234100	Clear Creek near Elmwood, OK	170	1966 – 1993
07234150	White Woman Ck Trib near Darrouzett, TX	3.62	1966 – 2019
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)
07234000	Beaver River at Beaver, OK	8,970	5,664	22,760
07234100	Clear Creek near Elmwood, OK	24,200	14,544	33,856
07234150	White Woman Ck Trib near Darrouzett, TX	1,170	703	1,637
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 estimtes. 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 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	49	69	79	84
41	Deciduous Forest	30	48	57	63
42	Evergreen Forest	35	58	73	80
43	Mixed Forest	36	60	73	79
52	Shrub Scrub	35	56	70	77
71	Herbaceous	55	71	81	89
81	Hay Pasture	49	69	79	84
82	Cultivated Crops	63	73	80	83
90	Woody Wetlands	72	80	87	93
95	Emergent Herbaceous Wetlands	72	80	87	93

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 MSE2, 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 Precipitation Total (in)					
	10	4	2	1	0.2	1% Minus	1% Plus
Town of Fort Supply – Beaver River	4.0	4.8	5.6	6.3	8.3	5.3	7.5
Town of Rosston – Beaver River	3.9	4.8	5.5	6.2	8.2	5.2	7.4
Upper Kiowa Creek	4.0	4.9	5.6	6.4	8.3	5.3	7.7

Figure 6, Figure 7 and Figure 8 show the precipitation hyetographs applied to the 2D computational mesh.

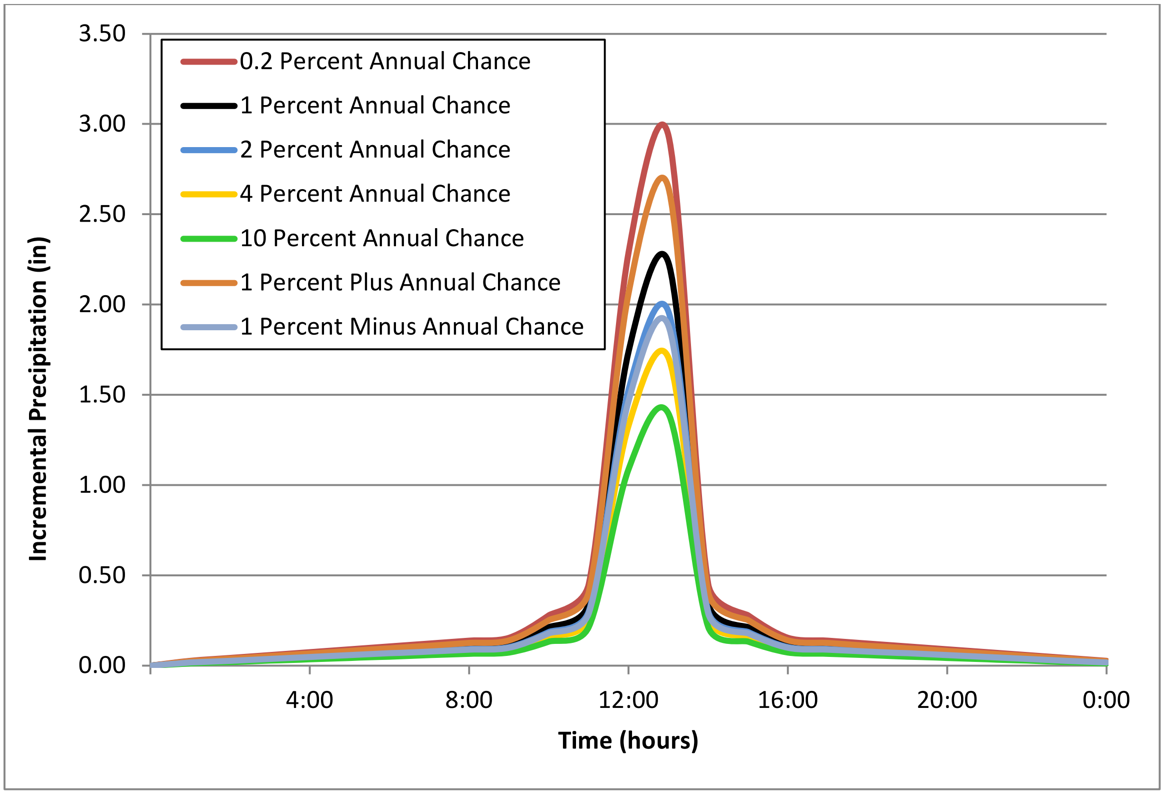

Figure 6: Precipitation Hyetographs (post ARF) applied to the Town of Fort Supply – Beaver River Computational Mesh

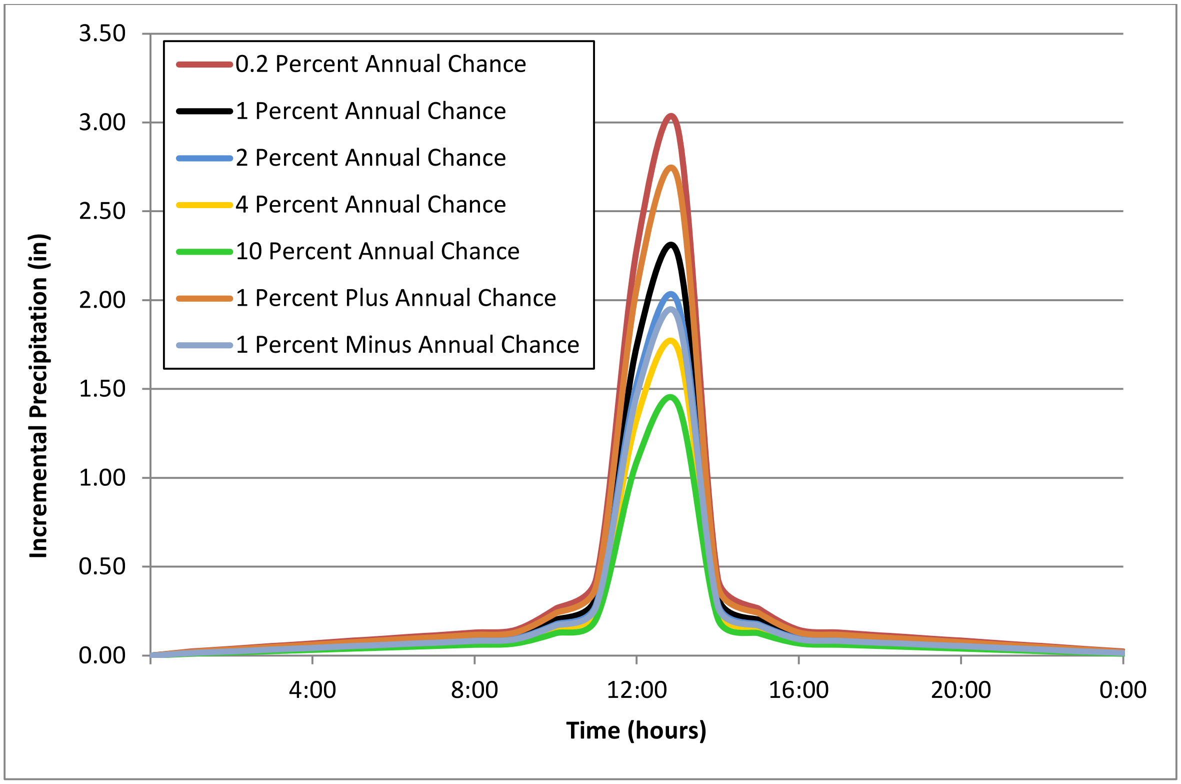

Figure 7: Precipitation Hyetographs (post ARF) applied to the Town of Rosston – Beaver River Computational Mesh

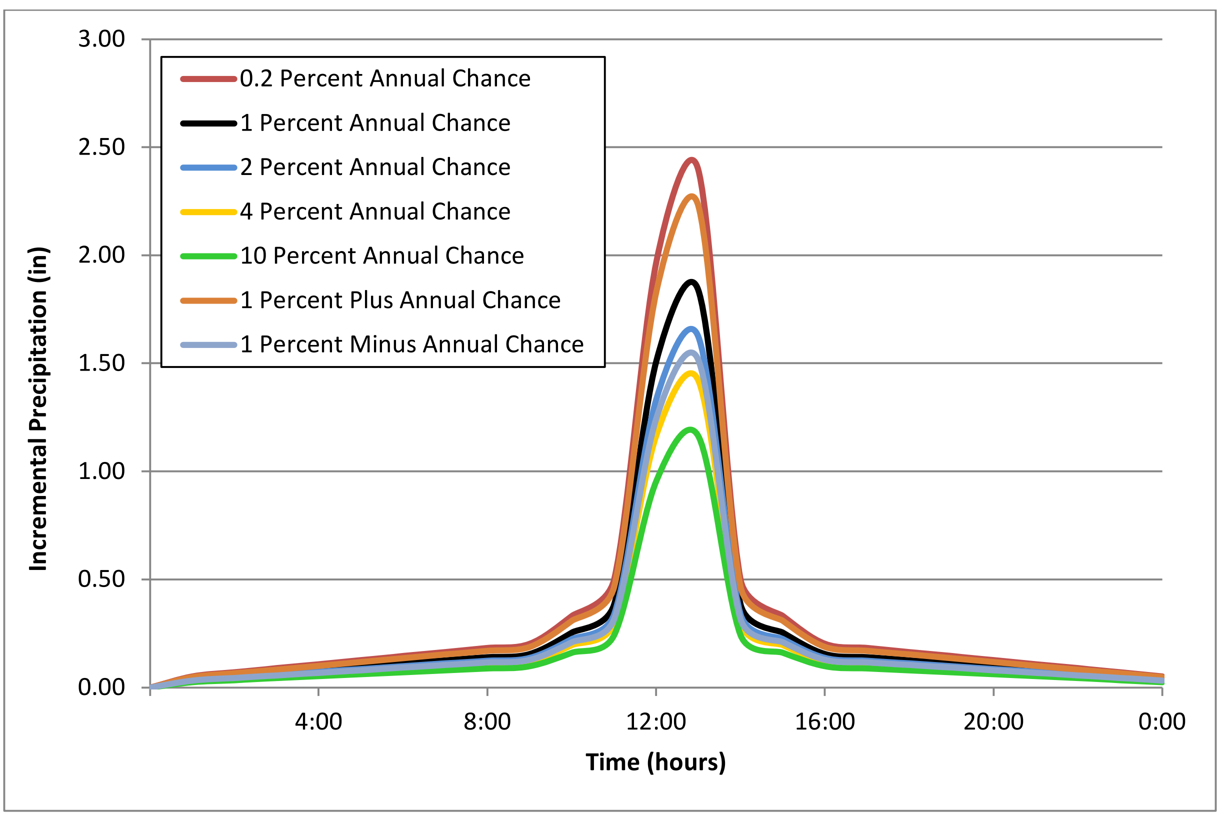

Figure 8: Precipitation Hyetographs (post ARF) applied to the Upper Kiowa Creek Computational Mesh

Hydrograph Boundary Conditions

The Town of Rosston – Beaver River model utilized an inflow hydrograph (Figure 9), developed from USGS gage data (USGS gage 07234000), that was used as a boundary condition to the 2D computational mesh.

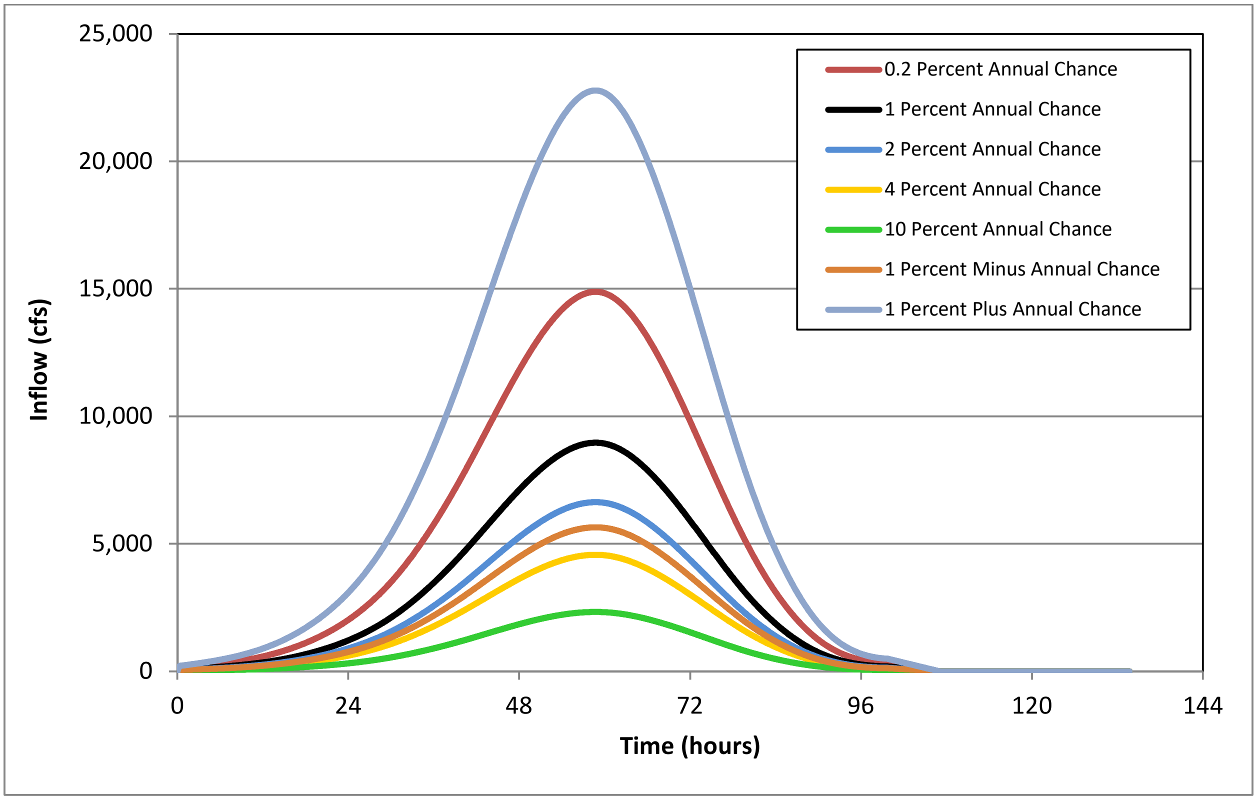

Figure 9: Town of Rosston – Beaver River Flow Hydrograph

Figure 10 and Figure 11 show the flow hydrographs from the Town of Rosston – Beaver River model and the Upper Kiowa Creek model that were input into the Fort Supply – Beaver River model, respectively.

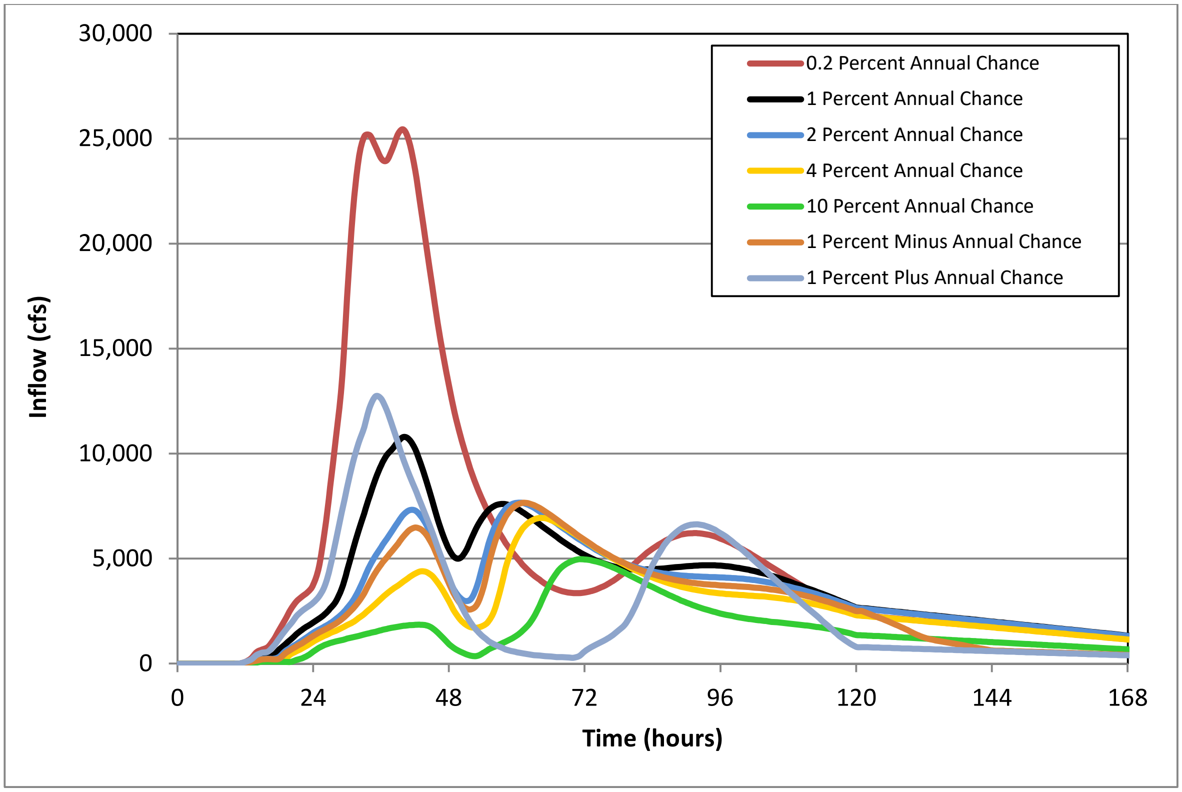

Figure 10: Flow Hydrograph for Fort Supply – Beaver River from Town of Rosston – Beaver River

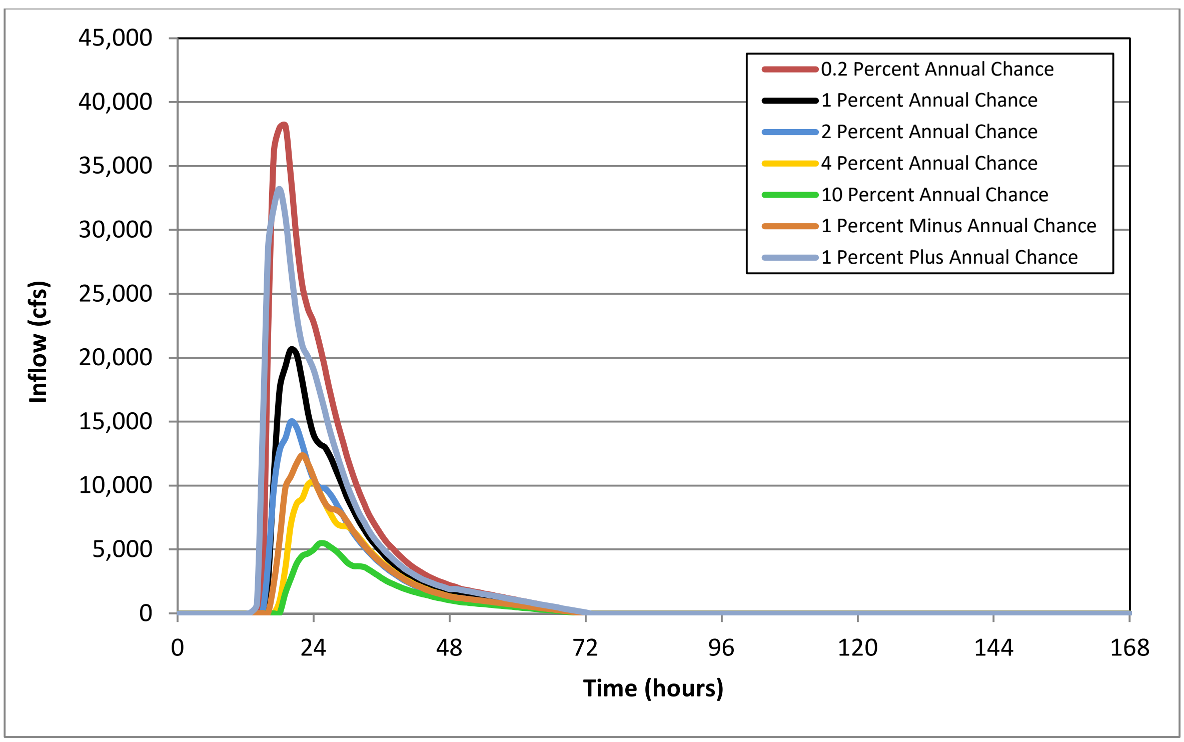

Figure 11: Flow Hydrograph for Fort Supply – Beaver River from Upper Kiowa Creek

Figure 12 represents the stage and flow hydrographs from the Fort Supply Reservoir in the Fort Supply Lake Wolf Creek hydraulic model developed for the Lower Wolf HUC 8 Watershed. The spillway at this reservoir is not engaged in the lower storm events and are therefore not shown as zero in the figure below. Stage hydrographs were utilized for the 1% plus and 0.2% events to allow for tie ins between the Lower Wolf and Lower Beaver HUC 8s.

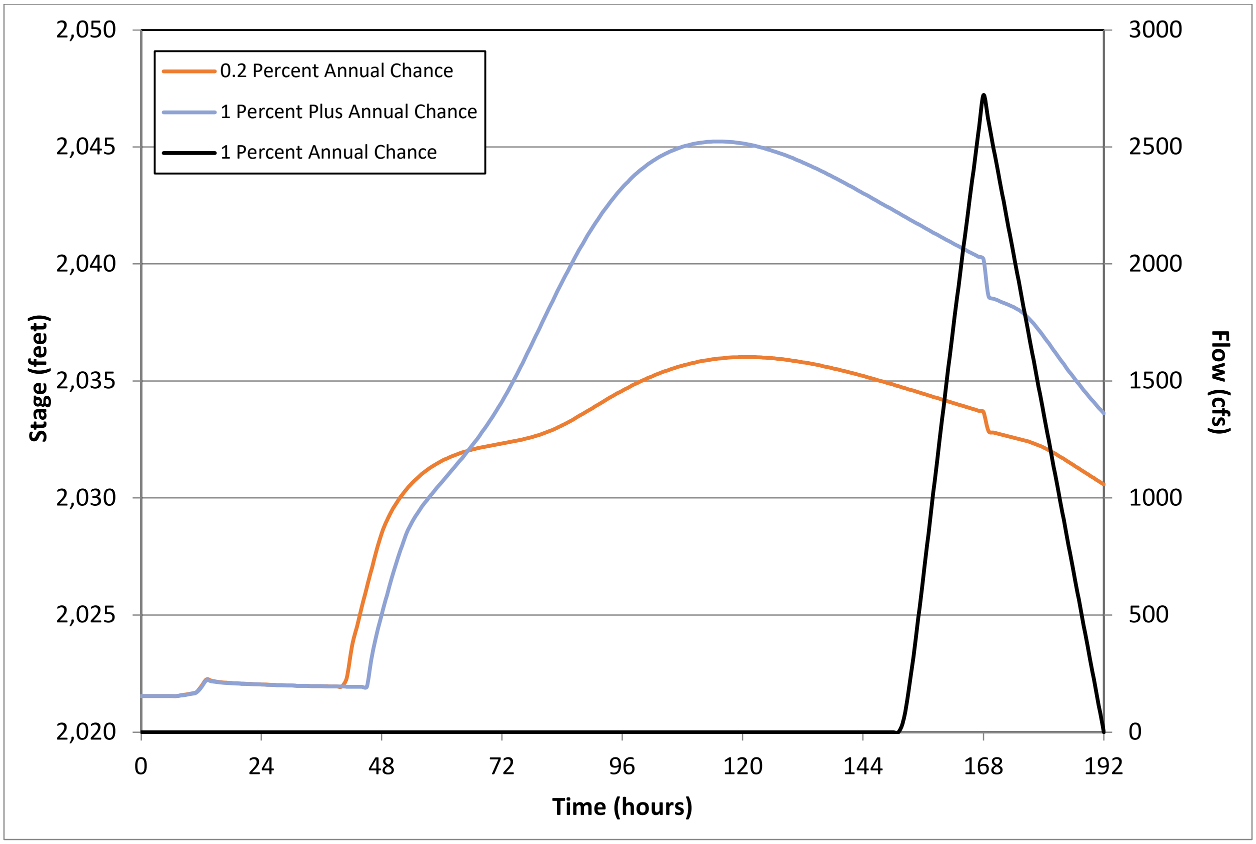

Figure 12: Flow and Stage Hydrographs for Fort Supply – Beaver River from Fort Supply Reservoir

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	Source
Open Water	0.040	0.040	Ven Te Chow 1959
Developed, Open Space	0.040	0.035	2D User's Manual, 2016
Developed, Low Intensity	0.080	0.035	2D User's Manual, 2016
Developed, Medium Intensity	0.100	0.035	2D User's Manual, 2016
Developed, High Intensity	0.150	0.040	2D User's Manual, 2016
Barren Land	0.040	0.030	Ven Te Chow 1959
Deciduous Forest	0.160	0.060	Ven Te Chow 1959
Evergreen Forest	0.160	0.060	Ven Te Chow 1959
Mixed Forest	0.160	0.060	Ven Te Chow 1959
Scrub/Shrub	0.100	0.040	Ven Te Chow 1959
Grassland/Herbaceous	0.060	0.040	Ven Te Chow 1959
Pasture/Hay	0.060	0.040	Ven Te Chow 1959
Cultivated Crops	0.060	0.040	Ven Te Chow 1959
Woody Wetlands	0.120	0.050	Ven Te Chow 1959
Emergent Herbaceous Wetland	0.070	0.045	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.

Private dams were not modeled as showing protection and no major dams or reservoirs are present in this HUC 8 nor does this watershed include any FEMA accredited levees.

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.

Four 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. Gage 07234000 was used as the inflow for the Town of Rosston – Beaver River Model and is, therefore, not listed in model calibration results. Given that Gage 07237000 is downstream of the Fort Supply Reservior dam, the resulsts were not analyzed.

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)
Upper Kiowa Creek	USGS Gage 07234150	4	703	1,170	1,637	1,145
	StreamStats UKC_2	40	2,452	4,080	5,708	3,728
	StreamStats UKC_3	70	3,011	5,010	7,009	6,804
Town of Rosston – Beaver River	USGS Gage 07234100	170	14,544	24,200	33,856	31,151
	StreamStats TR_BR_1	16	1,755	2,920	4,085	3,784
	StreamStats TR_BR_2	27	2,104	3,500	4,897	4,206
	StreamStats TR_BR_3	36	2,344	3,900	5,456	5,767
	StreamStats TR_BR_5	575	15,927	26,500	37,074	13,136
Fort Supply – Beaver River	USGS Gage 07234290	9	2,326	3,870	5,414	4,697
	StreamStats TFS_BR_3	23	1,989	3,310	4,631	3,192
	StreamStats TFS_BR_4	103	3,498	5,820	8,142	4,990
	StreamStats TFS_BR_5	29	2,170	3,610	5,050	3,501
	USGS Gage 07234290	1,739	1,989	3,310	4,631	2,479

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 Beaver BLE project, floodplain mapping delineation was completed using connected raster cells at the extent of the CNMS mapped and unmapped features in the project footprint with raster depths greater than 0.5 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 polygon less than 2 acres that intersected a flooding source were assessed individually. These edits adhere to traditional and approved floodplain mapping approaches.

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

Flood Hazard Area Layer

Special Flood Hazard Areas, as noted above, were developed to the extent of the CNMS features or up to 1 square mile drainage area and effective zone A study locations. The Regional CNMS database, National Flood Hazard Layer, and paper inventory 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 Beaver Watershed.

The inventory of Zone A studies (7.7 miles) in the Lower Beaver Watershed were classified in CNMS with validation status of "UNVERIFIED" (7.7 miles) and with status type of "BEING STUDIED." The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A3 were evaluated for the CNMS inventory of Zone A studies.

Initial Assessment A1 – Significant Topography Update Check

This check involves determining whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. All effective Zone A studies within this watershed did not use LiDAR data in their effective studies. 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.

Effective Zone A reaches within Woodward County, Oklahoma used the regression equations, WRIR 97-4202, and newer regression equations were published in 2015, SIR 2015-5134. Therefore, these two reaches fail this check.

All other reaches in this HUC-8 were not known to have used regression equations in their effective analysis and, therefore, 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 12.

Table 12: 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 not known to be used in effective / New equations were published since effective analysis
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.

Effective Zone A reaches within Woodward County, Oklahoma are model-backed studies and pass this check. All other reaches in this HUC-8 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 Beaver Watershed. The validation of the effective Zone A boundaries using 2D flood hazard products differ from the standard 1D methods due to the lack of cross sections and their use with standard 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 500 feet.

For each test point, a 75-foot buffer was created. Using this buffer, the minimum and maximum values of the DEM were extracted, as a proxy for the effective base flood elevation. The minimum value of the 1% minus raster, and the maximum value of the 1% plus raster are also extracted. These 1% plus maximum and 1% minus minimum values are products of the new 2D BLE study and act as the vertical tolerance. The test point passes if the DEM maximum value is less than or equal to the 1% plus maximum value and the DEM minimum value is greater than or equal to the 1% minus minimum value. This can be visualized as a short 75-foot radius cylinder, with a height of 1% plus maximum – 1% minus minimum. This test verifies that at least one point from the ground surface (i.e. proxy BFE) falls both vertically and horizontally within this range.

Validation Results

All 7.7 total miles of available CNMS features representing the effective Zone A studies were categorized as UNVERIFIED – BEING STUDIED. Total miles are summarized in Table 13 and illustrated in Figure 13 below. Table 14 summarizes the validation results based on the individual HUC 12 watersheds within Lower Beaver Watershed.

Table 13: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment/Total Miles
VALID	BEING STUDIED	0	0
UNVERIFIED	BEING STUDIED	7.7	7.7

Table 14: BLE Comparison Results

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	HUC12 ID						
Lower Beaver	All Streams	262	96	166	63%	Fail	
Plummer Creek-Kiowa Creek	111002010306	19	1	18	95%	Pass	2.6
Spring Creek-Beaver River	111002010501	8	4	4	50%	Fail	45.0
Town of Fort Supply-Beaver River	111002010610	235	64	171	73%	Fail	6.8

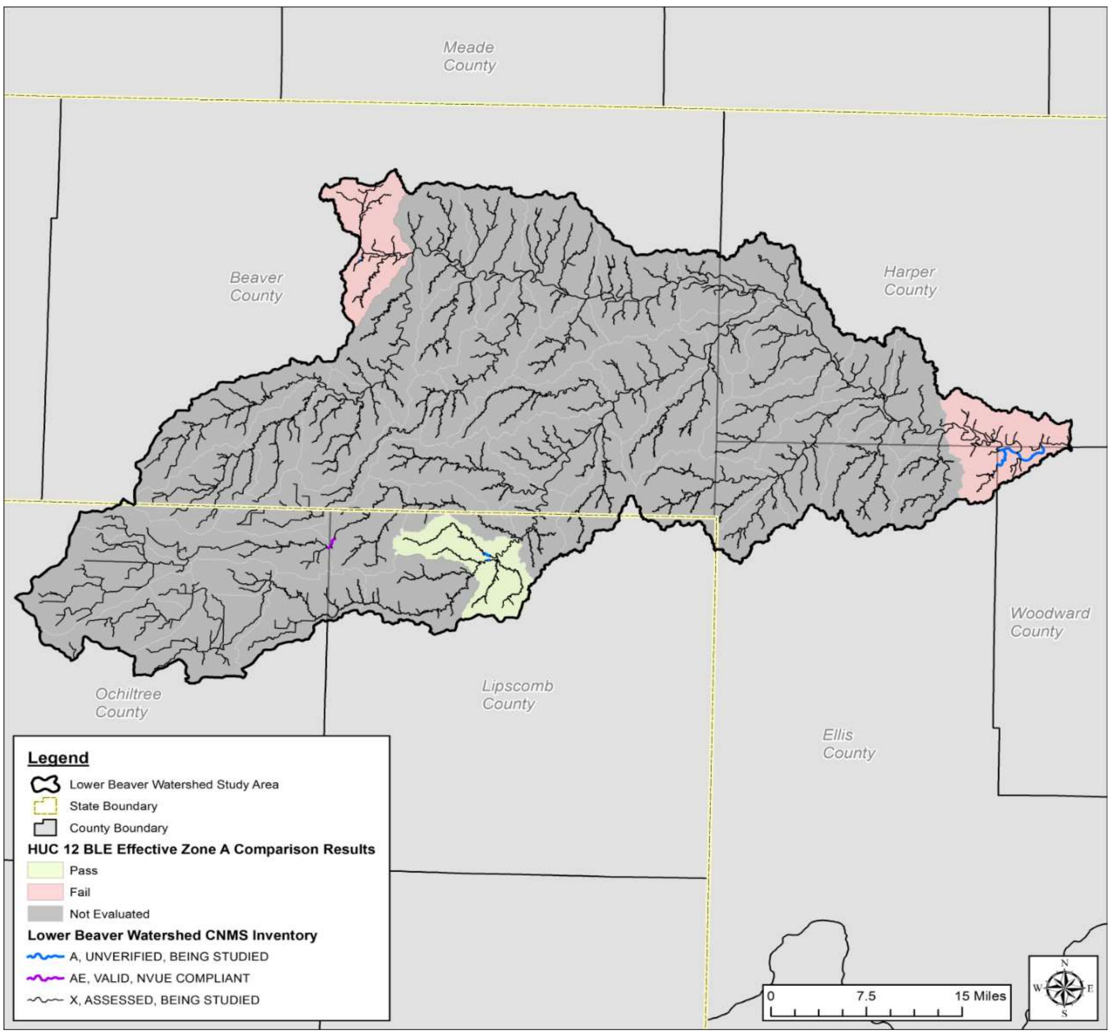

Figure 13: CNMS Validation Results

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 14 below shows the range of the Lower Beaver HUC 12 priority scores which can be used to initiate discussions during the Discovery phase. The Town of Fort Supply – Beaver River is the only HUC 12 watershed with a significant number of points to include in a comparison of highest and lowest priority, so for the Lower Beaver HUC 8, this summary is not included in this report.

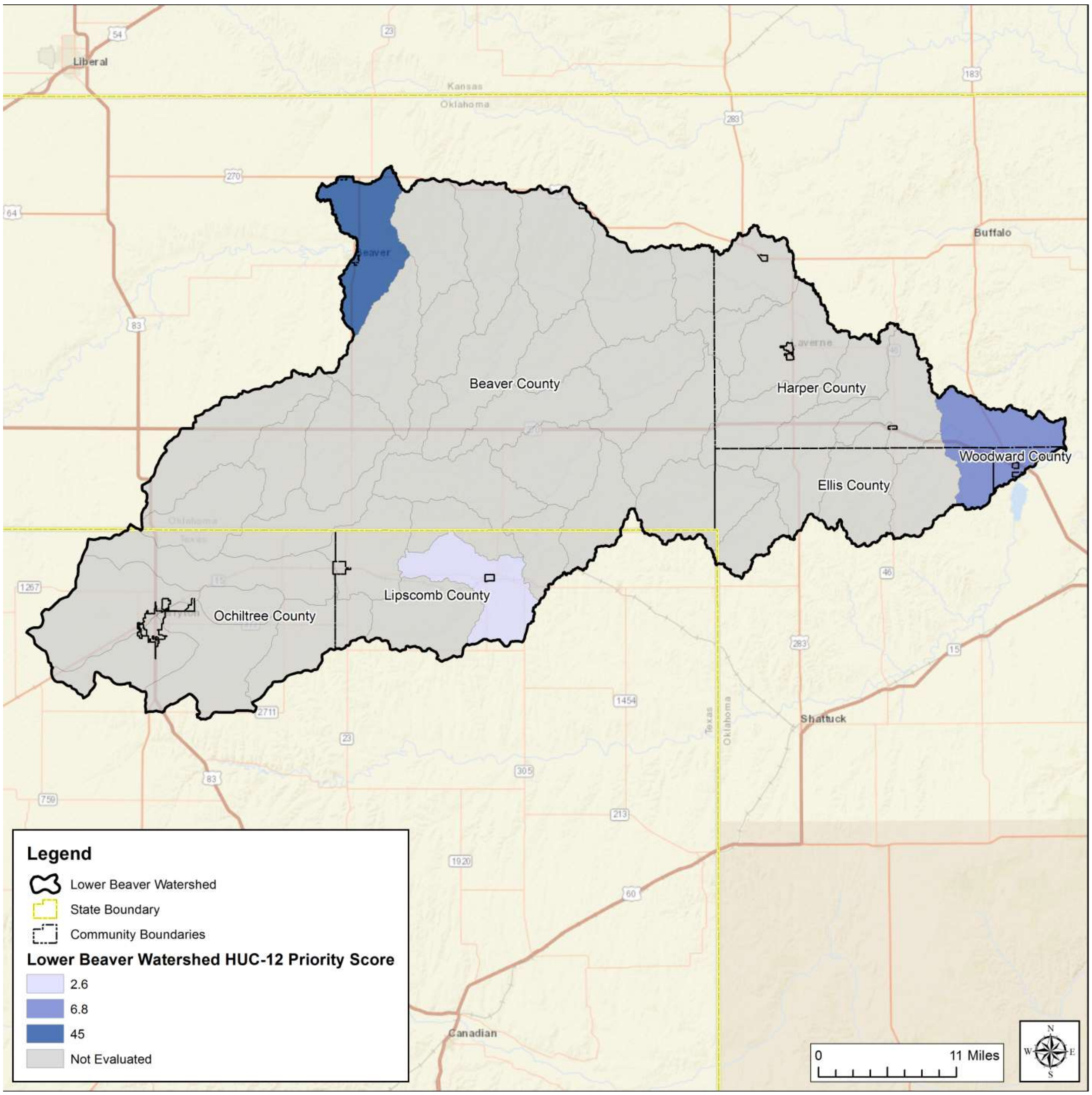

Figure 14: Ranking of Lower Beaver Watersheds HUC-12s

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 extents for each return period to ensure proper model processing. A summary of results per county for the 100-year scenarios are shown in Table 15.

Table 15: Hazus 6.1 Results for 1-percent-annual-chance scenario for Lower Beaver Watershed, Oklahoma/Texas

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Beaver	$2,313,000	$466,361,000	$323,844,000
Ellis	$118,000	$21,111,000	$10,546,000
Harper	$12,478,000	$295,906,000	$211,119,000
Lipscomb	$6,869,000	$451,071,000	$374,799,000
Ochiltree	$226,952,000	$2,806,770,000	$2,270,850,000
Woodward	$1,135,000	$87,227,000	$55,220,000
Total	**$249,865,000**	**$4,128,446,000**	**$3,246,378,000**

Quality Assurace & Quality Control

The 2D BLE results were independently assured to meet quality standards of the project. Standard checklists compling with FEMA standards were used to review hydrology and hydraulics results, the resulting flood hazard area delineations and CNMS dataset. QA 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 Beaver Watershed BLE process were uploaded to the FEMA's 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, if applicable)
- 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 is not available in Texas which is where the majority of the Upper Kiowa Creek model lies. A regression analysis was completed for this model inside the State of Texas while the areas in Oklahoma utilized Streamstat data. Flow reducers were utilized in the Town of Fort Supply – Beaver River model to replicate the losses seen in the gage analysis. These losses could be associated with the known subterranean landscapes in this region.

The Town of Fort Supply – Beaver River model extends just downstream of the Lower Beaver HUC 8 Watershed and into the Lower Wolf HUC 8 Watershed. The Fort Supply Reservoir dam provided a cleaner tie in between the two HUC 8s at the crest of the dam spillway. Stage hydrographs from the Fort Supply Lake Wolf Creek model in Lower Wolf HUC 8 were utilized for the 1% plus and the 0.2% events. A flow hydrograph was used for the 1% event and there was no flow from Fort Supply Lake Wolf Creek for the more frequent events. Using both stage and flow hydrographs allowed for tie ins between the models and HUC 8s.

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