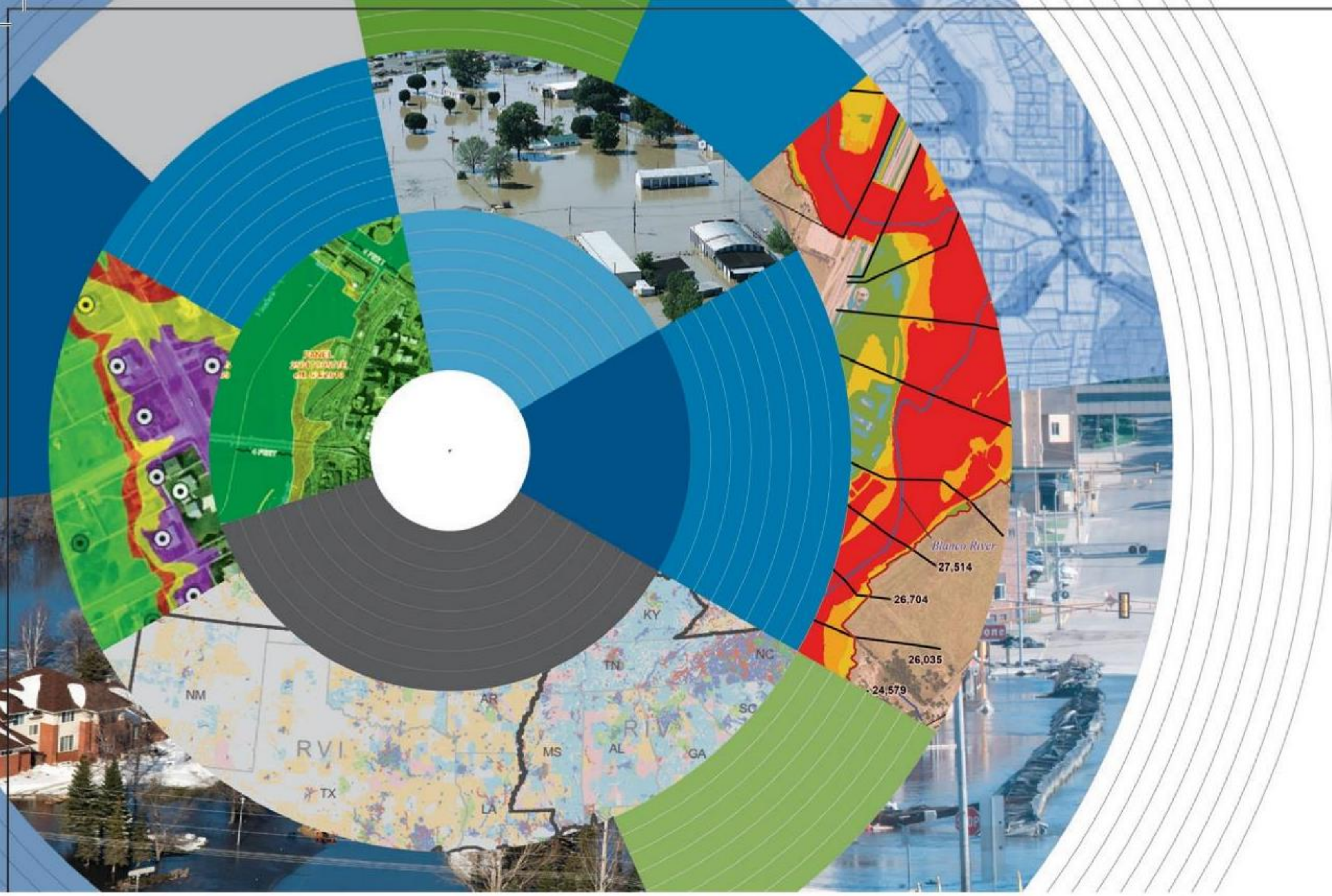

2D Base Level Engineering Report

Upper Guadalupe (HUC 8 12100201)

FEMA

August 31, 2024

Version 1.0

Report Prepared for:

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Revision History

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

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Executive Summary

FEMA Region 6 contracted Compass to complete a Base Level Engineering (BLE) analysis for Upper Guadalupe Hydrologic Unit Code 8 (HUC 8) Watershed in Texas 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 below.

Flood discharges for this study were calibrated using both the United States Geological Survey (USGS) regression equations and the 2019 InFRM Watershed Hydrology Assessment for the Guadalupe River Basin, where peak flow estimates were generated for various stream reaches within the Guadalupe River basin during the interagency study. This study used up-to-date statistical analysis along with state-of-the-art rainfall runoff watershed modeling and reservoir modeling to estimate the flow values throughout the Guadalupe River basin. Regression equation discharges were obtained using the 2016 Upper Guadalupe 1D BLE engineering results.

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) program version 6.3.1 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)	1671.7
New Study Streams – CNMS (S_Unmapped_Ln) Informed by NHD 1:100	0.0
Total (BLE) Stream Miles	**1671.7**

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	NVUE COMPLIANT	49.6	65.2
VALID	BEING STUDIED	75.1	119.3
ASSESSED	BEING STUDIED	673.4	564
UNVERIFIED	BEING STUDIED	863.2	814
UNVERIFIED	TO BE STUDIED	109.1	109.1

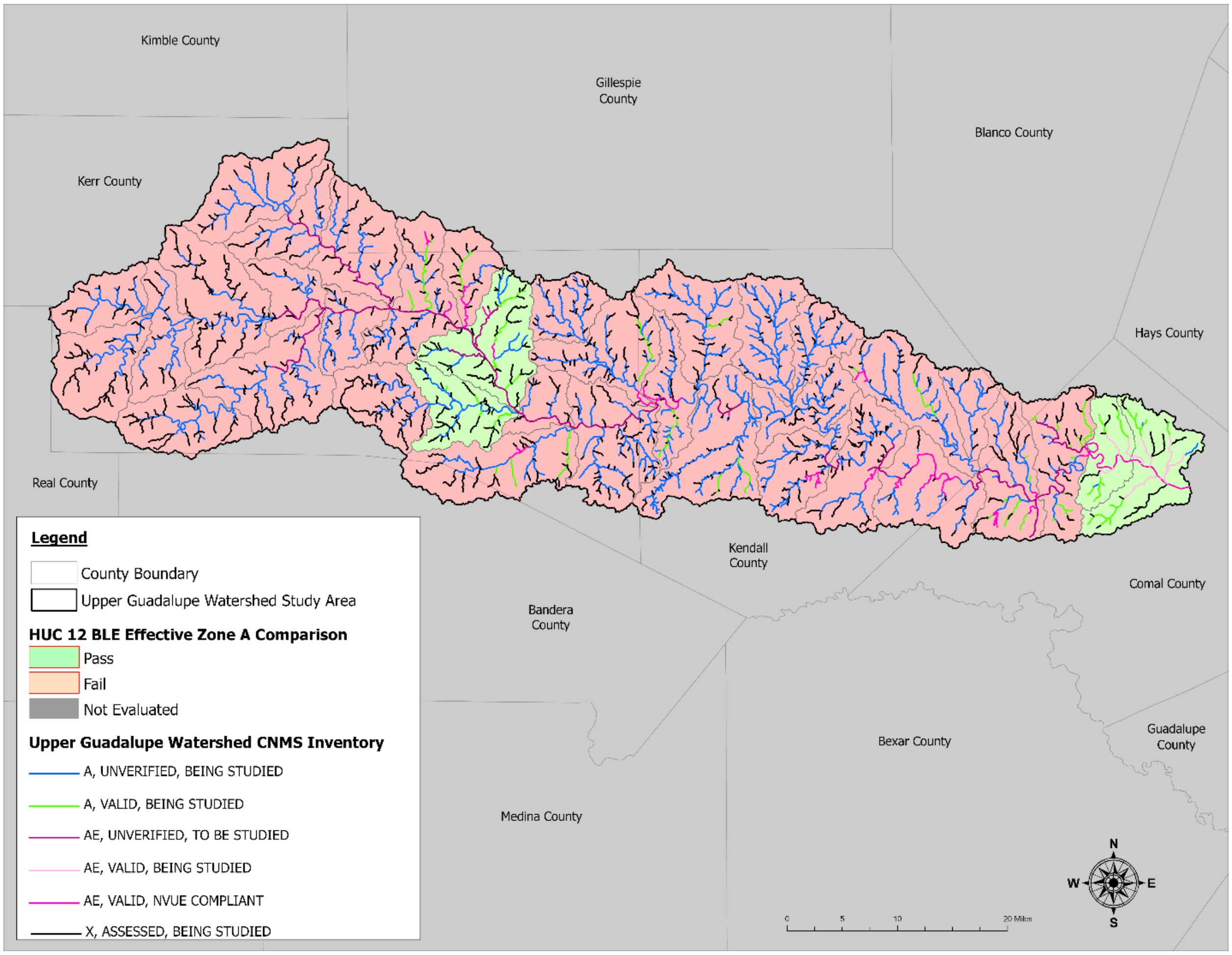

Figure 1: Upper Guadalupe – CNMS Validation Results

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 Upper Guadalupe 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, FEMA Region VI contracted the Compass PTS JV to perform a BLE analysis for the Upper Guadalupe Watershed within the State of Texas. The Upper Guadalupe watershed does have a history of riverine flooding. In July 2002, the Canyon Lake reservoir overflowed the spillway for the first time in the history of Canyon Lake. Other large flooding events in this area include August 1978, and July 1987. This report documents the BLE process, products, and results for this watershed. Figure 2 depicts the Upper Guadalupe Watershed footprint.

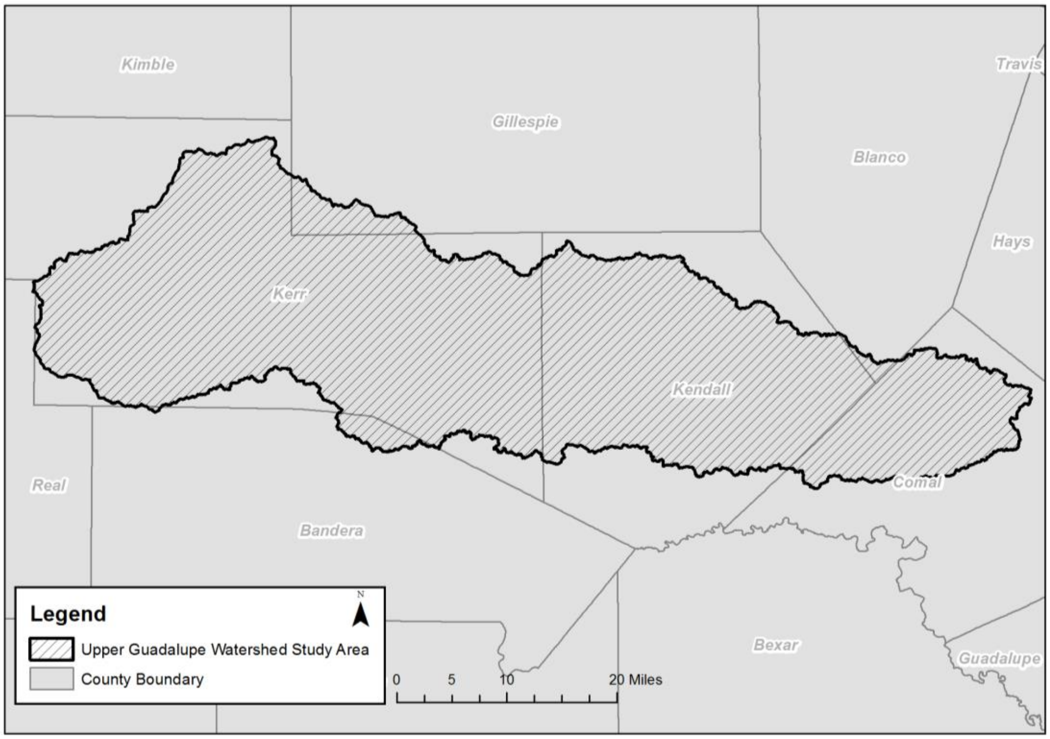

Figure 2: Upper Guadalupe Watershed

The BLE assessment prepared Zone A analyses for approximately 1,675 miles of stream reaches within the Upper Guadalupe 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 floodplains received an updated analysis. The following sections will summarize the BLE process and will discuss the results along with their recommended use.

Topographic Data

A high-resolution Digital Elevation Model (DEM) is a fundamental component for 2D engineering analyses by providing a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the Upper Guadalupe BLE project by leveraging available high-resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the entire state of Texas. The 10-foot DEM developed to support the 2D BLE modeling and analysis, within the Upper Guadalupe Watershed, was executed using the following steps:

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

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

Inventory

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

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 Upper Guadalupe 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)
2018 USGS TX Hurricane D18 Supplemental DRRA Lidar	January 4, 2019 to February 20, 2019	NVA of DEM tested at 7.2 cm at 95-percent confidence level	USGS	1,767
2018 TX Lower CO San Bernard D18 Lidar	February 12, 2018 to April 22, 2018	Bare Earth DEM tested 4.53 cm NVA at a 95-percent confidence level using RMSEz x 1.9600 as defined by the NSSDA	USGS	104
2018 USGS TX Red River Atacosa B2 Lidar	January 4, 2018 to January 22, 2018	DEM tested 5.9 cm NVA at a 95-percent confidence interval RMSEz x 1.9600 was equal to 11.6 cm	USGS	33
2017 USGS TX Central B1 Lidar	January 20, 2017 to March 22, 2017	DEM tested 0.06 meters NVA at a 95-percent confidence interval	USGS	6

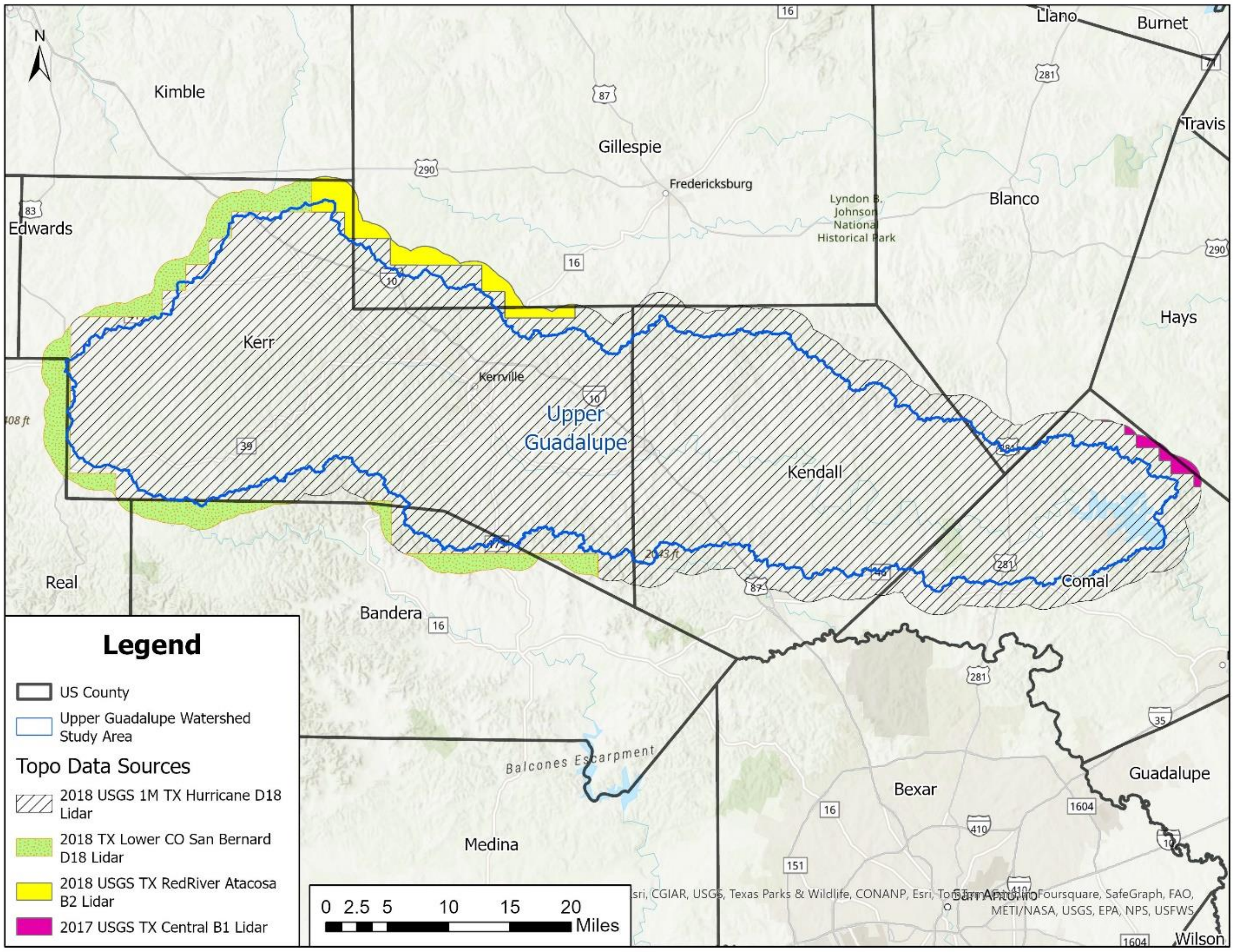

Figure 3: Extent of LiDAR Data

Upper Guadalupe Watershed Source Terrain Data

The source elevation data for the Upper Guadalupe Watershed are DEMs derived from the 2018 USGS TX Hurricane D18 Supplemental DRRA Lidar; 2018 TX Lower CO San Bernard D18 Lidar; 2018 USGS TX Red River Atacosa B2 Lidar; and the 2017 USGS TX Central B1 Lidar. Only points classified as "ground" points (i.e., bare earth) were imported from the LiDAR and used for development of the project DEMs. Bare-earth LiDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the raw laser returns. Figure 3 depicts the extent of the data defined in

Table 4. The 2018 USGS TX Hurricane D18 Supplemental DRRA Lidar was compiled to meet 7.2 cm non-vegetated vertical accuracy at 95% confidence level. The 2018 TX Lower CO San Bernard D18 Lidar was compiled to meet 4.53 cm non-vegetated vertical accuracy at 95% confidence level (Root Mean Square Error (RMSEz) * 1.96). The 2018 USGS TX Red River Atacosa B2 Lidar was compiled to meet 5.9 cm vertical accuracy at 95% confidence level (Roost Mean Square Error (RMSEz) * 1.96). The RMSEz may not exceed 11.6 cm. The 2017 USGS TX Central B1 Lidar was compiled to meet 0.06 cm vertical accuracy at 95% confidence level (Roost Mean Square Error (RMSEz) * 1.96).

Data Development Methodology

The source topographic data were processed for an area covering the Upper Guadalupe Watershed and contributing drainage areas for the Upper Guadalupe BLE modeling efforts. The topographic data for Upper Guadalupe Watershed was projected horizontally, as needed, to North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS) Texas South Central in feet (4204-SPC83). All topographic data were adjusted vertically, as needed, to 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 Upper Guadalupe 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 Upper Guadalupe 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 6.3.1 was used for this project. This analysis was performed for the portion of the Upper Guadalupe HUC 8 Watershed within the State of Texas and was split into four modeling areas based on HUC 10 watersheds (Headwaters Guadalupe River, Block Creek-Guadalupe River, Guadalupe River-Canyon Lake, and Turtle Creek-Guadalupe River). Figure 4 identifies the footprint of the hydrologic and hydraulic analysis for this study.

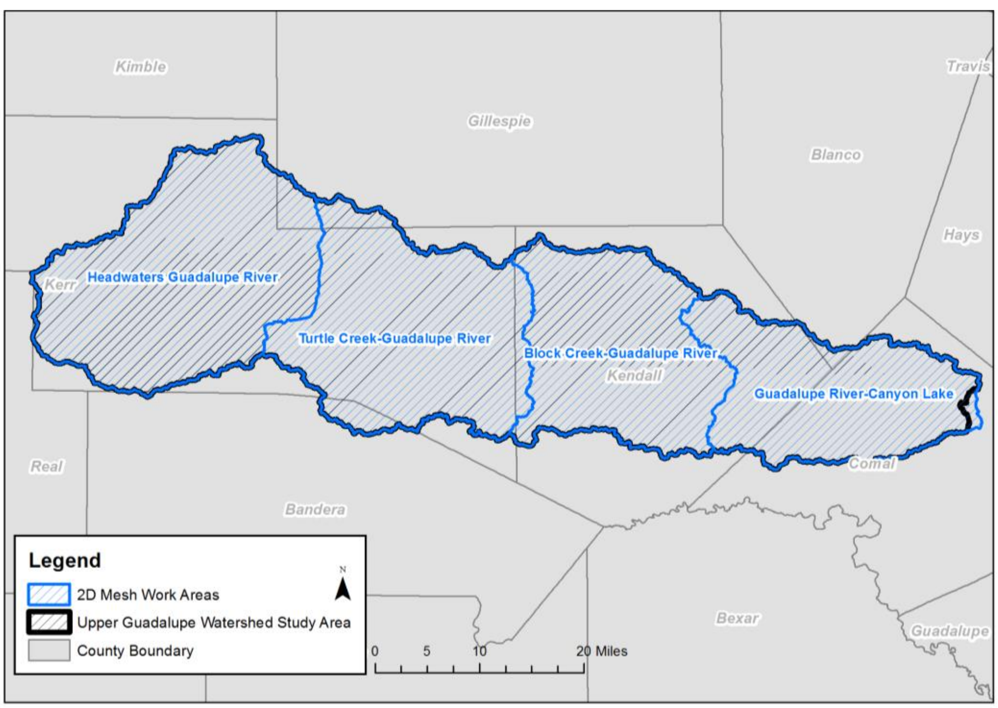

Figure 4: HEC-RAS 2D BLE Model Area

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 1,000-foot buffer was added to the HUC boundary.

The HEC-RAS 2D computational meshes were created for the four hydraulic 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 1.5 and minimum Courant of 0.45 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
Turtle Creek – Guadalupe River (UPGU2)	622,548
Block Creek – Guadalupe River (UPGU3)	292,677
Guadalupe River – Canyon Lake (UPGU4)	1,063,548
Headwaters Guadalupe River (UPGU1)	413,150

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.

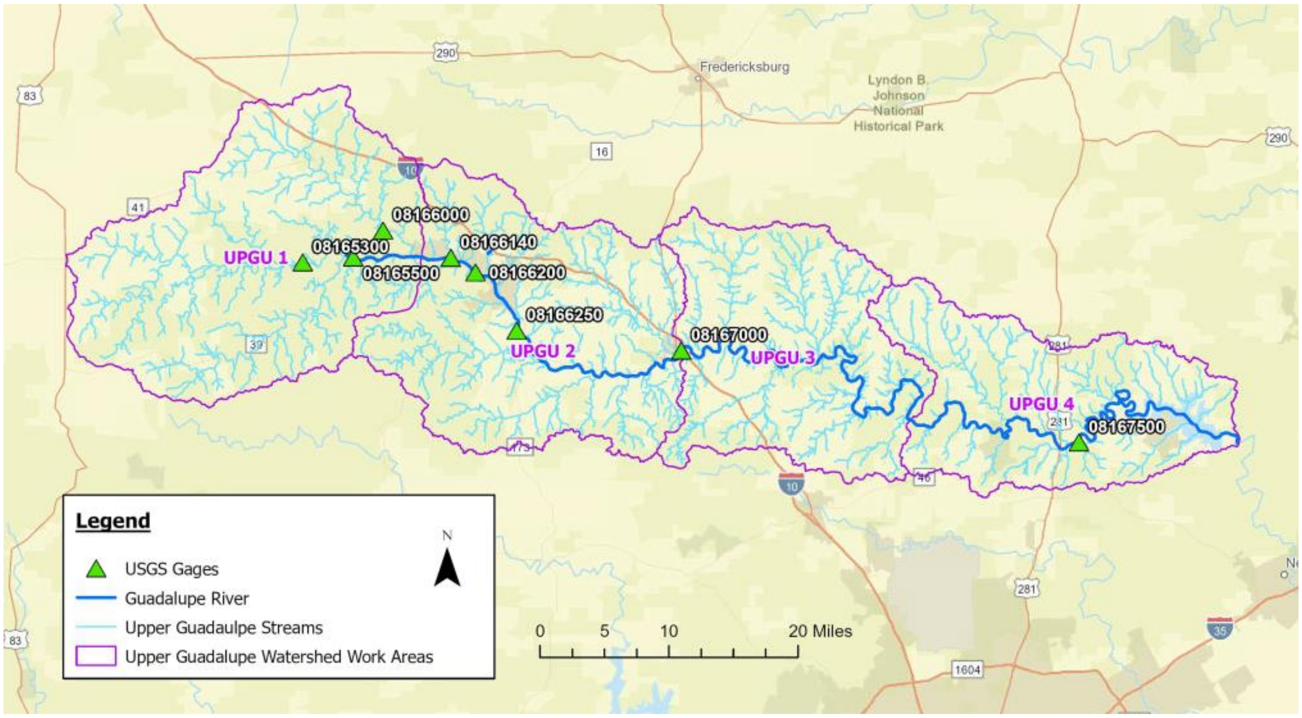

Figure 5: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages

Hydrology

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

Precipitation frequency estimates for the Study were acquired from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 data server, which is accessible at (https://hdsc.nws.noaa.gov/pfds/pfds_gis.html). The geographical focus of the Study pertains to the Upper Guadalupe watershed in Texas. The data retrieval process involved obtaining spatial grids in the ASC file format, which depict 24-hour precipitation depths for various return periods, including 10-year, 25-year, 50-year, 100-year, and 500-year events. For Upper Guadalupe, the study areas falls primarily under the Texas A (TX-A) temporal distributions, which was applied to the gridded data. To incorporate these rasters into the DSS format, a specialized tool, developed by the US Army Corps of Engineering, Vortex, was employed. Vortex seamlessly integrated these 6-minute interval rasters into the DSS file generated by HEC-DSSVue. Subsequently, this precipitation file in DSS format was used in the HEC-RAS model, employing the rain-on-mesh technique to simulate the runoff process.

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

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

The NRCS Nested Distribution developed for the Texas region, as shown in Figure 6: NRCS Nested Distribution Zones – Figure 6, was used for defining storm distributions of the spatially varied rainfall input. The nested distribution approach allows for smaller duration rainfall events to be nested within the greater 24-hour duration storm event for every recurrent interval. This is important to represent hydrology in smaller sub-basins within each model, where the controlling duration is often shorter and more intense than larger basins.

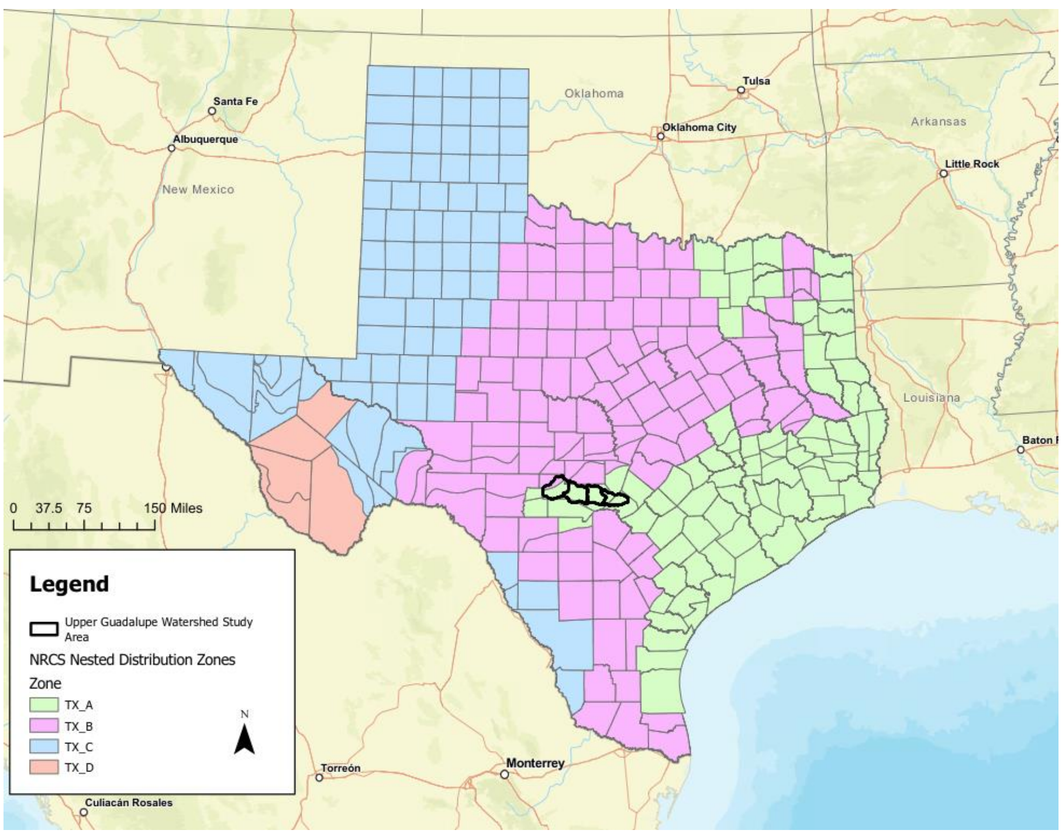

Figure 6: NRCS Nested Distribution Zones – Texas

Figure 7 shows an example spatially varied precipitation depths after the application of the areal reduction factor at the scalar (cell) level. These precipitation depths represent the total accumulated rainfall in the RAS model during the 24-hour design storm period at that physical location.

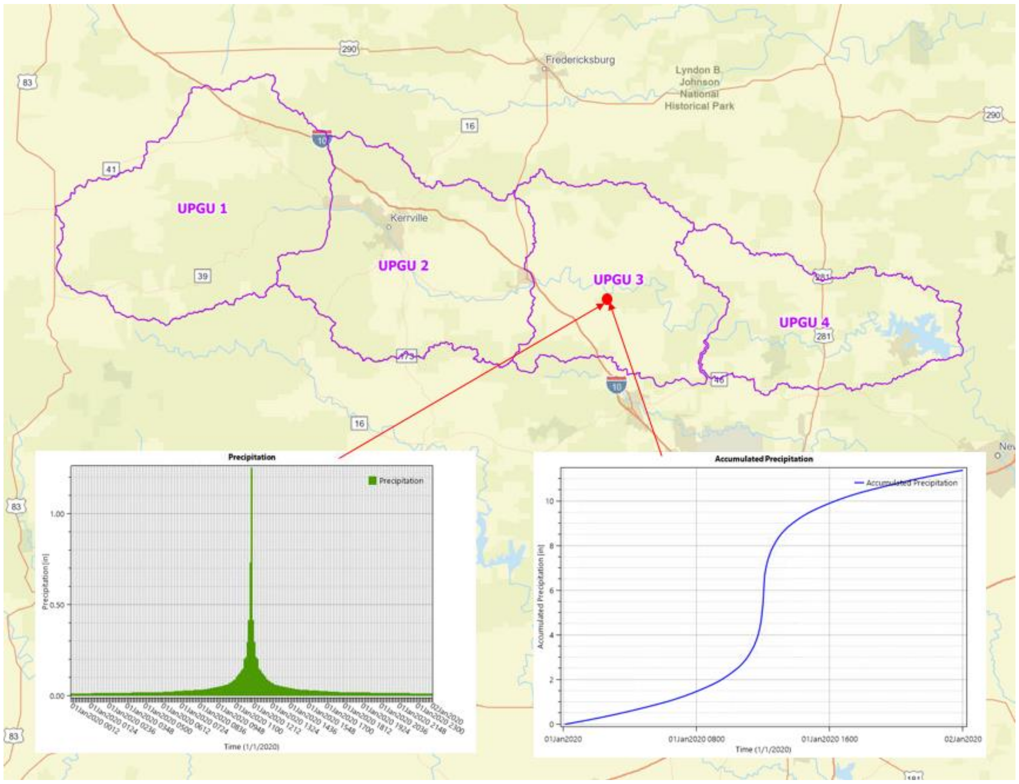

Figure 7: Spatially Varied Precipitation Example

1% (+/-) Annual Chance Gridded Precipitation Data

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

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

- Given precipitation values (lower 90%, median, and upper 90%) from NOAA.
- Calculate μ (natural log of medial rainfall)
  - $\mu = \ln(Precip_{median})$
- Calculate σ_{max} $(the \max natural \log of\ the\ standard\ deviation\ of\ data)$
  - $\sigma_{lower} = \frac{[\mu - ln(Precip_{lower\ 90\%})]}{1.645}$
  - $\sigma_{upper} = \frac{[ln(Precip_{upper\ 90\%}) - \mu]}{1.645}$

- $\sigma_{max} = \max(\sigma_{lower}, \sigma_{upper})$

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

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

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

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

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

Areal Reduction Factor (ARF)

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

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

Areal reduction factors were determined using Table 7.1 of the 2019 InFRM Report. Table 6 shows the areal reduction factors applied to each work area.

Table 6: Depth Area Reduction Factors

Work Area	Depth Area Reduction Factor (ARF)
Headwaters Guadalupe River (UPGU1)	0.8768
Turtle Creek – Guadalupe River (UPGU2)	0.8827
Block Creek – Guadalupe River (UPGU3)	0.8937
Guadalupe River – Canyon Lake (UPGU4)	0.8968

Excess Precipitation for 2D Computational Mesh

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 TXA temporal regions.

Excess precipitation and infiltration losses are determined in HEC-RAS 6.3.1 using the NRCS Curve Number (CN) Loss Method. HEC-RAS calculates a separate Curve Number for each 2D cell based on a combination of land use and soils datasets. This will vary the excess precipitation throughout the 2D model domain to represent varied geography within the larger model area. Initial Curve Numbers were computed by intersecting the National Land Cover Dataset (NLCD) 2019 and NRCS soils data based on the matrix presented in Table 7. Curve Numbers were based on TWDB BLE Guidelines Version 1.0. During the calibration of the model, Curve Numbers were adjusted to achieve flows that are closer to regression equation and flood frequency analysis estimates.

Table 7: 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	99	99	99	99
21	Developed Open Space	49	69	79	84
22	Developed Low Intensity	39	61	74	80
23	Developed Medium Intensity	39	61	74	80
24	Developed High Intensity	39	61	74	80
31	Barren Land	39	61	74	80
41	Deciduous Forest	30	55	70	77
42	Evergreen Forest	30	55	70	77
43	Mixed Forest	30	55	70	77
52	Shrub Scrub	30	48	65	73
71	Herbaceous	49	62	74	85
81	Hay Pasture	39	61	74	80
82	Cultivated Crops	51	67	76	80
90	Woody Wetlands	72	80	87	93
95	Emergent Herbaceous Wetlands	72	80	87	93

Boundary Condition Setup

Using HEC-RAS 6.3.1 RoM modeling requires a 2D computational mesh boundary and often requires defining inflow boundary conditions and application of RoM precipitation. A spatially varied precipitation input was applied to each model 2D mesh as a meteorological variable. Models that have contributing drainage from upstream areas used inflow hydrograph boundary conditions. These inflow hydrographs are the results of the upstream 2D model to ensure continuity between models. The HEC-RAS models include a 1,000-foot buffer around each model boundary with further buffer distances at flow transition locations to increase the overlap between models. Including model boundary buffers helps to improve hydraulic routing and model tie-ins. The summary of the boundary conditions is shown in Table 8.

Table 8: Summary of Boundary Conditions

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

Outflow Boundary Conditions

Outflow boundary conditions (from the computational 2D mesh) were used along model boundaries. Unique outflow boundaries were established for obvious riverine outflows, while the remaining boundaries were defined as continuous boundaries to allow drainage to adjacent basins to leave the model area freely. Normal depth was used for all non-unique outflow boundary conditions using approximate energy grade-line slopes estimated from the LiDAR terrain data.

Inflow Hydrograph Boundary Conditions

A coupled pluvial fluvial approach was used in this project. The upstream modelers were tasked with furnishing the inflow hydrograph data for the designated work area and maintained seamless coordination with the downstream modeler. These inflow hydrograph serve as the basis for capturing all contributing drainage area upstream of the models.

The Turtle Creek – Guadalupe River (UPGU2) model utilized one flow hydrograph from the Headwaters Guadalupe River (UPGU1) model as shown in Figure 8.

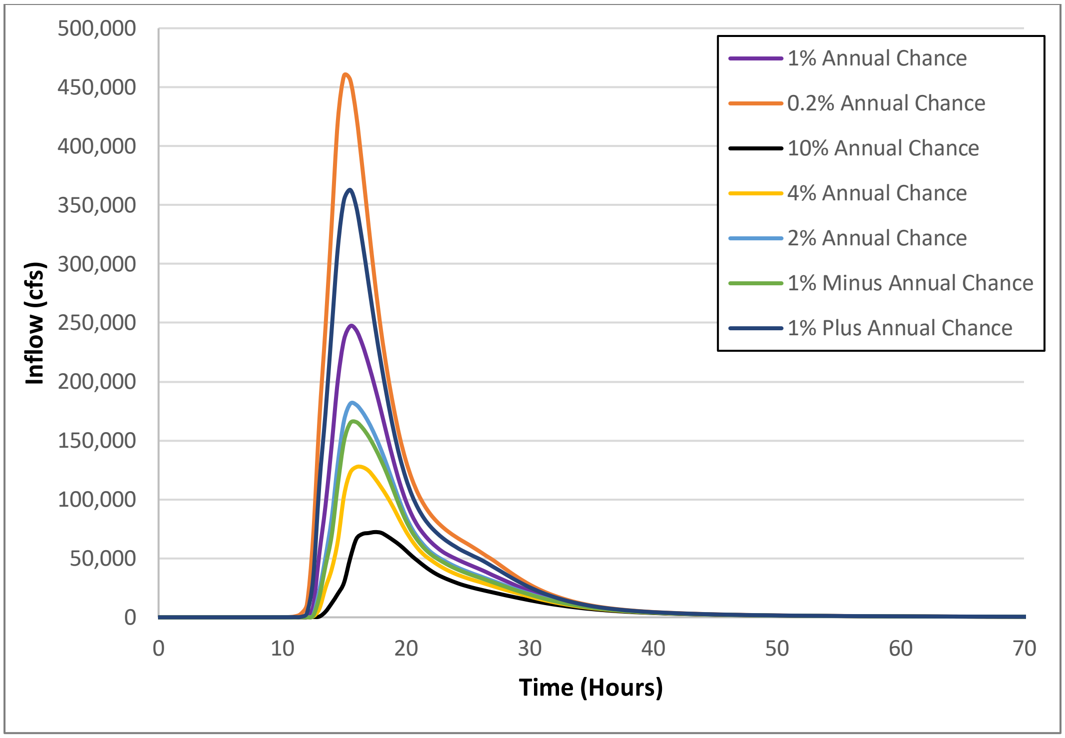

Figure 8: Turtle Creek – Guadalupe River (UPGU2) Inflow Hydrograph from Headwaters Guadalupe River (UPGU1)

The Block Creek – Guadalupe River (UPGU3) model use one flow hydrograph from the Turtle Creek – Guadalupe River (UPGU2) model as shown in Figure 9.

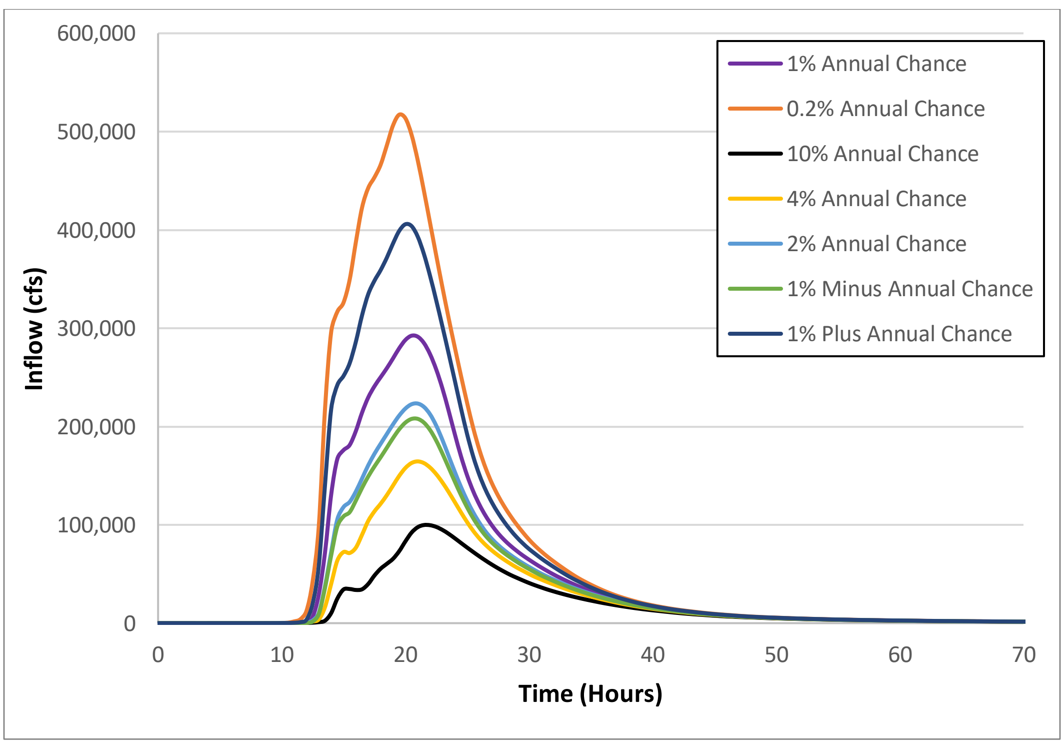

Figure 9: Block Creek – Guadalupe River (UPGU3) Inflow Hydrograph from Turtle Creek – Guadalupe River (UPGU2)

The Guadalupe River – Canyon Lake (UPGU4) model uses one flow hydrograph from the Block Creek – Guadalupe River (UPGU3) model as shown in Figure 10:

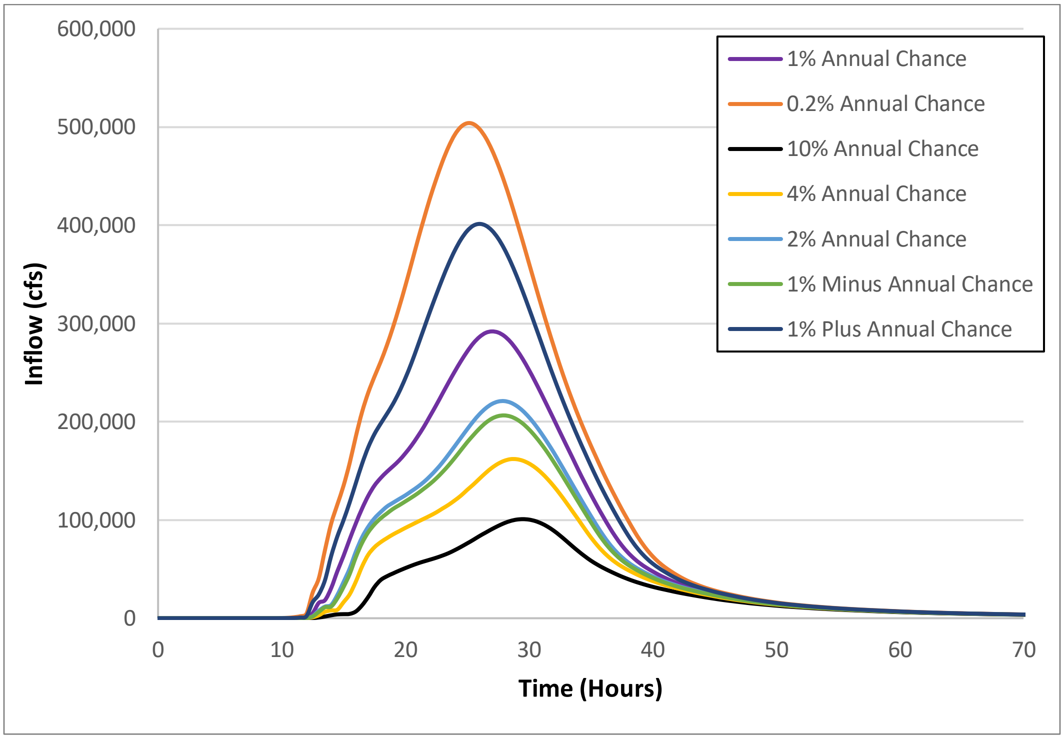

Figure 10: Guadalupe River – Canyon Lake (UPGU4) Inflow Hydrograph from Block Creek- Guadalupe River (UPGU3)

Gage Analysis

Due to the detailed HEC-HMS modeling methods of the 2019 InFRM Watershed Hydrology Assessment for the Guadalupe River Basin study, peak flow estimates at stream gages were prioritized from the InFRM study over the USGS streamflow gage data estimates. Table 6 outlines the data associated with these gages. Other gages were not utilized in this study due to the minimal years of record and the date of the records.

Table 9: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
08167000	Guadalupe Rv at Comfort, TX	839	1869-2021
08165500	Guadalupe Rv at Hunt, TX	288	1932-2021
08166200	Guadalupe Rv at Kerrville, TX	510	1932-2021
08167500	Guadalupe Rv nr Spring Branch, TX	1,315	1869-2021
08166000	Johnson Ck nr Ingram, TX	114	1932-2022
08165300	N Fk Guadalupe Rv nr Hunt, TX	169	1932-2021

Annual chance peak flows were calculated at each gage using USGS Bulletin 17C methodology. The 54% 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 10 for each gage utilized in this study.

Table 10: USGS Peak Streamflow Gage Analysis Results

Gage ID	Flooding Source and Location	1% Peak Q (cfs)	1%- Peak Q (cfs)	1%+ Peak Q (cfs)
08167000	Guadalupe Rv at Comfort, TX	263,900	159,786	435,852
08165500	Guadalupe Rv at Hunt, TX	167,400	101,357	276,475
08166200	Guadalupe Rv at Kerrville, TX	215,300	130,360	355,585
08167500	Guadalupe Rv nr Spring Branch, TX	235,800	142,772	389,442
08166000	Johnson Ck nr Ingram, TX	105,200	63,697	173,746
08165300	N Fk Guadalupe Rv nr Hunt, TX	107,800	65,271	178,040

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 11: 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	0.050	0.035	Calenda, et al. 2005
Developed, Low Intensity	0.080	0.035	Calenda, et al. 2005
Developed, Medium Intensity	0.100	0.035	Calenda, et al. 2005
Developed, High Intensity	0.150	0.040	Calenda, et al. 2005
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.

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 terrain modifications were used 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.

Dams with the purpose of flood risk reduction were modeled as showing protection with a breakline placed on top of the dam. Dams where flood risk reduction was not the purpose of the structure had a breakline placed along the top of terrain crest and a terrain modification was used to allow flow to continue downstream. These dams were identified using the US Army Corps of Engineers National Inventory of Dams (NID). No FEMA accredited levees are present within this watershed.

A breakline was enforced along the FEMA accredited levee, Kerrville Reuse Pond. This levee was shown as providing protection along the left overbank of Third Creek.

An internal connection was enforced along the Canyon Dam along the Guadalupe River. A rating curve was applied to simulate the discharge from the spillway and outlet structure of the reservoir. This discharge-elevation release rating curve was based on the 2019 InFRM study and the Canyon Lake Water Control Manual. The rating curve is shown below in Figure 11.

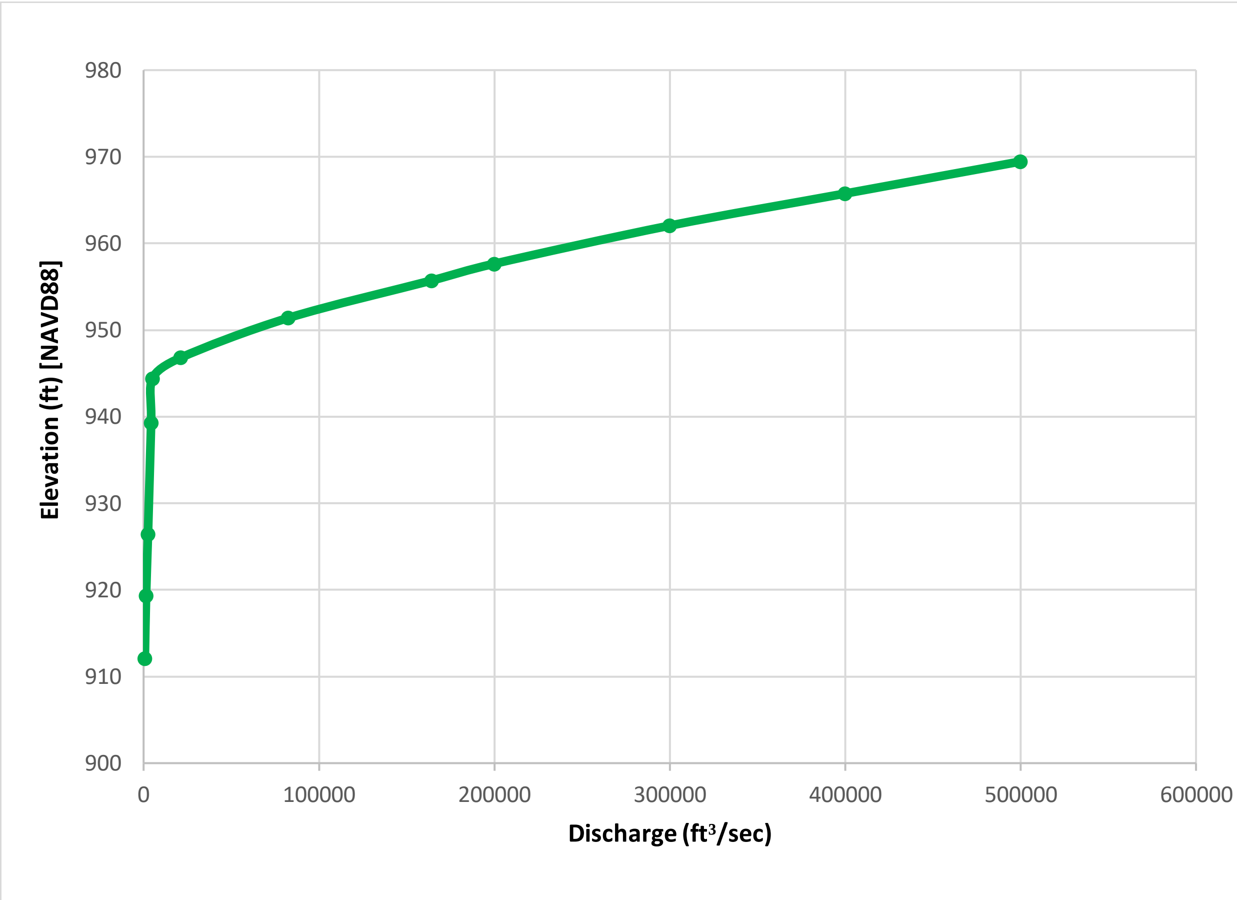

Figure 11: Canyon Lake Rating Curve

In accordance with the Canyon Lake Water Control Manual, the dam features two gates that open when the stage headwater reaches 911' [NAVD88] and close when the stage headwater reaches 943' [NAVD88]. Moreover, the total gate flow for the Canyon Lake Dam is capped at 5000 ft^3/s. To incorporate these specifications into the dam modeling, Rules were employed as a boundary condition for the internal connection within HEC-RAS 6.3.1. The user-defined Gate Performance Curve, which governs the flow through the gates, is shown in Figure 14 below.

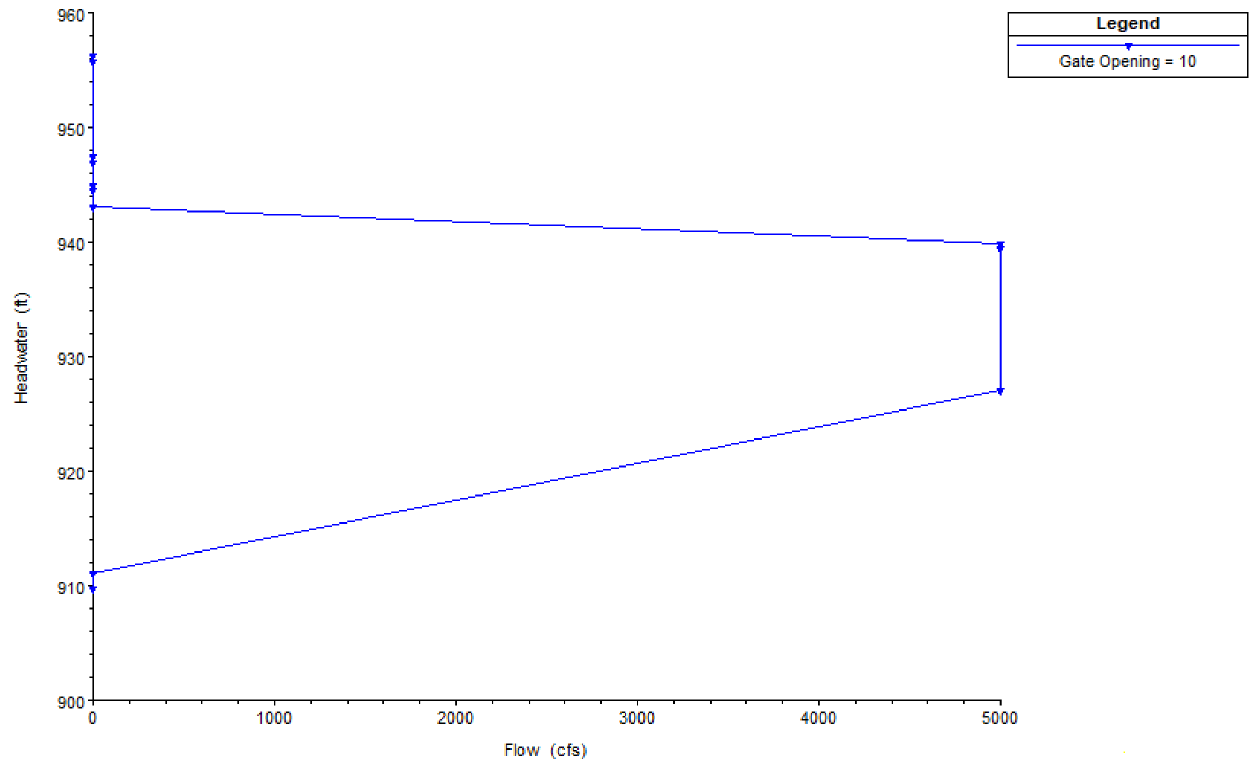

Figure 12: User Defined Gate Performance Curve

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.

Peak flows within the model were calibrated with the results from the 2019 InFRM Watershed Hydrology Assessment Study for the Guadalupe River Basin and the 1D BLE Upper Guadalupe watershed study performed by Compass for Region VI in 2016. The 2019 InFRM study assessed results using the following methods: HEC-HMS NOAA Atlas 14 Uniform Rainfall, HEC-HMS NOAA Atlas 14 Elliptical Storms, and the Canyon Dam Reservoir Study. The 2016 Compass BLE study applied a multiplier to the regression equations based on taking the average of the differences between log10 of the gage discharge estimates and the regression discharge estimates for 19 stream gages within the Guadalupe River basin. This average difference was then added to the log10 of the regression discharge estimate, or equivalently, the average difference is converted back to the arithmetic space and used as a simple multiplier adjustment factor on the computer regression discharge. Therefore, before using regression equations to calibrate this study, the regression equation multiplier was re-assessed. The results of the re-assessment showed that the multiplier did not need to be updated and a multiplier of 1.564 was applied to all regression equation 1%

flows to calibrate this study. Several other locations were selected throughout each model area to compare model flows. Final results of the flow comparisons are presented in Table 12.

Table 12: Model Calibration Results

Work Area	Calibration Location	Drainage Area (mi^2)	Lower Limit (cfs)	Q1% (cfs)	Upper Limit (cfs)	2D Model flow (cfs)	Calibration Source
Headwaters Guadalupe River (UPGU1)	Guadalupe Rv at Hunt, TX (USGS)	286.6	101,357	167,400	276,475	165,953	InFRM
	Johnson Ck nr Ingram, TX (USGS)	113.5	63,697	105,200	173,746	98,658	InFRM
	N Fk Guadalupe Rv nr Hunt, TX (USGS)	168.2	65,271	107,800	178,040	103,003	InFRM
	Johnson Creek above Guadalupe River	126.8	66,179	109,300	180,518	100,229	InFRM
	Guadalupe River above Johnson Creek	311.4	98,875	163,300	269,703	171,237	InFRM
	North Fork Guadalupe River above South Fork Guadalupe River	189.2	66,966	110,600	182,665	108,114	InFRM
	South Fork Guadalupe River	97.5	36,924	60,983	100,719	77,114	InFRM
	Johnson Creek	48.0	27,411	54,685	109,096	54,790	Regression Equations
	South Fork Guadalupe River	52.1	23,811	47,504	94,770	46,293	Regression Equations
	Guadalupe River	115.1	41,025	81,846	163,282	82,773	Regression Equations
	Stream0095	14.9	9,978	19,907	39,714	17,477	Regression Equations
	Bear Creek 2	32.0	19,917	39,735	79,272	32,269	Regression Equations
	Contrary Creek	10.9	10,487	20,921	41,738	15,297	Regression Equations
	Dry Branch	10.8	11,179	22,302	44,492	16,182	Regression Equations
	Flat Rock Creek_US	21.0	14,247	28,422	56,702	24,532	Regression Equations
	Indian Creek 03	8.1	9,957	19,864	39,630	14,332	Regression Equations
Turtle Creek – Guadalupe River (UPGU2)	Guadalupe River at Kerville, TX (USGS)	485.7	130,360	215,300	355,585	251,289	InFRM
	Guadalupe River below Cypress Creek at Comfort, TX (USGS)	837	159,786	263,900	435,852	292,480	InFRM
	Guadalupe River above Turtle Creek	563.8	135,567	223,900	369,789	259,145	InFRM
	Guadalupe River below Turtle Creek	634.3	152,642	252,100	416,364	275,290	InFRM
	Guadalupe River below Verde Creek	652.4	155,185	256,300	423,300	283,290	InFRM
	Guadalupe River above Verde Creek	708.6	157,062	259,400	428,420	272,386	InFRM
	Goat Creek	19.1	17,648	35,209	70,241	26,882	Regression Equations

Work Area	Calibration Location	Drainage Area (mi^2)	Lower Limit (cfs)	Q1% (cfs)	Upper Limit (cfs)	2D Model flow (cfs)	Calibration Source
	Turtle Creek	70.5	35,306	70,435	140,518	70,132	Regression Equations
	Cypress Creek_US	71.5	33,479	66,791	133,247	90,647	Regression Equations
	Verde Creek	48.7	31,830	63,500	126,683	45,657	Regression Equations
	Turtle Creek	40.3	24,816	49,509	98,769	48,407	Regression Equations
	Third Creek	13.5	14,725	29,376	58,605	20,436	Regression Equations
	Town Creek	22.7	20,302	40,502	80,802	33,504	Regression Equations
	Cypress Creek_US	28.8	21,208	42,309	84,406	52,709	Regression Equations
Block Creek – Guadalupe River (UPGU3)	Guadalupe River above Block Creek	865.1	172,199	284,400	469,710	293,259	InFRM
	Guadalupe River below Block Creek	909.7	157,788	260,600	430,402	298,143	InFRM
	Guadalupe River below Joshua Creek	929.7	156,698	258,800	427,429	299,999	InFRM
	Guadalupe River above Joshua Creek	971.3	157,183	259,600	428,751	296,608	InFRM
	Guadalupe River above Sister Creek	983.9	157,607	260,300	429,907	296,983	InFRM
	Guadalupe River below Sister Creek	1048.2	158,575	261,900	432,549	301,163	InFRM
	West Sister Creek	38.3	22,426	44,739	89,255	63,798	Regression Equations
	Joshua Creek	41.3	24,498	48,873	97,503	67,423	Regression Equations
	Flat Rock Creek	8.6	7,383	14,728	29,383	19,592	Regression Equations
	Block Creek	44.4	21,541	42,974	85,732	70,908	Regression Equations
	Big Joshua Creek	19.3	14,060	28,049	55,958	33,827	Regression Equations
	Wasp Creek	15.1	13,851	27,633	55,128	24,411	Regression Equations
	East Sister Creek	24.9	16,552	33,022	65,879	55,590	Regression Equations
	Block Creek	21.3	14,183	28,296	56,450	45,184	Regression Equations
Guadalupe River – Canyon Lake (UPGU4)	Guadalupe River nr Spring Branch, TX (USGS)	1313.7	142,772	235,800	389,442	287,621	InFRM
	Peak Inflow into Canyon Lake	1431.1	144,528	238,700	394,232	263,035	InFRM
	Guadalupe River above Cypress Creek	763.5	150,280	248,200	409,922	288,793	InFRM
	Guadalupe River above Curry Creek	1197.2	138,473	228,700	377,716	287,574	InFRM
	Guadalupe River below Curry Creek	1266.4	143,680	237,300	391,920	289,436	InFRM
	Curry Creek	69.2	34,701	69,229	138,112	67,234	Regression Equations

Work Area	Calibration Location	Drainage Area (mi^2)	Lower Limit (cfs)	Q1% (cfs)	Upper Limit (cfs)	2D Model flow (cfs)	Calibration Source
	Honey Creek	9.5	9,657	19,267	38,437	16,081	Regression Equations
	Cypress Creek	11.7	9,569	19,090	38,085	14,310	Regression Equations
	Spring Branch	10.8	11,376	22,694	45,275	12,924	Regression Equations
	Walter Creek	6.5	6,509	12,985	25,904	8,309	Regression Equations
	Curry Creek	27.7	18,473	36,853	73,522	42,597	Regression Equations
	Krause Creek	7.5	10,091	20,132	40,163	13,895	Regression Equations
	Swine Creek	10.7	9,866	19,682	39,267	19,672	Regression Equations
	Sheps Creek	8.2	7,810	15,581	31,084	17,709	Regression Equations
	Tom Creek	10.5	8,908	17,771	35,453	19,451	Regression Equations
	Rebecca Creek	13.6	12,129	24,196	48,272	25,832	Regression Equations
	Panther Creek	4.7	5,314	10,601	21,148	8,445	Regression Equations
	Guadalupe River at Sattler	4.0[1]	12,776	21,100	34,848	21,555	InFRM

[1]Drainage area does not include the areas above Canyon Dam

Calibration was also made at the Canyon Lake Reservoir based on the 2019 InFRM study which provided recommended flows and pool elevations for the reservoir. Table 13 below shows the comparison of the model results with the 2019 InFRM study elevations.

Table 13: Canyon Lake Pool Elevation Results

Storm Event	Canyon Lake Pool Elevations 2019 InFRM Study (Feet – NAVD88)	Canyon Lake Pool Elevations 2D Model Results (Feet – NAVD88)
10-year	926.75	920.8
25-year	939.65	930.47
50-year	944.75	938.81
100-year	947.15	947.18
500-year	956.05	958.95

Floodplain Mapping

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

Model Outputs

The floodplains are derived from the raw modeled depth grids using the maximum value. These depth grids are exported from HEC-RAS as TIFF format rasters with an interpolated rendering that slope values at the center and along the faces/edges of the computational mesh cells. Using GIS, the TIFF rasters are post processed into 1% SFHA and 0.2% shaded X polygons.

Methodology

The use of 2D modeling methods results in water surface elevation values at every cell in the model's computational mesh. In order to represent the desired model results and eliminate extraneous disconnected cells, post processing of the depth grids is required. For the purposes of the Upper Guadalupe 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 Upper Guadalupe Watershed.

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

A map showing the BLE results is included as Figure 13.

CNMS Validation of Effective Zone A SFHA

The inventory of Zone A studies (918.47 miles) in the Upper Guadalupe were classified in CNMS with validation status of "UNVERIFIED" (918.47 miles) or "VALID", and with status type of "BEING STUDIED." The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A3 were evaluated for the CNMS inventory of Zone A studies.

Initial Assessment A1 – Significant Topography Update Check

This check involves determining whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. For the three LOMR studies in the watershed, topographic sources that meet SID 43 requirement was used in the effective studies and, therefore, pass this check. For all the other effective studies in the watershed, lower quality topographic sources were used in the effective studies and the topographic sources used in this BLE study are considered significant improvements. Therefore, these streams fail this check.

Initial Assessment A2 – Check for significant hydrology changes

This check involves first determining if regression equations were used for the effective study. Next, it must be determined whether new regression equations have become available from the USGS since the date of the effective Zone A study. If newer regression equations exist for the area of interest, then an engineer must determine whether these regression equations would significantly affect the 1-percent annual chance flow.

For streams in Comal County, regression equations from USGS fact sheet 96-4307 were used. These equations were published in 2001 and new equations were published in 2009 (SIR 2009-5087). All other effective Zone A studies in this watershed did not use regression equations and automatically pass this check.

Initial Assessment A3 – Check for significant development

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

All effective Zone A studies within the watershed are classified as rural or have not had a significant increase in the urban area and, therefore, pass this check.

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

Table 14: Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Pass / Fail	Effective study used high quality topographic data / LiDAR sources available are considered significant improvements from the effective Zone A topographic sources
A2 – Hydrology	Pass/Fail	Regression equations were not used / New equations that create a significant change in BFE are now available
A3 – Development	Pass	Watershed does not meet urban threshold OR has not experienced a significant increase in urbanization

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. The three LOMR studies and studies in Comal County are known to be supported by technical data and pass this check. All other Zone A studies within this watershed are not model-backed studies 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 Salt Fork Arkansas 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 200 feet.

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

Validation Results

All 1,671.7 total miles of available CNMS features representing the effective Zone A studies were categorized as VALID – BEING STUDIED, VALID – NVUE COMPLIANT, ASSESSED – BEING STUDIED, UNVERIFIED – BEING STUDIED or UNVERIFIED – TO BE STUDIED. Total miles in each of these categories are summarized in Table 15 and illustrated in Figure 13 below. Table 16 summarizes the validation results based on the individual HUC 12 watersheds within Upper Guadalupe Watershed.

Table 15: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment/Miles
VALID	NVUE COMPLIANT	49.6	65.2
VALID	BEING STUDIED	75.1	119.3
ASSESSED	BEING STUDIED	673.4	564
UNVERIFIED	BEING STUDIED	863.2	814
UNVERIFIED	TO BE STUDIED	109.1	109.1

Table 16: BLE Comparison Results

HUC 12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	HUC12 ID						
	All Streams	104,107	29,798	74,309	72%	Fail	
Headwaters North Fork Guadalupe River	121002010101	1962	552	1410	72%	Fail	14.00
Boneyard Draw	121002010102	2154	689	1465	68%	Fail	15.99
Upper North Fork Guadalupe River	121002010103	2817	936	1881	67%	Fail	16.61
Middle North Fork Guadalupe River	121002010104	2787	1449	1338	48%	Fail	32.02
Lower North Fork Guadalupe River	121002010105	1058	553	505	48%	Fail	40.90
Upper South Fork Guadalupe River	121002010106	2492	602	1890	76%	Fail	16.68
Lower South Fork Guadalupe River	121002010107	3780	1930	1850	49%	Fail	34.77
Tegener Creek-Guadalupe River	121002010108	2237	915	1322	59%	Fail	32.72
Upper Johnson Creek	121002010109	3108	721	2387	77%	Fail	10.75
Middle Johnson Creek	121002010110	1801	656	1145	64%	Fail	25.52
Lower Johnson creek	121002010111	1755	561	1194	68%	Fail	6.50
Goat Creek-Guadalupe River	121002010201	3484	850	2634	76%	Fail	18.43
Town Creek	121002010202	1038	190	848	82%	Fail	6.13
Quinlan Creek-Guadalupe River	121002010203	3192	473	2719	85%	Pass	6.88
Upper Turtle Creek	121002010204	2066	760	1306	63%	Fail	28.86
Lower Turtle Creek	121002010205	2973	434	2539	85%	Pass	10.71
Steel Creek-Guadalupe River	121002010206	736	151	585	79%	Fail	15.27

Verde Creek	121002010207	3273	551	2722	83%	Fail	13.47
Cherry Creek-Guadalupe River	121002010208	4652	1091	3561	77%	Fail	18.91
Upper Cypress Creek	121002010209	3432	1497	1935	56%	Fail	21.81
Lower Cypress Creek	121002010210	3870	969	2901	75%	Fail	14.01
Block Creek	121002010301	3738	721	3017	81%	Fail	9.69
Flat Rock Creek-Guadalupe River	121002010302	2782	717	2065	74%	Fail	16.27
Joshua Creek-Guadalupe River	121002010303	6403	1941	4462	70%	Fail	21.97
West Sister Creek	121002010304	5262	1488	3774	72%	Fail	14.45
East Sister Creek	121002010305	3261	979	2282	70%	Fail	14.97
Sister Creek-Guadalupe River	121002010306	3871	1888	1983	51%	Fail	29.67
Wasp Creek-Guadalupe River	121002010307	3207	903	2304	72%	Fail	19.44
Goss Creek-Guadalupe River	121002010308	2891	1153	1738	60%	Fail	25.50
Honey Creek-Guadalupe River	121002010401	2235	648	1587	71%	Fail	22.11
Simmons Creek	121002010402	1862	338	1524	82%	Fail	9.08
Curry Creek	121002010403	5346	1245	4101	77%	Fail	11.64
Spring Branch-Guadalupe River	121002010404	3051	525	2526	83%	Fail	13.33
Rebecca Creek-Canyon Lake	121002010405	2596	537	2059	79%	Fail	16.09
Jentsch Creek-Canyon Lake	121002010406	1149	63	1086	95%	Pass	4.39
Tom Creek-Canyon Lake	121002010407	1786	122	1664	93%	Pass	5.31

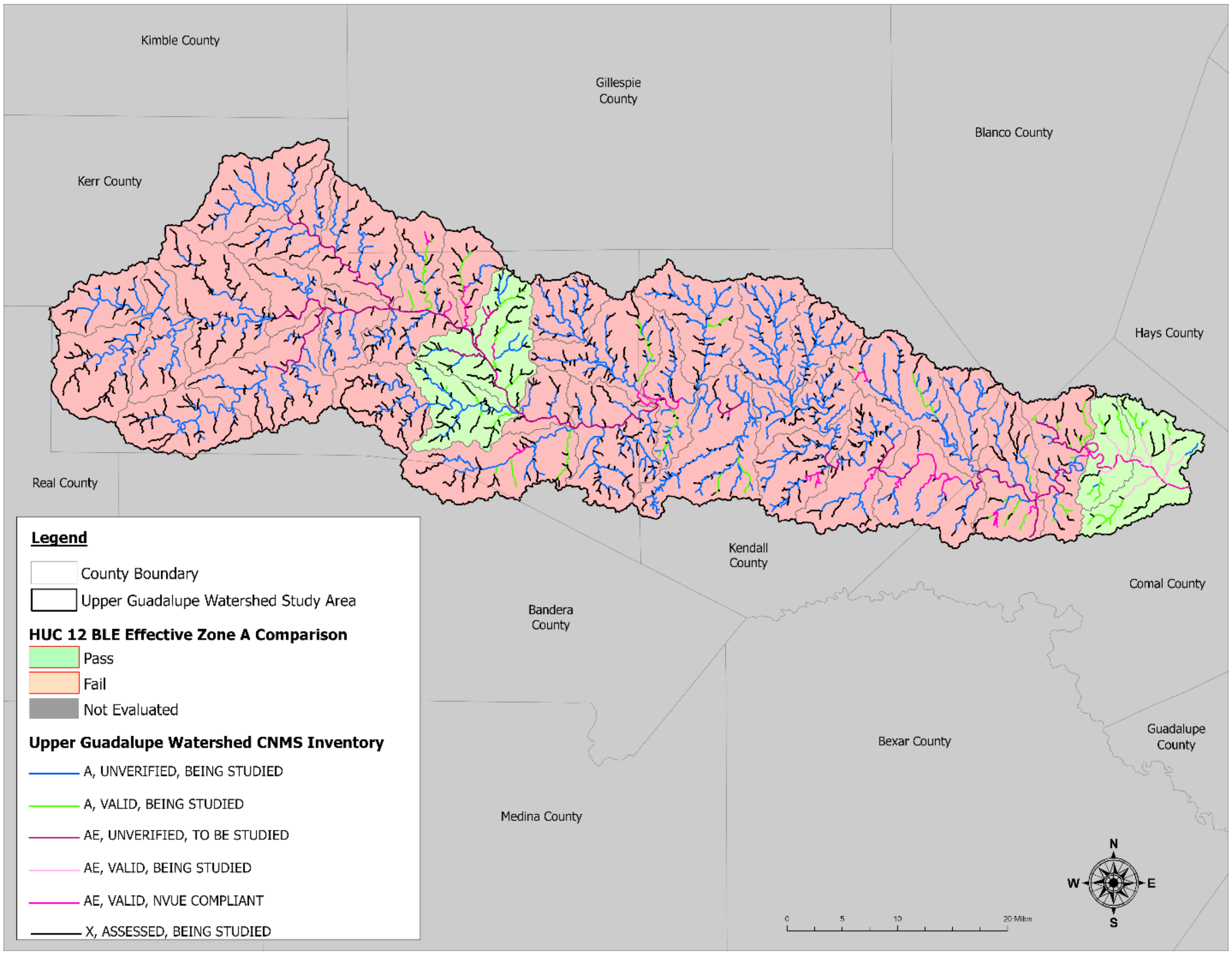

Figure 13: CNMS Validation Results

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 Upper Guadalupe HUC 12 priority scores which can be used to initiate discussions during the Discovery phase. Lower North Fork Guadalupe River HUC 12 was determined to have the highest priority score and the most need while Jentsch Creek-Canyon Lake HUC 12 has the lowest score.

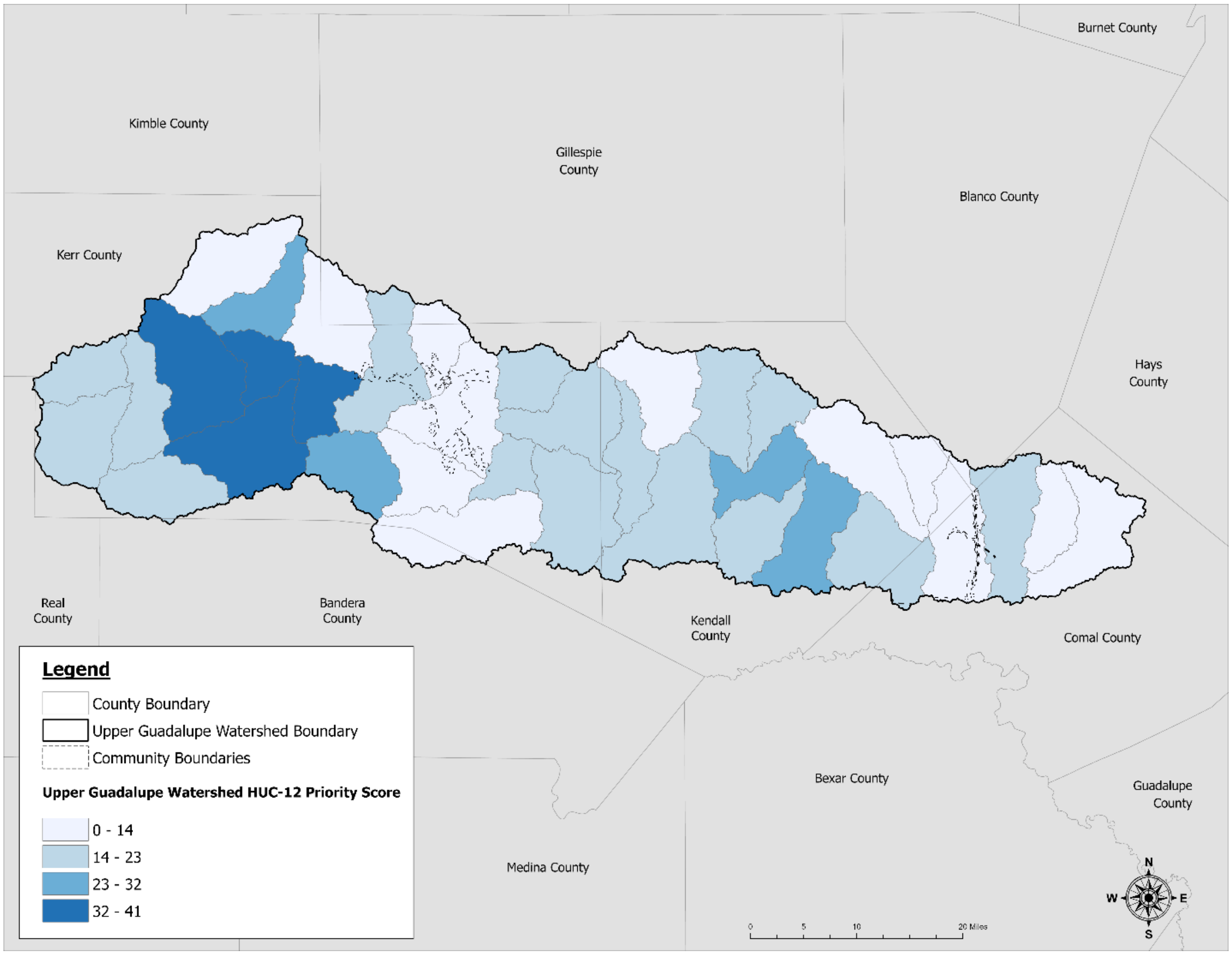

Figure 14: Ranking of Upper Guadalupe Watershed HUC-12s

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 (SP02) was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 6.1 uses dasymetric census blocks. Dasymetric mapping removes undeveloped areas (such as areas covered by other bodies of water, wetlands, or forests) from the census blocks, changing their shape and reducing their size in these areas. For more information on dasymetric data visit FEMA's Media Library for the Hazus-MH Data Inventories: Dasymetric vs. Homogenous, or Hazus 3.0 Dasymetric Data Overview.

Hazus analysis was performed by county within the project watershed extents for the 1-percent annual chance scenario and are shown in Table 17.

Table 17: Hazus 6.1 Results for 1-percent-annual-chance scenario for Upper Guadalupe Watershed, Texas

County	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents	Full Replacement - Total Loss
Bandera	$544,000	$231,008,000	$207,332,000
Blanco	$900,000	$100,005,000	$59,161,000
Comal	$434,880,000	$7,248,507,000	$4,443,863,000
Gillespie	$1,764,000	$224,917,000	$145,436,000
Kendall	$535,814,000	$5,523,465,000	$4,397,381,000
Kerr	$2,810,357,000	$10,533,270,000	$7,950,967,000
Real	$10,000	$46,047,000	$42,435,000
Total	**$3,784,269,000**	**$23,907,219,000**	**$17,246,575,000**

Quality Assurance & Quality Control

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

- Hydrological QC – included checks for Curve Number calculation, input precipitation, flood events, areal reduction factor and human error.
- Hydraulic QC – included checks for 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 Upper Guadalupe, TX Watershed BLE process were uploaded to the FEMA MIP. Items included with this deliverable include:

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

Considerations

Challenges

The Canyon Lake Reservoir was a challenge in achieving water surface elevations and flows consistent with the 2019 InFRM study. In order to model the dam, the spillway was removed from the terrain as HEC-RAS will ignore any weir flow when utilizing the outlet rating curve. A terrain modification was applied to the lake in order to calibrate the model to the water surface elevations suggested in the 2019 InFRM study.

Given that the operation of the gates was contingent upon the pool elevation of the lake, and the flow through the gates was restricted to 5000 ft^3/s, integrating the operational protocols of the dam into the modeling while accurately calibrating the flow and pool elevation to align with the findings of the 2019 InFRM study presented a significant challenge. Also near the Canyon Lake Reservoir, the refinement region for the Canyon Lake census-designated place (CDP) was adjacent to a non-refinement region within the reservoir itself. A non-refinement region was applied within the reservoir due to the lack of change in the terrain. This resulted in some sharp transitions between areas of smaller cells with larger cells.

Structures have not been added to the BLE model despite evidence of cross structures which allow the streams to convey water through numerous structures. In these locations, the model may be overestimating the water surface elevation upstream of the road until the road is overtopped and underestimating the water surface elevation downstream of the road.

Coordination was made between the concurrent Upper Guadalupe and Middle Guadalupe 2D BLE studies to ensure a smooth tie-in for all modeled flooding events. This tie-in occurs just downstream of the Canyon Lake reservoir.

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.

References

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Appendix A – Exhibits – Base Level Engineering Results