Cibolo HUC-8 Watershed, Texas
Base Level Engineering (BLE) Results

MAS No. FY20-CTP-FRP-MAST#2 T.O. No. 8

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Executive Summary

The Texas Water Development Board (TWDB) contracted Halff Associates (Halff) to complete a Base Level Engineering (BLE) analysis for the HUC-8 watershed No. 12100304 – Cibolo in South Central Texas, to support the U.S. Department of Homeland Security's Federal Emergency Management Agency's (FEMA) Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHAs). The BLE process involves using best available data and incorporating automated techniques with standard 2D model development procedures to produce flood hazard boundaries for the 1-percent annual chance event as well as estimates of 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 in Section 1.1.

Precipitation depths for this study were established using NOAA Atlas 14 rainfall. An average precipitation depth was computed for the study area. The Hydrologic Engineering Center's (HEC) Hydrologic Modeling System (HMS) was used to develop a simplified hydrologic model to compute excess rainfall which was then used in a rain-on-grid, 2D hydraulic model using HEC-RAS. This hydraulic model was used to compute flood depths and peak water surface elevations within the study area.

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 ES-1-1 lists the stream miles associated with this validation analysis.

Table ES-1-1: Summary of Stream Miles

Source	Cibolo Stream Miles
CNMS	1,118.9

The full inventory of Zone A studies in the watershed were classified in CNMS. Total miles validated in CNMS are summarized in Table ES-1-2.

Table ES-1-2: Aggregated Zone A Validation Results

Validation Status	Status Type	Total Miles
Valid	NVUE Compliant	15.6
	Being Studied	279.0
	Being Assessed	125.5
Unverified	To be Studied	102.8
	Being Studied	588.3
Unknown	Being Studied	6.7
Assessed	Being Studied	0.9

01 Introduction

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 called Base Level Engineering (BLE), which can be used to address current program challenges, including the validation of Zone A studies and the availability of flood risk data in the early stages of a flood risk project. The BLE process involves using best available data and incorporating automated techniques with standard 2D model development procedures to produce flood hazard boundaries for the 1-percent annual chance event as well as estimates of flood hazard boundaries for multiple recurrence intervals. The cost for developing the data and estimates resulting from the BLE process are lower than standard flood production costs. The BLE results may be used for eventual production of regulatory and non-regulatory products.

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 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 SID #29 requires that during Discovery, data must be identified that illustrates potential changes in flood elevation and mapping that may result from the proposed project scope. If available data does not clearly illustrate the likely changes, an analysis is required that estimates the likely changes. This data and any associated analyses should be shared, and results should be discussed with stakeholders.

An important goal of the BLE process is the scalability of the results. Scalability means that the results of a BLE analysis can not only be used for CNMS evaluations of Zone A studies but can also be leveraged throughout the Risk Mapping, Assessment and Planning (Risk MAP) program. The data resulting from a BLE analysis 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.

The TWDB contracted Halff to complete a BLE analysis for the Cibolo HUC-8 Watershed (12100304) in South Central Texas to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHA). The study extents include portions of Bandera, Bexar, Comal, Guadalupe, Karnes, Kendall, and Wilson Counties, and include the following communities: The Cities of Boerne, Bulverde, Fair Oaks Ranch, Universal, Live Oak, Schertz, Cibolo, Converse, New Berlin, La Vernia, and Stockdale; as well as the Town of St. Hedwig. The study area consists of four HUC-10 basins: Headwaters Cibolo Creek, Upper Cibolo Creek, Middle Cibolo Creek, and Lower Cibolo Creek. Figure 1.1 shows the location and extent of the Cibolo watershed.

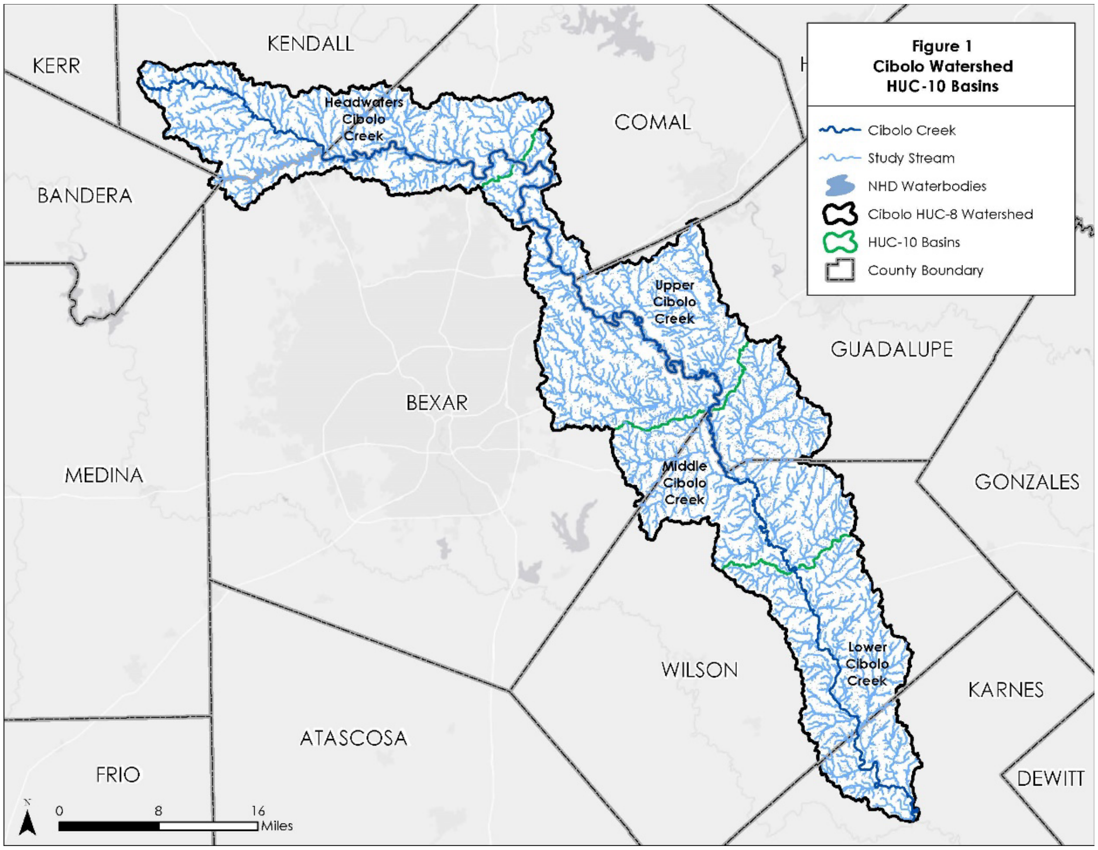

Figure 1.1: Cibolo Watershed

02 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2-dimensional (2D) hydraulic engineering analysis for the Cibolo Watershed. Inputs such as elevation data, hydrology for rain-on-grid and inflow hydrographs, and hydraulic analyses and variables are defined herein. HEC-RAS 5.0.7 rain-on-grid utility was applied in the production of the 2D BLE products produced for this watershed.

2.1 Topographic Data

A high-resolution Digital Elevation Model (DEM) is a fundamental component for two-dimensional engineering analyses by providing a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the Cibolo 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 Cibolo 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 Cibolo Watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Cibolo BLE project footprint. Figure 2.1 depicts the datasets identified for leverage across the project area. FEMA, NOAA, USGS, and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

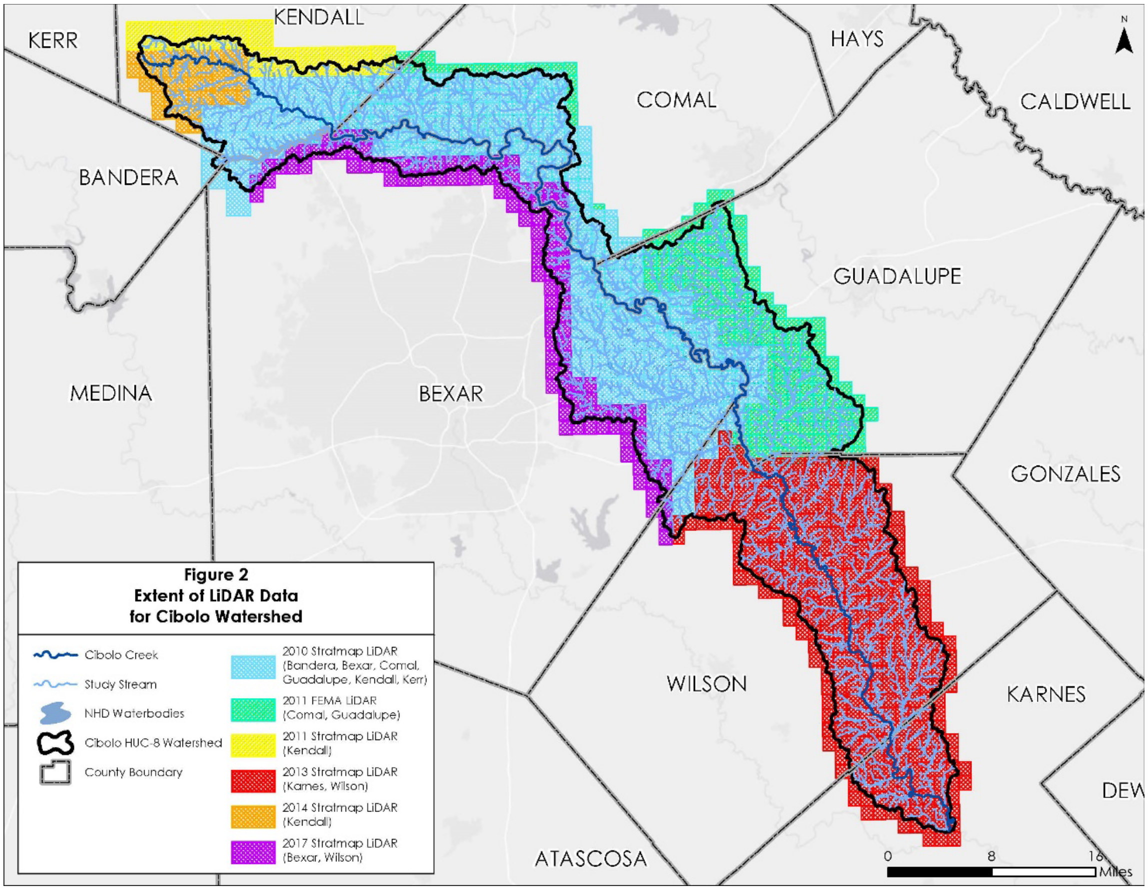

Figure 2.1: Cibolo Watershed BLE Source Terrain Data

2.1.2 Evaluation

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

- Data meet FEMA vertical accuracy standards (Table 2.1)
- Date of origination
- Data density and coverage

Table 2-1 depicts the Risk Map SID #43 vertical accuracy requirements based on flood risk and terrain slope within the floodplain being mapped.

Table 2-1: FEMA Vertical Accuracy Requirements for Leveraged Data

Level of Flood Risk	Typical Slopes	Specification Level	Vertical Accuracy*	LiDAR Nominal Pulse Spacing (NPS)
High (Deciles 1,2,3)	Flattest	Highest	24.5 cm / 36.3 cm	≤ 2 meters
High (Deciles 1,2,3)	Rolling or Hilly	High	49.0 cm / 72.6 cm	≤ 2 meters
High (Deciles 2,3,4,5)	Hilly	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Flattest	High	49.0 cm / 72.6 cm	≤ 2 meters
Medium (Deciles 3,4,5,6,7)	Rolling	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Hilly	Low	147 cm / 218 cm	≤ 5 meters
Low (Deciles 7,8,9,10)	All	Low	147 cm / 218 cm	≤ 5 meters

***Vertical Accuracy at 95% Confidence Level (FVA or NVA)/(CVA or VVA)**

Table 2-2.2 depicts the complete list of source elevation data and attributes leveraged for the Cibolo Watershed BLE project. All datasets used for hydraulic analyses and mapping meet the highest specification level defined in Table 2-1. Further explanation of the Table 2-2 datasets can be referenced in section 2.1.2.1.

Table 2-2: Source Topographic Data Available for the Cibolo Watershed

Year	Description	Data Type	RMSE	Source/Owner
2017	2017 Stratmap LiDAR (Bexar, Wilson)	Airborne LiDAR	6.175 cm	TWDB
2014	2014 Stratmap LiDAR (Kendall)	Airborne LiDAR	8.577 cm	TWDB
2013	2013 Stratmap LiDAR (Karnes, Wilson)	Airborne LiDAR	3.428 cm	TWDB
2011	2011 Stratmap LiDAR (Kendall)	Airborne LiDAR	18.02 cm	TWDB
2011	2011 FEMA LiDAR (Comal, Guadalupe)	Airborne LiDAR	4.08 cm	FEMA
2010	2010 Stratmap LiDAR (Bandera, Bexar, Comal, Guadalupe, Kendall, Kerr)	Airborne LiDAR	0.108m	TWDB

2.1.2.1 Cibolo Watershed Source Terrain Data

The source elevation data for the Cibolo Watershed are DEMs derived from 2010 TWDB and 2011 FEMA LiDAR data. Preprocessed Bare-earth, hydro-enforced DEMs from the acquiring entity (via Texas Natural Resources Information System (TNRIS)) were projected and adjusted as needed into one seamless DEM in Texas State Plane 4204 NAD83, Vertical Feet NAVD88. Bare-earth LIDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the processed LiDAR returns. Please see brief descriptions of the LiDAR sources below.

2011 FEMA LiDAR, Comal, Guadalupe, TX – The 2011 FEMA LiDAR was acquired and processed from November 2010 to September 2011 and collected with a point spacing of 61 cm. Fundamental Vertical Accuracy (FVA) in open terrain was tested and reported at the 95% confidence level, computed as the root mean square error of the checkpoint elevations (RMSEz) x 1.9600 and found as 4.08 cm for open terrain.

2010 Stratmap LiDAR, Bandera, Bexar, Comal, Guadalupe, Kendall, Kerr, TX – The data for the 2010 Stratmap LiDAR was collected with a point spacing of 50 cm. The accuracy assessment results found the RMSE for the data is 0.108m with vertical accuracy at the 95% confidence level equals RMSEZ x 1.9600, which is under the specification of 0.185m.

2.1.3 Data Development Methodology

The source topographic data were processed for an area covering the Cibolo Watershed and contributing drainage areas for the Cibolo BLE modeling efforts. The topographic data for Cibolo Watershed was projected horizontally, as needed, to North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS) Texas S Central in feet (4204-SPC83). All topographic data were adjusted vertically, as needed, to NAVD88 in feet. Halff 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.

2.1.4 DEM QA/QC

DEMs developed for use in the Cibolo Watershed BLE analysis were developed and independently assured to meet quality standards of the project. The data were developed using a controlled process, evaluated, and assured by a topographic data development team and were evaluated and assured by the engineering team. Quality assurance 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 quality control 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

Quality assurance 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 computations.

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

2.2 2D BLE Methods

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.

2.2.1 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 model run times. The 2D mesh for the model was set as evenly spaced cells at approximately 200 feet. The mesh was refined by placing breaklines along roads, berms, ridges, and other high ground that can impede flow as well as stream centerlines to allow flow conveyance. To ensure all adjacent inflows into the Cibolo Watershed were captured, a buffer was added to the HUC boundary.

The HEC-RAS 2D computational mesh was created for the Cibolo Watershed 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 consists of 604,954 cells and a 200-foot nominal mesh cell size; 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. A 20-second time step was used in the HEC-RAS model, applying the Diffusion Wave (simplified Full Momentum) equations.

2.2.2 Model and Boundary Condition Setup

Using HEC-RAS rain-on-grid modeling requires establishing a 2D computational mesh boundary and applies the excess precipitation directly to the mesh. For the Cibolo basin, excess precipitation was applied to the mesh. Figure 2.2 shows the 2D computational mesh for the Cibolo basin, along with USGS peak streamflow gages pertinent to the study. The development of the excess precipitation hyetographs for the 2D mesh, are described in Section 2.2.3.

Outflow boundary conditions (from the computational 2D mesh) were utilized along basin boundaries. Unique outflow boundaries were established for 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 non-unique outflow boundary conditions using approximate energy grade-line slopes estimated from the LiDAR terrain data.

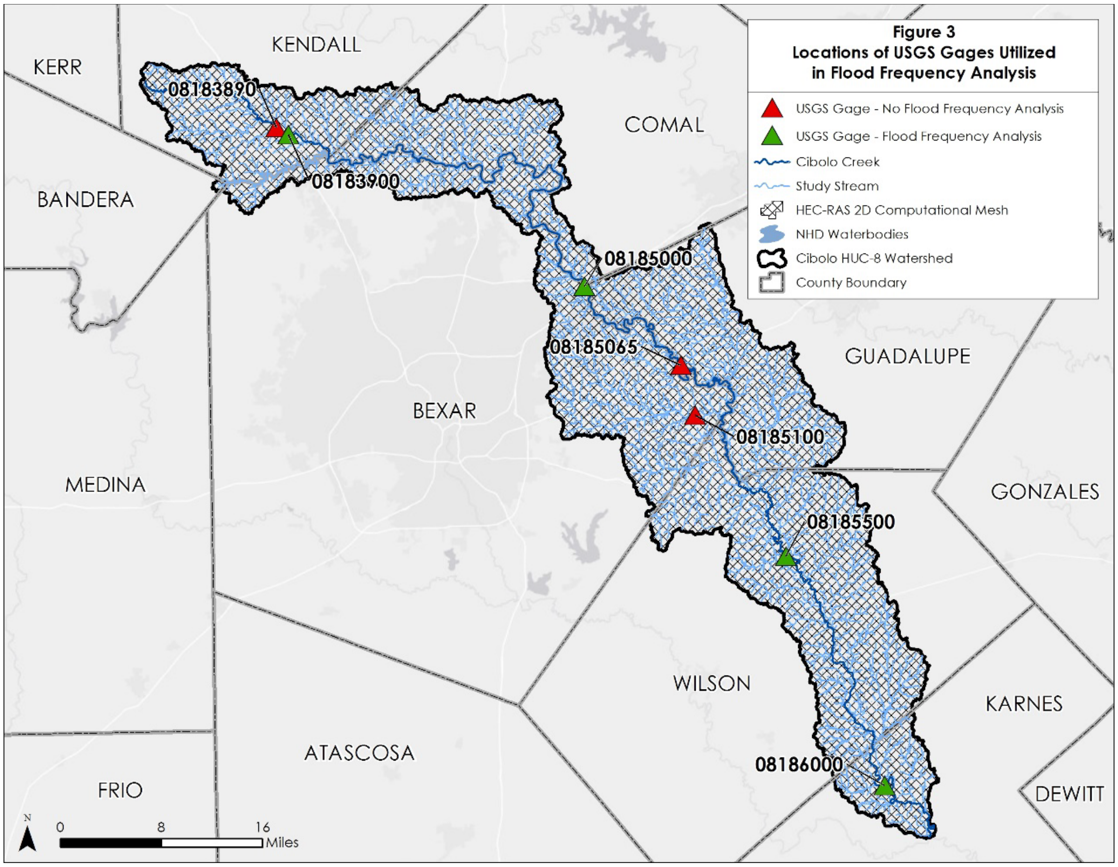

Figure 2.2: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages

2.2.3 Hydrology

HEC-HMS, version 4.3, was used solely for the development of excess precipitation hyetographs which were applied to the 2D mesh. Precipitation frequency data published in NOAA Atlas 14, Volume 11 Version 2.0 (NOAA, 2018) were used for this study. These data were obtained from NOAA's Precipitation Frequency Data Server (PFDS) (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html). The 10-, 4-, 2-, 1-, and 0.2-percent annual chance 24-hour precipitation depths for the watershed were determined by area-weighted intersection of gridded PFDS data within the study area.

USGS streamflow gage data were leveraged to estimate peak flows for downstream gages within each work area for calibration purposes, as discussed in Section 2.3.1.1. The gages utilized for this study are presented in Table 2-3.

Table 2-3: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
08183900	Cibolo Ck nr Boerne, TX	69	1977-2019
08185000	Cibolo Ck at Selma, TX	274	1976-2019
08185500	Cibolo Ck at Sutherland Springs, TX	665	2000-2020
08186000	Cibolo Ck nr Falls City	827	1930-2020

Annual chance peak flows were calculated at each gage using USGS Bulletin 17B methodology. Calculated discharges for the 1%, 1% plus, and 1% minus events used for comparison of flow validation within the upper and lower confidence intervals are presented in Table 2-4 for each gage utilized in this study.

Table 2-4: USGS Peak Streamflow Gage Analysis Results

Gage ID	Flooding Source and Location	1% Peak Q (cfs)	1%- Peak Q (cfs)	1%+ Peak Q (cfs)
08183900	Cibolo Ck nr Boerne, TX	48,030	22,460	176,500
08185000	Cibolo Ck at Selma, TX	234,900	107,100	621,700
08185500	Cibolo Ck at Sutherland Springs, TX	43,990	22,650	128,200
08186000	Cibolo Creek nr Falls City	47,760	35,330	74,330

2.2.3.1 Excess Precipitation for 2D Computational Mesh

HEC-HMS, Version 4.3, was used to apply the SCS Curve Number method to calculate losses and define excess precipitation for the study watershed. Temporal distributions of point rainfall totals were defined using frequency storm distributions. The plus and minus standard error for the 1-percent annual chance precipitation depths were determined as the upper and lower 84% confidence limits on the nominal 1-percent depth, assuming a normal distribution of the logarithms for the precipitation depths.

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.

Curve Numbers were computed by intersecting the National Land Cover Dataset (NLCD) 2016 coverage and NRCS soils data based on the matrix presented in Table 2-5.

Table 2-5: 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	39	61	74	80
41	Deciduous Forest	30	55	70	77
42	Evergreen Forest	30	55	70	77
43	Mixed Forest	30	55	70	77
52	Shrub Scrub	30	48	65	73
71	Herbaceous	49	62	74	85
81	Hay Pasture	39	61	74	84
82	Cultivated Crops	51	67	76	80
90	Woody Wetlands	72	80	87	93
95	Emergent Herbaceous Wetlands	72	80	87	93

The time of concentration for the study area was approximated as the square root of the drainage area, then multiplied by 0.6 to compute the lag time. The lag time does not impact the excess rainfall hyetograph so it was not necessary to compute a more accurate basin travel time. Table 2-6 shows the curve numbers and lag time values used in this study.

Table 2-6: Rainfall-Runoff Parameters (Curve Number, Lag Time)

Sub-basin Description	CN	Tlag (min)
Cibolo	72	1,052

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including curve numbers for defining rainfall losses and lag time for transforming the runoff temporally. No routing was considered in the rainfall-runoff modeling. Frequency storm distributions were used for defining temporal distributions of point rainfall totals. Areal reduction was applied using TP40 curves and an assumption of storm area equivalent to approximately one half of the total study area. Table 2-7 provides the precipitation totals used for determining excess precipitation.

Table 2-7: 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
Cibolo	6.51	8.43	10.10	12.00	17.80	9.44	14.56

Figure 2.3 shows the hyetographs applied to the 2D computational mesh.

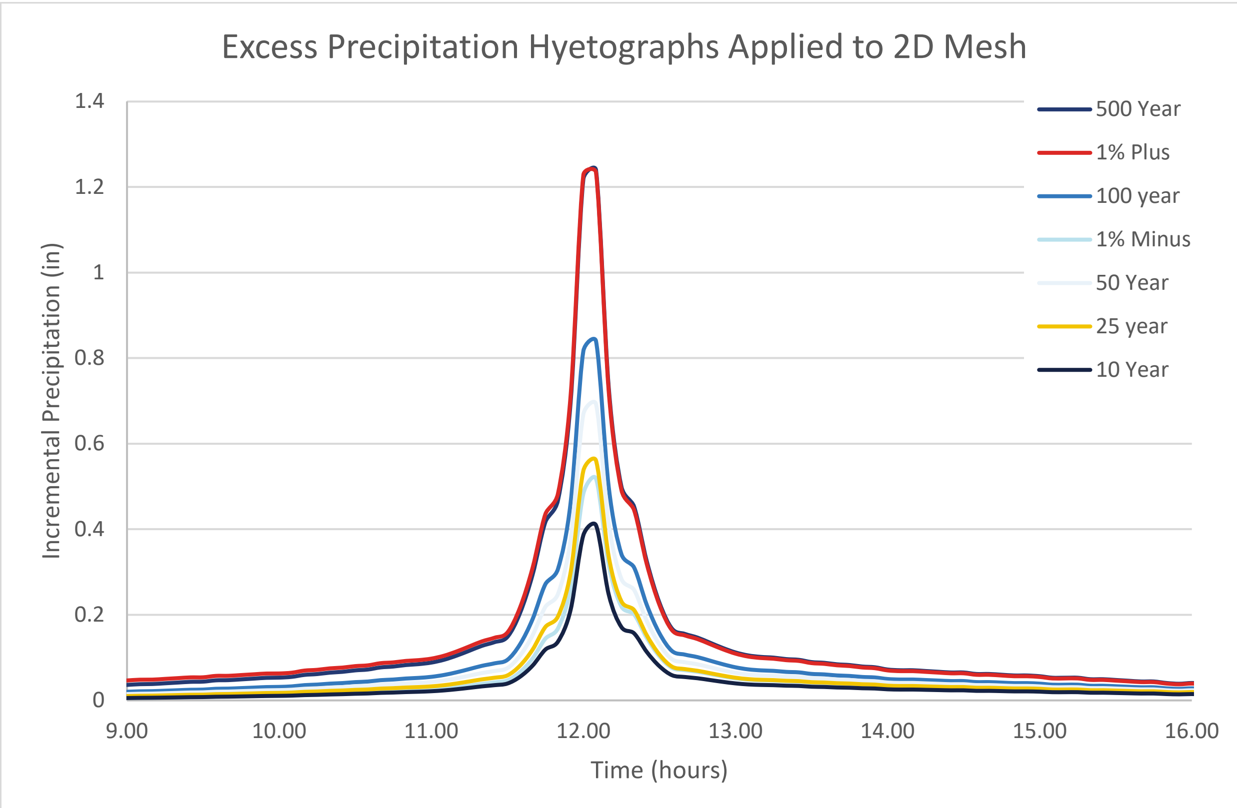

Figure 2.3: Precipitation Hyetographs (post ARF) applied to the Computational Mesh

2.2.3.2 Rainfall-Runoff Hydrograph Boundary Conditions

Inflow hydrographs were not used in the Cibolo 2D BLE Model.

2.2.4 Hydraulics

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

2.2.4.1 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. Different channel buffers were used for main stem channels, mainstem tributaries, and connecting tributaries. The buffers used were 90 feet, 40 feet, and 20 feet, respectively. A channel roughness value of 0.045, taken from the HEC-RAS User's Manual, was applied throughout the buffer to ensure that the 2D cells through the channel area had appropriate conveyance. Table 2-8 shows a typical land use-roughness matrix used in defining the roughness coverage for the study area.

Table 2-8: NLCD 2016-Manning's N Roughness Matrix

NLCD Classification	Recommended	Minimum	Normal	Maximum	Source
Open Water	0.030	0.025	0.030	0.033	Chow 1959
Developed, Open Space	0.050	0.010	0.013	0.016	Calenda, et al. 2005
Developed, Low Intensity	0.070	0.038	0.050	0.063	Calenda, et al. 2005
Developed, Medium Intensity	0. 100	0.056	0.075	0.094	Calenda, et al. 2005
Developed, High Intensity	0.120	0.075	0.100	0.125	Calenda, et al. 2005
Barren Land	0.050	0.025	0.030	0.035	Chow 1959
Deciduous Forest	0.100	0.100	0.120	0.160	Chow 1959
Evergreen Forest	0.100	0.100	0.120	0.160	Chow 1959
Mixed Forest	0.100	0.100	0.120	0.160	Chow 1959
Scrub/Shrub	0.070	0.035	0.050	0.070	Chow 1959
Grassland/Herbaceous	0.050	0.025	0.030	0.035	Chow 1959
Pasture/Hay	0.050	0.030	0.040	0.050	Chow 1959
Cultivated Crops	0.050	0.025	0.035	0.045	Chow 1959
Woody Wetlands	0.100	0.080	0.100	0.120	Chow 1959
Emergent Herbaceous Wetland	0.100	0.075	0.100	0.150	Chow 1959
Main Channel[1]	0.045				HEC-RAS User's Manual

[1] Clean, winding, some pools and shoals, some weeds and stones, lower stages, more ineffective slopes and sections

2.2.4.2 Breaklines

Breaklines align grid cell faces and were used within the 2D mesh area to define prominent features including, road embankments and hydraulic structures 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 were modeled by burning channels through the embankment in the DEM to prevent unnecessary impoundment of water. This approach was used for most hydraulic structures because it could be implemented in ArcGIS on a large scale with much less effort than alternative methods.

Bridge/culvert crossings that were not processed out of the terrain data were modeled by adding v-notches, u-notches, or offset 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. An example of the offset breakline approach is shown in Figure 2.4.

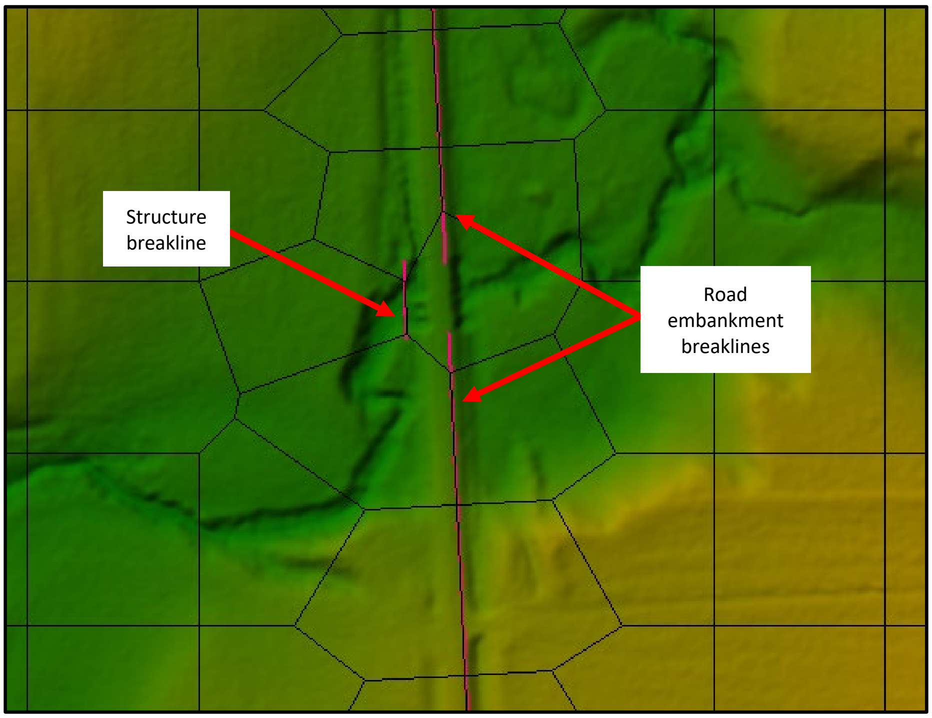

Figure 2.4 : Offset Breakline Approach at Bridge Crossing

County, interstate, common name, state recognized, and U.S. roads were incorporated for road breaklines from the ESRI North America Detailed Streets layer. The stream centerlines were input as breaklines to ensure cells lined up perpendicular to the stream and to capture stream conveyance. Levees from the National Levee Inventory and railroads from the TIGER Railroads layer were also incorporated.

2.2.4.3 Initial Conditions

Initial conditions were not used in the Cibolo 2D BLE model.

2.2.5 Special Assumptions

During model validation, it was determined that Manning's n-values were not representative of existing terrain conditions, with an emphasis on the stream networks. The typical 20-foot channel buffer for application of a channel specific n-value did not appropriately cover the full width of the channels in the watershed, resulting in misrepresented flows due to the poor portrayal of channel roughness conditions. To address this issue, stream centerlines in the Cibolo watershed were rebuffered based on their river system classification. For the main river, represented by Cibolo Creek (flowing left to right) in Figure 2.5 below, a total buffer distance of 90-feet was applied as this was determined to be a reasonable estimation of the channel area. For secondary tributaries, seen below tying into Cibolo Creek, a total buffer distance of 40-ft was used. For tertiary tributaries, a buffer distance of 20-feet was applied, which was consistent with previous BLE recommendations. Applying these buffers allowed for more appropriate application of the channel n-values, seen in Figure 2.6, and allowed flows to converge more closely with provided FIS data.

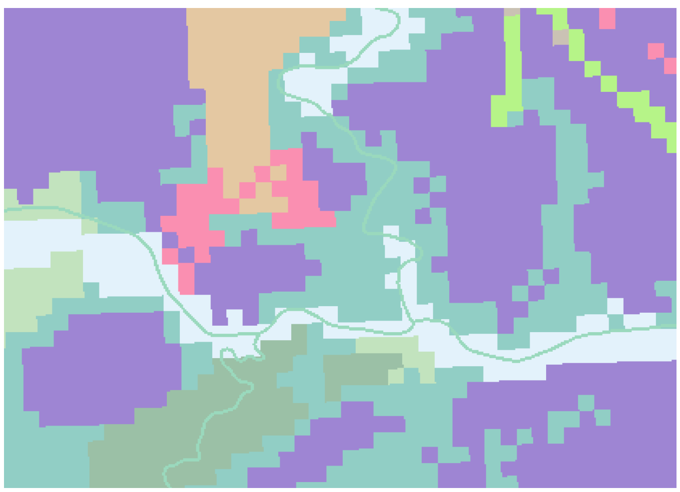

Figure 2.5 : Manning's N-value Layer with Standard BLE Buffer Width of 20-Feet

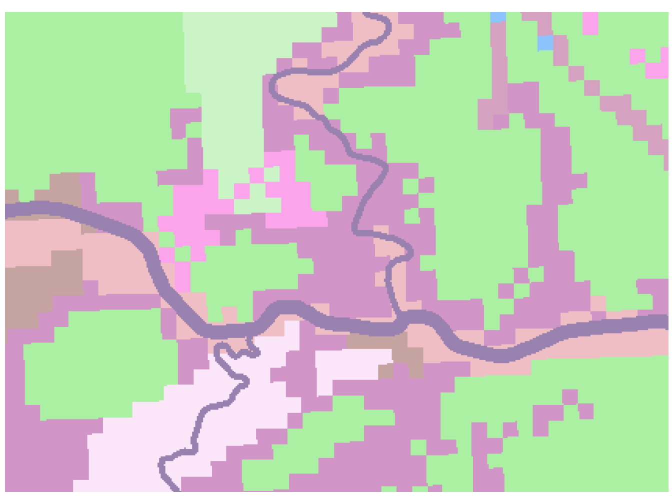

Figure 2.6 : Manning's N-value Layer with Variable Buffer Widths

During model validation and review of the USGS gage data, except for the Selma gage station along Cibolo Creek, concerns about the reliability of the gage data was noted. The most upstream stream gage located in Boerne, Texas had been adjusted in the past and had not captured a representative series of storm events to compare against model results. Additionally, Boerne Lake was newly constructed during the reinstallation of this gage and had changed the flow patterns in the area. USGS gages to the south, primarily in Wilson County, were also determined to provide unreliable data due to modeled behavior of the floodplain. Expansive areas exhibited 2D flow characteristics not adequately measured by stream gages. Figure 2.7 below illustrates the expansive floodplain extents at the Sutherland Springs USGS gage. Additionally, the USGS gage data suggested peak flows decreased while moving downstream through the watershed. Review of the terrain and modeled floodplains did not provide sufficient overland storage to support the reduction in flows experienced in the USGS gages. For these reasons, RAS model flows were compared solely to the FIS data provided for Bexar, Kendall, and Wilson Counties.

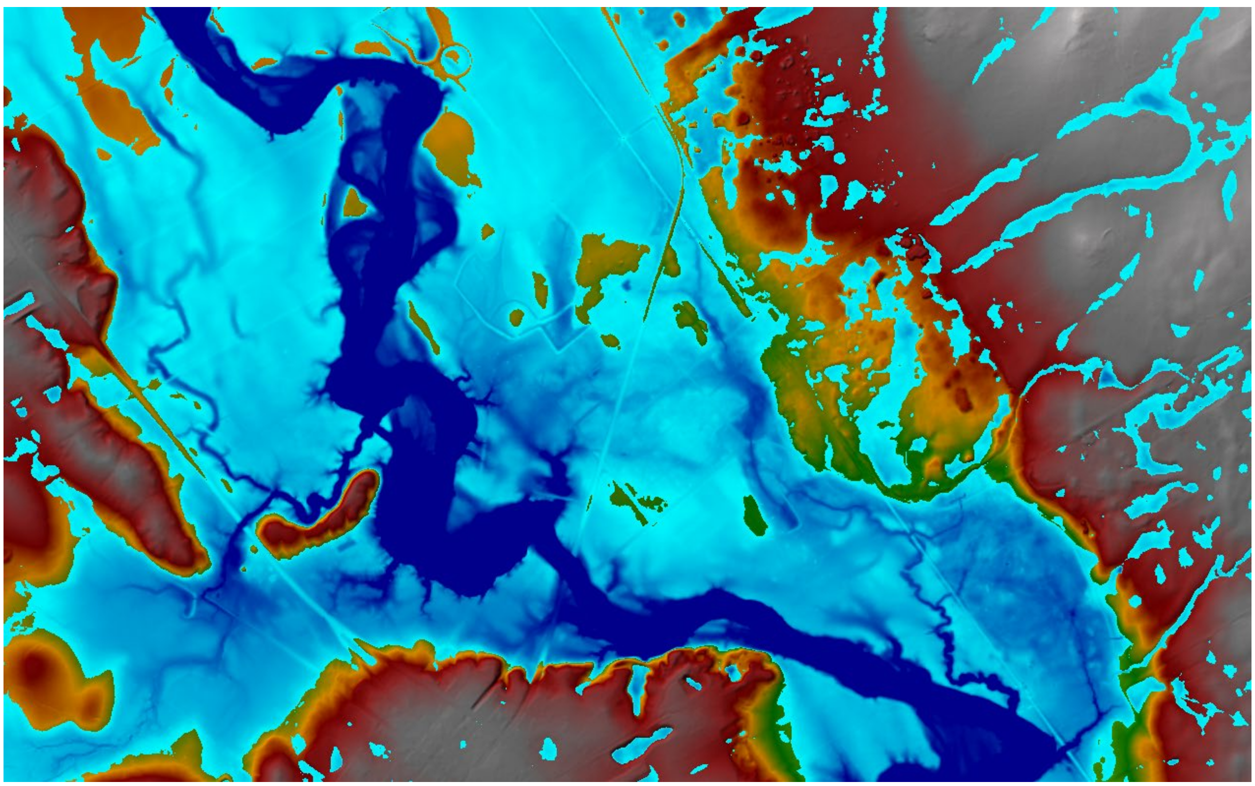

Figure 2.7: Floodplain Extents Near Sutherland Springs USGS Gage

2.3 Model Results

The 2D BLE results for the study produced flood risk mapping that compared reasonably well with the effective SFHA in most cases. The 2D BLE flood risk mapping extends the traditional SFHA due to the nature of the watershed wide approach of rain-on-mesh methodology. Additionally, the application of rain-on-mesh modeling allowed for the identification of localized flood risk beyond the extents of the traditional SFHA. 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 as a regulatory product.

2.3.1.1 Calibration & Sensitivity Analysis

Four USGS gages were identified within the model area having more than 20-years of flow record. Review of the gages and gage analysis results revealed the gages provided poor calibration and validation values for the model results. The four gages and reference flows from Bulletin 17B Analyses and EMA Analyses of the gage data are presented in Table 2-9.

Table 2-9: 1% Annual Chance Reasonability Comparisons

Flooding Source	USGS Gage Used for Verification	Drainage Area (Sq Mi)	HEC-RAS 5.0.7 (2D) Discharge (cfs)	Gage Analysis Reference Discharge (cfs)
Cibolo Creek near Boerne, TX	08183900	68	29,771	62,823
Cibolo Creek at Selma, TX	08185000	274	81,854	199,773
Cibolo Creek at Sutherland Springs, TX	08185500	655	88,808	34,823
Cibolo Creek near Falls City, TX	08186000	827	86,694	46,040

The model results compared to the gage analysis revealed significant differences at all gage locations. For additional comparison with the gage analysis flows, the confidence limits for 0.05 and 0.95 were also calculated to determine if the model discharges fell within the 95% confidence limit range. At each gage location the model results did not fall within the 95% confidence limits. As discussed in the previous section, the gage comparison did not provide a reasonable validation for this model. Each specific gage comparison is briefly reviewed below.

- Cibolo Creek near Boerne, TX – 08183900: The Boerne gage had been relocated after Boerne Lake was constructed and is directly downstream of this control structure. The HEC-SSP analysis was originally conceived to be representative of a rural watershed with no dams, particularly not directly upstream of the gage.
- Cibolo Creek at Selma, TX – 08185000: The results from the gage analysis do not seem reasonable. The gage maximum reported flow rate was 98,100 cfs. This is far below the calculated 199,773 cfs from the 1-percent peak flow from the gage analysis. Additionally, the upstream and downstream results are also significantly lower. There should not be a 300-percent increase from the upstream gage then a drop of 164,950 cfs to the downstream gage.
- Cibolo Creek at Sutherland Springs, TX – 08185500: The results from the gage analysis do not seem reasonable. The gage maximum reported flow rate was 23,800 cfs. This is well below the calculated 34,823 cfs from the 1-percent peak flow from the gage analysis. The 95% confidence

limits for this gage have an extremely wide range indicating a poor quality of analysis for this data set. (87,810 cfs range from upper to lower limit)

- Cibolo Creek near Falls City, TX – 08186000: The results from the gage analysis are somewhat reasonable but lower than anticipated with 827 square miles of watershed contributing to the gage.

This watershed is particularly challenging due to the significant influence from karst features in the upper watershed and the significant sinuosity and storage in the lower watershed. The karst features are inconsistent in their capacity to divert flow into the aquifer. Where lower flow rates can be completely taken up in the karst area, higher flow may bypass or fill the karst features so that there are little recordable losses at the gage locations. Due to these challenges and the poor gage calibration analysis, the current Flood Insurance Study (FIS) flows were used to validate the BLE model. The River Authority has recently updated the Cibolo Creek hydrologic model and these results were used to compare to the BLE model results. The Effective FIS discharges are from the River Authority's Cibolo model dated May 15, 2020. Table 2.10 shows a comparison between existing FIS data and measured discharge points against the model results.

Table 2-10: Effective and Model FIS Discharge Comparison

Stream	Effective FIS Comparison Location	Effective FIS Discharge (cfs)	Model Discharge (cfs)	Difference (%)
Cibolo Creek	At Small Dam (Boerne, TX)	17,303	17,594	1.7
Cibolo Creek	Upstream from Highway 87 Business (Boerne, TX)	17,422	17,874	2.6
Frederick Creek	Downstream of IH-10 Dual Bridges (Boerne, TX)	5,203	5,576	6.9
Cibolo Creek	At School St. (Boerne, TX)	12,567	12,465	-0.8
Cibolo Creek	Upstream of Lewis Creek	78,600	73,701	-6.4
Cibolo Creek	Downstream of Meusebach Creek	72,230	76,416	5.6
Cibolo Creek	Downstream of Balcones Creek	53,270	51,465	-3.4
Cibolo Creek	Approx. 1,500' Downstream of FM 537	71,237	85,521	18.2
Cibolo Creek	Approx. 2,600' Upstream of FM 539	70,265	83,349	17.0

The FIS comparison shows good agreement across the watershed and provides more locations for comparison.

To determine which factors were significantly impacting the model results, a sensitivity analysis was run to evaluate the impact of five parameters including Manning's roughness values, breaklines, hydrologic losses, initial conditions, and boundary conditions. Further discussion of the roughness coefficients can be found in Section 2.2.4.1. It was determined that enforced breaklines at major roads and centerlines were needed and are discussed further in Section 2.2.4.2. No changes were made to the precipitation values. Table 2-11, Table 2-12, Table 2-13, and Table 2-14 summarizes the results of each run at each of the USGS gages.

Table 2-11: Sensitivity Analysis Results at USGS Gage 08183900

Iteration	Manning's N Zones	Breaklines[1]	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)	Volume[2] (ac-ft)
1	Original Land Use	None	Excess Precipitation	Dry / 1 min	Normal Depth	30,046	1,358.81	16,137
2	Original Land Use	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	30,138	1,358.78	16,068
3	2D BLE Land Use	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	29,552	1,358.76	16,024
4	Original Land Use w/ Widened Buffers	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	30,569	1,358.85	16,071
5	2D BLE Land Use w/ Widened Buffers	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	29,771	1,358.75	16,149

[1] All iterations included breaklines for roads and centerlines.
[2] Sensitivity runs were completed to pass the peak flow and elevations, and do not capture the full volume of the hydrograph.
[3] Normal depth boundary conditions used except directly next to inflow boundaries in low lying areas due to the some of the flow immediately leaving the model.
[4] Parameters from Iteration 5 were used for the final model, however additional computational mesh was implemented following the results of the sensitivity analysis.

Table 2-12: Sensitivity Analysis Results at USGS Gage 08185000

Iteration	Manning's N Zones	Breaklines[1]	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)	Volume[2] (ac-ft)
1	Original Land Use	None	Excess Precipitation	Dry / 1 min	Normal Depth	82,302	758.24	92,296
2	Original Land Use	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	85,050	756.94	91,856
3	2D BLE Land Use	Major roads w/	Excess Precipitation	Dry / 1 min	Normal Depth	81,833	758.38	91,744

Iteration	Manning's N Zones	Breaklines[1]	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)	Volume[2] (ac-ft)
		Centerlines Enforced						
4	Original Land Use w/ Widened Buffers	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	85,629	756.97	91,859
5	2D BLE Land Use w/ Widened Buffers	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	81,854	758.30	92,370

[1] All iterations included breaklines for roads and centerlines.
[2] Sensitivity runs were completed to pass the peak flow and elevations and do not capture the full volume of the hydrograph.
[3] Normal depth boundary conditions used except directly next to inflow boundaries in low lying areas due to the some of the flow immediately leaving the model.
[4] Parameters from Iteration 5 were used for the final model, however additional computational mesh was implemented flowing the results of the sensitivity analysis.

Table 2-13: Sensitivity Analysis Results at USGS Gage 08185500

Iteration	Manning's N Zones	Breaklines[1]	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)	Volume[2] (ac-ft)
1	Original Land Use	None	Excess Precipitation	Dry / 1 min	Normal Depth	88,989	421.57	226,059
2	Original Land Use	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	97,493	421.82	223,825
3	2D BLE Land Use	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	88,596	421.83	223,604
4	Original Land Use w/ Widened Buffers	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	97,756	422.73	223,854
5	2D BLE Land Use w/ Widened Buffers	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	88,808	421.56	226,157

[1] All iterations included breaklines for roads and centerlines.
[2] Sensitivity runs were completed to pass the peak flow and elevations and do not capture the full volume of the hydrograph.
[3] Normal depth boundary conditions used except directly next to inflow boundaries in low lying areas due to the some of the flow immediately leaving the model.
[4] Parameters from Iteration 5 were used for the final model, however additional computational mesh was implemented flowing the results of the sensitivity analysis.

Table 2-14: Sensitivity Analysis Results at USGS Gage 08186000

Iteration	Manning's N Zones	Breaklines[1]	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)	Volume[2] (ac-ft)
1	Original Land Use	None	Excess Precipitation	Dry / 1 min	Normal Depth	86,763	306.60	295,675
2	Original Land Use	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	95,479	306.87	291,866
3	2D BLE Land Use	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	86,387	306.58	290,891
4	Original Land Use w/ Widened Buffers	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	95,739	306.87	291,979
5	2D BLE Land Use w/ Widened Buffers	Major roads w/ Centerlines Enforced	Excess Precipitation	Dry / 1 min	Normal Depth	86,694	306.59	295,791

[1] All iterations included breaklines for roads and centerlines.
[2] Sensitivity runs were completed to pass the peak flow and elevations and do not capture the full volume of the hydrograph.
[3] Normal depth boundary conditions used except directly next to inflow boundaries in low lying areas due to the some of the flow immediately leaving the model.
[4] Parameters from Iteration 5 were used for the final model, however additional computational mesh was implemented flowing the results of the sensitivity analysis.

2.4 Challenges

Major challenges in the Cibolo watershed included a lack of confidence in peak streamflow records throughout the HUC, primarily with the USGS gage data. Completing model validation with USGS gage data comparisons alone proved to be inappropriate, which led to further comparisons using FIS data. FIS data in the northern and central portions of the HUC, represented by Bexar and Kendall County, had more recent updates from 2019 and 2020. However, Wilson County, in the southern portions of the watershed had not been updated since 2010, which did not include Atlas-14 rainfall. For these reasons, it is believed that the overestimation of flows in the south, with both USGS and FIS data, is appropriate given the increase in rainfall estimations in the Cibolo models. Simplifications of hydrology and land use also presented challenges as the Cibolo watershed has two distinctly different regions: high ground with distinct channels mainly in the northern half of the watershed and low, flat ground at the southern portion of the watershed. Having different terrain led to the model generally underestimating flows in the northern half, converging more closely towards the center of the basin, and overestimating further downstream. The difference in terrain caused the balance of the time step used to be a factor in model stability. It was determined that a smaller time step of 20 seconds would be needed to stabilize the model in the high ground portion.

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. Storm drain systems were also not included in the BLE model which may impact incoming flows when compared to FIS data.

HEC-RAS, Version 5.0.7 has a known error in the rain on mesh interpolation of flood depths between adjacent cells in the overbank area. This error produces artificially higher depths of flooding on the flood fringe referred to as cupping. Since this is a known issue in HEC-RAS and HEC is working on a solution, effort to remove these errors from the flood extents was not performed. Figure 2.8 below provides an example of cupping for reference. Once a solution is provided by HEC, it may be possible to update mapping to reduce and/or remove the cupping effects on the fringe of the floodplains.

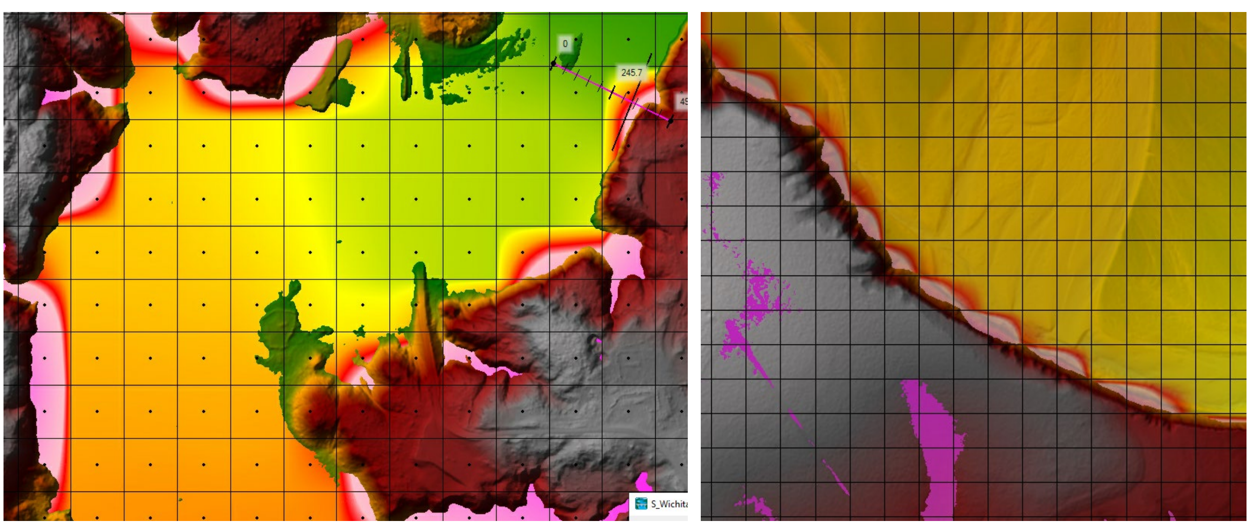

Figure 2.8: Cupping Examples

2.5 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.

03 Floodplain Mapping and Effective Zone A Validation

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. The results of the validation effort can be found below in section 3.2.

3.1 Special Flood Hazard Area

3.1.1 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.

3.1.2 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 Cibolo BLE study, floodplain mapping delineation was completed using connected raster cells at the extent of the CNMS mapped and unmapped features in the project footprint. 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-percent 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 footprint were aggregated with the larger surrounding polygons to merge them and make the floodplain complete. In alignment with the TWDB's 2D BLE Guidelines (May 2022) floodplain polygons were cleaned against the criteria provided below in Table 3.1 which provides thresholds for mapping removal based on depth and area of flood risk.

Table 3.1: Mapping Threshold Matrix

Area (ac)	Depth (ft)
< 0.33	-
0.33 - 0.5	< 0.33
0.5 - 1.0	< 0.25
1.0 - 2.0	<0.1

For example, if flooding polygons were disconnected from a flooding source and less than two acres in area and 0.1 feet of depth, the polygon was removed from the SFHA. These edits align to the mapping standards adopted by the TWDB and those required by FEMA.

In addition to the SFHA, all other flooding associated with the 1- and 0.2-percent raw results were retained as "on the shelf" data that may be leveraged for future needs and analysis. This information is available in the included Supplemental Data associated with this study.

3.1.3 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.

3.2 Validation of Effective Zone A SFHA

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

3.2.1 Initial Assessment A1 – Significant Topography Update Check

The significant topography update check determines whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. For this study area, the best available lidar data was used. Recent quality lidar provided coverage for the entire study area, therefore this check is set to PASS.

3.2.2 Initial Assessment A2 – Check for Significant Hydrology Changes

The significant hydrology changes check determines 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. This element was set to PASS for all reaches within the study area.

3.2.3 Initial Assessment A3 – Check for Significant Development

The significant development check, using the National Urban Change Indicator (NUCI) dataset, assesses increased urbanization in the watershed of the BLE. If the percentage of urban area within the HUC-12 watershed containing the effective Zone A study is 15 percent or more and has increased by 50 percent or more since the effective analysis, the study would fail this check. The check for significant development in the watershed was completed by evaluating percentage of urban change at the HUC-12 level. The majority of this watershed is classified as rural with same pockets of suburban development. All reaches were set to PASS this assessment after a spatial analysis.

Table 3-2 presents the summarized results of checks A1 through A3.

Table 3-2: A1-A3 Validation Results

Assessment Checks	Pass / Fail	Notes
A1 – Topography	Pass	LiDAR significantly better than effective USGS topo source/Effective mapping leveraged LiDAR data.
A2 – Hydrology	Pass	Effective hydrology methods are unknown
A3- Development	Pass/Fail	Less than 15% of study area is under urban cover/>50% increase in urban area in an urban HUC-12

3.2.4 Validation Check A4 – Check of Studies Backed by Technical Data

Zone A studies that pass all initial assessment checks described above may be categorized as “Valid” in the CNMS Inventory only if the effective Zone A study is supported by modeling or sound engineering judgment and all regulatory products are in agreement. If the effective Zone A study passes all initial assessment checks, but is not supported by modeling, or if the original engineering method used is unsupported or undocumented, a comparison of the BLE results and effective Zone A's is performed. While this 2D analysis is backed by technical data, some of the original modeling is lacking documentation. This watershed has varied PASS and FAIL reaches.

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

The effective Zone A comparison was performed at the full extent of the Cibolo Bay 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. A test point was created around the perimeter of the floodplain area every 100'.

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.

3.2.6 Validation Results

All 2,019 total miles of available CNMS features representing the effective Zone A studies were categorized as shown in Table 3-3 and illustrated in Figure 3.1. Table 3-4 summarizes the validation results based on the individual HUC 12 watersheds within the Cibolo Watershed.

Table 3-3: Aggregated Zone A Validation Results

Validation Status	Status Type	Total Miles
Assessed	Being Studied	1,050
Unknown	Being Studied	6
Unverified	Being Studied	509
	To Be Studied	89
Valid	Being Assessed	109
	Being Studied	242
	NVUE Compliant	14

Table 3-4: HUC 12 Zone A Validation Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>90%)
Watershed Name	Watershed Number					
Cibolo	All Streams	**414,804**	**4,245**	**410,559**	**99%**	**Pass**
Alum Creek	121003040305	14,183	26	14,157	**100%**	**Pass**
Balcones Creek-Cibolo Creek	121003040102	29,391	345	29,046	**99%**	**Pass**
Clear Fork-Cibolo Creek	121003040201	17,741	221	17,520	**99%**	**Pass**
Clifton Branch-Cibolo Creek	121003040401	16,267	107	16,160	**99%**	**Pass**
Dietz Creek-Cibolo Creek	121003040202	27,101	206	26,895	**99%**	**Pass**
Dry Hollow Creek-Cibolo Creek	121003040302	19,452	262	19,190	**99%**	**Pass**
Elm Creek	121003040303	23,227	207	23,020	**99%**	**Pass**
Frederick Creek-Cibolo Creek	121003040101	42,938	408	42,530	**99%**	**Pass**
Gum Branch-Cibolo Creek	121003040304	25,757	262	25,495	**99%**	**Pass**
Headwaters Dry Hollow Creek	121003040301	9,492	83	9,409	**99%**	**Pass**
Indian Creek-Cibolo Creek	121003040104	20,521	500	20,021	**98%**	**Pass**
Lewis Creek	121003040105	9,007	95	8,912	**99%**	**Pass**
Lower Santa Clara Creek	121003040204	7,795	85	7,710	**99%**	**Pass**
Martinez Creek-Cibolo Creek	121003040206	19,207	215	18,992	**99%**	**Pass**
Mulifest Creek-Cibolo Creek	121003040405	21,197	145	21,052	**99%**	**Pass**
Pleasant Valley Creek-Cibolo Creek	121003040103	17,216	284	16,932	**98%**	**Pass**
Pulashi Creek-Cibolo Creek	121003040403	10,649	64	10,585	**99%**	**Pass**
Salitrillo Creek-Martinez Creek	121003040205	42,250	578	41,672	**99%**	**Pass**
Town of Denhawken-Dry Creek	121003040404	14,550	50	14,500	**100%**	**Pass**
Upper Santa Clara Creek	121003040203	16,425	74	16,351	**100%**	**Pass**

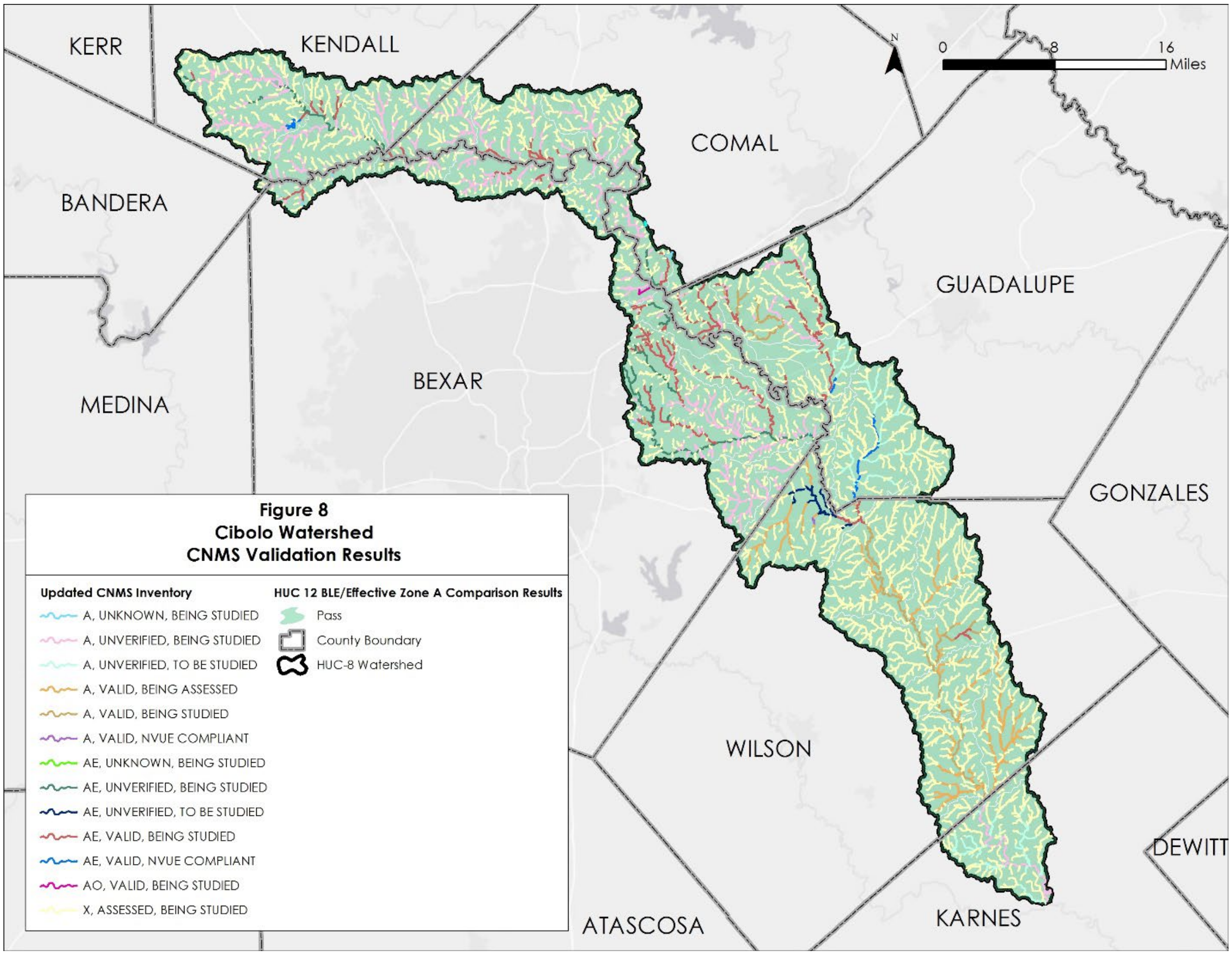

Figure 3.1: Cibolo Watershed CNMS Validation Results

3.3 Flood Risk Analysis

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 4.2 (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 4.2 (SP02) 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 parish within the project watershed extends for each return period to ensure proper model processing. A summary of results per parish for the 100-year scenarios are shown in Table 3-5.

Table 3-5: Hazus 4.2 (SP02) Results for 1-percent-annual-chance (100 year) scenario for Cibolo Watershed, Texas

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Bandera	2	1	1
Bexar	581,158	13,223,994	7,448,119
Comal	131,192	2,428,403	1,404,865
Guadalupe	353,557	5,875,576	3,280,913
Karnes	8,518	54,754	28,372
Kendall	197,401	2,666,379	1,585,034
Wilson	121,142	1,339,200	743,671
Total	**1,392,968**	**25,588,306**	**14,490,974**

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