Upper San Antonio HUC-8 Watershed, Texas
Base Level Engineering (BLE) Results

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

Case No. 22-06-0046S

July 2022

Prepared for:

Federal Emergency Management Agency &
Department of Homeland Security
FEMA Region VI
800 North Loop 288
Denton, TX 76209

Submitted by:

Texas Water Development Board
1700 North Congress Avenue
Austin, TX 78701

Table of Contents

Executive Summary iv

01 Introduction 1-1

02 2D BLE Modeling Inputs and Controls 2-3

2.1 Topographic Data 2-3
2.1.1 Inventory 2-3
2.1.2 Evaluation 2-5
2.1.3 Data Development Methodology 2-7
2.1.4 DEM QA/QC 2-7
2.2 2D BLE Methods 2-8
2.2.1 2D Computational Mesh and Settings 2-8
2.2.2 Model and Boundary Condition Setup 2-8
2.2.3 Hydrology 2-10
2.2.4 Hydraulics 2-14
2.2.5 Special Assumptions 2-16
2.3 Model Results 2-16
2.4 Challenges 2-25
2.5 Recommendations 2-25

03 Floodplain Mapping and Effective Zone A Validation 3-26

3.1 Special Flood Hazard Area 3-26
3.1.1 Model Outputs 3-26
3.1.2 Methodology 3-26
3.1.3 Flood Hazard Area Layer 3-26
3.2 Validation of Effective Zone A SFHA 3-27
3.2.1 Initial Assessment A1 – Significant Topography Update Check 3-27
3.2.2 Initial Assessment A2 – Check for Significant Hydrology Changes 3-27
3.2.3 Initial Assessment A3 – Check for Significant Development 3-27
3.2.4 Validation Check A4 – Check of Studies Backed by Technical Data 3-28
3.2.5 Validation Check A5 – Comparison of BLE and Effective Zone A 3-28
3.2.6 Validation Results 3-28
3.3 Flood Risk Analysis 3-30

04 References 4-32

List of Tables

Table ES-1.1: Summary of Stream Miles iv
Table ES-1.2: Aggregated Zone A Validation Results iv
Table 2.1: FEMA Vertical Accuracy Requirements for Leveraged Data 2-5
Table 2.2: Source Topographic Data Available for the San Antonio Watershed 2-5
Table 2.3: USGS Peak Streamflow Gages 2-10
Table 2.4: USGS Peak Streamflow Gage Analysis Results 2-10
Table 2.5: Land Use-Soils-CN Matrix for Computing Initial Curve Numbers 2-11
Table 2.6: Rainfall-Runoff Parameters (Curve Number, Lag Time) 2-11
Table 2.7: Precipitation Totals for HEC-RAS 2D Computational Mesh (post ARF) 2-12
Table 2.8: NLCD 2016-Manning's N Roughness Matrix 2-14
Table 2.9: Effective and Model Peak Flow Comparison 2-16
Table 2.10: 1% Annual Chance Reasonability Comparisons 2-17
Table 2.11: 1% Annual Chance 95% Confidence Limits of Gage Analysis 2-17
Table 2.12: Sensitivity Analysis Results at USGS Gage 08177700 2-19
Table 2.13: Sensitivity Analysis Results at USGS Gage 08178000 2-20
Table 2.14: Sensitivity Analysis Results at USGS Gage 08178565 2-21
Table 2.15: Sensitivity Analysis Results at USGS Gage 08178700 2-22
Table 2.16: Sensitivity Analysis Results at USGS Gage 08178800 2-23
Table 2.17: Sensitivity Analysis Results at USGS Gage 08181800 2-24
Table 3.1: Mapping Threshold Matrix 3-26
Table 3.2: A1-A3 Validation Results 3-27
Table 3.3: Aggregated Zone A Validation Results 3-28
Table 3.4: HUC 12 Zone A Validation Results 3-29
Table 3.5: Hazus 4.2 (SP02) Results for 1-percent-annual-chance (100 year) scenario for Upper San Antonio Watershed, Texas 3-31

List of Figures

Figure 1-1: Upper San Antonio Watershed 1-2
Figure 2-1: Upper San Antonio Watershed BLE Source Terrain Data 2-4
Figure 2-2: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages 2-9
Figure 2-3: HEC-RAS 2D Computational Mesh and Inflow Boundary Conditions for Medina HUC 2-9
Figure 2-4: Precipitation Hyetographs (post ARF) applied to the Computational Mesh 2-12
Figure 2-5: Medina Basin Contributing Drainage Area Inflow Hydrographs 2-13
Figure 2-6: Offset Breakline Approach at Bridge Crossing 2-15
Figure 2-7: Cupping Examples 2-25
Figure 3-1: Upper San Antonio Watershed CNMS Validation Results 3-30

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. 12100406 – Upper San Antonio 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	Upper San Antonio Stream Miles
CNMS	742.6

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
Assessed	Being Studied	2.6
	Deferred	1.4
Unknown	Being Studied	4.3
Unverified	Being Studied	141.9
	To Be Studied	357.1
Valid	Being Assessed	8.8
	Being Studied	13.3
	NVUE Compliant	213.1

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 Upper San Antonio HUC-8 Watershed (12100406) 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 Bexar and Wilson Counties, and include the following communities: The Cities of San Antonio, Fair Oaks Ranch, Shavano Park, Castle Hills, Windcrest, Kirby, and Elmendorf, the Town of Hollywood Park, and the census-designated places of Scenic Oaks and Timberwood Park. The study area consists of three HUC-10 basins: Headwaters San Antonio River, Calaveras Creek – San Antonio River, and Headwaters Salado Creek. Figure 1-1 shows the location and extent of the Upper San Antonio HUC-8 watershed.

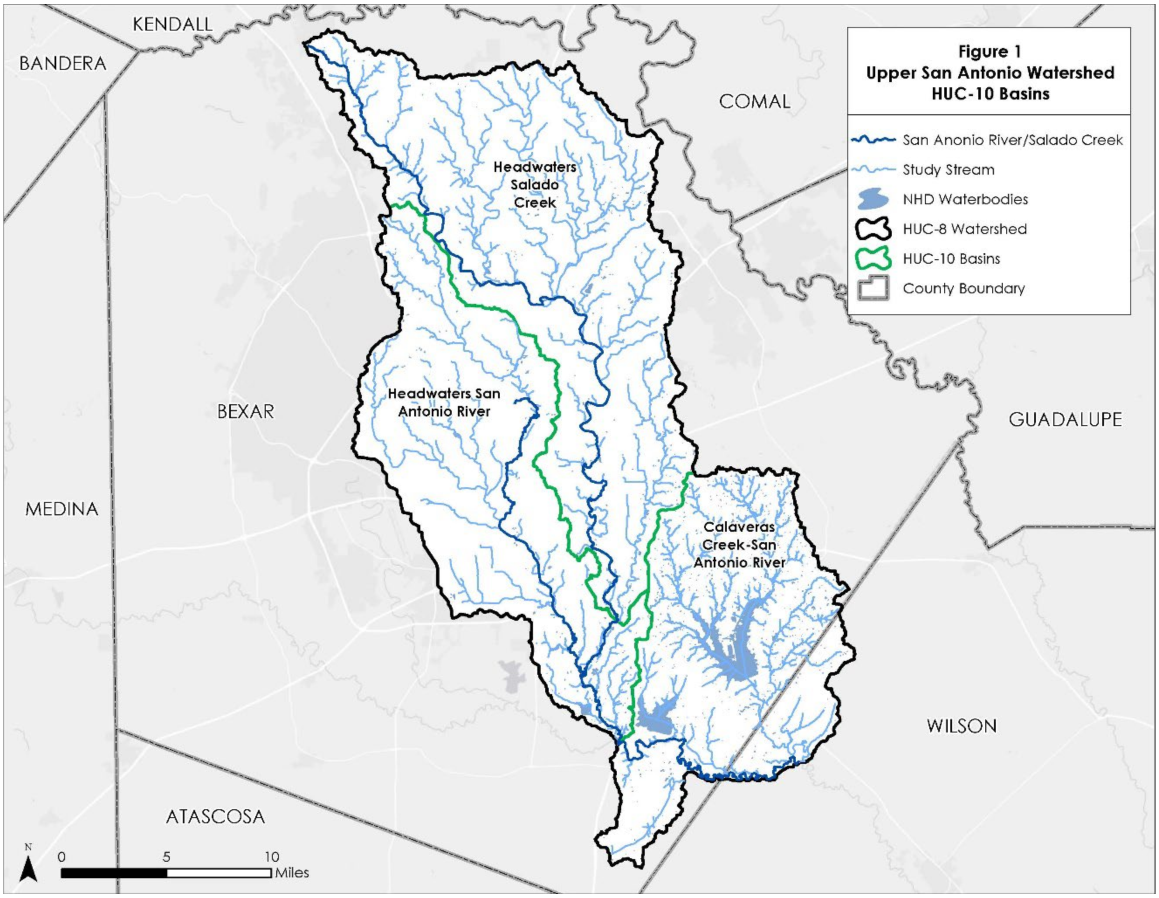


Figure 1-1: Upper San Antonio Watershed

02 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2-dimensional (2D) hydraulic engineering analysis for the Upper San Antonio 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 Upper San Antonio 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 San Antonio 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 San Antonio Watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Upper San Antonio 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.

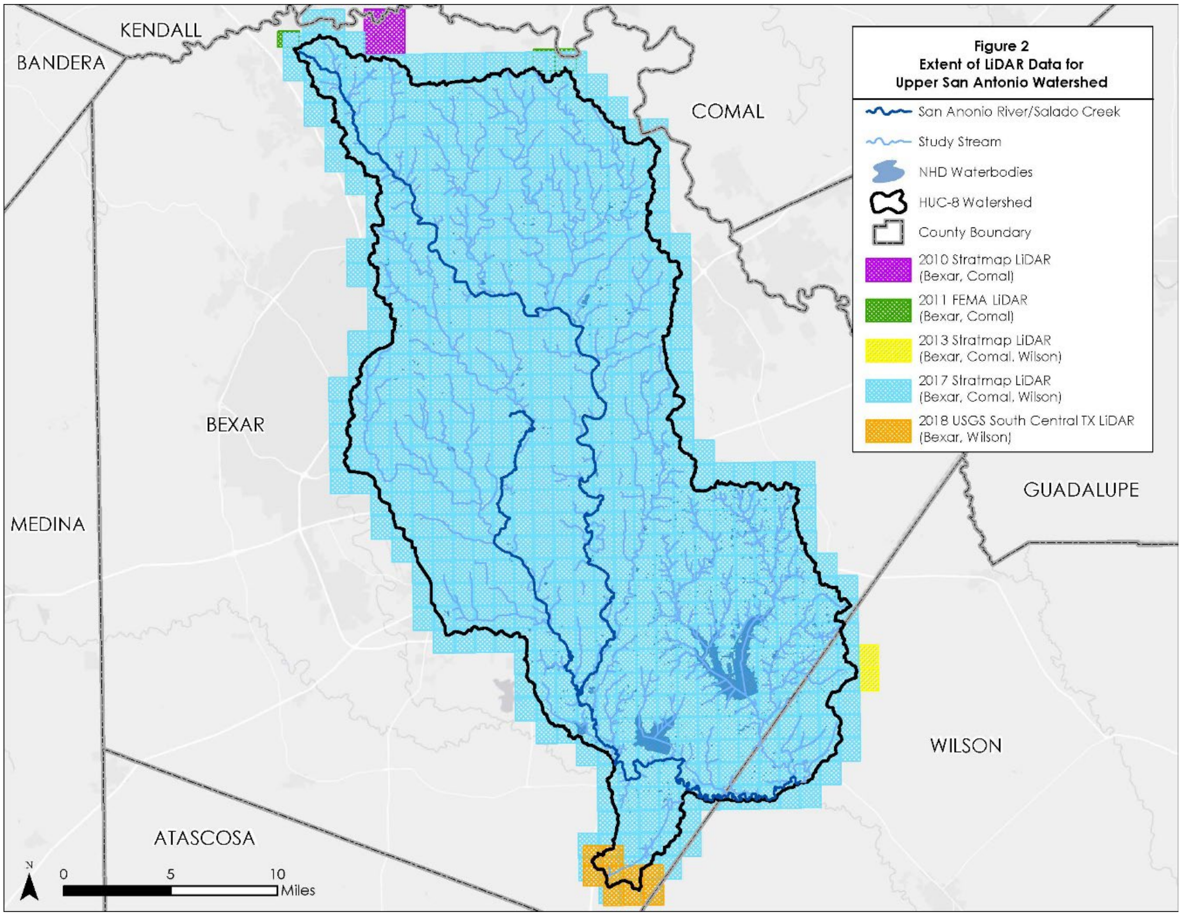


Figure 2-1: Upper San Antonio Watershed BLE Source Terrain Data

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 depicts the complete list of source elevation data and attributes leveraged for the Upper San Antonio 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 San Antonio Watershed

Year	Description	Data Type	RMSE	Source/Owner
2018	2018 USGS South Central TX LiDAR (Bexar, Wilson)	Airborne LiDAR	5.6 cm	USGS
2017	2017 Stratmap LiDAR (Bexar, Comal, Wilson	Airborne LiDAR	6.175 cm	TWDB
2013	2013 Stratmap LiDAR (Bexar, Comal, Wilson)	Airborne LiDAR	3.428 cm	TWDB
2011	2011 FEMA LiDAR (Bexar, Comal)	Airborne LiDAR	4.08 cm	FEMA
2010	2010 Stratmap LiDAR (Bexar, Comal)	Airborne LiDAR	0.108m	TWDB

2.1.2.1 Upper San Antonio Watershed Source Terrain Data

The source elevation data for the Upper San Antonio Watershed are DEMs derived from TWDB (2017 and 2013), USGS (2018) and FEMA (2011) LiDAR data. Preprocessed Bare-earth, hydro-enforced DEMs from the acquiring entity (via 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.

2018 USGS South Central TX LiDAR, Bexar, Wilson – The 2018 USGS LiDAR was acquired in January 2018 and collected with a point spacing of 70 cm. The Non-Vegetated Vertical Accuracy (NVA) was reported as RMSEz = 5.6 cm, equating to +/- 10.9 cm at 95% confidence level which meets project accuracy specifications of the NSSDA.

2017 Stratmap LiDAR Bexar, Comal, Wilson, TX – The data for the 2017 Stratmap LiDAR was acquired from December 2016 to December 2017 and collected with a point spacing of 50 cm. The accuracy assessment results found 6.175 cm vertical accuracy at 95% confidence level in bare earth using RMSEz x 1.96 which meets project accuracy specifications.

2013 Stratmap LiDAR, Dewitt, Karnes, Wilson, TX – The data for the 2013 Stratmap LiDAR was acquired from April 2013 through October 2013 and collected with a point spacing of 50 cm. The bare earth vertical accuracy statistics results found 3.428 cm RMSEz which meets FEMA/NSSDA specifications.

2011 FEMA LiDAR, Bexar, Comal, 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, Bexar, Comal, 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 Upper San Antonio Watershed and contributing drainage areas for the Upper San Antonio BLE modeling efforts. The topographic data for Upper San Antonio 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 Upper San Antonio 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 Upper San Antonio 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 Upper San Antonio Watershed were captured, a variable buffer was added to the HUC boundary.

The HEC-RAS 2D computational mesh was created for the Upper San Antonio 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 1,137,733 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 1-minute 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 often requires defining inflow boundary conditions in addition to excess precipitation applied to the mesh. For the Upper San Antonio basin, an inflow hydrograph from the Medina HUC was used, along with excess precipitation applied to the mesh. Figure 2-2 shows the 2D computational mesh for the Upper San Antonio basin, along with USGS peak streamflow gages pertinent to the study. Figure 2-3 shows the inflow boundary condition location for the Medina basin.

The development of the inflow hydrograph, and excess precipitation hyetographs for the 2D mesh, is described in Section 2.2.3.

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

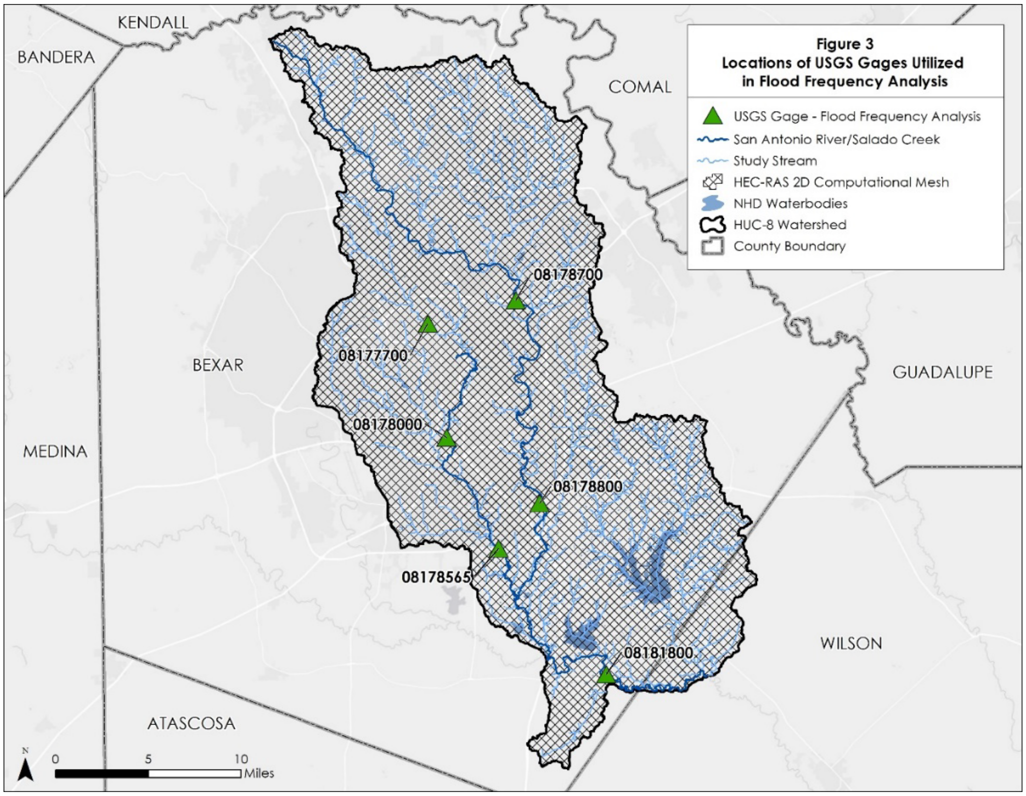


Figure 2-2: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages

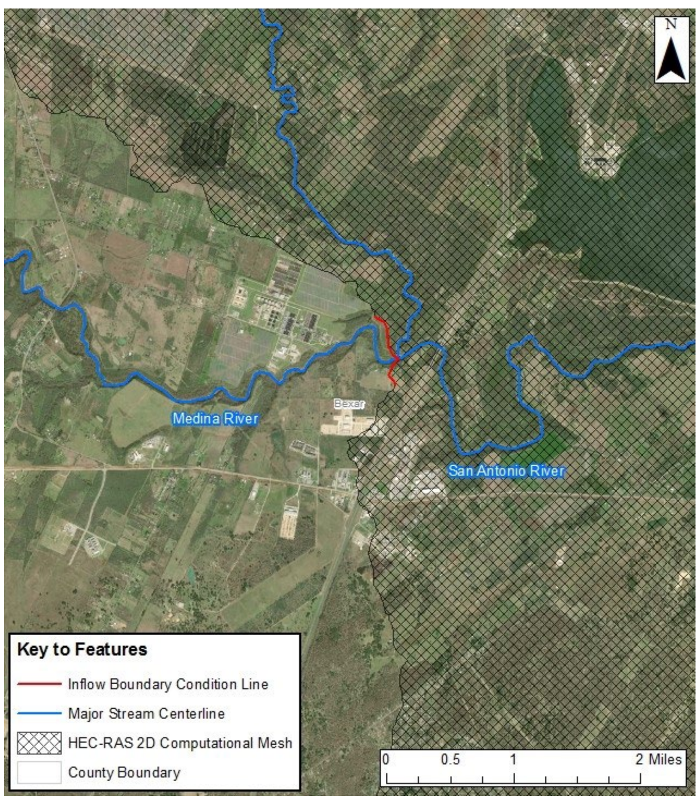


Figure 2-3: HEC-RAS 2D Computational Mesh and Inflow Boundary Conditions for Medina HUC

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. Excess precipitation for the 2D mesh was developed as described in Section 2.2.3.1.

USGS streamflow gage data were leveraged to develop the inflow hydrograph and 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
08177700	Olmos Ck at Dresden Dr, San Antonio, TX	21.2	1947 – 2018
08178000	San Antonio Rv at San Antonio, TX	41.8	1914 – 2019
08178565	San Antonio Rv at Loop 410 at San Antonio, TX	125	1987 – 2019
08178700	Salado Ck at Loop 410 at San Antonio, TX	137	1960 – 2019
08178800	Salado Ck at Loop 13 at San Antonio, TX	189	1960 – 2019
08181800	San Antonio Rv nr Elmendorf, TX	1,743	1963 – 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%-Minus Peak Q (cfs)	1%-Plus Peak Q (cfs)
08177700	Olmos Ck at Dresden Dr, San Antonio, TX	30,160	20,830	49,240
08178000	San Antonio Rv at San Antonio, TX	8,731	7,235	11,030
08178565	San Antonio Rv at Loop 401 at San Antonio, TX	121,200	74,330	332,800
08178700	Salado Ck at Loop 410 at San Antonio, TX	77,480	45,820	154,200
08178800	Salado Ck at Loop 13 at San Antonio, TX	25,930	18,470	40,190
08181800	San Antonio Rv nr Elmendorf, TX	62,090	42,120	116,100

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)
Upper San Antonio	81	803

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
Upper San Antonio	3.80	5.37	6.75	8.38	13.28	6.27	10.53

Figure 2-4 shows the hyetographs applied to the 2D computational mesh.

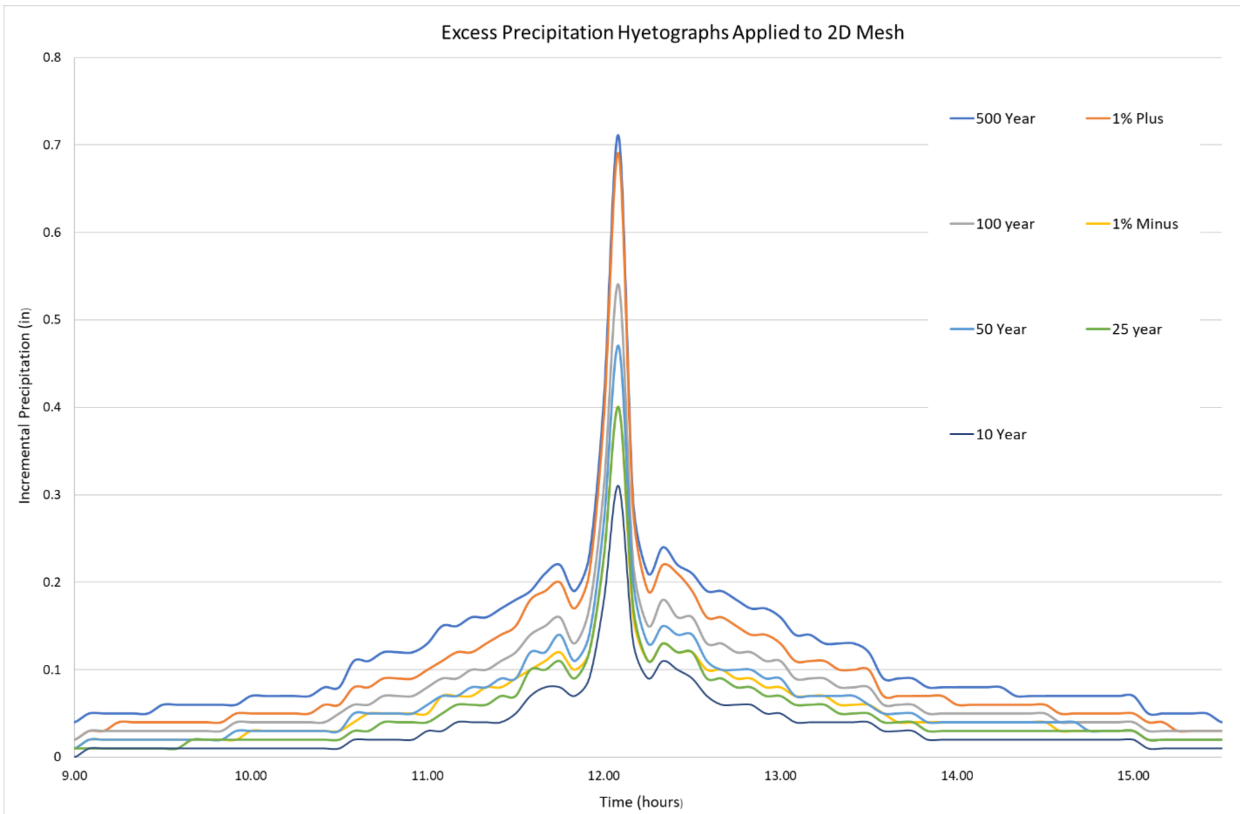
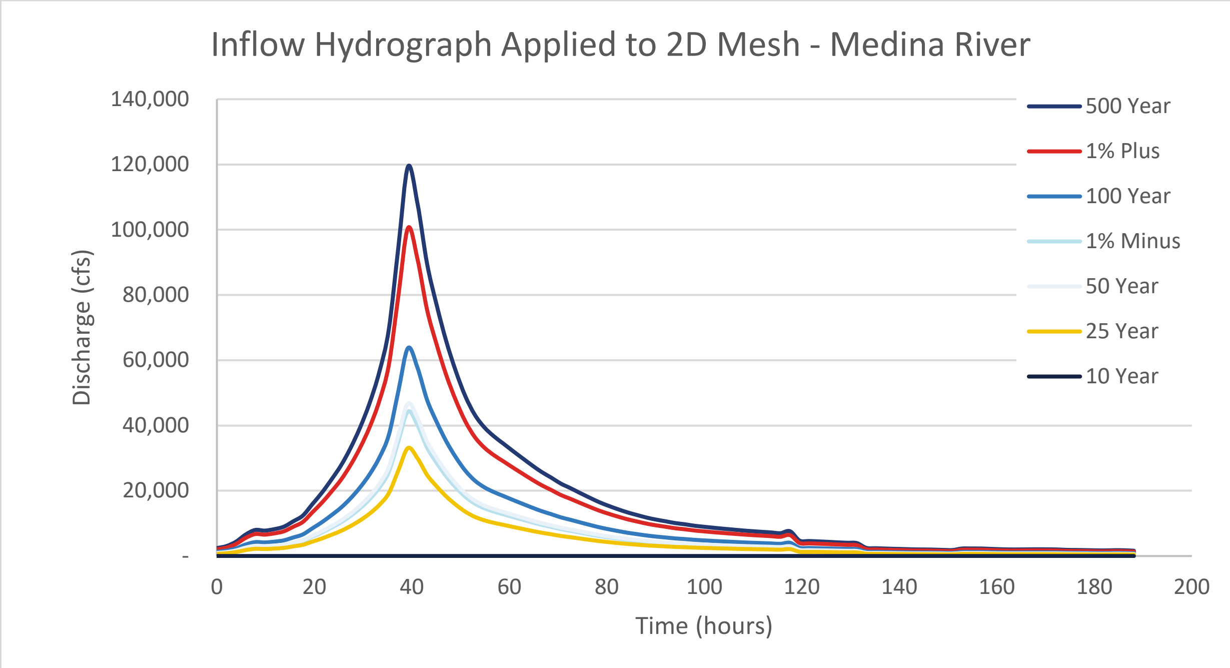


Figure 2-4: Precipitation Hyetographs (post ARF) applied to the Computational Mesh

2.2.3.2 Rainfall-Runoff Hydrograph Boundary Conditions

The Upper San Antonio model has an additional contributing drainage area outside of the extents of the HUC boundary that was accounted for with the addition of an inflow hydrographs, used as a boundary condition to the 2D computational mesh. Figure 2-5 shows the inflow hydrograph for the contributing flooding source applied to the 2D computational mesh for the Medina basin into Upper San Antonio.

Figure 2-5: Medina Basin Contributing Drainage Area Inflow Hydrographs



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 20-foot buffer zone was created by automated processes around each stream centerline (mainstem and tributaries) to create a main channel roughness zone. Due to the automated nature of this process, the buffer zone was not varied per stream. The channel roughness zone was given a Manning's n value of 0.045, obtained from the HEC-RAS User's Manual, to ensure the channel 2D cells have 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	Manning's N	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 using ArcGIS were modeled by adding v-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 below in Figure 2-6.

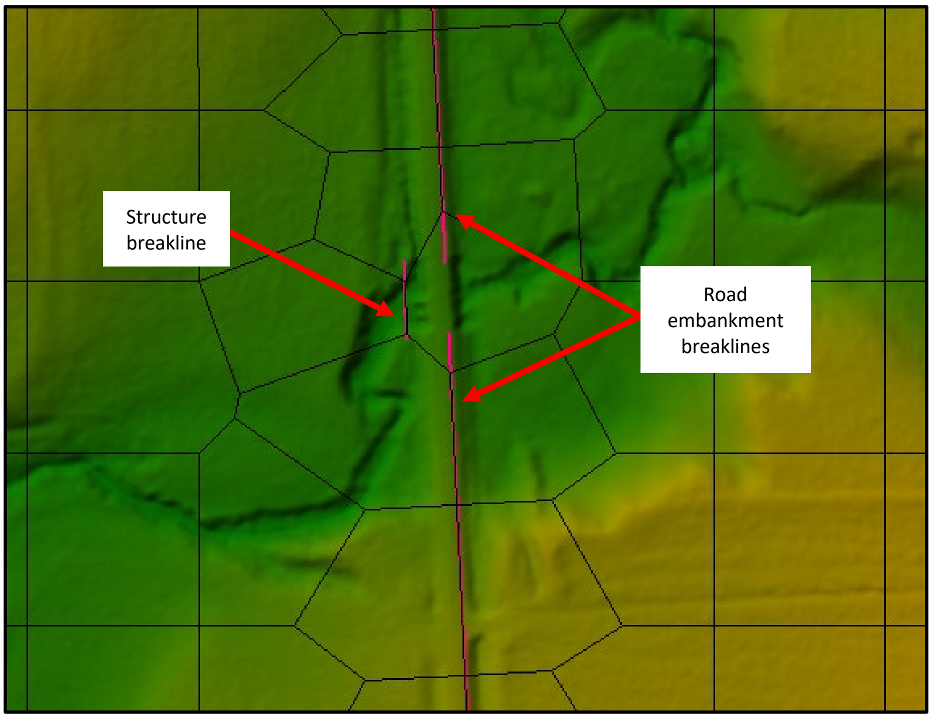


Figure 2-6: Offset Breakline Approach at Bridge Crossing

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. Berms and dams that were visible in the DEM were incorporated as breaklines. Railroads from the TIGER Railroads layer were also incorporated. No levees were present in the study area.

2.2.4.3 Initial Conditions

Initial conditions were not used in the Upper San Antonio 2D BLE model.

2.2.5 Special Assumptions

Regarding model results in the downtown area of San Antonio, it was assumed that flood levels would be much higher in this area than what gage results produce. This assumption was made since no flood conveyance structures are being implemented in the RAS model. There are two large drainage tunnels that run through downtown that, in realistic conditions, mitigate large amounts of flooding to keep the San Antonio Riverwalk water levels stable.

A unit hydrograph was also developed to model the Medina River that flows into the Upper San Antonio HUC from the southwest. This unit hydrograph was developed by averaging 5 different years of discharge data from the USGS stream gage closest to the Medina River outflow. The resulting hydrograph was then adjusted to have its time-to-peak realistically match conditions within the Medina watershed.

2.3 Model Results

The 2D BLE results for the study produced flood risk mapping which compared reasonably well with the effective SFHA. 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. Table 2.9 shows a comparison of some the effective BFE data with the model results. 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.

Table 2.9: Effective and Model Peak Flow Comparison

Stream	Effective FIS Comparison Location	Effective FIS Discharge (cfs)	Model Discharge (cfs)	Difference (%)
Elm Waterhole Creek	Approximately 400 feet upstream of confluence of Elm Creek	4,191	4,109	1.97%
Salado Creek	Upstream of Confluence with Lorence Creek	16,820	18,295	8.40%
Apache Creek	Just downstream of the confluence of Zarzamora Creek	24,724	15,579	45.38%
San Antonio River	Just downstream of the confluence of Medina River	89,335	128,994	36.33%

Several model tributaries have good correlation between the BLE and FIS discharges. These are typically at locations where there are no control structures, such as NRCS dams, upstream of the comparison location. In fully developed urban areas, such as the Apache Creek location, the peak flow from the BLE model may under-represent the fully urban runoff that occurs. In the case of the San Antonio River below the Medina River confluence, it is a matter of timing from the Medina River that significantly controls the comparison. As discussed in the following section, the Medina River peak is typically delayed several days as compared to the San Antonio River peak. This peak differential is not well represented in the model results and would contribute to reducing the BLE model peak flow moving more in line with the FIS results.

2.3.1.1 Calibration & Sensitivity Analysis

Known USGS gages within the model area with more than 20-years of flow record were used for calibration and validation of the 1% annual chance event. Peak flows within the model were compared with Bulletin 17B Analyses and EMA Analyses of the gage data using HEC-SSP 2.2 and with the current effective flow rates used by FEMA Flood Insurance Studies (FIS). Results of the flow comparisons are presented in Table 2.10.

Table 2.10: 1% Annual Chance Reasonability Comparisons

Flooding Source	USGS Gage Used for Verification	Drainage Area	HEC-RAS 5.0.7 (2D)	HEC-SSP[2]	FIS Flows
		Square Miles (sq mi)	Discharge (cfs)	Discharge (cfs)	Discharge (cfs)
Olmos Creek	08177700	21.2	20,915	24,238	23,870
San Antonio River	08178000	41.8	20,617	7,811	6,581
San Antonio River	08178565	125	63,434	107,870	83,372
San Antonio River	08181800	1,743	125,184	64,777	93,278
Salado Creek	08178700	137	31,655	61,704	19,904
Salado Creek	08178800	189	45,865	26,303	27,640

[1] Water surface elevation is approximate based on HEC-SSP input data rating curve and adjusted to NAVD 88 Datum.
[2] HEC-SSP analysis used weighted skew for all gages except 08178050 and 08178565 which used regional skew.

The model results as compared with the gage analysis from HEC-SSP and the FIS flows reveal differences at several gage locations. For additional comparison with the HEC-SSP computed flow, 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 of the gage analysis. These ranges are presented in Table 2.11.

Table 2.11: 1% Annual Chance 95% Confidence Limits of Gage Analysis

Flooding Source	USGS Gage Used for Verificatio n	HEC-SSP Discharge (cfs)			HEC-RAS 5.0.7 (2D)
		Computed 1%	95% Confidence Limit - Upper	95% Confidence Limit - Lower	Discharge (cfs)
Olmos Creek	08177700	24,238	37,228	17,636	20,915
San Antonio River	08178000	7,811	9,922	6,526	20,617
San Antonio River	08178565	107,870	237,443	64,926	63,434
San Antonio River	08181800	64,777	101,983	47,956	125,184
Salado Creek	08178700	61,689	107,838	39,360	31,655
Salado Creek	08178800	26,303	45,011	18,533	45,865

- Olmos Creek Gage – 08177700: Modeled discharge is within the confidence limits of the HEC-SSP computed value. There is a 14.7% difference in the flow rates which is acceptable for a base level engineering modeled flow as compared to the gage analysis. The FIS flow has close agreement to the gage analysis at this location showing a 13.1% difference from the modeled flows.
- San Antonio River Gage – 08178000: The large difference in the modeled flow as compared to the gage analysis is due to the impact of the San Antonio River tunnel that diverts approximately 12,000 cfs of flow in the San Antonio River to this underground tunnel, bypassing the gage. Therefore, a direct comparison is not valid, but adding the diverted flow to the gage flow results in a close comparison of 19,811 cfs to 20,617 cfs. The FIS flows support the HEC-SSP results at this location.
- San Antonio River Gage – 08178565: The modeled flow rate shows to be 51% difference. The modeled value is at the edge of being within the lower 95% confidence limit. The modeled flow does not include headwater spring flow or aquifer flow that is pumped into the stream system. This is one source of error than would contribute to the modeled value being low. This additional flow that is not accounted for in the BLE model can bring the gage location flow to within the lower 95% confidence limit. A second source of potential error is the HEC-SSP calculation was developed for undeveloped and uncontrolled basins. The Upper San Antonio River basin is predominately fully developed and has a large portion controlled by Olmos Dam, particularly at this gage location. This would contribute to the HEC-SSP value overestimating the 1% peak flow rate.
- San Antonio River Gage – 08181800: The modeled flow rate shows to be 63% difference between the model and the gage analysis. This gage location is impacted by both Salado Creek inflow and the Medina River inflow. A significant portion of this watershed area is associated with the Medina River inflow which includes impacts from Leon Creek basin, Macdona basin, LaCoste basin, and Somerset basin along with effects from Medina Lake. These basins and lakes change the timing of the peak significantly particularly for specific storm events relative to the pattern of rainfall over this very large basin. The inflow used in the Upper San Antonio model uses a separate model to prepare the input hydrograph for the Medina River. Using the same design rainfall, the Medina River peak occurs in close timing with the San Antonio River peak. This close peak timing results in a significantly high value for the gage location. Analysis of the real-time gage values for several storms indicate the delay from Medina to be significantly behind the San Antonio River. In July 2002, the Medina River peak was three days later than the San Antonio River and in October 2007, there was a two-day separation in peak flow. Applying this type of delay to the Medina River design storms would bring the San Antonio River flows within confidence limits of the HEC-SSP gage analysis.
- Salado Creek Gage – 08178700: The modeled flow rate shows to be 64% difference from the gage analysis. The gage analysis shows that a single significant storm, occurring in October of 1998 skewed the results of the HEC-SSP much higher. The HEC-SSP at this location is 80% higher than the next gage lower in the creek. While there is significant loss that occurs and is recognized in this lower reach of Salado Creek, the difference in flow rate appears to be exaggerated. Removing this single event brings the BLE modeled flow within the confidence limits. The FIS flows, in this case, tend to support the BLE peak flows.
- Salado Creek Gage – 08178800: The modeled flow rate shows to be 54% difference from the gage analysis. The modeled value is at the edge of being just above the upper 95% confidence limit. As mentioned in the previous gage review, there is significant storage loss through this lower reach of the San Antonio River that is not represented well in the model. The FIS flow rates support the HEC-SSP gage analysis peak flows at this location.

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. Tables 2.12 through 2.17 summarize the results of each run at each of the USGS gages.

Table 2.12: Sensitivity Analysis Results at USGS Gage 08177700

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 / 1min	Normal Depth	21,041	745.10	8,621
2	Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	20,871	745.04	8,580
3	Max Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	19,638	744.46	8,606
4	Minimum Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	24,497	742.6	8,655
5	Recommended Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	21,703	744.25	8,637
6[4]	Original Landuse w/ Buffered Channels	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth[3]	20,907	745.13	8,607
					Gage Analysis:	30,160	749.57[5]	

[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 6 were used for the final model, however additional computational mesh was implemented following the results of the sensitivity analysis.
[5] Water surface elevation is approximate based on PeakFQ input data.

Table 2.13: Sensitivity Analysis Results at USGS Gage 08178000

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 / 1min	Normal Depth	22,913	634.74	16,567
2	Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	20,616	634.18	16,677
3	Max Manning's N values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	20,221	633.8	16,799
4	Minimum Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	28,820	633	17,076
5	Recommended Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	22,020	633.53	16,789
6[4]	Original Landuse w/ Buffered Channels	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth[3]	20,670	634.18	16,806
					Gage Analysis:	8,731	622.65[5]	

[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 6 were used for the final model, however additional computational mesh was implemented flowing the results of the sensitivity analysis.
[5] Water surface elevation is approximate based on PeakFQ input data.

Table 2.14: Sensitivity Analysis Results at USGS Gage 08178565

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 / 1min	Normal Depth	63,557	522.72	52,603
2	Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	63,433	522.65	52,165
3	Max Manning's N values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	63,983	522.87	52,607
4	Minimum Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	88,339	521.84	52,930
5	Recommended Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	69,561	522.32	52,845
6[4]	Original Landuse w/ Buffered Channels	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth[3]	63,195	522.56	52,589
					Gage Analysis:	121,200	525.43[5]	

[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 6 were used for the final model, however additional computational mesh was implemented flowing the results of the sensitivity analysis.
[5] Water surface elevation is approximate based on PeakFQ input data.

Table 2.15: Sensitivity Analysis Results at USGS Gage 08178700

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 / 1min	Normal Depth	26,809	703.82	21,609
2	Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	31,655	704.95	22,640
3	Max Manning's N values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	28,806	705.17	23,499
4	Minimum Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	37,993	703.93	23,913
5	Recommended Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	26,388	703.5	21,206
6[4]	Original Landuse w/ Buffered Channels	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth[3]	26,191	703.68	20,729
					Gage Analysis:	77,480	709.01[5]	

[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 6 were used for the final model, however additional computational mesh was implemented following the results of the sensitivity analysis.
[5] Water surface elevation is approximate based on PeakFQ input data.

Table 2.16: Sensitivity Analysis Results at USGS Gage 08178800

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 / 1min	Normal Depth	37,980	559.2	42,505
2	Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	45,864	560.16	42,809
3	Max Manning's N values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	40,740	560.36	44,521
4	Minimum Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	56,571	559.54	45,210
5	Recommended Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	37,544	558.94	42,348
6[4]	Original Landuse w/ Buffered Channels	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth[3]	36,823	559.01	41,616
					Gage Analysis:	25,930	558.77[5]	

[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 6 were used for the final model, however additional computational mesh was implemented flowing the results of the sensitivity analysis.
[5] Water surface elevation is approximate based on PeakFQ input data.

Table 2.17: Sensitivity Analysis Results at USGS Gage 08181800

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 / 1min	Normal Depth	121,361	443.97	186,942
2	Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	152,681	441.2	177,992
3	Max Manning's N values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	127,814	445.07	185,164
4	Minimum Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	163,409	442.6	192,746
5	Recommended Manning's N Values	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth	148,121	446.05	677,386
6[4]	Original Landuse w/ Buffered Channels	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 1min	Normal Depth[3]	128,631	443.9	186,070
					Gage Analysis:	62,090	441.25	

[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 6 were used for the final model, however additional computational mesh was implemented flowing the results of the sensitivity analysis.
[5] Water surface elevation is approximate based on PeakFQ input data.

2.4 Challenges

Major challenges included a lack of peak streamflow records at the outlet as well as modeling the inflow in the southern portion of the HUC coming from the Medina River. Within the watershed, there are two distinct terrain types: high ground with defined channels mainly in the northern half of the watershed and low, shallow-sloped ground at the southern portion of the watershed. 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 (30 seconds) would be needed to stabilize the model in the high ground portion. However, the results were not significantly different when using a larger time step, so it was decided a larger time step (1 minute) was appropriate.

A larger challenge posed in this model was proper modeling of the Medina River inflow coming into the southern portion of the Upper San Antonio HUC. Currently, there are no working 1-day HMS models that can provided a usable unit hydrograph for the inflow. A unit hydrograph was manually developed in excel to mimic a one 1-day storm event from the Medina watershed.

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.

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 2-7 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.

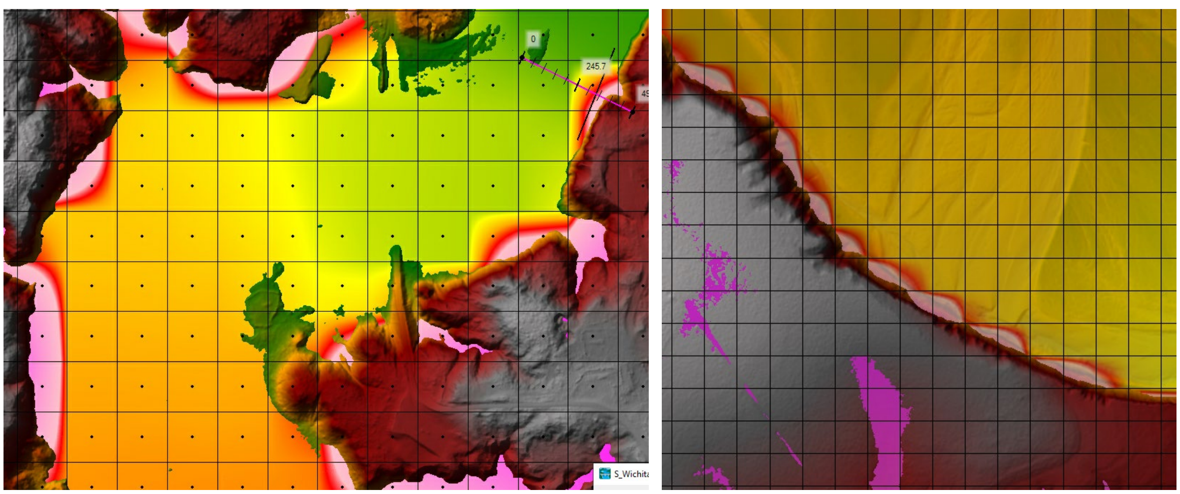


Figure 2-7: Cupping Examples

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 Upper San Antonio 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 Upper San Antonio 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. While this watershed does pass through a metropolitan area (San Antonio, Tx), the urban change percentages were all within the criteria previously described. 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	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. The existing linework did not have any backed models. This analysis is model backed and thus is marked as PASS.

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 Upper San Antonio 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 1,553 total miles of available CNMS features representing the effective Zone A studies were categorized as shown in Table 3.3 and Table 3.4 and illustrated in Figure 3-1. Table 3.4 summarizes the validation results based on the individual HUC 12 watersheds within the Upper San Antonio Watershed.

Table 3.3: Aggregated Zone A Validation Results

Validation Status	Status Type	Total Miles
ASSESSED	BEING STUDIED	273
ASSESSED	DEFERRED	3
UNKNOWN	BEING STUDIED	7
UNVERIFIED	TO BE STUDIED	247
UNVERIFIED	TO BE STUDIED	621
VALID	BEING ASSESSED	15
VALID	BEING STUDIED	23
VALID	NVUE COMPLIANT	370

Table 3.4: HUC 12 Zone A Validation Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	Pass/Fail
Watershed Name	Watershed Number					
All	**All Streams**	**698,650**	**7,488**	**691,162**	**99%**	**Pass**
Beitel Creek-Salado Creek	121003010104	44,132	534	43,598	**99%**	**Pass**
Blue Wing Lake-San Antonio River	121003010204	17,579	161	17,418	**99%**	**Pass**
Braunig Lake-San Antonio River	121003010301	49,244	502	48,742	**99%**	**Pass**
Lewis Creek-Salado Creek	121003010101	34,436	348	34,088	**99%**	**Pass**
Lower Calaveras Creek	121003010303	35,734	395	35,339	**99%**	**Pass**
Mud Creek	121003010103	62,914	657	62,257	**99%**	**Pass**
Olmos Creek-San Antonio River	121003010201	61,296	756	60,540	**99%**	**Pass**
Panther Spring Creek-Salado Creek	121003010102	32,775	424	32,351	**99%**	**Pass**
Rosillo Creek	121003010106	54,572	534	54,038	**99%**	**Pass**
Salado Creek-San Antonio River	121003010203	97,010	843	96,167	**99%**	**Pass**
San Pedro Creek	121003010202	80,418	825	79,593	**99%**	**Pass**
Upper Calaveras Creek	121003010302	70,307	863	69,444	**99%**	**Pass**
Walzem Creek	121003010105	58,233	646	57,587	**99%**	**Pass**

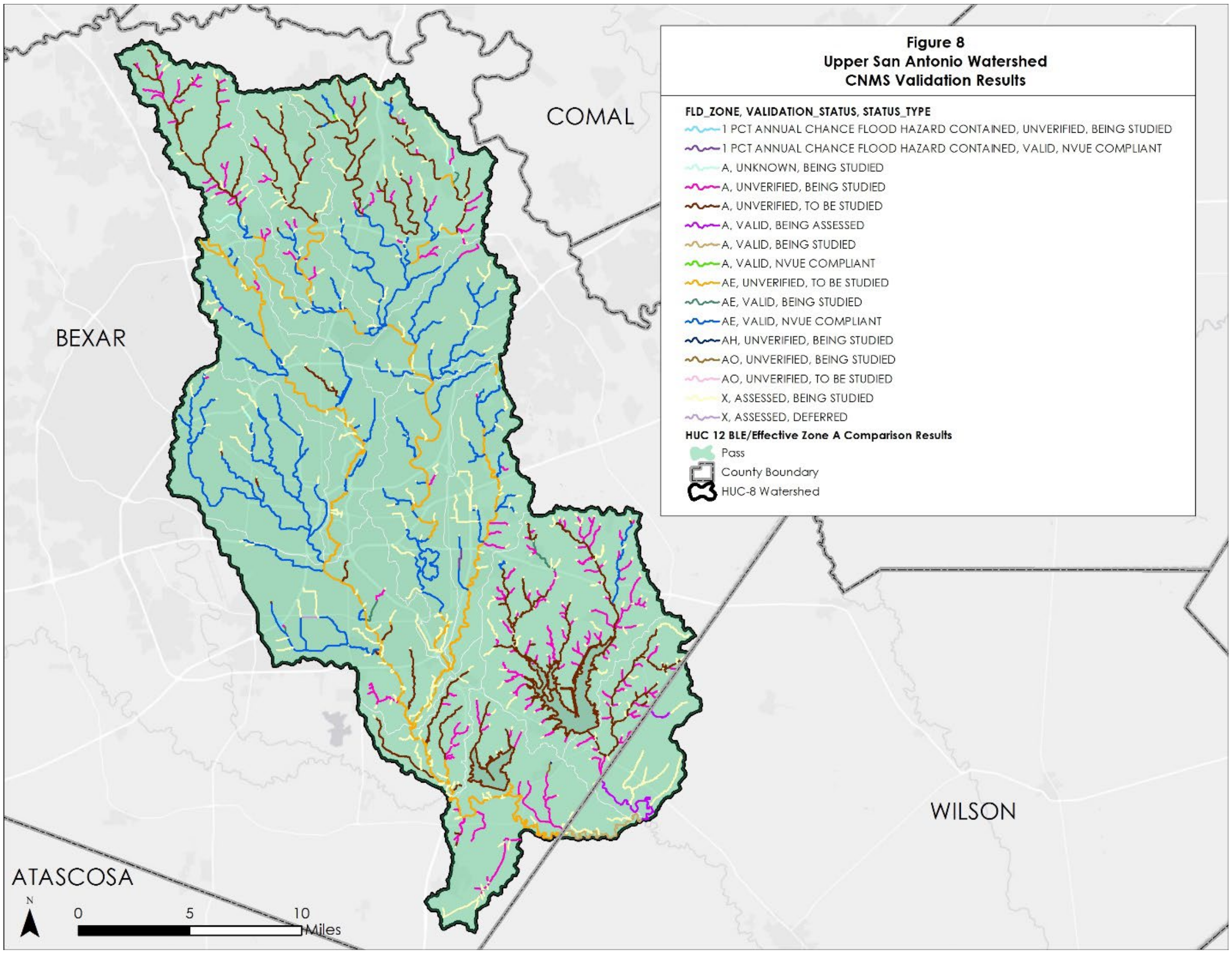


Figure 3-1: Upper San Antonio Watershed CNMS Validation Results

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 Upper San Antonio Watershed, Texas

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Bexar	5,482,062	104,917,624	65,587,119
Wilson	22,160	367,648	194,260
Total	**5,504,222**	**105,285,272**	**65,781,379**

04 References

1. Chow, Ven T. "Development of Uniform Flow and It Formulas." *Open Channel Hydraulics*. Caldwell, NJ: Blackburn, 1959. 109-113. Print.
2. FEMA, 'Data Capture Technical Reference", November 2021, (https://www.fema.gov/sites/default/files/documents/fema_data-capture-technical-reference_112021.pdf).
3. FEMA, "Flood Risk Database Technical Reference", February 2018 (https://www.fema.gov/sites/default/files/2020-02/Flood_Risk_Database_Technical_Reference_Feb_2018.pdf).
4. FEMA, "Guidance for Flood Risk Analysis and Mapping – Base Level Engineering (BLE) Analyses and Mapping", February 2018. (https://www.fema.gov/media-library-data/1526489690918-2862bece100f28564c4167aaf4b2378b/Base_Level_Engineering_Guidance_Feb_2018.pdf).
5. NOAA, "NOAA Atlas 14 Precipitation-Frequency Atlas of the United States", 2013. Volume 9, Version 2.0. (https://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume9.pdf).
6. San Antonio River Authority, November 2021. Upper San Antonio River Watershed - Hydrologic Report. Mapping Activity Statement FY19 between San Antonio River Authority and FEMA: FEMA Case No. 20-06-0030S.
7. U.S. Army Corps of Engineers, Hydrologic Engineering Center. (March 2019). HEC-RAS River Analysis System, Version 5.0.7 Davis, California.
8. USGS, "Estimating Magnitude and Frequency of Floods Using PeakFQ Program: USGS Fact Sheet", 2006.
9. USGS. Multi-Resolution Land Characteristics Consortium. *National Land Cover Database 2016*. (https://www.mrlc.gov/national-land-cover-database-nlcd-2016).