

Navidad Watershed, Texas 2D Base Level Engineering and Mapping Methods and Results

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1. Introduction

Base Level Engineering (BLE) provides technically credible flood data for various geographies - community, county, watershed and/or state level. BLE data can be shared with Federal, State, local and tribal governments, this data sharing provides stakeholders at all levels the necessary data to make informed decisions to reduce future flood losses. Without the mapping of flood prone areas, there can be a lack of information to effectively communicate flood risk to community officials, citizens, and businesses.

BLE is a riverine hydrologic and hydraulic modeling approach that builds on lessons learned to produce a baseline understanding of flood risk to communities, produced to support the assessment and maintenance of the national flood hazard inventory. Engineering models are created during a BLE assessment, producing information that meets the mapping Standards for Flood Risk Projects (FEMA Policy Memo FP 204-078-1) to produce Zone A (1-percent-annual-chance flood) information. BLE data is intended to represent the base level of investment needed for all flood study efforts FEMA will undertake. The Navidad watershed BLE documented here was designed to use two-dimensional (2D) modeling techniques with enhancements and calibration to develop products that can be communicated and shared with stakeholders, and transitioned into FEMA regulatory data development workflows.

The intent of BLE is to provide communities technically credible flood hazard information in a cost efficient and timely manner. Additionally, BLE provides communities a chance to review draft modeling information, reflecting the potential changes in risk within their community. Providing additional flood risk datasets, like water surface elevation (WSEL) grids and flood depth grids, delivers alternative information that reinforces the variability of flood risk within a designated floodplain and supports historic community requests for a source to determine a Base Flood Elevation in Zone A areas.

For floodplain management purposes, BLE data may be used as best available information in areas that are designated as Zone A floodplain. It may also be used to regulate development in areas where no Special Flood Hazard Area (SFHA) has been mapped before. Communities may adopt BLE data to support local regulations, which facilitates use of the data in local floodplain management activities, including in the post disaster environment where a need for updated and/or enhanced flood hazard information may be necessary.

BLE provides information to communities who are currently unmapped and provides a digital entry to communities that are currently un-modernized. BLE acts as a measuring tool to allow FEMA to assess the current Zone A inventory identified as unknown or unverified in FEMA's Coordinated Needs Management Strategy (CNMS), which FEMA is required to evaluate once every five years, as described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e). FEMA makes this determination of flood hazard data validity by examining flood study attributes and change characteristics, as specified in the Validation Checklist of the Coordinated Needs Management Strategy (CNMS) Technical Reference. The CNMS Validation Checklist provides a series of critical and secondary checks to determine the validity of flood hazard areas studied by detailed methods (e.g., Zone AE, AH, or AO). While the critical and secondary elements in CNMS provide a comprehensive method of evaluating the validity of Zone AE studies, a cost-effective approach for evaluating Zone A studies has been lacking. Another important goal of the BLE process is scalability of the results, meaning that the model produced during the BLE assessment may be refined to produce a more enhanced model with additional manual correction and on the ground survey. If BLE modeling exists, FEMA will recommend that it be used as the base model for any detailed studies performed in those areas.

BLE practices leverage high-resolution topography that meets or exceeds the United States Geological Survey (USGS) 3-D Elevation Program (3DEP) standards and often applies flood engineering at a large scale as opposed to targeting stream reaches within a watershed. BLE can be conducted at any scale, commonly for larger areas (Hydrologic Unit Code (HUC)-8 watershed) but may be produced at the county or local level too. It is encouraged to do BLE for wider areas in order to build on efficiencies in modeling and ensure cost efficiency. Using current technologies, multiple watersheds or watersheds with large land areas can be analyzed at a more efficient rate to produce water-surface elevations and site-specific hazard data replacing outdated flood studies shown in existing Flood Insurance Rate Maps (FIRMs). All flood prone areas within a watershed will have an engineering model calculating multiple flood recurrence intervals and defining floodplains with elevation grids using high-resolution topography.

Per standard identification SID #84 and #133, BLE will include all recurrence intervals (0.2-percent, 1-percent, 1-percent plus, 1-percent minus, 2-percent, 4-percent, and 10-percent-annual-chance floods). As such, hydrologic and hydraulic analysis should be performed to determine the expected WSELs for each of the seven recurrence intervals previously identified.

The Navidad watershed 2D BLE project was scoped as described in the Texas Water Development Board (TWDB) Task Order 8. In an effort to increase and enhance the flood risk products in Texas, the study was contracted through the TWDB's Cooperative Technical Partner (CTP) program to AECOM Technical Services, Inc. This report documents the BLE process, products, and results for this watershed. Figure 1 depicts the Navidad watershed footprint.

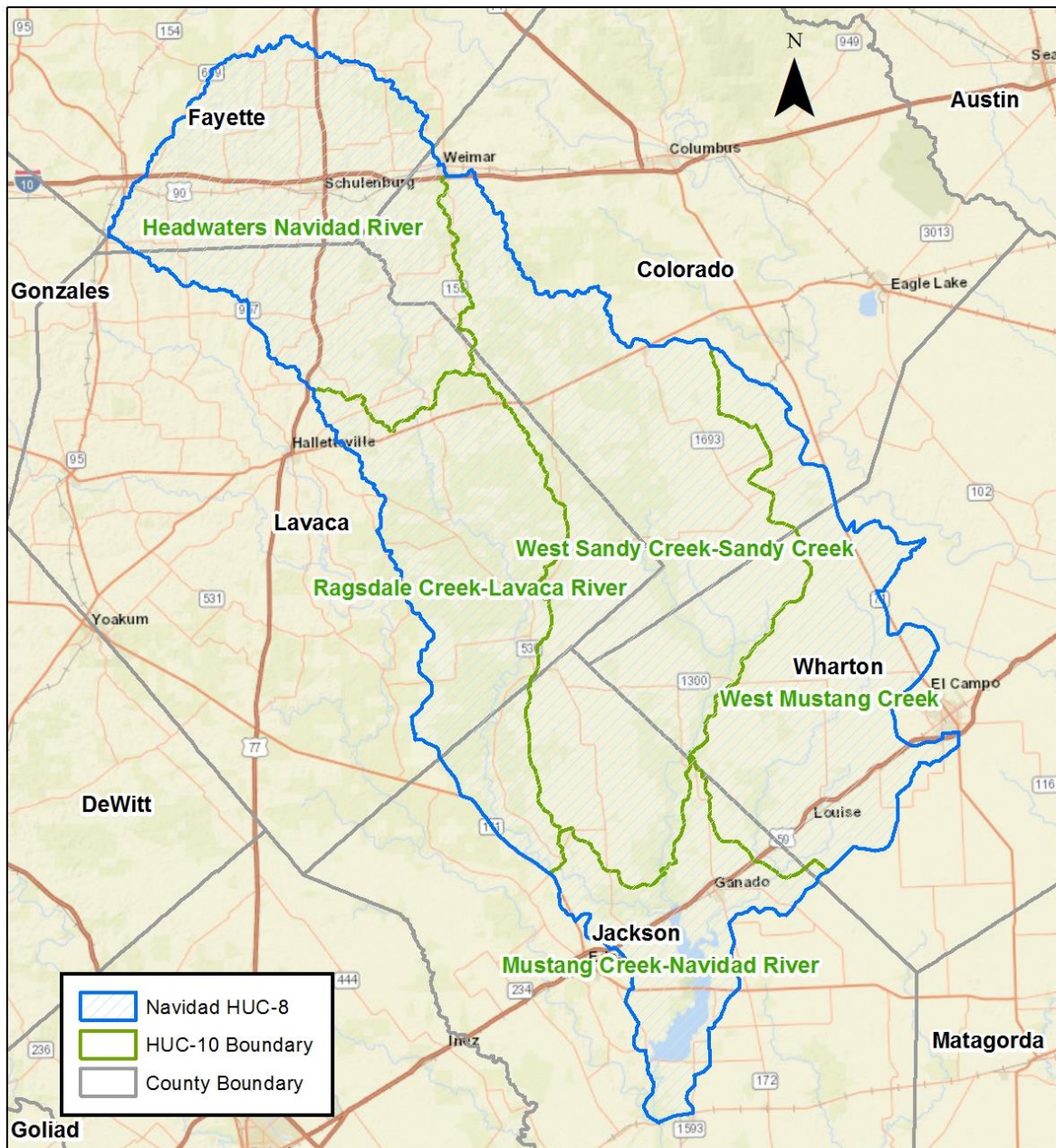


Figure 1: Navidad Watershed

2. 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2D hydraulic engineering analysis for the Navidad watershed. Inputs such as elevation data, hydrology from 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 2D engineering analyses by providing a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the Navidad BLE project by leveraging available high resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the States of Texas. The 10 foot DEM developed to support the 2D BLE modeling and analysis, within the Navidad 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 Geographic Information Systems (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 within Section 2.1.2. 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 Navidad watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Navidad BLE watershed footprint. Figure 2 depicts the datasets identified and leveraged across the project area. FEMA, National Oceanic and Atmospheric Administration (NOAA), USGS, Texas Natural Resources Information System (TNRIS) and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

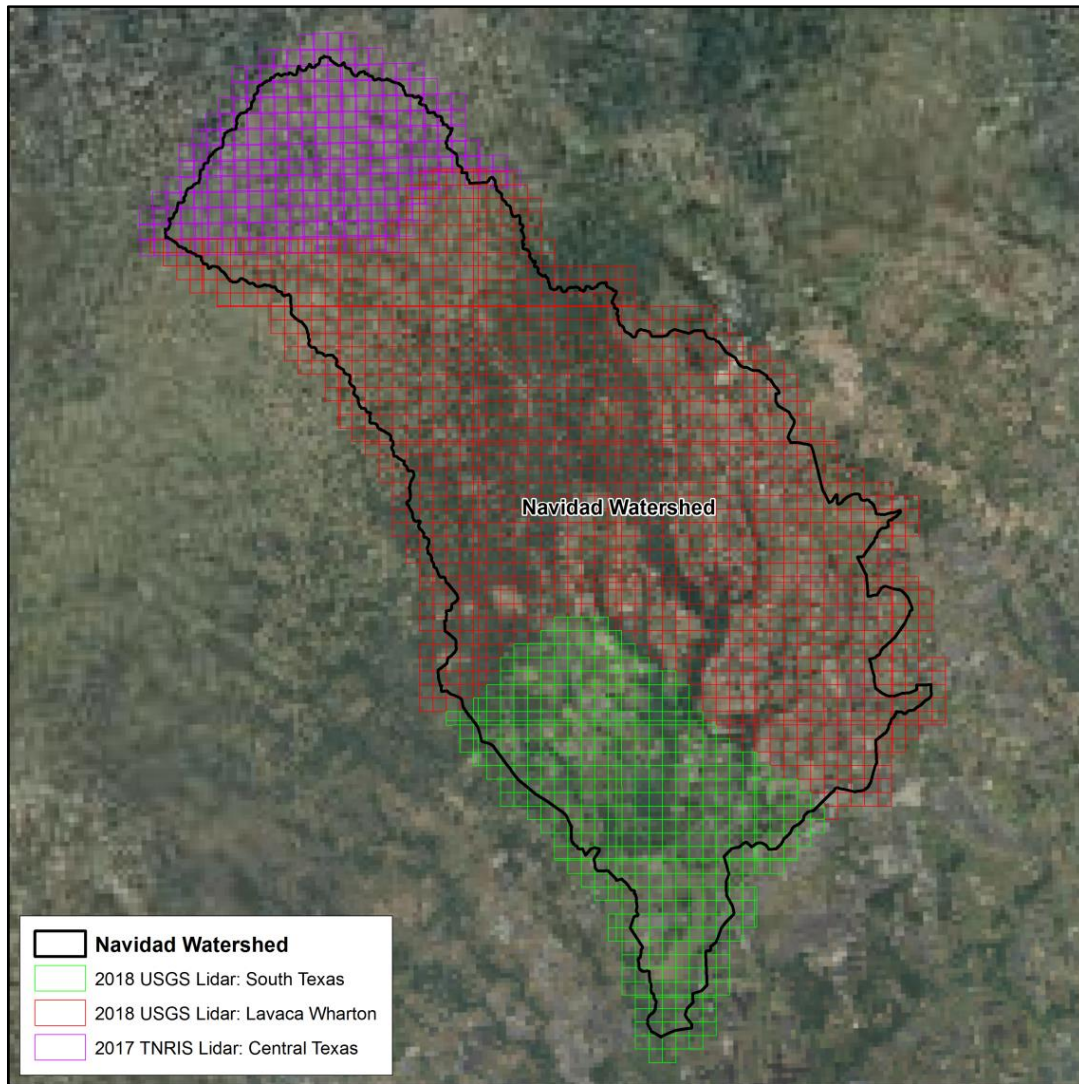


Figure 2: Navidad Watershed BLE Source Terrain Data

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 1)
- Date of origination
- Data density and coverage

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

Table 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 depicts the complete list of source elevation data and attributes leveraged for the Navidad watershed. All datasets used for hydraulic analyses and mapping meet the highest specification level defined in Table 1. The following datasets were evaluated and prioritized as best available:

Table 2: LiDAR Topographic Data Available for the Navidad Watershed

Year	Description	Source/Owner	Accuracy ¹	Approximate Footprint (mi ²) ²
2018	2018 TNRIS LiDAR: South Texas	TNRIS/TWDB	17.64 cm	370.7
2017	2018 Lavaca and Wharton Counties LiDAR	TNRIS/TWDB	16.3 cm	1,133.5
2017	2017 TNRIS LiDAR: Central Texas	TNRIS/TWDB	6.175 cm	224.9

¹RMSEz reported at the 95% confidence level

²Size of LiDAR DEM footprint utilized for BLE study

2.1.2.1 Navidad Watershed Source Terrain Data

The source elevation data for the Navidad watershed are DEMs derived from the 2018 TNRIS LiDAR:South Texas; the 2018 Lavaca and Wharton Counties LiDAR; and the 2017 TNRIS LiDAR: Central Texas. Only points classified as “ground” points (i.e., bare earth) were imported from the LiDAR and used for development of the project DEMs. Bare-earth LiDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the raw laser returns. Figure 2 depicts the extent of the data defined in Table 2.

2018 TNRIS LiDAR: South Texas

The USGS LiDAR project covers 22,229 square miles over South Texas including 30 counties. The project was developed to create a consistent and accurate surface elevation dataset for the USGS FEMA VI Red River, Texas Project Area. The acquisition was conducted from January 13, 2018 to February 23, 2019. Quantum Spatial served as the prime contractor for the project and was responsible for LAS classification, all LiDAR products, breakline production, Digital Elevation Model (DEM) production, and quality assurance.

Quantum Spatial utilized Leica ALS70, Leica ALS80, Optech Orion H300, Riegl VQ1560i, and Riegl LMS Q1560 LiDAR sensors during the project.

LiDAR acquired from this project will be used for floodplain management and planning, feature extraction, water quality modeling, stream restoration potential analysis, change detection, 9-1-1, wildfire mitigation, habitat identification/modeling for endangered species, and hurricane recovery projects.

The RMSEz reported for the dataset was 17.64 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

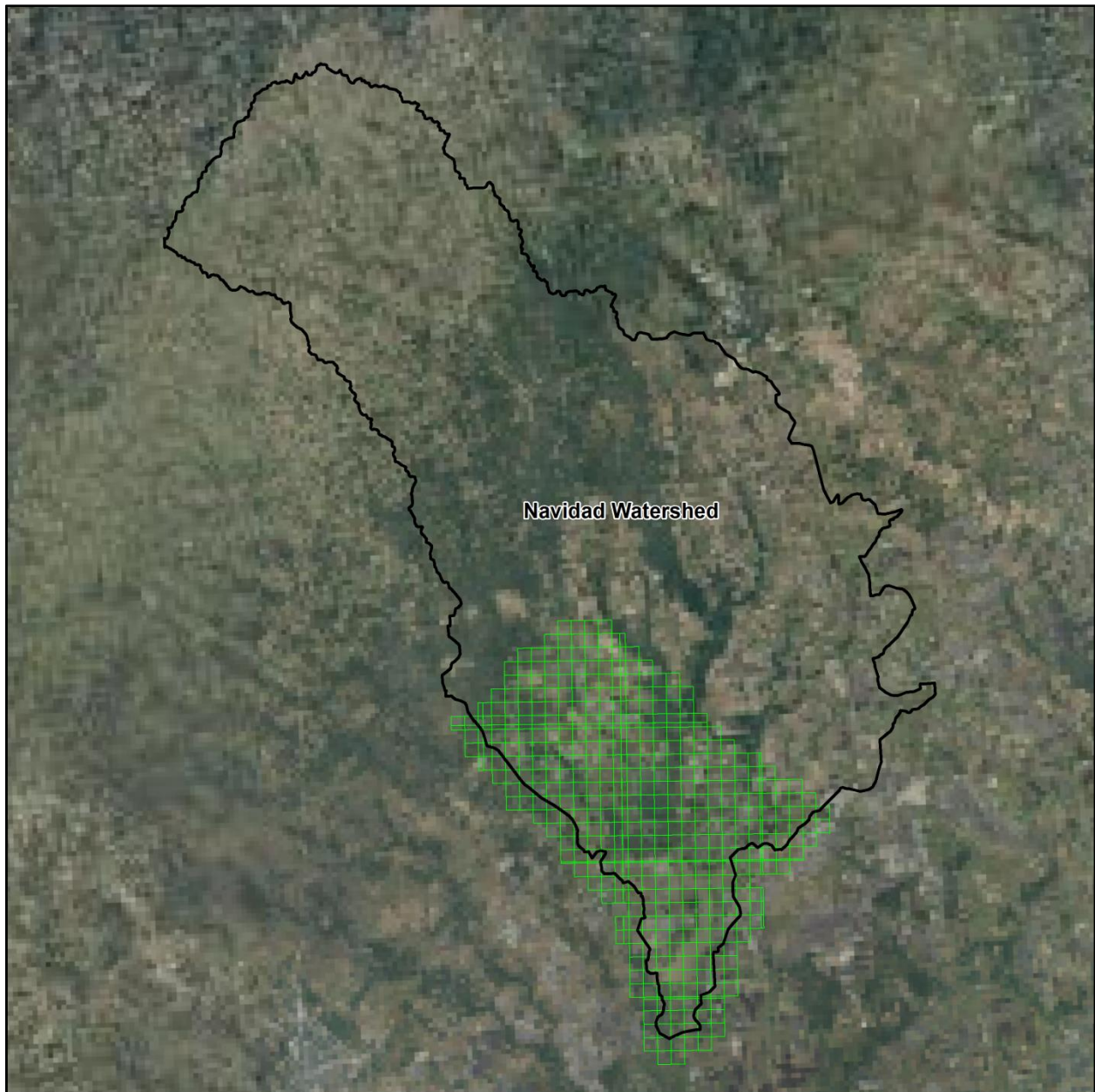


Figure 3: 2018 TNIRIS LiDAR: South Texas LiDAR

2018 Lavaca and Wharton Counties LiDAR

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy LiDAR technology for the Texas Lavaca Wharton FEMA R6 Project Area. Dewberry served as the prime contractor for the project. Dewberry elected to subcontract the LiDAR acquisition and calibration activities to Digital Aerial Solutions, LLC. Digital Aerial Solutions, LLC was responsible for providing LiDAR acquisition, calibration and delivery of LiDAR data files to Dewberry. The LAS classification was sub-contracted to E-terra. Digital Aerial Solutions, LLC operated a Cessna 421 (Tail # N112MJ) outfitted with a LEICA ALS80-HP LiDAR system during the collection of the study area. The project was funded by FEMA to assist with hydrologic studies and hydraulic analysis to determine the risk of flood hazards. The RMSEz reported for the dataset was 16.3 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

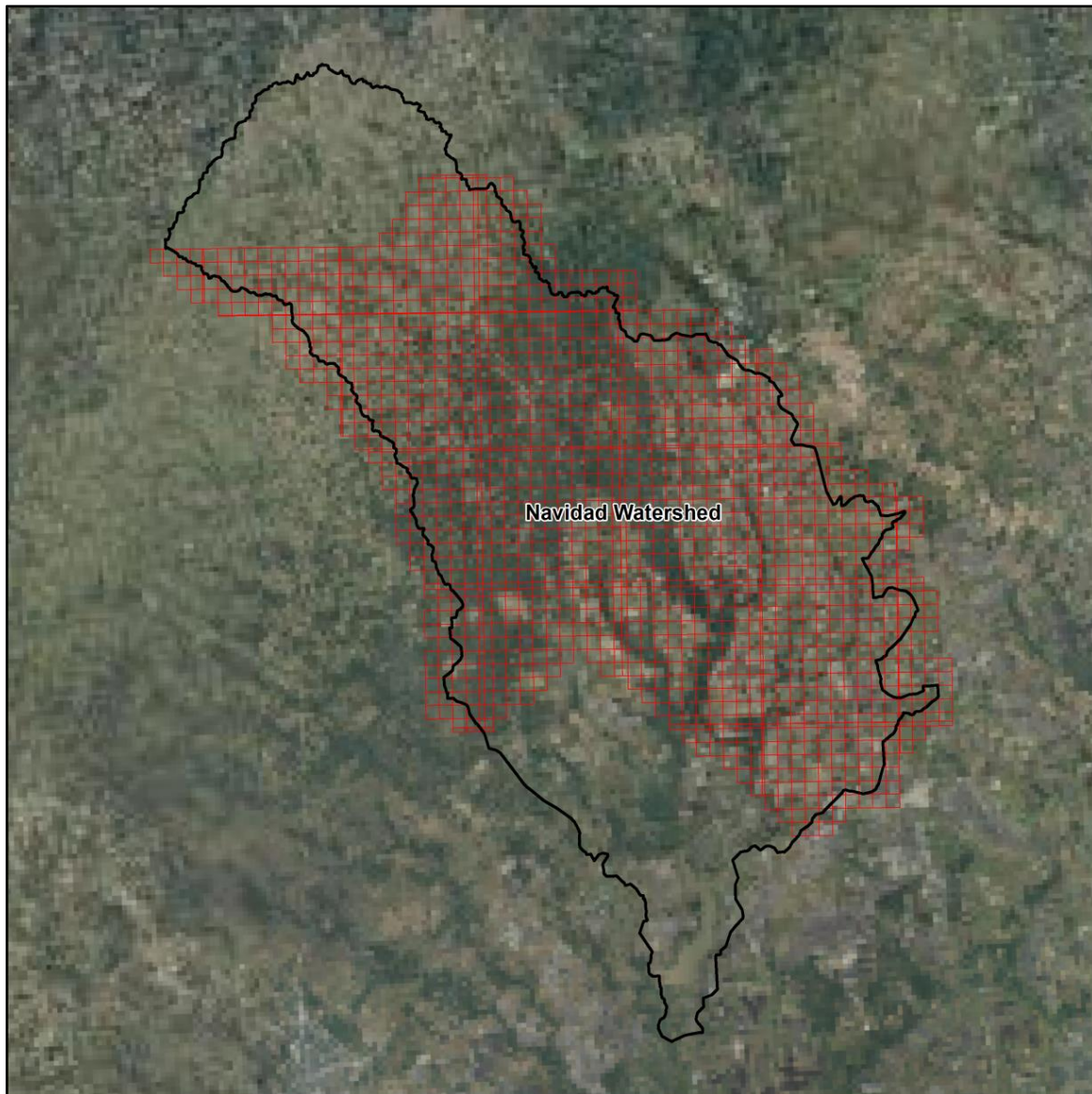


Figure 4: 2018 Lavaca and Wharton Counties LiDAR

2017 TNRIS LiDAR: Central Texas

Texas Water Development Board (TWDB) in cooperation with their project partners tasked Fugro Geospatial, Inc. (Fugro) under the Department of Information Resources (DIR) Geographic Information Systems (GIS) Hardware, Software and Services contract also known as the StratMap contract to acquire high resolution elevation data and associated products from airborne LiDAR systems during the 2016-2017 leaf-off season. The collection took place from January 28th through March 22nd, 2017. The StratMap Program promotes inter-governmental collaboration and partnerships to purchase geospatial data products that provide cost savings and project efficiencies. Both the StratMap Program and the StratMap Contract are administered by Texas Natural Resources Information System (TNRIS), a division of TWDB. Project partners include: Williamson County (Wilco), City of San Marcos (COSM), City of Round Rock (CORR), United States Fish and Wildlife Service (USFWS), USGS, (NRCS), and the River Authority. This Central Texas project consists of approximately 6,570 square miles and is located in Central Texas around the I-35 corridor from Williamson County to Bexar County. The project includes large metropolitan areas as well as various vegetation classifications spanning farmland to dense forest. The San Antonio Area of Interest (AOI) consists of approximately 887 square miles and was acquired utilizing a Riegl LMS-Q680i sensor; collecting multiple return x, y, and z as well as intensity data. Specialized in-house and commercial software processes the native LiDAR data into 3-dimensional positions that can be imported into GIS software for visualization and further analysis. The horizontal

datum for the data is the NAD83, 2011 in meters and the vertical datum is the NAVD88 in meters realized with GEOID12B. The RMSEz reported for the dataset was 6.175 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

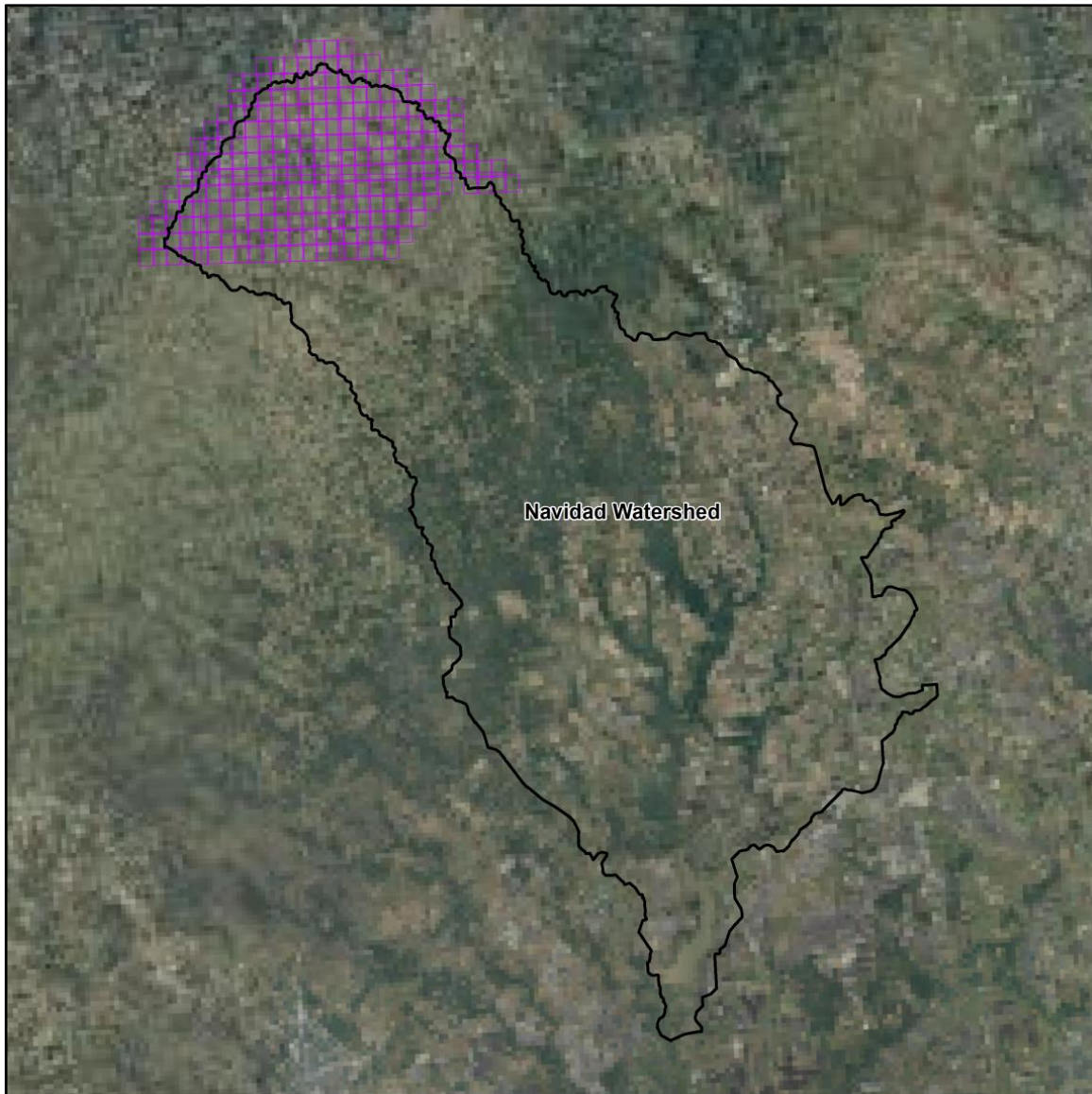


Figure 5: 2017 TNRIS LiDAR: Central Texas

2.1.3 Data Processing

ArcGIS software was utilized in order to create a digital surface model for the Navidad HUC-8 watershed project area. The LiDAR datasets were added to a mosaic dataset and prioritized by date with the most recent dataset taking the first priority. If two datasets are from the same year or flown at similar dates, the accuracy was reviewed to determine the priority. The mosaic dataset was exported to make a seamless bare earth DEM.

The exported DEM was reviewed through automated quality control (QC) to check for anomalies and outlier locations based on slope and cells that exceed z value differences from surrounding cells. Visual review was also performed to check for ground differences at the extents of the datasets for differences in ground values.

2.1.4 DEM QA/QC

DEMs developed for use in the Navidad watershed BLE analysis were developed and independently assured to meet quality standards of the project. The data were developed using a controlled process, were evaluated and assured by a topographic data development team, and were evaluated and assured by the engineering team. Quality assurance (QA) during the data development process includes, but is not limited to the following QC checks:

- Horizontal Projection Check
- Vertical Datum Check
- Resolution Check
- Format Check
- Seamless Data Check to ensure the DEM files are consistent and seamless along source data edges

The QC after the development process by the DEM development team included visual observations using hillshade, contouring, color rendering, and/or other visual aids to review and identify potential impactful anomalies within the DEM surface. This QC step included, but was not limited to the following QC checks:

- Seamless Data Check to ensure no voids along the edges and between the prioritized datasets
- NoData Value Check to ensure no null values
- Manual Elevation Check using hillshade rasters to find erroneous elevation issues
- Unit Consistency Check
- Legacy Cell Value Anomalies

QA conducted after the seamless DEM development conducted by the engineering team included visual or automated assessments to identify potentially impactful anomalies or slope changes that may adversely impact hydraulic analysis.

The final DEM data developed for the Navidad watershed is 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

HEC-RAS 5.0.7 (RAS5) rain-on-grid utility was applied in the Texas 2D BLE products workflow. The following sections describe the engineering methods and model inputs used.

2.2.1 2D Computational Mesh and Settings

Due to the size of the Navidad watershed (approximately 1400 sqmi) and presence of highly populated and urbanized areas, HUC-8 was split into 2 separate HEC-RAS geometries due to computational and modeling limitations as shown in Figure 6. The HUC-8 was split into modeling areas as Headwaters and Mustang Creek HUC-10s. Minor adjustments have been made to HUC-10 boundaries to improve modeling efficiency. The RAS5 watershed boundary was created for the Navidad model area using ArcGIS toolsets, which reduce the need for manual edits to mesh cells within RAS5 that result in error generation. The Navidad Headwaters and Mustang Creek 2D meshes contain 504,247 and 750,194 cells, respectively, consisting of 200 foot cells, with the exception of 100 foot along the 1 square mile streams and 50 foot cells within community boundaries using refinement regions. Internal connections were used to extract flow readings for gage locations throughout the model, while profile lines were used for all other flow extractions. An adaptive 30 second time step was used to allow the model to lower the time step, as necessary, to keep the maximum courant number under 3 for the duration of the simulation. The time step was allowed to reach 120 seconds for a maximum and 3.75 seconds for the minimum. A theta value of 0.6 was used due to the models alignment with the coast. The RAS5 model was run with Diffusion Wave (simplified Full Momentum) equations.

2.2.2 Model and Boundary Condition Setup

Using RAS5 rain-on-grid modeling requires a 2D computational mesh boundary and often requires defining inflow boundary conditions and application of excess precipitation. Excess precipitation was applied to the 2D mesh as a precipitation boundary condition. The process to determine the excess precipitation to be applied is outlined in the hydrology section. Figure 6 depicts the Navidad Headwaters and Mustang Creek model boundaries, flow transition points between models, and USGS stream gages used in the study.

Because the Navidad HUC-8 was split into two work areas, the outflow from the Navidad Headwaters model along the Navidad River was used as an inflow hydrograph for the Mustang Creek work area. This hydrograph was extracted from the Headwaters model using a 2D connection, and then placed as a flow hydrograph external boundary condition for the Mustang Creek model.

Besides the Mustang Creek inflow hydrograph, outflow boundary conditions (from the computational 2D mesh) were used along model boundaries. Outflow boundaries were established as normal depth using approximate energy grade-line slope estimated from the LiDAR data. This allowed the boundary conditions defined as continuous boundaries to allow drainage to leave the model area freely to adjacent basins.

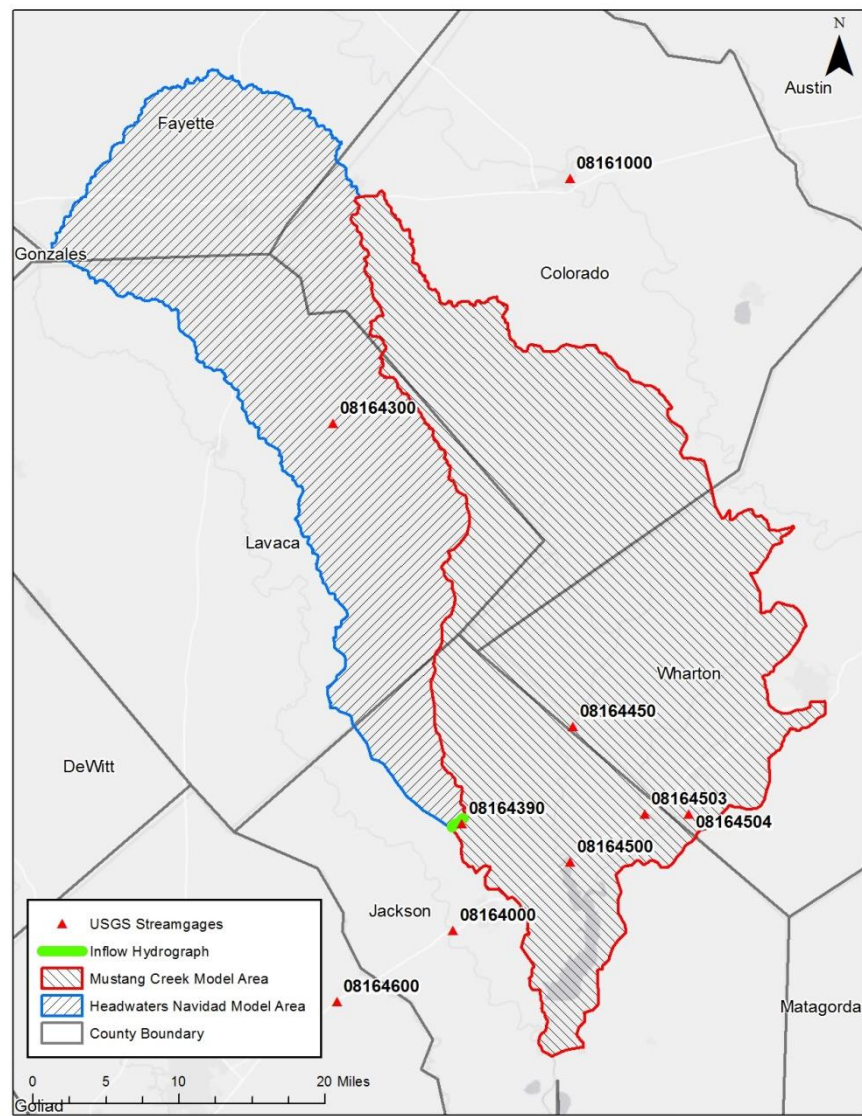


Figure 6: RAS5 2D Computational Mesh and Boundary Conditions and USGS Peak Streamflow Gages

2.2.3 Hydrology

Precipitation frequency data (NOAA, 2018) was 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>), and appropriate values for all sub-basin elements were determined considering spatial variation and a representative total for both the Navidad Headwaters and Mustang Creek model areas. Excess precipitation for the 2D meshes were developed as described in Section 2.2.3.1 USGS streamflow gage data were leveraged to estimate peak flows for downstream gages within each work area for calibration purposes, as discussed in Section 3.1. The 10-, 4-, 2-, 1-, and 0.2-percent annual chance 24-hour precipitation depths for all sub-basin elements were determined by area-weighted intersection of gridded PFDS data with sub-basins.

USGS streamflow gage data were leveraged to estimate peak flows for downstream gages within each model for calibration purposes. Models are compared to known USGS peak flows to validate the model results. USGS stream gages with less than 10 years of record were not considered for this study. The gages used for analysis in this study are listed in Table 3.

Table 3: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (mi ²)	Period of Record
08164300	Navidad Rv nr Hallettsville, TX	332	1936-2020
08164390	Navidad Rv at Strane Pk nr Edna, TX	579	1997-2020
08164450	Sandy Ck nr Ganado, TX	289	1978-2020
08164503	W Mustang Ck nr Ganado, TX	178	1978-2020
08164504	E Mustang Ck nr Louise, TX	53.9	1997-2020

2.2.3.1 Excess Precipitation for 2D Computational Mesh

HEC-HMS version 4.6 was used to apply the Soil Conservation Service (SCS) Curve Number method to calculate losses and define excess precipitation for this watershed. Temporal distributions of point rainfall totals were defined using 24-hour, frequency-based 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. An areal reduction as per Technical Paper 40 (TP-40) was used in HEC-HMS on all recurrence interval total precipitation depths in order to determine the effective precipitation for the sub-basin representing 2D mesh.

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-percent plus and minus events are defined to be one standard deviation above and below the 1-percent event. It should be noted that the standard errors for the 1-percent rainfall depth were based on the depth used post-areal reduction. The estimated 1-percent plus and minus rainfall depths are shown, alongside the other events, in Table 6 later in this section.

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 4.

Table 4: Land Use(LU)-Soils-CN Matrix for Defining Initial Curve Number

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

In addition to rainfall, the 1-percent plus and minus event estimates were further refined by adjustment of their respective curve numbers. A Curve Number (CN) can be considered a parameter, exhibiting variability that follows some frequency distribution. While Antecedent Runoff Condition (ARC) II CNs were used for a 1-percent event, the range between ARC I and ARC III for the ARC II CN was assumed to correspond to an 80% confidence interval of the ARC II CN. The CN loss method assumes a maximum potential retention parameter, S, is inversely related to a CN by $S = 1000 / CN - 10$; this relationship is based on a median value of S determined from plotting a large number of observations.

Chapter 5 of the NRCS National Engineering Handbook (NEH) Part 630 provides an example of computing a CN for a watershed based on annual peak gage observations. The example involves computing a CN and corresponding S value for each event, then taking the logarithms of the S values. Further, the logarithm of S is assumed to vary normally, and the mean of the logarithms corresponds to the arithmetic median. Therefore, 10% (S10) and 90% (S90) extremes of lognormally distributed S values can be assumed to correspond to ARC III and ARC I condition CN values, respectively. This range represents an 80% confidence interval, corresponding to ± 1.282 standard deviations from the mean. The following procedure was used to estimate one standard deviation of a given CN (in fact, one standard deviation of the logarithm of S) for the purposes of modeling 1-percent plus and minus events. First, ARC III (corresponding to S10) and ARC I (corresponding to S90) CN values can be estimated from a 1-percent CN (ARC II) by:

$$CNI = 4.2 * CNII / (10 - 0.058 * CNII)$$

$$CNIII = 23 * CNII / (10 + 0.13 * CNII)$$

Next, S90 and S10 can be computed by:

$$S10 = 1000 / CNIII - 10$$

$$S90 = 1000 / CNI - 10$$

The following relationship can then be used to compute one standard deviation of the logarithm of S:

$$\log(S_{10}) = \text{mean}(\log(S)) + 1.282 \text{ std. dev.}(\log(S))$$

$$\log(S_{90}) = \text{mean}(\log(S)) - 1.282 \text{ std. dev.}(\log(S))$$

$$1 \text{ std. dev.}(\log(S)) = (\log(S_{10}) - \log(S_{90})) / 1.282$$

Therefore, 1-percent plus and minus S values can be estimated by:

$$\log(S_{\text{Plus}}) = \log(S) + [1 \text{ std. dev.}(\log(S))]$$

$$\log(S_{\text{Minus}}) = \log(S) - [1 \text{ std. dev.}(\log(S))]$$

Finally, 1-percent plus and minus CNs can be computed by:

$$CN_{\text{Plus}} = 1000 / (S_{\text{Plus}} + 10)$$

$$CN_{\text{Minus}} = 1000 / (S_{\text{Minus}} + 10)$$

Since the 1-percent plus and minus events represent plus and minus one standard deviation of a 1-percent event, CNs used in a rainfall-runoff simulation for modeling 1-percent plus and minus events were developed, as described above. A single basin was used in HEC-HMS for simulation to estimate excess precipitation.

The table below shows the curve numbers both initially computed and revised values based on reasonability check revisions.

Table 5: Rainfall-Runoff Curve Numbers

Sub-basin Description	CN (initial)	CN (verified)	CN 1-percent Minus	CN 1-percent Plus
Navidad – Headwaters	70.11	60	43.6	74.4
Navidad – Mustang Creek	75.04	73	58.2	84.0

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including curve numbers for defining rainfall losses. No routing was considered in the rainfall-runoff modeling. Frequency-based storm with 50% storm centering were used for defining temporal distributions of point rainfall totals. Table 6 provides the precipitation totals applied to the model including areal reduction.

Table 6: Precipitation Totals estimated in HEC-HMS (post ARF)

Percent Annual Chance Precipitation Depths (in.)							
Sub-Basin Description	1-percent	0.2-percent	2-percent	4-percent	10-percent	1-percent Plus	1-percent Minus
Navidad – Headwaters	13.5	19.4	11.3	9.39	7.23	16.28	10.72
Navidad – Mustang Creek	14.2	20.0	12.0	10.1	7.81	17.12	11.28

Table 7 shows the excess precipitation totals determined from the HMS model. These values are a factor of the average curve number and precipitation depths for each model area. Note that CNs were modified during the calibration process and the excess precipitation depths were recalculated to install confidence in the final model results.

Table 7: Total Excess Precipitation Applied to 2D Mesh

Sub-Basin Description	Percent Annual Chance Precipitation Depths (in.)						
	1-percent	0.2-percent	2-percent	4-percent	10-percent	1-percent Plus	1-percent Minus
Navidad – Headwaters	6.81	11.59	5.13	3.75	2.31	11.36	2.56
Navidad – Mustang Creek	9.35	14.41	7.47	5.88	4.03	13.51	4.87

Figure 7 shows the excess precipitation hyetograph used for Navidad. Curve Number and precipitation depth are the two factors used by the HMS model to determine the magnitude of the excess precipitation event. The excess precipitation hyetograph is calculated in 6-minute increments. All models in this study have excess hyetograph shapes that closely resemble this one, but with varying maximum excess precipitation values.

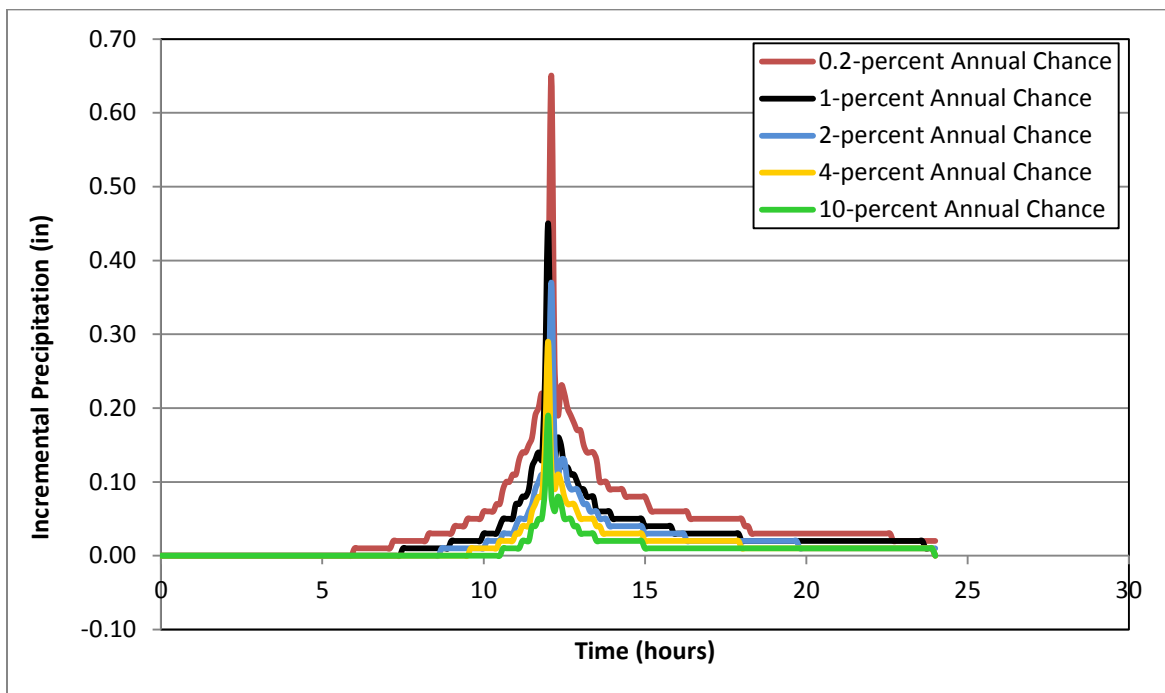


Figure 7: Excess Precipitation Hyetograph Applied to 2D Mesh – Navidad Headwaters

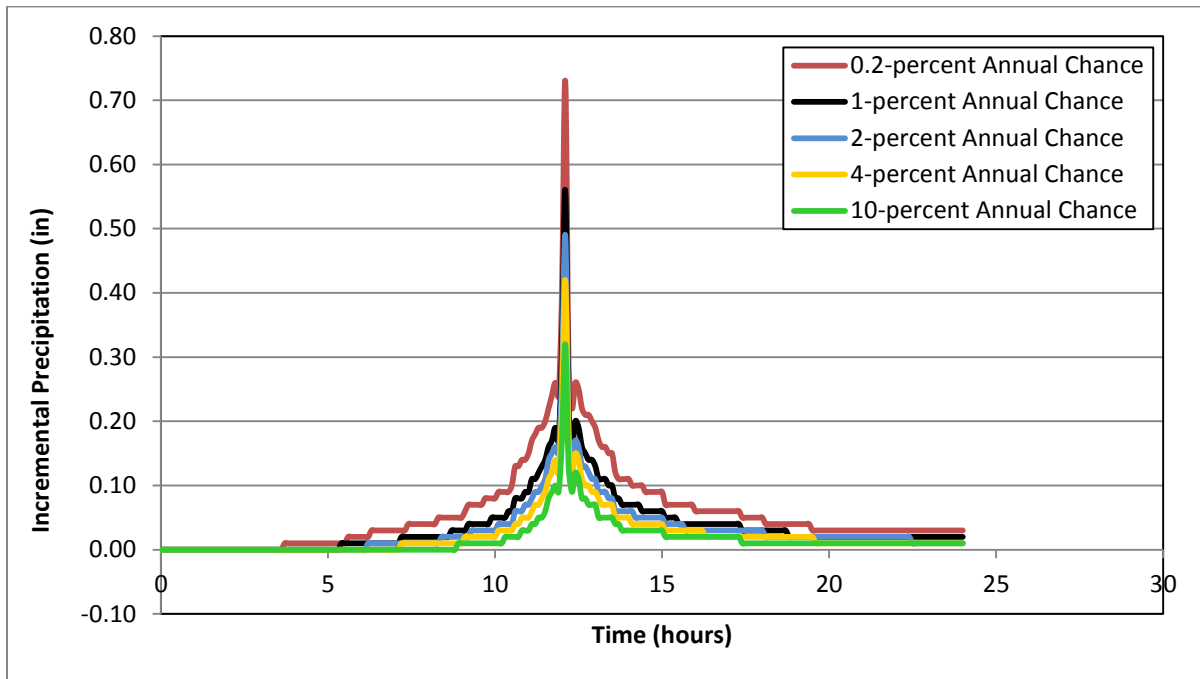


Figure 8: Excess Precipitation Hyetograph Applied to 2D Mesh – Navidad Mustang Creek

2.2.3.2 Inflow Hydrograph Boundary Conditions

Flow from the Navidad River in the Navidad Headwaters model was used as an inflow into the Mustang Creek model. The inflow hydrograph was derived by utilizing the results of the HEC-RAS model for Navidad Headwaters directly upstream. By using upstream model results as inflow hydrographs to the downstream model, this allows the two separate HEC-RAS models to act as one continuous model of the larger Navidad watershed area. The inflow hydrograph was extracted from the Navidad Headwaters model using a 2D connection. The inflow hydrograph applied to Mustang Creek RAS model is represented in Figure 9.

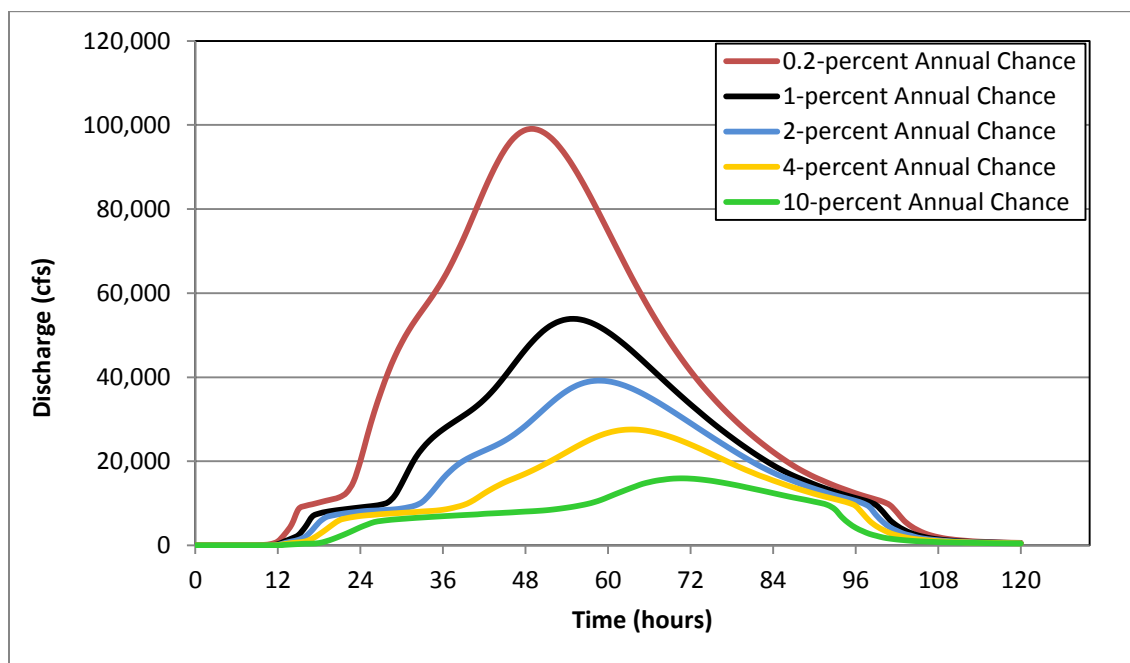


Figure 9: Inflow Hydrograph for Navidad Headwaters

In order to achieve a seamless flood hazard result at a transition location (locations where flow is exchanged between 2D model areas), the water surface elevation and inundation tie-ins between models must be made as close as possible. A 1,000 feet buffer was applied to each model work area for the mesh boundary. This is done so that the inflow boundary condition of the downstream model and the normal depth outlet boundary condition of the upstream model are far enough away from the work area transition location that they do not impact the Water Surface elevation tie-ins between models in an undesired way. To make this overlap work without double accounting for rainfall, an internal 2D connection is placed in the upstream model to extract a hydrograph at the exact same location as the inflow boundary condition to the downstream model location. This internal 2D connection is placed well upstream of the normal depth outlet boundary condition to ensure the flow hydrograph being passed to the downstream model is not affected by normal depth assumptions. Approximately halfway between the model overlap is the actual model area boundaries where the mapped floodplain products switch from the upstream model results to the downstream model results. This transition location is the targeted area to have the water surface elevation and inundation tie-in as closely as possible.

2.2.4 Hydraulics

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

2.2.4.1 Roughness Coefficients

Manning's n roughness coverage was developed for the 2D computational mesh using typical roughness values for given NLCD land classifications. Two different sets of Manning's n values were used for areas within the channel and all other areas outside of the channels of the stream network. The channel layers were created using a 100 foot buffer. This allows for the model to accurately represent deep, swift flow within the channel and shallow overland flow outside of the channel areas. The table below shows a typical landuse-roughness matrix used in defining the roughness coverage for the study area for areas both inside and outside of the channel.

Table 8: NLCD 2016 Manning's n Roughness Matrix

NLCD Classification	Channel		Overbank	
	N Value	Source	N Value	Source
Open Water	0.03	Chow, 1959	0.03	Chow 1959
Developed, Open Space	0.035	Chow, 1959	0.04	NRCS KS Dam Breach, 2016
Developed, Low Intensity	0.035	Chow, 1959	0.08	NRCS KS Dam Breach, 2016
Developed, Medium Intensity	0.035	Chow, 1959	0.1	NRCS KS Dam Breach, 2016
Developed, High Intensity	0.035	Chow, 1959	0.15	NRCS KS Dam Breach, 2016
Barren Land	0.03	Chow, 1959	0.03	NRCS KS Dam Breach, 2016
Deciduous Forest	0.05	Chow, 1959	0.16	NRCS KS Dam Breach, 2016
Evergreen Forest	0.05	Chow, 1959	0.16	NRCS KS Dam Breach, 2016
Mixed Forest	0.05	Chow, 1959	0.15	NRCS KS Dam Breach, 2016
Scrub/Shrub	0.04	Chow, 1959	0.1	NRCS KS Dam Breach, 2016

Table 8, continued: NLCD 2016 Manning's n Roughness Matrix

NLCD Classification	Channel		Overbank	
	N Value	Source	N Value	Source
Grassland/Herbaceous	0.04	Chow, 1959	0.15	HCFCF modeling Guidelines, 2018
Open Water	0.03	Chow, 1959	0.03	Chow 1959
Developed, Open Space	0.035	Chow, 1959	0.04	NRCS KS Dam Breach, 2016
Developed, Low Intensity	0.035	Chow, 1959	0.08	NRCS KS Dam Breach, 2016
Developed, Medium Intensity	0.035	Chow, 1959	0.1	NRCS KS Dam Breach, 2016

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. Road embankment features were delineated in GIS and imported into RAS5 as breaklines to contain water where appropriate. Similarly, significant bridge/culvert crossings that were not processed out of the terrain data were modeled by v-notch breaklines adjacent to the road embankment to align grid cells around the embankment and allow water to be routed through the embankment without creating artificial backwater. An example of the v-notch breakline approach is shown in Figure 10.

County, interstate, common name, state recognized, and U.S. roads were incorporated for road breaklines from the U.S. Census Bureau TIGER/Line road layer.

A breakline is added to represent Palmetto dam which is at the downstream of Navidad HUC-8. Private dams were not modeled as showing protection. This is to lessen the burden on private dam owners to maintain their dams in order to sustain the regulatory products created as a result of this study. The study area does not include any FEMA accredited levees.

Breaklines were also used along all the stream centerlines of streams draining greater than one square mile of drainage area. Each streamline was topo-derived and the stream centerline was enforced with 100 feet cell spacing in order to align cells along the stream line and capture more detail along the one square mile stream network. Stream names were referenced from other sources such as NFHL and NHD datasets.

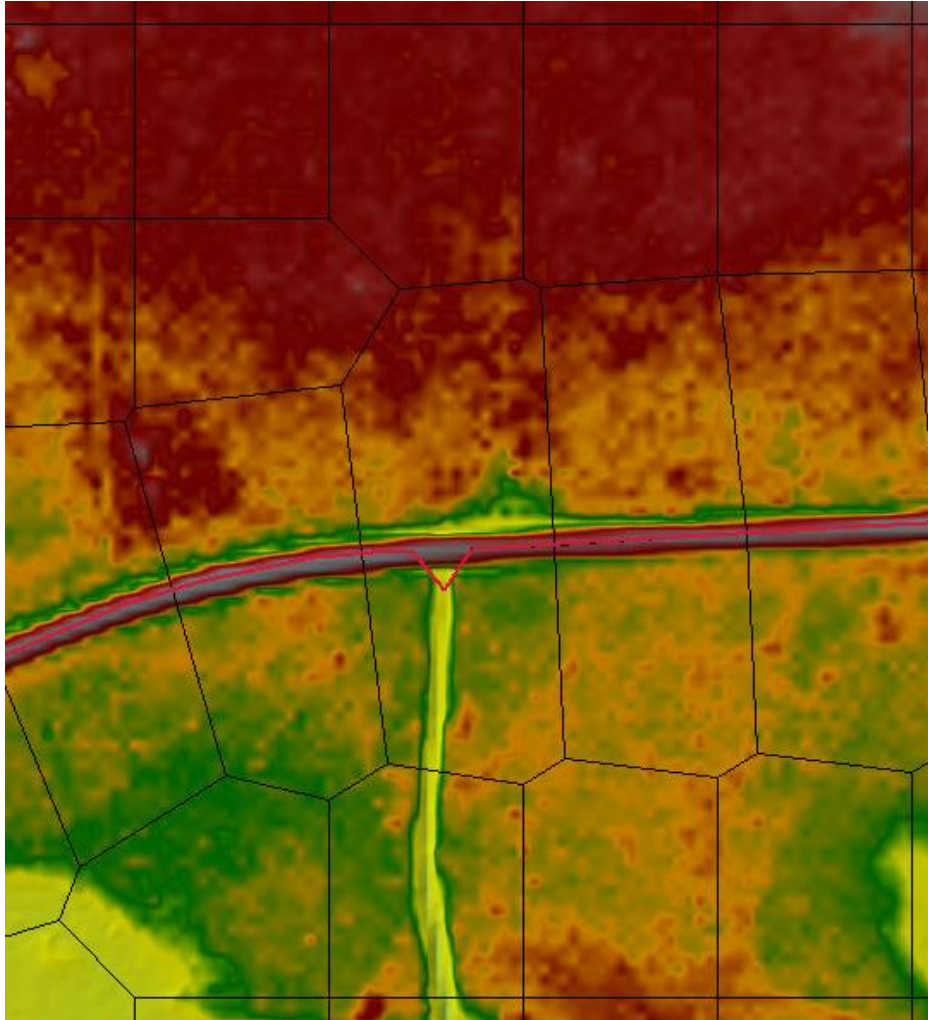


Figure 10: V-notch Breakline Approach at Bridge Crossing

2.2.4.3 Refinement Regions

Refinement regions were created for each community within the model. The political boundary was used to determine the shape of the refinement region. The regions were assigned a cell spacing of 50 feet by 50 feet. This finer cell spacing allows for more hydraulic calculations and mapping detail near areas where there are likely to be more structures. Table 9 shows the communities contained within Navidad watershed that were modeled with refinement regions as well as the square mileage of the refinement region.

Table 9: Communities with 2D Mesh Refinement

Community Name	Area (mi ²)
Edna City	0.02
El Campo City	0.89
Flatonia Town	0.69
Ganado City	1.16
Lolita CDP	0.22
Louise CDP	6.71
Schulenburg City	2.50
Weimar City	1.62

2.2.5 Quality Control

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

- Hydrological QC – included checks for curve number calculation, input precipitation, flood events, areal reduction factor and human error.
- Hydraulic QC – included checks for RAS geometry, breakline placement, v-notch placement to ensure water conveyance at crossings, refinement regions, roughness coefficients, boundary/initial conditions, timestep and mapping outputs
- Mapping – included checks for spot checking flood inundation accuracies based on floodplain mapping criteria described in section 4.1.2, ensuring flood extents from higher frequency events did not exceed lower frequency extents due to GIS smoothing algorithms, and topological overlap and cluster tolerance errors were resolved
- CNMS - Included review of the A1-A5 analysis for all effective approximate reaches in the HUC, geometry updates to newly studied reaches added as Zone X, and removal of scoped areas which lie outside of the final BLE footprint.

3. Results

The 2D BLE results for the study produced flood hazard area that compared reasonably well with effective SFHA in most cases, and provides additional estimated flood hazard risk area where not previously mapped. The HEC-RAS peak (max) results were exported for mapping and the HEC-RAS model was run with a hydrograph output interval of 30 minutes, mapping output interval of 1 hour and the detailed output interval of 1 hour. The Navidad watershed is sufficient to facilitate FEMA regulatory processes while also providing the best available information for planning purposes. The 2D BLE results should be verified through community work map meetings as part of the regulatory workflow.

Table 10: Effective and Model Base Flood Elevation(BFE) Comparison after calibration

Location Description	Effective BFE (feet)	Model BFE (feet)	Difference (feet)
Navidad River at County Road 283	97.1	102.61	5.51
Navidad River at FM Road 530	57.9	61.86	3.96
Navidad River Tributary No. 23 at State Highway 111	53.9	54.76	0.86
Mustang Creek at State Highway 172	49.1	55.98	6.88

3.1 Calibration

Known USGS gages within the model area with more than 10-years of flow record were used as the first priority for calibration of the 1-percent annual chance event. Discharges at gages were compared to discharges in the 2D models at the exact same locations. If a published rating curve was available, Water Surface Elevation from the model was compared to the calculated 1-percent Water Surface Elevation from the gage analysis.

Effective data was the second priority for calibration. Modeled flows were compared to flows from the summary of discharges tables from the Jackson County Flood Insurance Study (Effective September 2014) and Wharton County

Flood Insurance Study (Effective December 2017). Known water surface elevations were used for validation, not calibration. Upper and lower limits for the effective flows were calculated by hand and were not taken from the FIS report. They were calculated by:

$$\text{Upper Limit} = 0.501 * 1\%Q$$

$$\text{Lower Limit} = 1.995 * 1\%Q$$

Five USGS gage that fall within the boundary of Navidad watershed were utilized for calibration purposes. Additional effective data was used for secondary calibration, but priority was given to the USGS gage analysis results. Adjustments to hydraulic features within the model were made until the flows in the model matched closely with the peak flows determined from gage and effective data. No adjustments were needed for the curve number or the n-values. Final results following model calibration at the calibration locations were presented in Table 11. The discharge from HEC-RAS model were calibrated with four USGS stream gages, however due to the limitations and scope of this study, extensive efforts were not feasible. Therefore, model flows were accepted although they are a slightly higher than the specified range of USGS gage 08164390.

Table 11: Calibration Results

Calibration Location	Source	Method Used in Original Study	Reference			HEC-RAS 5.0.7 (2D) (cfs)
			Lower Limit (cfs)	1-percent (cfs)	Upper Limit (cfs)	
Gage 08164300	Navidad Rv nr Hallettsville, TX	USGS	36,875	58,232	79,589	61,663
Gage 08164390	Navidad Rv at Strane Pk nr Edna, TX	USGS	20,856	32,756	44,656	53,882
Gage 08164450	Sandy Ck nr Ganado, TX	USGS	32,382	50,670	68,958	58,793
Gage 08164503	W Mustang Ck nr Ganado, TX	USGS	15,794	24,775	33,756	24,623
Gage 08164504	E Mustang Ck nr Louise, TX	USGS	4,163	6,652	9,141	7,553
Mustang Creek Tributary No. 9 above confluence	Jackson County FIS	USGS Report 77-110 methodologies	517	1,031	2,057	1,365
East Mustang Creek at U.S. Highway 59	Wharton County FIS	USGS Report 77-110 methodologies	1,197	2,390	4,768	3,701
East Mustang Creek above confluence	Wharton County FIS	USGS Report 77-110 methodologies	1,353	2,701	5,388	3,154

Figure 11 shows the final results of the calibration locations compared to modeled flows throughout the Navidad watershed along with error bars created using the difference between 1-percent and 1-percent plus discharges and 1-percent and 1-percent minus discharge as minimum and maximum values. Eight comparisons were made with varying drainage areas to ensure the calibration of excess precipitation for different points over the entire watershed area. This large collection of calibration points provides confidence in results throughout the entire watershed.

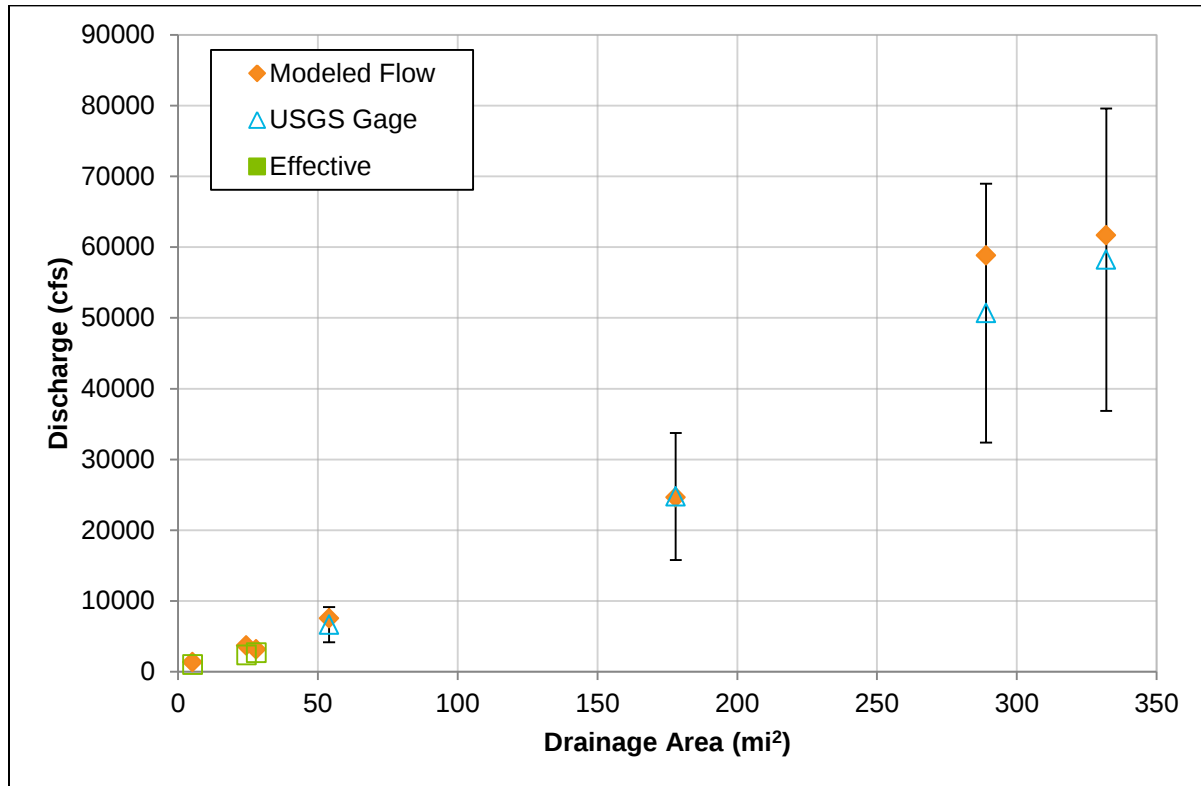


Figure 11: Calibration Comparison

Based on the published rating curve was available, water surface elevation from the model was compared to the calculated 1-percent WSEL from the gage analysis, as shown in Table 12.

Table 12: 1-percent Gage WSEL and RAS WSEL Comparison

USGS Gage ID	Lower Bound (feet)	Gage WSEL 1-percent (feet)	Upper Bound (feet)	HEC-RAS 5.0.7 WSEL (feet)
08164300	194.0	195.46	196.5	196.25
08164390	72.84	74.85	76.25	74.07
08164450	88.67	91.16	93.47	81.83
08164503	66.14	70.91	74.91	59.52
08164504	64.88	65.97	66.68	63.42

It was observed that Navidad Headwaters was calibrated much better than Navidad Mustang Creek model. Water surface elevation (WSE) at the gage locations (Gages 08164450, 08164503 and 08164504) in Mustang Creek model do not fall within the estimated range. Because Mustang Creek model drains into Lake Texana that lies along the Navidad River in the middle of Jackson County. It is likely that the WSE is affected by the backwater of the lake. Due

to the limited engineering efforts put in the Base Level Engineering, 1-percent discharge from the model is accepted within the scope of the study.

3.2 Challenges

A considerable challenge for the Navidad watershed was the size of the HUC8 basin. In order to create this model without creating runtime or cell number issues, it was decided that the watershed would be split into two working models. The outflow from the upstream model containing the Navidad River was then used as an inflow boundary condition to the downstream model. The Navidad watershed contains the Palmetto Bend Dam at the outlet of Lake Texana. Due to the project scope, structure outlet data was not included in this analysis, and the outlet was left unrestricted. The HUC-8 also included a large urbanized area.

Within the watershed, there are several populated areas and agricultural fields that appear to be trapping water which prevents runoff from reaching the channel in the model. Various v-notches were applied to represent cross culverts and improve conveyance. Several breaklines and refinement regions increased the total number of cells and thereby increasing the model runtime.

3.3 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.

Point source Atlas 14 rainfall was used in the analysis, and due to the large size of the modeled area (the entire HUC-8 watershed), the point rainfall used has a tendency to vary more widely from the actual point rainfall data at any specific location within the watershed. For detailed modeling and further improvements, smaller-sized modeled areas are recommended, which will result in smaller rainfall and curve number variability. In addition, future versions of HEC-RAS are anticipated to include the capability to utilize spatially varying rainfall, which may result in additional improvements. The hydraulic model can further be improved by using a smaller cell size than 200 foot along with adding structural and survey data for each crossing.

4. Floodplain Mapping and Effective Zone A Validation

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

4.1 Special Flood Hazard Area

4.1.1 Model Outputs

The HEC acknowledged RAS Mapper may not render water surface elevation values and/or delineate inundation extent appropriately for direct use in FEMA regulatory mapping products. With guidance from TWDB, AECOM created a workflow to export model water surface elevation values for each 2D mesh cell to develop regulatory-ready water surface elevation grids and subsequent flood hazard area mapping features.

4.1.2 Methodology

Maximum water surface elevation values were exported for each model's two-dimensional computational mesh cell centroid. Densified points were added to the cell centroid points along the edges of the floodplain in the water surface elevation rasters (exported from the model in sloping render mode) and areas of zero slope (ponds) from the terrain DEM to help meet FEMA regulatory mapping product requirements. A triangular irregular network (TIN) was created from the points, and water surface elevation and depth grids were created from the TIN to match the resolution of the input terrain DEM.

Discussion with AECOM, Half Associates and TWDB determined that floodplain outputs should reduce the overall inundation using statistical analysis of flood hazard depths and areas. In watersheds that include areas in the

headwaters that follow more typical riverine channel flooding, the methodology is different compared to the areas near the coastal floodplain.

In order to determine whether an area should be mapped with Riverine or Coastal methodology, statistical analysis was performed on the slope of the DEM. The slope DEM was clipped into individual HUC12 rasters and the mean value and standard deviation values were reviewed for each HUC12. The coefficient of variation (CV) was calculated using the following formula.

$$CV = \text{Standard Deviation} / \text{Mean}$$

Using a visual review, CV values less than 1.35 were found to correspond to areas that appeared to be largely made up of riverine channel terrain, while areas above 1.45 contained less channelization and were more typical of coastal terrain. Values that were between 1.35 and 1.45 were reviewed and the methodology was determined based on engineering/mapping judgement. The Navidad HUC12 CV calculations are found in Table 13.

Table 13: Navidad HUC-8 Slope Analysis

HUC-12	Mean	Standard Deviation	CV	Methodology
121001020101	2.50	2.48	0.99	Riverine
121001020102	2.38	2.54	1.06	Riverine
121001020103	2.53	2.57	1.02	Riverine
121001020104	2.61	2.83	1.09	Riverine
121001020105	2.66	2.90	1.09	Riverine
121001020106	2.39	2.57	1.07	Riverine
121001020107	2.20	2.47	1.13	Riverine
121001020108	2.44	2.85	1.17	Riverine
121001020201	2.18	2.56	1.17	Riverine
121001020202	1.82	2.45	1.34	Riverine
121001020203	1.59	2.32	1.46	Coastal
121001020204	1.78	2.28	1.28	Riverine
121001020205	1.27	2.11	1.66	Coastal
121001020206	1.25	2.21	1.76	Coastal
121001020301	1.98	2.38	1.20	Riverine
121001020302	1.79	2.51	1.40	Riverine
121001020303	1.49	2.11	1.41	Riverine
121001020304	0.86	2.09	2.44	Coastal
121001020305	1.34	2.14	1.59	Coastal
121001020306	0.83	1.85	2.24	Coastal
121001020307	0.84	1.66	1.97	Coastal
121001020308	0.93	1.79	1.93	Coastal
121001020309	0.81	1.67	2.05	Coastal
121001020310	1.29	2.41	1.86	Coastal

Table 13, Continued: Navidad HUC-8 Slope Analysis

HUC-12	Mean	Standard Deviation	CV	Methodology
121001020401	1.18	3.31	2.80	Coastal
121001020402	0.70	1.52	2.17	Coastal
121001020403	0.91	2.17	2.39	Coastal
121001020404	0.80	1.93	2.41	Coastal
121001020405	0.84	2.09	2.49	Coastal
121001020501	1.22	2.15	1.77	Coastal
121001020502	0.90	1.66	1.84	Coastal
121001020503	0.74	1.71	2.33	Coastal

For the Navidad watershed, the following parameters were applied to remove or reduce floodplain inundation:

4.1.2.1 Riverine Methodology

- Removal of all polygons smaller than 10,890 square feet, regardless of average depth.
- Removal of polygons between 10,890 and 21,780 square feet with an average depth less than ½ foot.
- Removal of polygons between 21,780 and 43,560 square feet with an average depth less than ¼ foot.
- Removal of polygons between 43,560 and 87,120 square feet with an average depth less than 1/10th foot.

4.1.2.2 Coastal Methodology

- Removal of all depths below 1/3rd of a foot across the watershed.
- Removal of all polygons smaller than 10,890 square feet, regardless of average depth.
- Removal of polygons between 10,890 and 21,780 square feet, with an average depth between 1/3rd and ½ foot.

The final polygons were smoothed and simplified in order to meet FEMA regulatory mapping specifications. Small islands less than 13,068 square feet in the polygons were filled in.

Minor adjustments were made to the floodplain boundaries along open water rivers, ponds and other waterways to ensure floodplain connectivity in situations where floodplain areas were removed based on the parameters mentioned above. Minor tributaries or roadside ditches that aren't fully inundated were not adjusted. The watershed does contain open water detention ponds that are elevated compared to surrounding areas. These ponds have not been included in the floodplain boundaries in situations that the sloping model raster did not show inundation.

Mapping for the 0.2-percent annual chance was also performed in a similar manner as mentioned above in regard to the removal of depths and areas. Due to methodologies and tolerances applied in the ArcGIS smoothing tool, minor differences between 1-percent and 0.2-percent boundaries where the extent of the 1-percent boundary would exceed the 0.2-percent have been resolved by copying the 1-percent boundaries into the 0.2-percent boundaries and merging the boundaries together.

Mapping for the 10-percent annual chance was also performed in a similar manner in regard to the removal of depths and areas. No adjustments were made beyond the removal of very minor differences that could result from the smoothing methodologies and tolerances, as mentioned previously. In locations where the 10-percent boundary exceeded the 1-percent boundary due to smoothing, those areas have been removed.

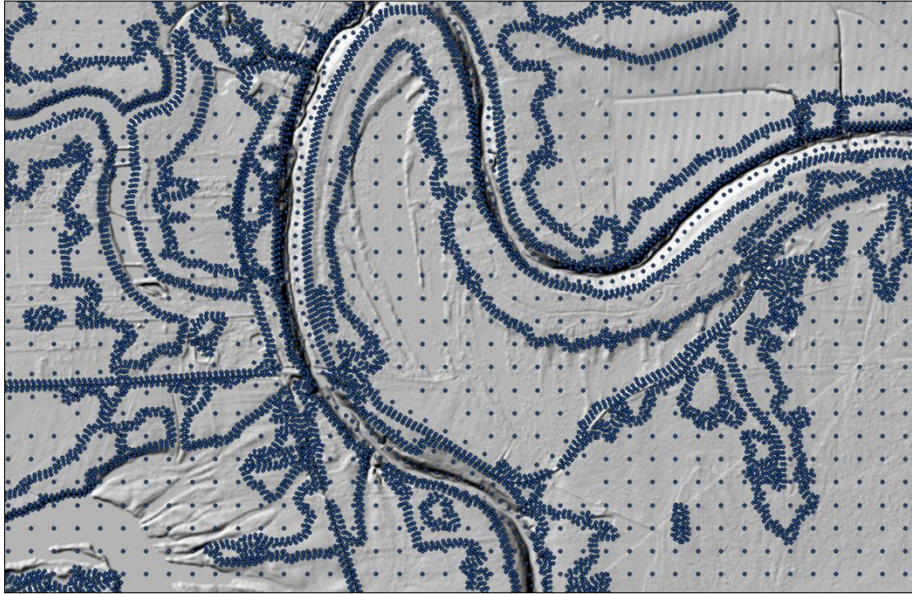


Figure 12: 2D BLE Model Points for Mapping Workflow

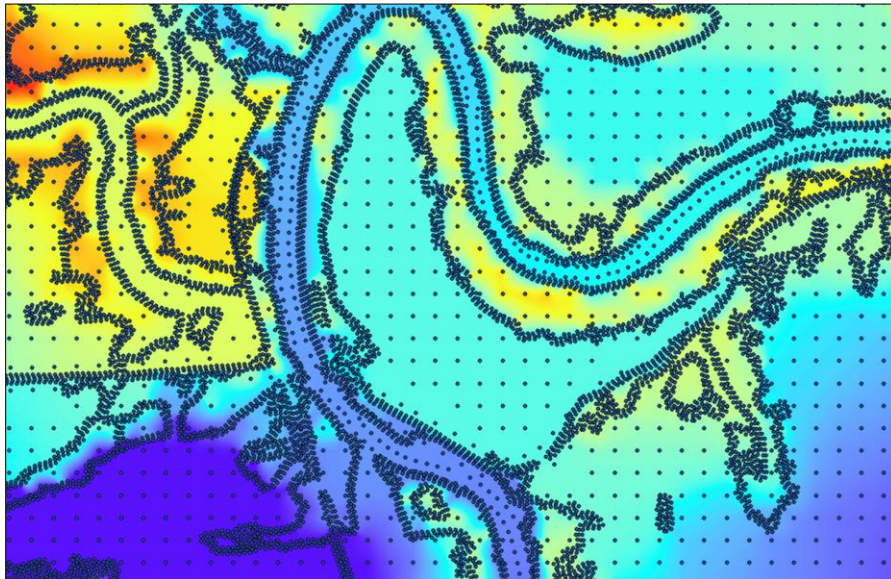


Figure 13: 2D BLE Model Points to Water Surface Elevation TIN

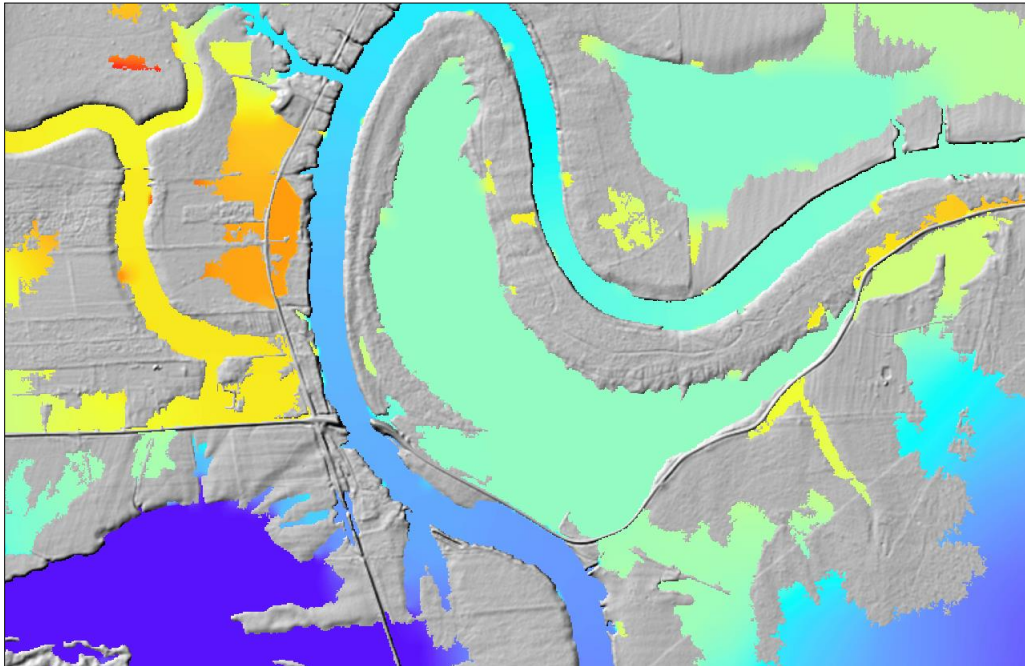


Figure 14: Water Surface Elevation TIN to Grid

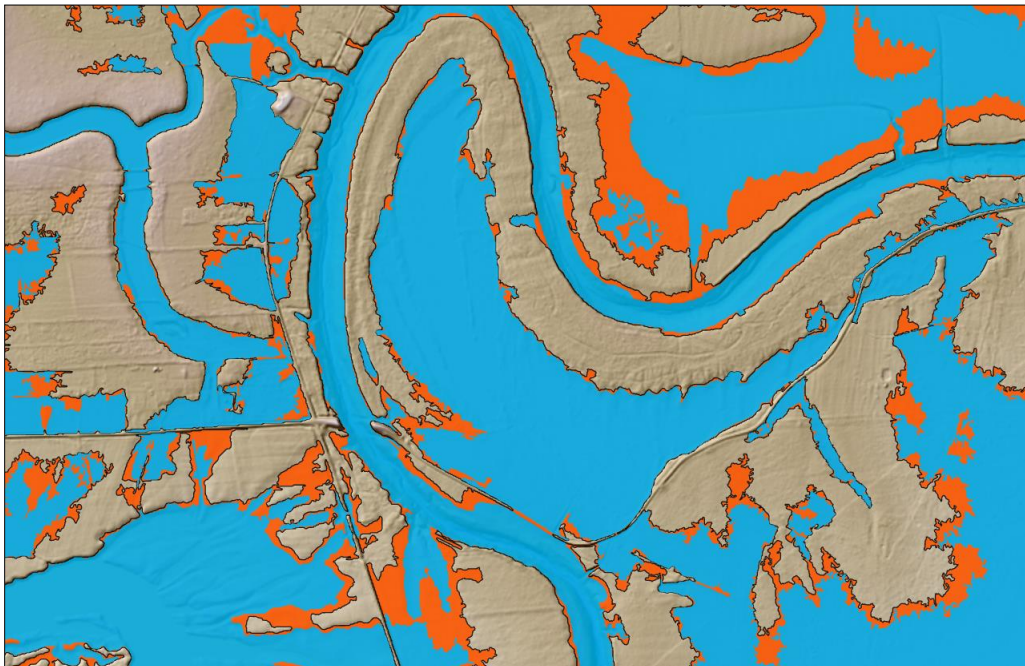


Figure 15: Water Surface Elevation Grid to Mapping Products

4.1.3 BLE Flood Hazard Layer

BLE database format FLD_HAZ_AR feature classes were developed and attributed with Zone A and Shaded Zone X features. The BLE FLD_HAZ_AR feature class was tested for topological errors described in the FIRM Database Technical Reference and all errors were fixed for data integrity and schema agreement. The 10-percent boundaries have been included in the BLE TENPCT_FP feature class.

4.1.4 Additional 1-Percent Features

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

A map showing the BLE results is included as Appendix A BLE Map.

BLE 1-percent annual chance inundation not mapped as BLE SFHA is retained in an additional 1-percent feature class that can be used at Discovery to communicate other areas of flood hazard.

4.2 Validation of Effective Zone A SFHA

The inventory of Zone A studies (815.3 miles) in the Navidad watershed were classified in CNMS with validation status of "UNVERIFIED" (262.7 miles) or "VALID" (552.6 miles), and with status type of "BEING STUDIED." The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A3 were evaluated for the CNMS inventory of Zone A studies.

4.2.1 Initial Assessment A1 – Significant Topography Update Check

This check involves determining whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. For the study area in the Navidad watershed, all effective Zone A topographic data utilized USGS topographic maps. The LiDAR sources now available used in this BLE study are considered significant improvements from the effective zone A topographic sources; therefore, all reaches fail this check.

4.2.2 Initial Assessment A2 – Check for Significant Hydrology Changes

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

Zone A streams in Wharton County utilized 1996 regression equations. The new regression equations published in 2009 create a significant change and, therefore, the reaches in Wharton County fail this check. For all other Zone A streams in the Navidad watershed, regression equations are not known to have been used for the effective studies and, therefore, pass this check.

4.2.3 Initial Assessment A3 – Check for Significant Development

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

All Zone A studies within the watershed are classified as rural and, therefore, pass this check.

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

Table 14: Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Pass	LiDAR sources available are a significant improvement from effective topography.
A2 – Hydrology	Pass/Fail	Regression equations not used in effective study/ New equations were published since effective analysis
A3 – Development	Pass	Watershed does not meet urban threshold

4.2.4 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.

All zone A streams in Wharton County are model backed and pass this check. All other zone A streams within the Navidad watershed are not known to be model backed and, therefore, fail this check.

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

The BLE /effective Zone A comparison method leverages the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach uses the 1-percent plus and 1-percent minus flood profiles and horizontal and vertical tolerances described in FEMA’s Automated Engineering guidance document dated May 2016. For the comparison of BLE and effective Zone A in the Texas study area, the following vertical and horizontal tolerances were used to conduct the modified FBS procedure. One point was placed every 200 feet along the floodplain boundaries for comparison.

- Vertical Tolerance: +/- 5 feet (one-half contour interval of effective topographic source).
- Horizontal Tolerance: +/- 75 feet (standard horizontal tolerance for BLE comparison testing).

Comparison results for these streams were grouped at the HUC-12 level and are summarized in Table 15 to better understand the general health of the HUC-12 watershed, but the validation check was performed at the stream level. Streams where the percentage of passing FBS sample points is greater than or equal to 85% are marked as “Pass”, otherwise marked as “Fail”.

Table 15: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Navidad Watershed	All Streams	48,902	6,691	42,211	86%	Pass	
Big Rocky Creek	121001020106	2,325	238	2,087	90%	Pass	5.0
Brushy Creek-Navidad River	121001020201	2,747	339	2,408	88%	Pass	7.1
Clear Creek-East Navidad River	121001020104	1,524	111	1,413	93%	Pass	3.2
Cottonwood Creek-Navidad River	121001020105	1,026	43	983	96%	Pass	2.1
Devers Creek-Mustang Creek	121001020502	571	92	479	84%	Fail	9.6
East Mustang Creek	121001020404	1,595	570	1,025	64%	Fail	19.6

Table 15, continued: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Goldenrod Creek	121001020307	679	69	610	90%	Pass	5.4
Hardys Sandy Creek-Navidad River	121001020205	2,152	158	1,994	93%	Pass	5.7
Honey Creek-Navidad River	121001020108	1,306	200	1,106	85%	Pass	7.7
Lost Fork Goldenrod Creek-Goldenrod Creek	121001020308	1,058	184	874	83%	Fail	11.8
Lower Pinoak Creek	121001020306	1,887	298	1,589	84%	Fail	9.6
Lower Sandy Creek	121001020310	875	168	707	81%	Fail	9.6
Lower West Sandy Creek	121001020302	1,471	169	1,302	89%	Pass	7.7
Middle Creek-East Navidad River	121001020102	2,050	203	1,847	90%	Pass	5.4
Middle Mustang Creek	121001020405	587	119	468	80%	Fail	9.6
Middle Sandy Creek	121001020305	1,030	265	765	74%	Fail	16.0
Middle West Mustang Creek	121001020403	1,643	495	1,148	70%	Fail	13.6
Mixon Creek	121001020107	1,729	206	1,523	88%	Pass	8.2
Mulberry Creek-West Navidad River	121001020103	2,283	170	2,113	93%	Pass	3.6
Porters Creek	121001020402	1,295	264	1,031	80%	Fail	10.2
Ragsdale Creek	121001020203	1,909	170	1,739	91%	Pass	4.5
Rocky Creek-West Navidad River	121001020101	2,423	184	2,239	92%	Pass	4.1
Sandies Creek-Navidad River	121001020204	1,779	158	1,621	91%	Pass	6.6
Sandy Creek-Navidad River	121001020501	693	61	632	91%	Pass	10.7
Stem Branch-Navidad River	121001020206	757	46	711	94%	Pass	3.7
Sutherland Creek-Brushy Creek	121001020309	1,520	315	1,205	79%	Fail	12.1
Upper Pinoak Creek	121001020304	1,713	446	1,267	74%	Fail	20.8
Upper Sandy Creek	121001020303	3,096	166	2,930	95%	Pass	3.4
Upper West Mustang Creek	121001020401	1,256	459	797	63%	Fail	24.6
Upper West Sandy Creek	121001020301	2,203	190	2,013	91%	Pass	4.3
Willow Creek-Navidad River	121001020202	1,720	135	1,585	92%	Pass	3.9

4.2.6 Validation Results

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Navidad watershed has been updated as summarized in Table 16 and illustrated in Figure 16.

Table 16: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	552.6
UNVERIFIED	BEING STUDIED	262.7

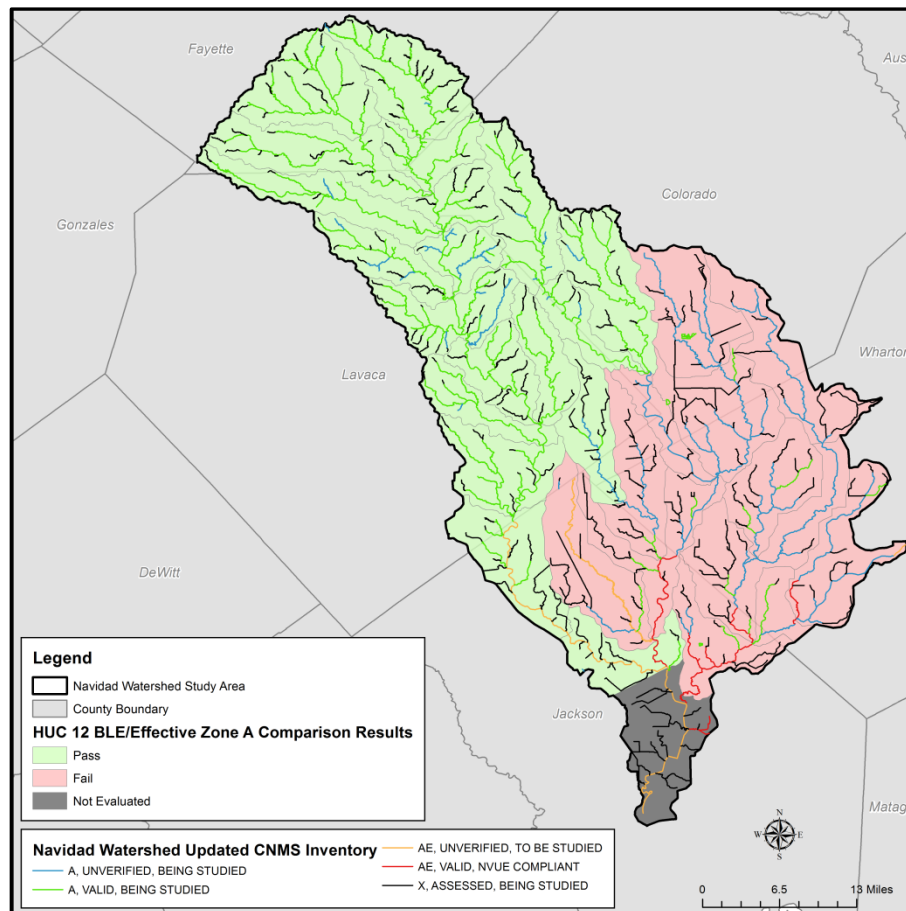


Figure 16: Navidad Watershed CNMS Validation Results

An overall risk for each HUC-12 watershed was calculated using the National Flood Risk Percentages Dataset and its proportional area. The weighted risk was multiplied by the percentage of points in the watershed that failed the CNMS comparison to effective to determine the priority score. Figure 17 below shows the range of the HUC-12 priority scores which can be used to initiate discussions during the Discovery phase.

Upper West Mustang Creek HUC-12 was determined to have the highest priority score and the most need while Cottonwood Creek-Navidad River HUC-12 had the lowest score.

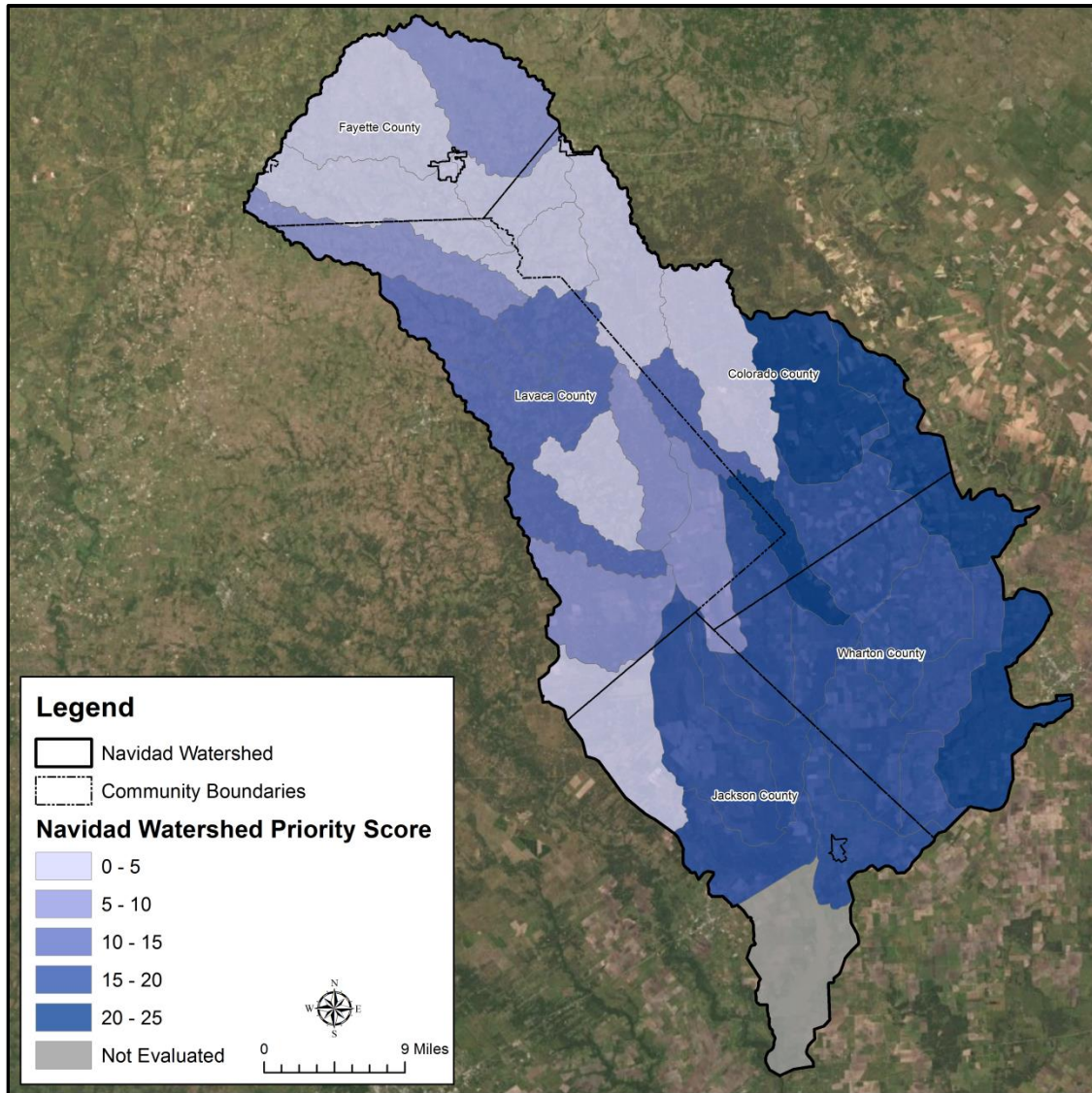


Figure 17: Ranking of Navidad Watershed HUC-12s

4.3 Flood Risk Analysis

A flood risk analysis was performed for this project. The updated 1-percent annual chance and 0.2-percent annual chance depth grids were 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 (SP03) 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 (SP03) uses dasymetric census blocks. Dasymetric mapping removes undeveloped areas (such as areas covered by other bodies of water, wetlands, or forests) from the census blocks, changing their shape and reducing their size in these areas. For more information on dasymetric data visit FEMA's [Media Library](#) for the [Hazus-MH Data Inventories: Dasymetric vs. Homogenous](#), or [Hazus 3.0 Dasymetric Data Overview](#).

Hazus analysis was performed by county within the project watershed extents for each return period to ensure proper model processing. A summary of results for these counties for the 1-percent a.c.e. scenarios are shown in Table 17.

Table 17: Hazus 4.2 (SP03) Results for 1-Percent-Annual-Chance (100 year) Scenario

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Colorado	\$16,317,000	\$418,017,000	\$236,122,000
Fayette	\$49,808,000	\$840,073,000	\$971,806,000
Jackson	\$51,612,000	\$492,412,000	\$359,786,000
Lavaca	\$18,376,000	\$318,476,000	\$171,488,000
Wharton	\$45,207,000	\$458,412,000	\$265,326,000
Total	\$181,320,000.00	\$2,527,390,000.00	\$2,004,528,000.00

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Appendix A BLE Map

