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

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Table of Contents

List of Figures

List of Tables

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 Lavaca 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 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 standards 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 water surface elevations for each of the seven recurrence intervals previously identified.

The Lavaca Watershed 2D BLE project was scoped as described in the TWDB Task Order 8. In an effort to increase and enhance the flood risk products in Texas, the study was contracted through the Texas Water Development Board's (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 Lavaca Watershed footprint.

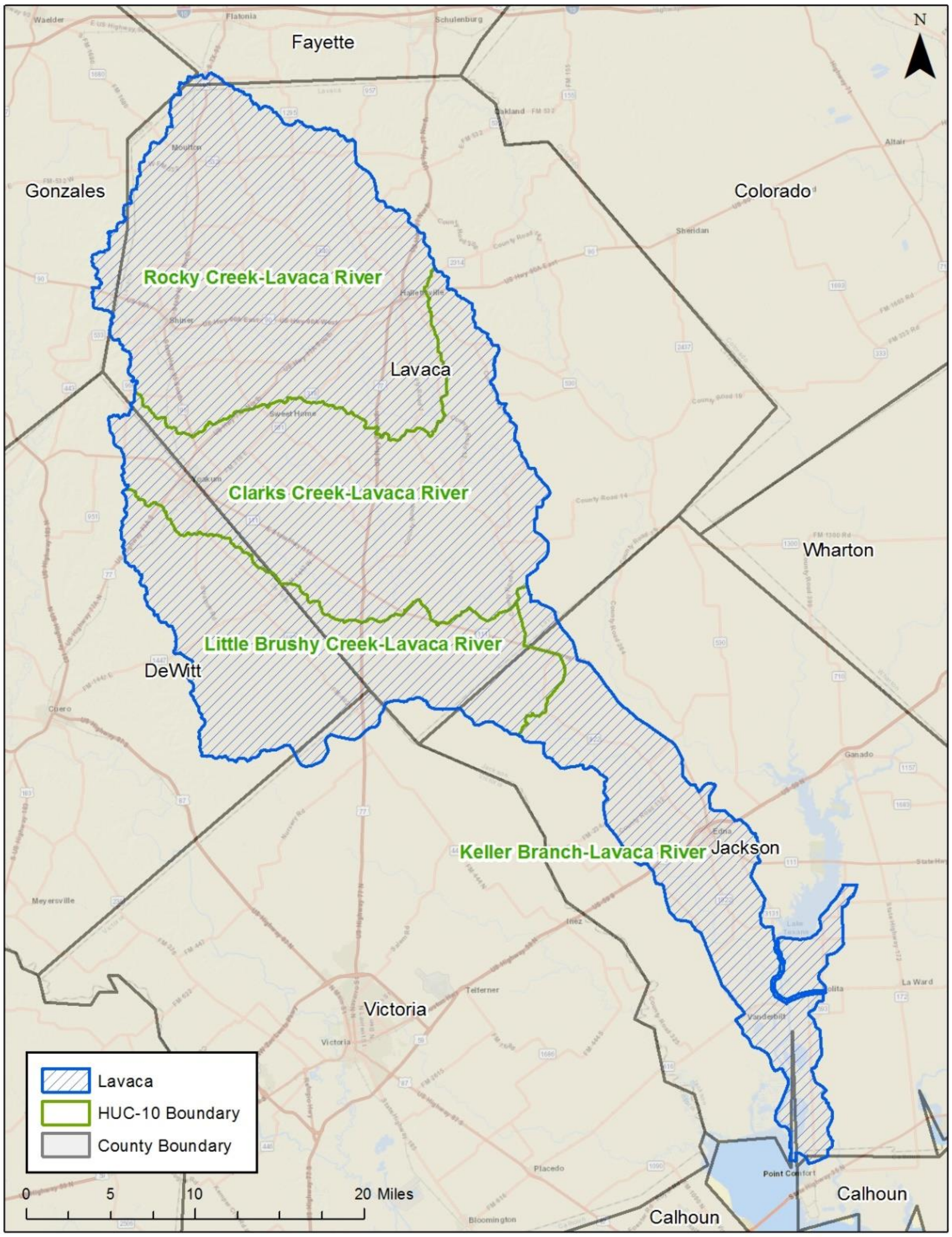

Figure 1: Lavaca Watershed

2. 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2D hydraulic engineering analysis for the Lavaca 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 Lavaca 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 feet DEM developed to support the 2D BLE modeling and analysis, within the Lavaca 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 Lavaca Watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Lavaca BLE Watershed footprint. Figure 2 depicts the datasets identified and leveraged across the project area. FEMA, National Oceanic and Atmospheric Administration (NOAA), United States Geological Survey (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.

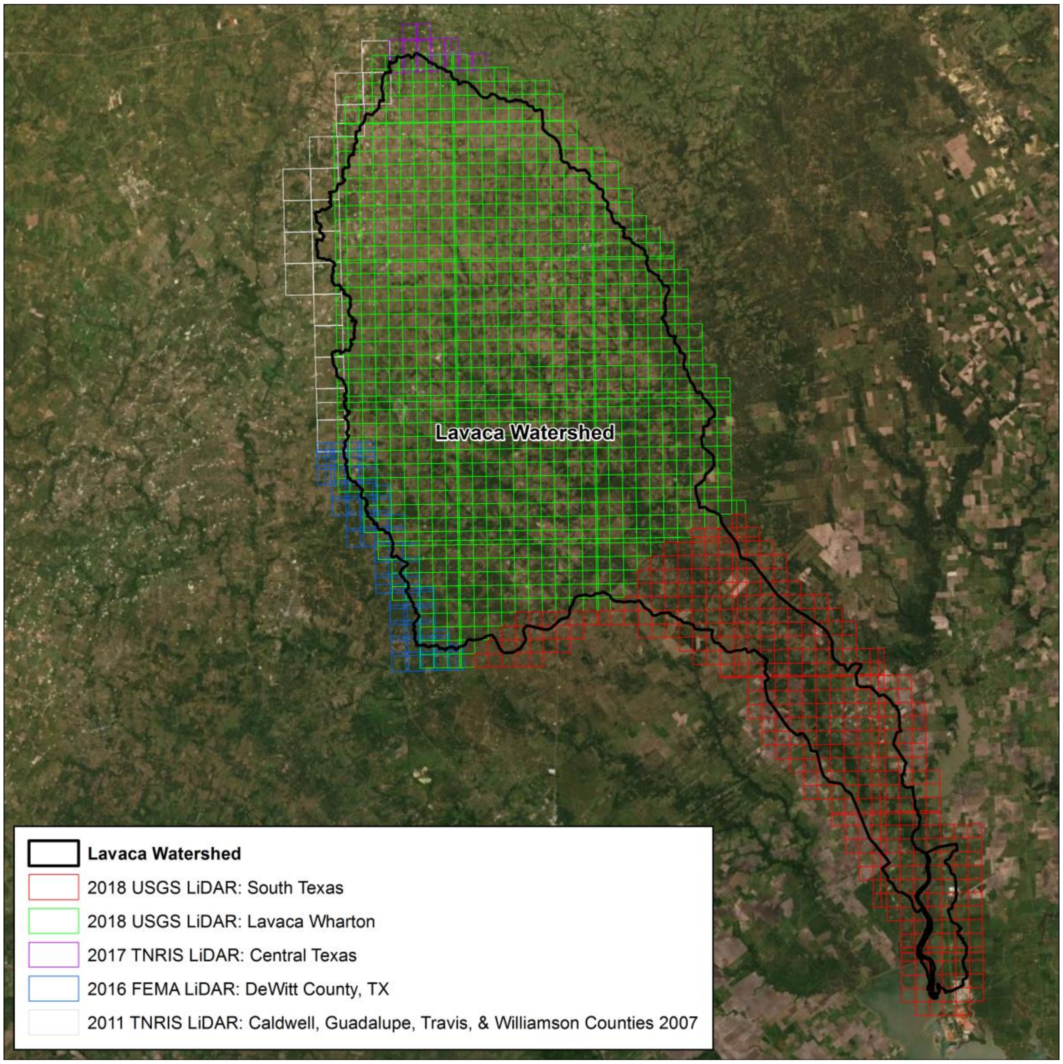

Figure 2: Lavaca Watershed BLE Source Terrain Data

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 Lavaca 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 Lavaca Watershed

Year	Description	Source/Owner	Accuracy[1]	Approximate Footprint (Sq. Miles)[2]
2018	2018 Texas: South Texas LiDAR	USGS	17.64 cm	327.3
2018	2018 Lavaca and Wharton Countries LiDAR	USGS	16.3 cm	834.4
2017	2017 TNRIS LiDAR: Central Texas	TNRIS/TWDB	6.175 cm	8.6
2016	2016 FEMA LiDAR: DeWitt County, TX	FEMA	14.3 cm	24.6
2011	2011 TNRIS LiDAR: portions of DeWitt, Gonzales and Lavaca	TNRIS/TWDB	18.02 cm	55.5

[1]RMSEz reported at the 95% confidence level

[2]Size of LiDAR DEM footprint utilized for BLE study

2.1.2.1 Lavaca Watershed Source Terrain Data

The source elevation data for the Lavaca Watershed are DEMs derived from the 2018 Texas – South Texas LiDAR; the 2018 Lavaca and Wharton Countries LiDAR; the 2017 TNRIS LiDAR: Central Texas; the 2016 FEMA LiDAR: DeWitt County, TX and the 2011 TNRIS LiDAR: portions of DeWitt, Gonzales and Lavaca. 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 Texas: South Texas LiDAR

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.

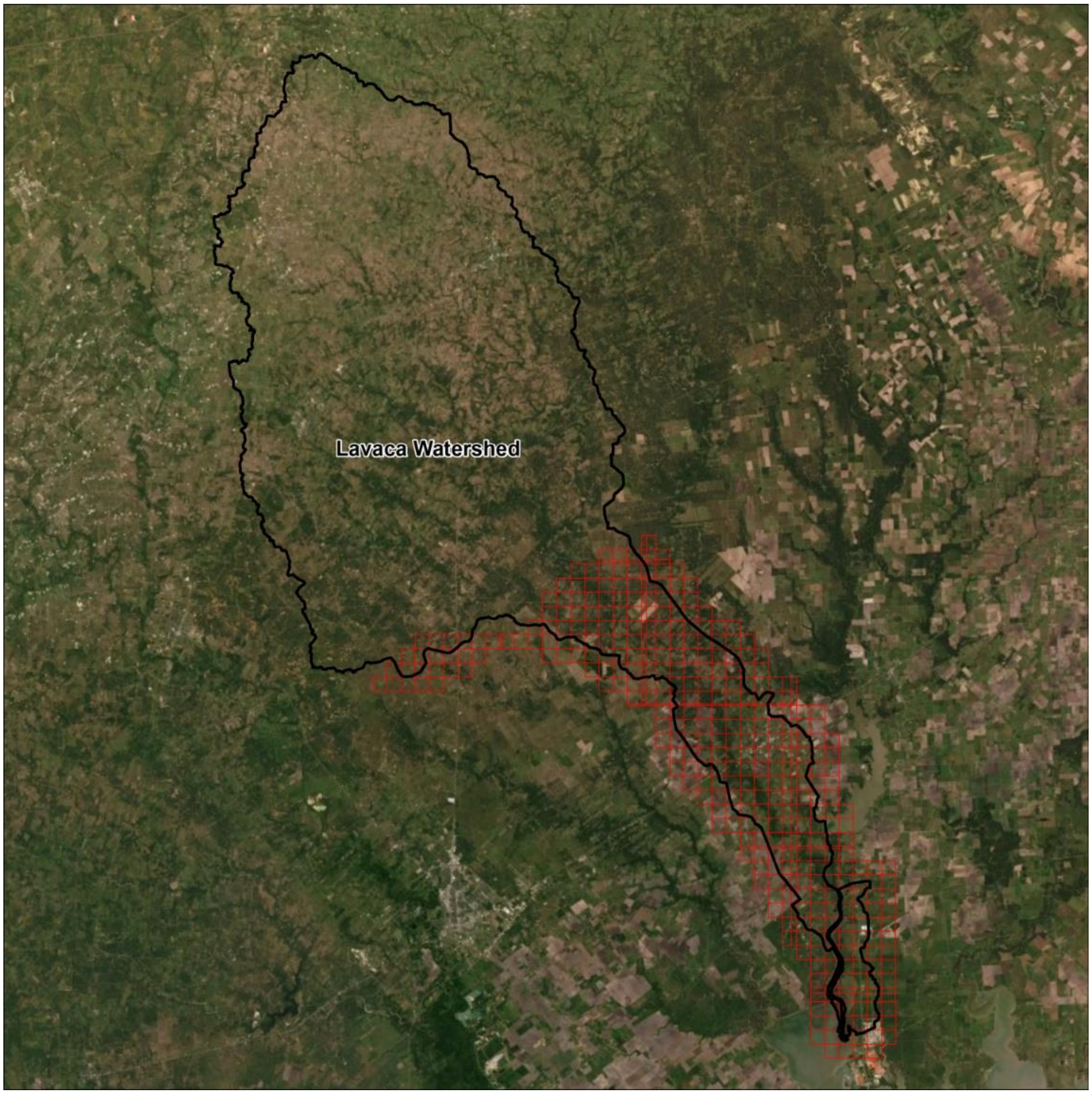

Figure 3: 2018 Texas – South Texas LiDAR

2018 Lavaca and Wharton Countries 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.

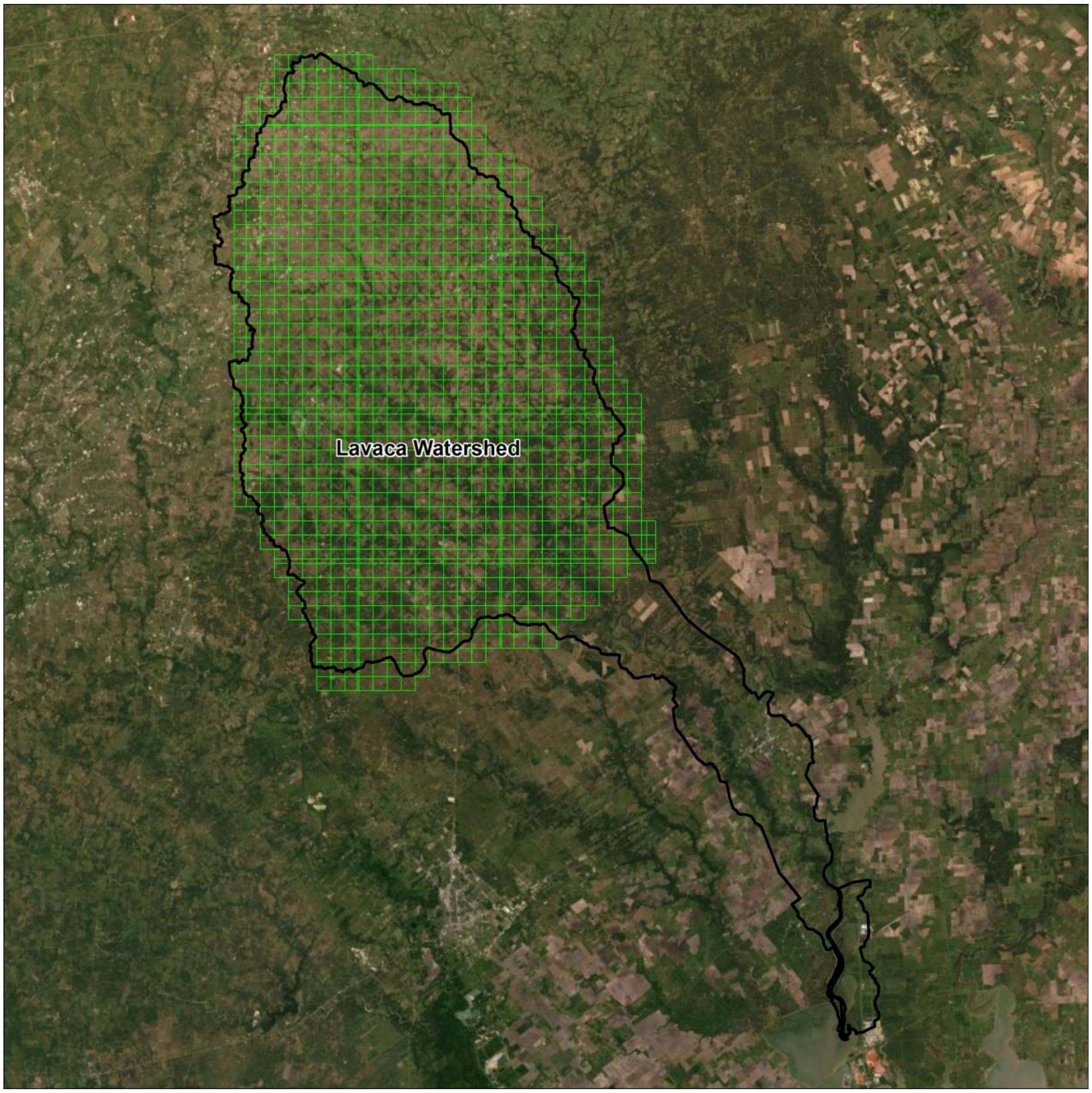

Figure 4: 2018 Lavaca & Wharton Countries LiDAR

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.

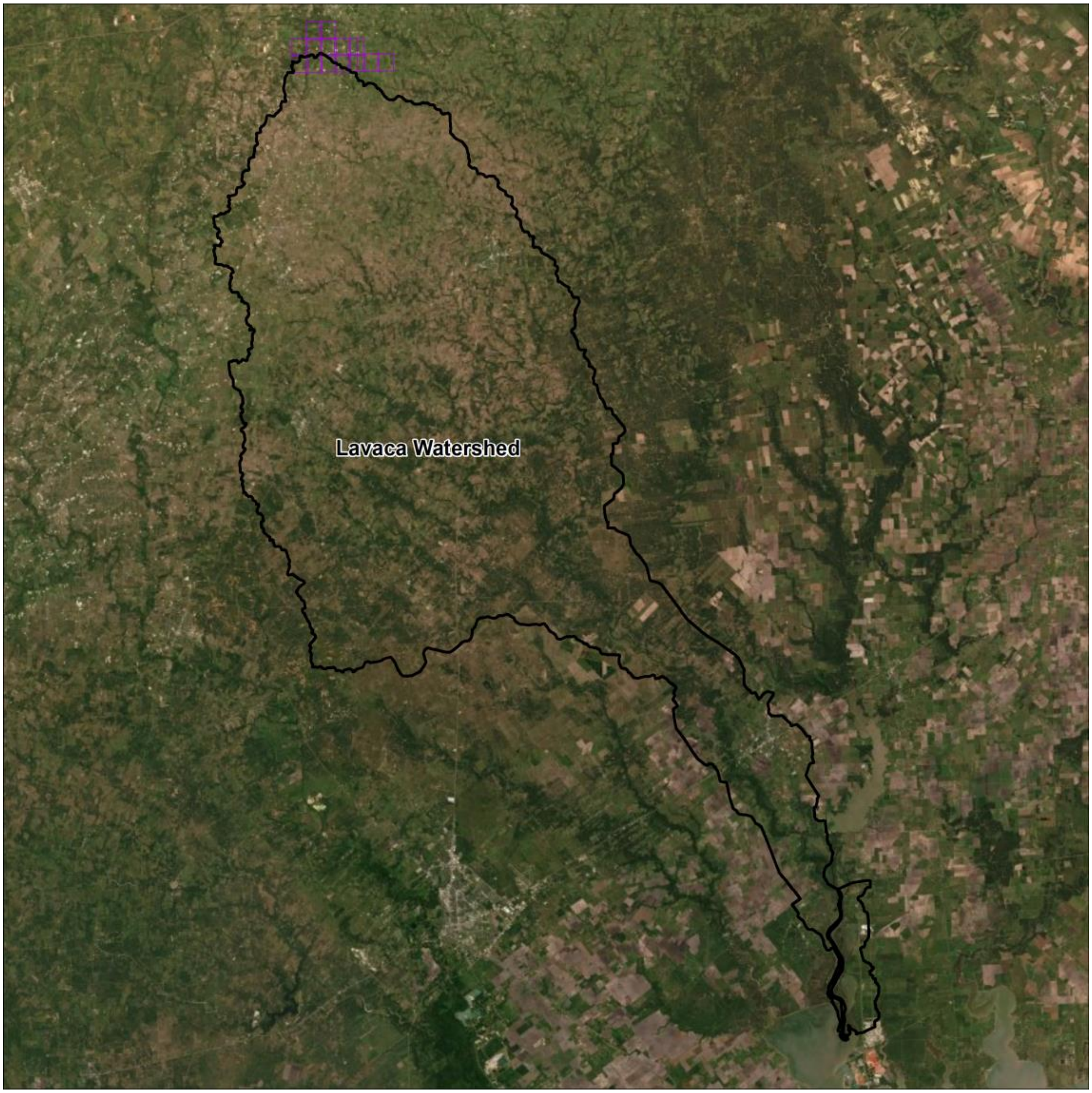

Figure 5: 2017 TNRIS LiDAR: Central Texas

2016 FEMA LiDAR: DeWitt County, TX

This federal LiDAR project funded by FEMA covers portions of DeWitt County, Texas. Fugro Geospatial captured the data between March 2nd and 4th, 2016. The project was funded by FEMA to assist with hydrologic studies and hydraulic analysis to determine the risk of flood hazards. The collection design required LiDAR be acquired to an aggregate nominal pulse spacing (ANPS) of 0.7 meters (2ppsm), including overlap, and processed according to the United States Geological Survey (USGS) National Geospatial Program (NGP) LiDAR Base Specification v1.2, to which FEMA Standards for Flood Risk Analysis and Mapping defer. The total area of the AOI is approximately 606.7 square miles. LiDAR were collected to the extent of the buffered project area (612.3 square miles with a 100-meter buffer of the AOI) and derivative products produced in compliance with this task order and the USGS NGP specifications. The RMSEz reported for the dataset was 14.3 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

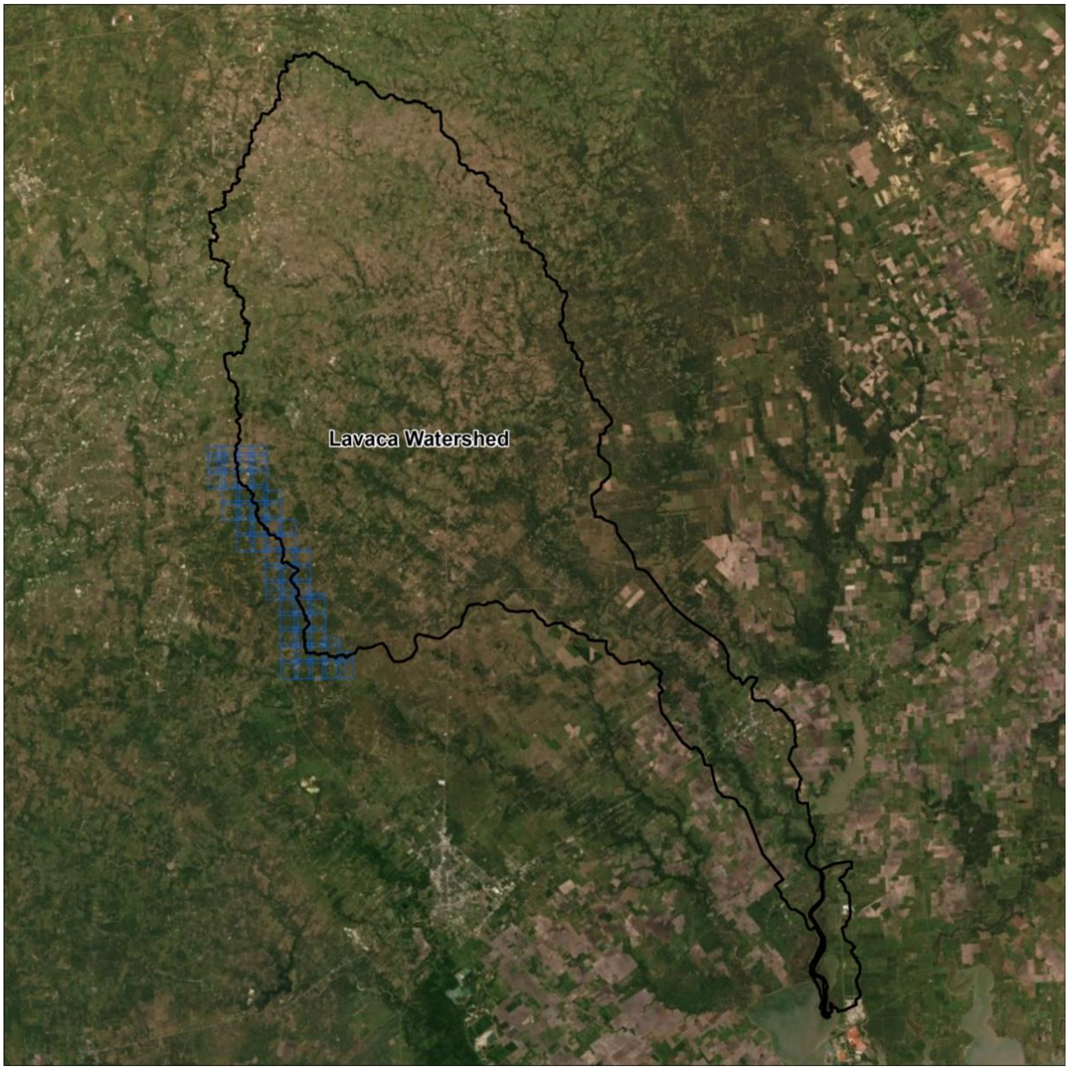

Figure 6: 2016 FEMA LiDAR: DeWitt County, TX

2011 TNRIS LiDAR: Portions of DeWitt, Gonzales and Lavaca

The 2011 Texas Natural Resources Information System (TNRIS) LiDAR: Central Texas (portions of Blanco, Caldwell, Dewitt, Gonzales, Kendall and Kerr Counties) was acquired from TNRIS. This LiDAR collection was flown and processed by Merrick & Company, covering portions of Blanco, Caldwell, DeWitt, Gonzales, Kendall and Kerr counties in central Texas. Aerial collection took place from January to March 2011 during the leaf-off season. URS provided third-party quality assurance and quality control (QA/QC). The collection was funded by the Floodplain Mapping Group in tandem with the Strategic Mapping Program (StratMap) and were procured through the Council on Competitive Government's High Priority Imagery and Datasets (HPIDS) contract. The RMSEz reported for the dataset is 18.02 cm at the 95% confidence level.

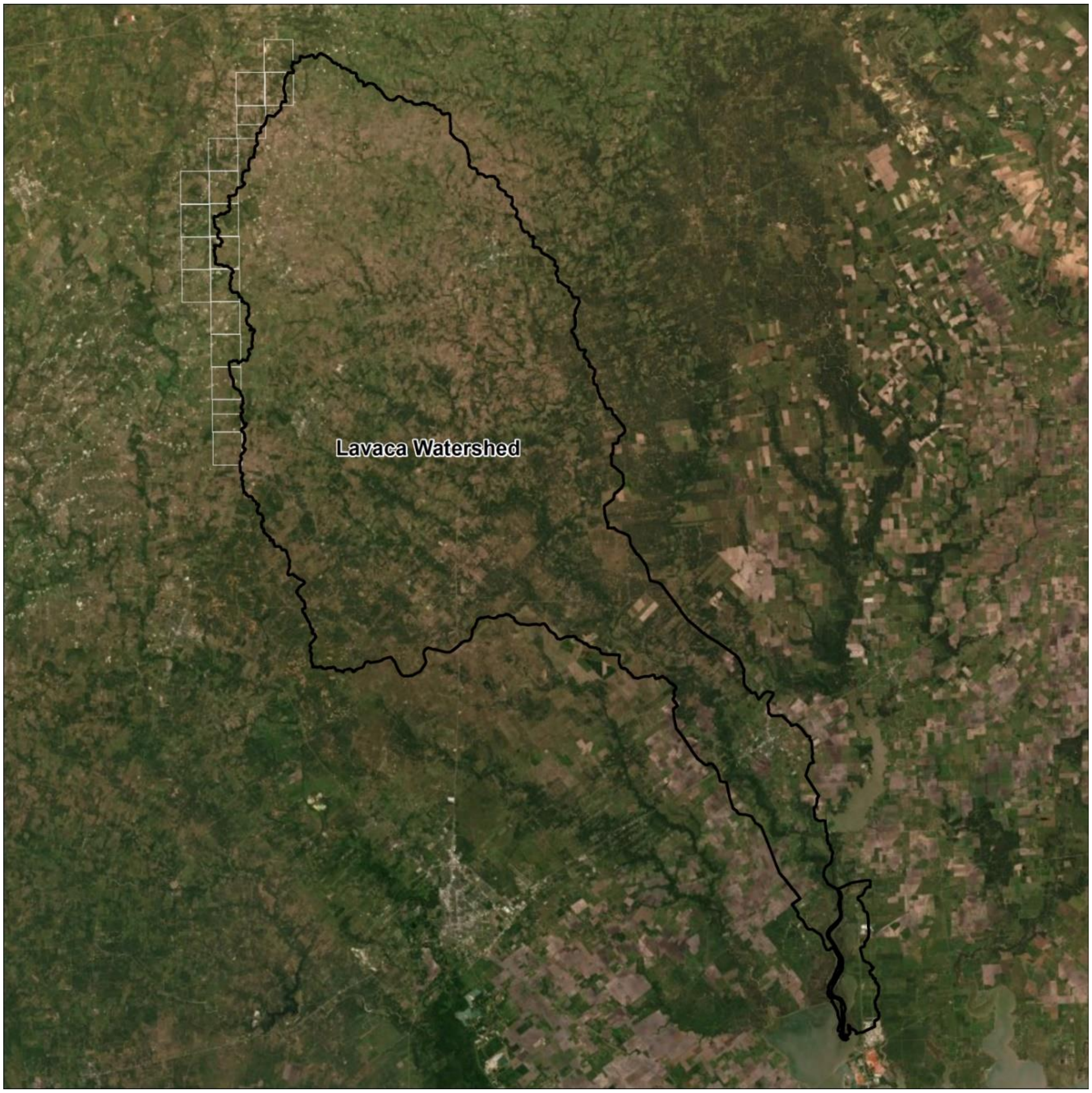

Figure 7: 2011 TNRIS LiDAR: portions of DeWitt, Gonzales and Lavaca

2.1.3 Data Processing

ArcGIS software was utilized in order to create a digital surface model for the Lavaca 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 Lavaca 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

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 analysis.

The final DEM data developed for the Lavaca 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

The RAS5 2D computational mesh was created for the Lavaca model area using ArcGIS toolsets, which reduce the need for manual edits to mesh cells within RAS5 that result in error generation. The model's 2D mesh contains 988,112 cells consisting of 200 feet cells, with the exception of 100 feet along the 1 square mile streams and 50 feet cells within community boundaries using refinement regions. Profile lines were used to extract flow readings for gage location and for other flow extractions throughout the model. 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 30 seconds for a maximum and 7.50 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. The figure below depicts the Lavaca model boundaries, flow transition points between models, and USGS stream gages used in the study.

The original HUC-8 Lavaca Watershed disconnects a downstream river (Dry Creek) in half with the other segment in the neighboring Navidad Watershed. To model the downstream of Lavaca Watershed accurately including the entire Dry Creek hydrograph, the modeling area of Lavaca Watershed was modified with an expansion to incorporate a small region along Lake Texana transferred from Navidad Watershed. The perimeter of Lavaca model is expanded to include this area with terrain, landcover, and streams from the Navidad HUC-8 watershed. The figure below displays this expanded triangular region located to the southeast of the original Lavaca Watershed inside Jackson County. The added region has an area of 13.17 sq mi, approximately 1.45% of the area of original Lavaca HUC8 Watershed (910.86 sq mi).

Outflow boundary conditions (from the computational 2D mesh) were used along model boundaries without an inflow boundary condition. 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.

A stage hydrograph was used as the unique outflow boundary condition along the coast. The water elevation was determined by the Mean Higher High Water (MHHW) of the nearby tide station. The tide stations referenced for these boundary conditions is Port OConnor (8773701). On the day it was accessed, the MHWW was 1.10 feet.

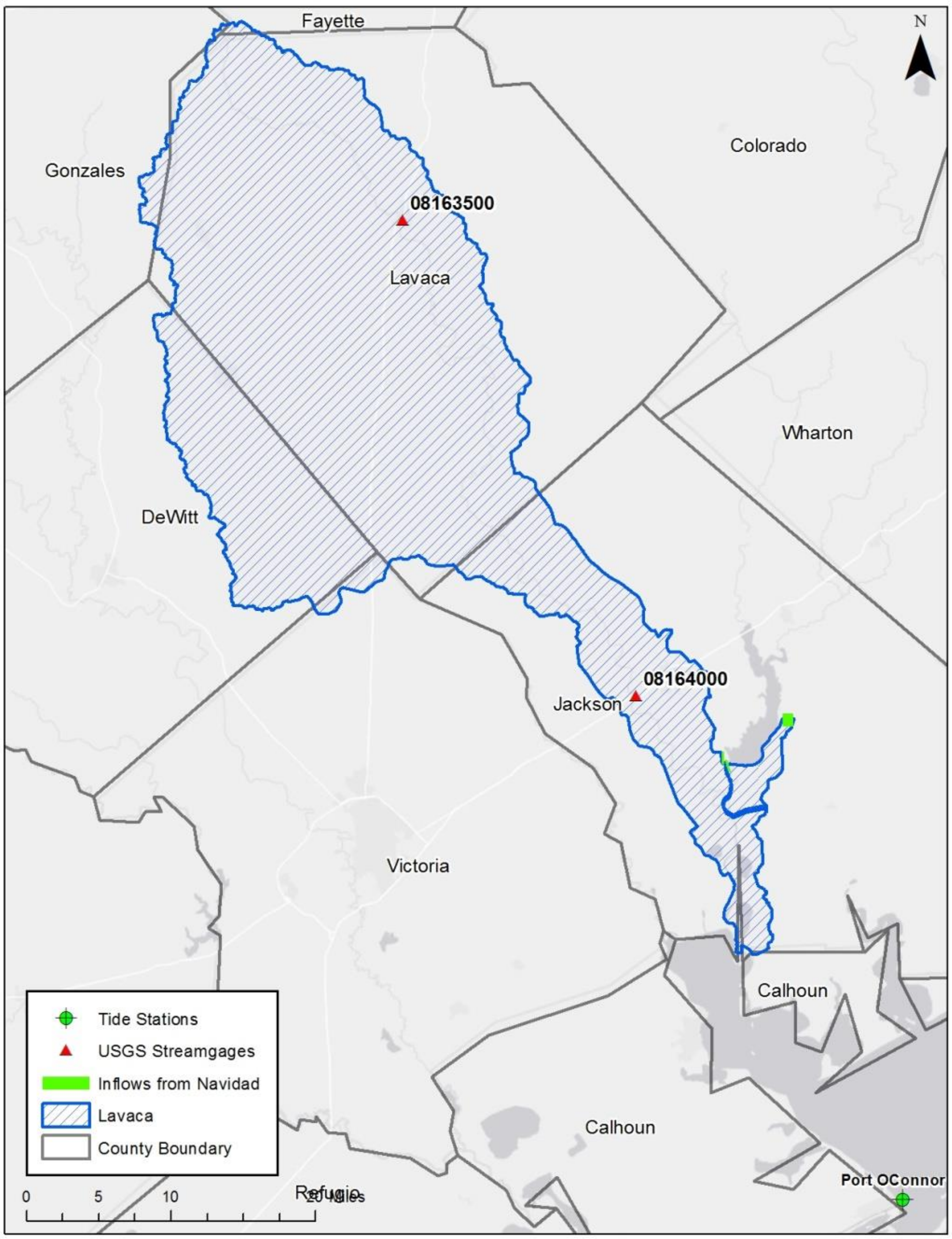

Figure 8: RAS5 2D Computational Mesh and Boundary Conditions and USGS Peak Streamflow Gages

2.2.3 Hydrology

Precipitation frequency data (NOAA Atlas 14, 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 the Lavaca Watershed. Excess precipitation for the 2D mesh was developed as described in Section 2.2.3.1. 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 ensure accurate results. USGS stream gages with less than 10 years of record or outdated records were not considered for this study. The gage used for analysis in this study is listed in Table 3.

Table 3: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (sq. Miles)	Period of Record
08164000	Lavaca River near Edna, TX	794	1923-2017

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% 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 National Resources Conservation Service (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

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

LU_GridCode	NLCD LU Description	Hydrologic Soil Group			
		A	B	C	D
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, 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:

$$\mathrm{CNI} = 4.2 * \mathrm{CNII} \;/\; (10 - 0.058 * \mathrm{CNII})$$

$$\mathrm{CNIII} = 23 * \mathrm{CNII} \;/\; (10 + 0.13 * \mathrm{CNII})$$

Next, S90 and S10 can be computed by:

$$\mathrm{S10} = 1000 \;/\; \mathrm{CNIII} - 10$$

$$\mathrm{S90} = 1000 \;/\; \mathrm{CNI} - 10$$

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

$$\log\,(\mathrm{S10}) = \mathrm{mean}\,(\log(\mathrm{S})) + 1.282\ \mathrm{std.dev.}\,(\log(\mathrm{S}))$$

$$\log\,(\mathrm{S90}) = \mathrm{mean}\,(\log(\mathrm{S})) - 1.282\ \mathrm{std.dev.}\,(\log(\mathrm{S}))$$

$$1\ \mathrm{std.dev.}\,(\log\mathrm{S}) = (\log\mathrm{S10} - \log\mathrm{S90}) \;/\; 1.282$$

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

$$\log\mathrm{SPlus} = \log\mathrm{S} + [1\ \mathrm{std.dev.}\,(\log\mathrm{S})]$$

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

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

$$\text{CNPlus} = 1000 / (\text{SPlus} + 10)$$

$$\text{CNMinus} = 1000 / (\text{SMinus} + 10)$$

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
Lavaca	79.0	66.0	59.0	81.6

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
Lavaca	12.01	17.20	10.10	8.49	6.60	14.46	9.56

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

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
Lavaca	7.48	13.22	6.53	5.09	3.45	12.07	4.42

Figure 9 shows the excess precipitation hyetograph used for Lavaca. 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.

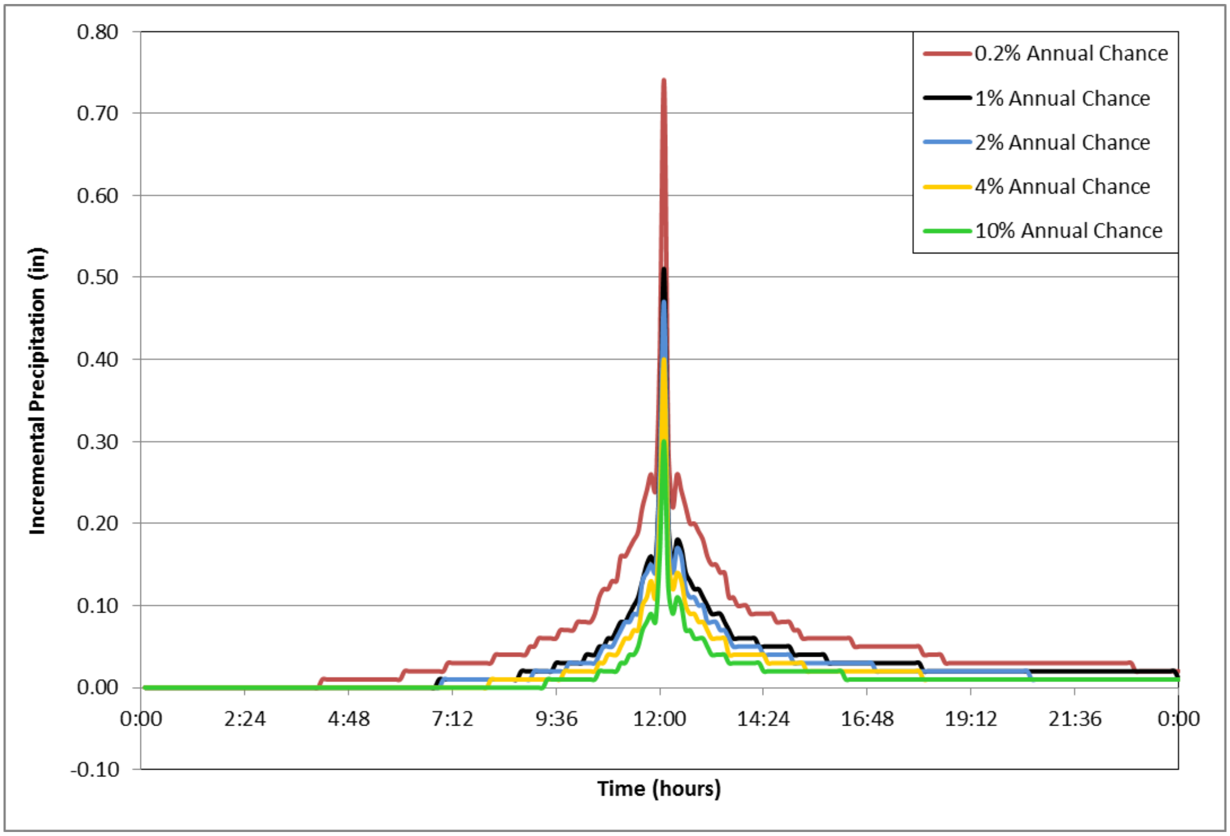

Figure 9: Excess Precipitation Hyetograph

2.2.3.2 Inflow Hydrograph Boundary Conditions

Inflow hydrographs from Navidad HUC-8 (Dry Creek) were used in Lavaca model. The inflow hydrograph were derived by utilizing the results of the Navidad 2D BLE HEC-RAS model. To incorporate the inflow completely downstream of Lake Texana, the boundary of Lavaca HUC-8 was expanded as described in Section 2.2.2. The Lavaca 2D mesh includes three inflow hydrographs from the calibrated Navidad Watershed model, including two ground overflow hydrographs and one Lake Texana outflow hydrograph. All of the Navidad inflow hydrographs contain outputs of the different model events to facilitate the simulation of Lavaca Watershed 2D model under multiple conditions. The Navidad inflow hydrographs represent the additional flow joining Lavaca watershed.

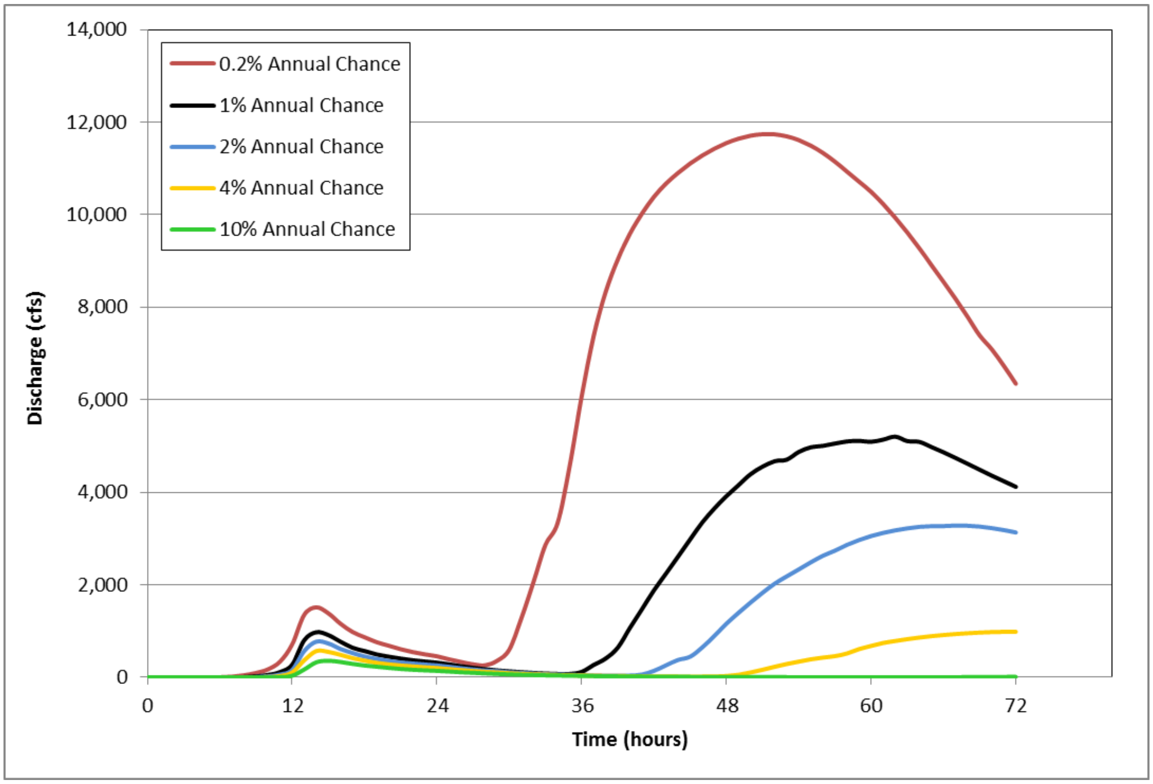

Figure 10: Inflow 1 from Navidad HUC-8

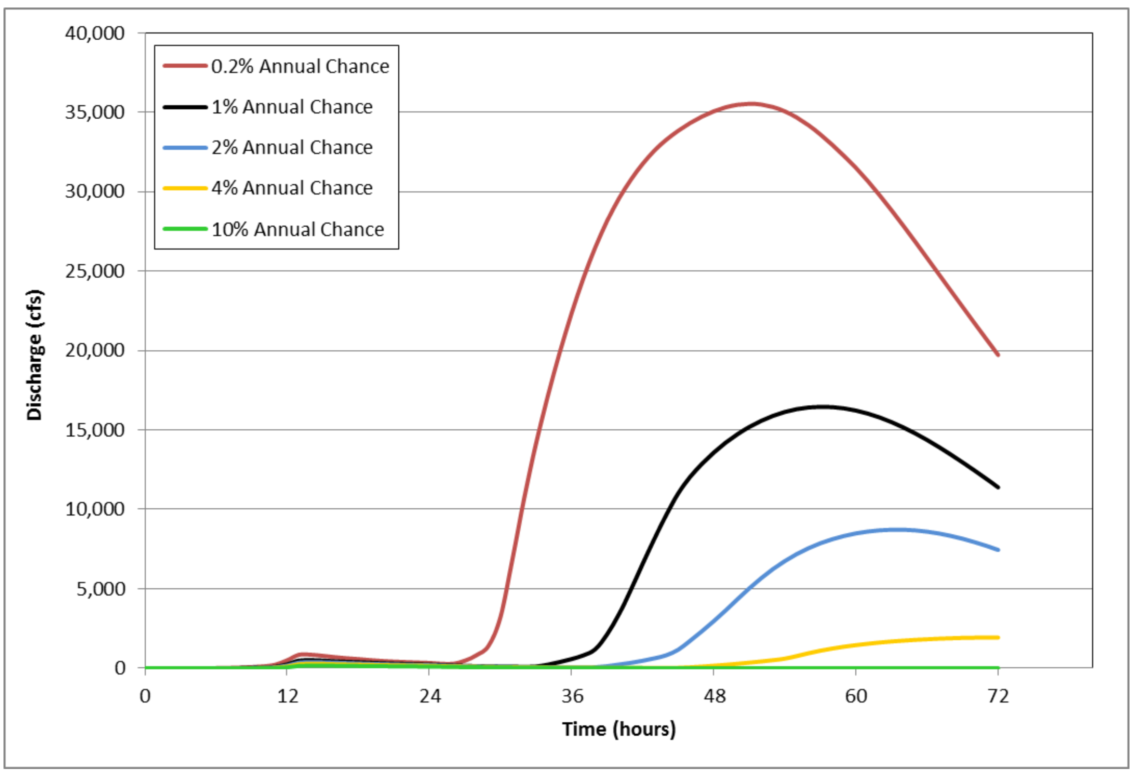

Figure 11: Inflow 2 from Navidad HUC-8

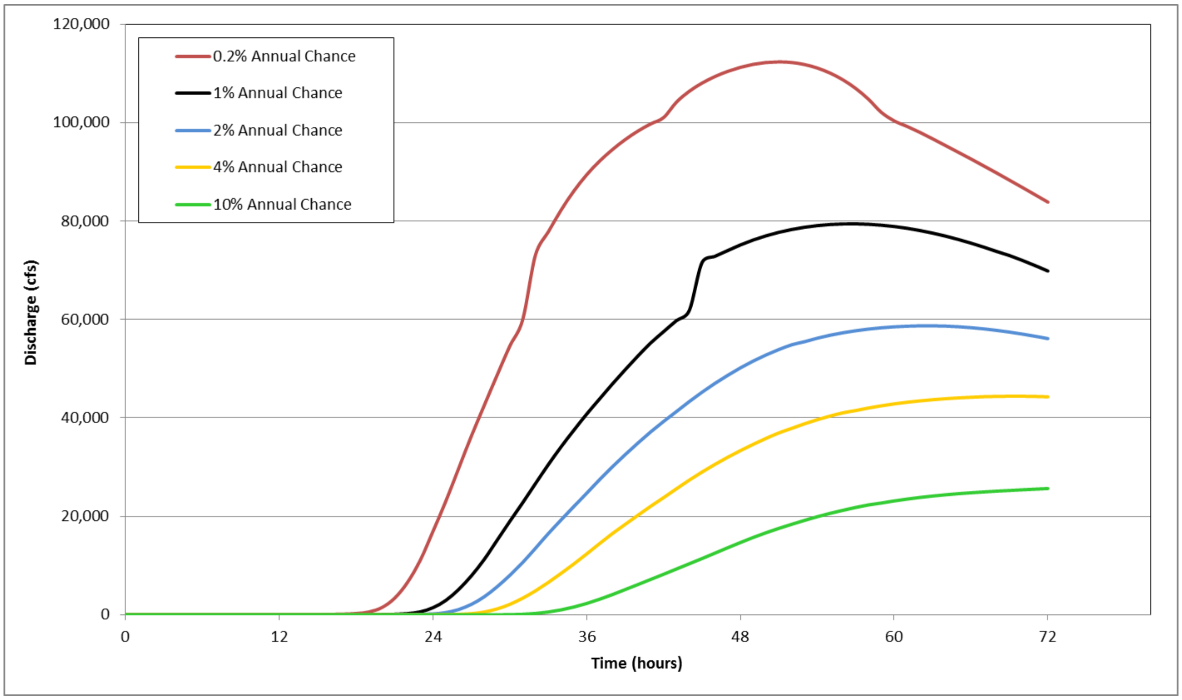

Figure 12: Inflow from Lake Texana

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 1,000ft 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. This procedure was utilized at all 3 inflow locations where the Lavaca watershed model is receiving flow from the Navidad watershed model outflow (hydrographs shown above in Figures 10-12).

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-ft 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
Grassland/Herbaceous	0.04	Chow, 1959	0.15	HCFCD modeling Guidelines, 2018
Pasture/Hay	0.04	Chow, 1959	0.15	HCFCD modeling Guidelines, 2018
Cultivated Crops	0.04	Chow, 1959	0.1	HCFCD modeling Guidelines, 2018
Woody Wetlands	0.04	Chow, 1959	0.12	NRCS KS Dam Breach, 2016
Emergent Herbaceous Wetland	0.04	Chow, 1959	0.07	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 13.

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.

As per 2018 National Inventory of Dams, no public owned dams were present in the 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.

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.

The study area does not include levee systems.

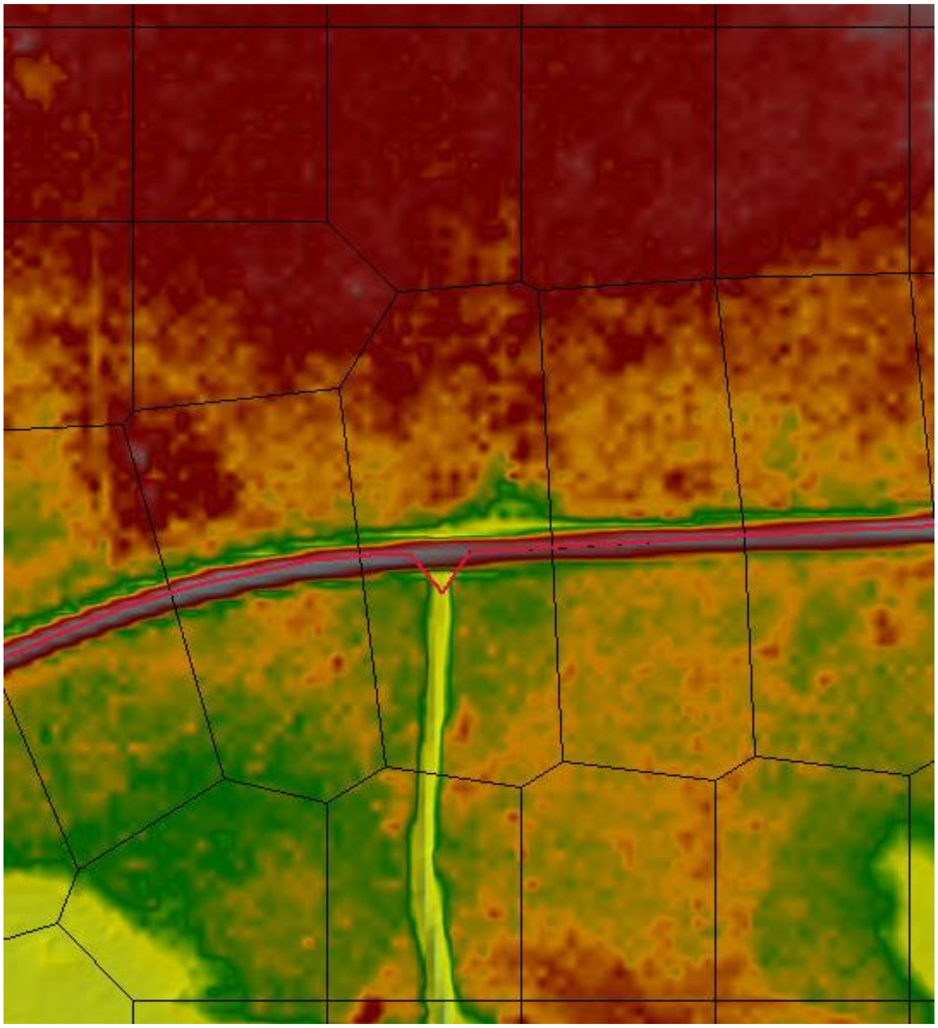

Figure 13: V-notch Breakline Approach at Bridge Crossing

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 Lavaca Watershed that were modeled with refinement regions as well as the square mileages of these regions.

Table 9: Communities with 2D Mesh Refinement

Community Name	Area (sq. Miles)
Edna City	4.15
Shiner City	2.42
Moulton Town	0.84
Hallettsville City	2.72
Yoakum City	4.54
Lolita CDP	0.59
Vanderbilt CDP	1.85

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 special flood hazard area (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 Lavaca 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 shows a difference of 1.81 ft at the mouth of Lavaca river when compared to effective BFE after calibration.

Table 10: Effective and Model Base Flood Elevation (BFE) Comparison Post-Calibration

Location Description	Effective BFE (feet)	Model BFE (feet)	Difference (feet)
Lavaca River at the mouth	32.0	30.19	1.81

3.1 Calibration

Within the Lavaca watershed study area, two USGS streamgages, 08164000 (Lavaca Rv nr Edna, TX) and 08163500 (Lavaca Rv at Hallettsville, TX) fit the calibration criteria with sufficient length of record or outdated record. Effective data from Lavaca and Jackson Counties Flood insurance Studies (FIS) were considered to be utilized for calibration.

Modeled flows were compared to flows in the summary of discharges table from Lavaca County Flood Insurance Study (effective November 2010) and Jackson County Flood Insurance Study (effective September 2014). 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:

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

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

Calibration efforts were performed to find highly fluctuated discharges in the downstream region of Lavaca River due to numerous branches of flow into Lavaca River. The peak 100-yr flow is calibrated with USGS gage and at the mouth of Lavaca River using Jackson County FIS as shown in Table 11. Adjustments to hydraulic features within the model were made until the flows in the model matched closely with the peak flows determined from the USGS Streamgage 08164000. The curve number was adjusted from 79.0 to 66.0 (see Table 5) to match the model's 100-year peak flow with the gage record. Due to the scale of the model (HUC-8 size), adjustment of CN was our primary approach to adjust the flows during the model calibration process. N-values were not modified in the calibration process.

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)	
Lavaca River at US-59 S	USGS Gage 08164000	USGS Report 77-110 methodologies	70,025	110,603	151,181	121,694
Lavaca River at Hallettsville, TX	USGS Gage 08163500	USGS Report 77-110 methodologies	43,076	61,515	79,954	44,262
Lavaca River (At the mouth)	Jackson County FIS	USGS Stream Flow Gage – Log-Pearson Type III	55,611	111,000	221,445	107,500

Figure 14 shows the final result of the calibration location compared to 100-year modeled flow throughout the Lavaca 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. Two comparisons were made with varying drainage areas to ensure the calibration of excess precipitation for different points over the entire watershed area. This calibration provides confidence in results throughout the entire Lavaca Watershed.

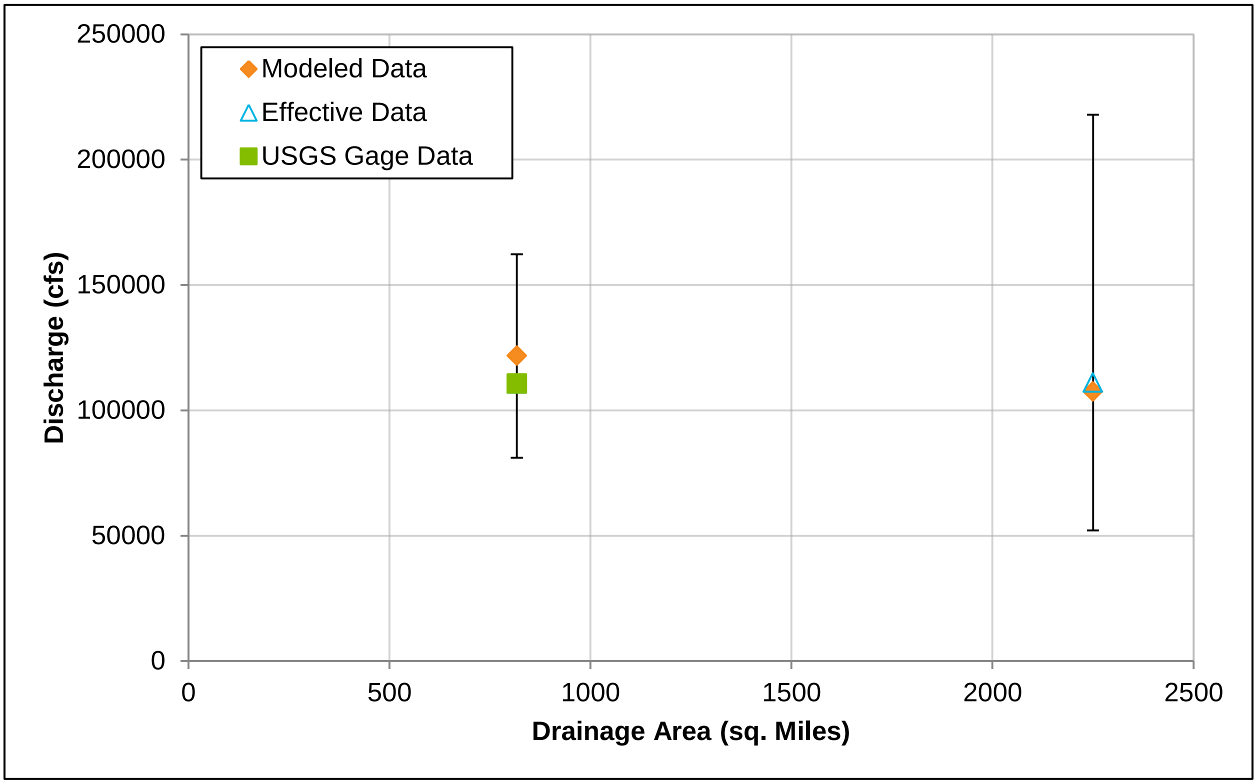

Figure 14: Calibration Comparison

Based on the 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, as shown in Table 12. The modeled WSEL and USGS gages' WSEL are within the acceptable range.

Table 12: 100-yr Gage WSEL and RAS WSEL Comparison

USGS Gage ID	Lower Bound (ft)	WSEL 1-percent (ft)	Upper Bound (ft)	HEC-RAS 5.0.7 WSEL (ft)
08164000	46.29	48.75	50.42	50.44
08163500	221.10	224.78	227.58	221.38

3.2 Challenges

Major challenges included presence of a single acceptable streamflow gage record and the proximity to the coast. However, Lavaca modeling provides full confidence in the results. 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 the model runtime.

The expansive modification of Lavaca model's study area to incorporate the entire segment of Dry Creek added on technical challenges to merge 2D mesh areas together and make streams flow smoothly. The Lavaca modeling solved these difficulties appropriately with included terrain, landcover, and streams from the Navidad model. Inflows from adjacent Navidad watershed to downstream Lavaca River were added as inflow hydrographs. This added difficulty and time in the Lavaca watershed modeling.

The calibration of the RAS model with the USGS gage and with the Jackson County FIS was challenging and required several model runs.

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 ft 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 Special Flood Hazard Areas (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, Halff 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.

$$CV = Standard\ Deviation/Mean$$

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 Lavaca HUC-8 CV calculations are found in Table 13.

Table 13: Lavaca HUC-8 Slope Analysis

HUC-12	Mean	Standard Deviation	CV	Methodology
121001010101	2.41	2.51	1.04	Riverine
121001010102	2.16	2.54	1.18	Riverine
121001010103	2.25	2.56	1.14	Riverine
121001010104	2.40	2.34	0.97	Riverine
121001010105	2.27	2.08	0.92	Riverine
121001010106	2.14	2.25	1.05	Riverine
121001010107	2.21	2.50	1.13	Riverine
121001010108	1.93	2.72	1.41	Riverine
121001010201	1.94	2.47	1.28	Riverine
121001010202	2.00	2.23	1.11	Riverine
121001010203	1.84	2.20	1.20	Riverine
121001010204	1.89	2.15	1.14	Riverine
121001010205	2.26	3.07	1.36	Riverine
121001010206	2.11	3.15	1.49	Coastal
121001010301	1.81	1.55	0.86	Riverine
121001010302	1.66	2.00	1.20	Riverine
121001010303	1.19	1.35	1.14	Riverine
121001010304	1.53	2.17	1.42	Riverine
121001010305	1.87	3.04	1.63	Coastal
121001010401	1.33	2.23	1.68	Coastal
121001010402	1.10	1.92	1.75	Coastal
121001010403	1.51	2.63	1.74	Coastal
121001010404	1.17	2.14	1.83	Coastal

For the Lavaca 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 mapped in a similar manner as mentioned above with regard to 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 with regard to 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 that the 10-percent boundary exceeded the 1-percent boundary due to smoothing, those areas have been removed.

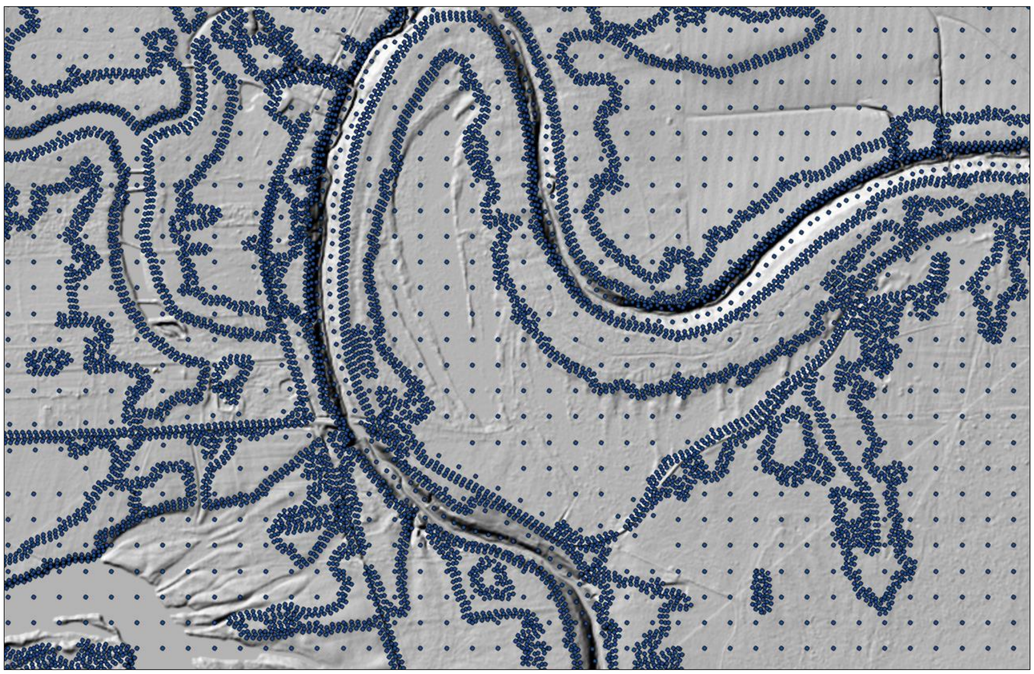

Figure 15: 2D BLE Model Points for Mapping Workflow

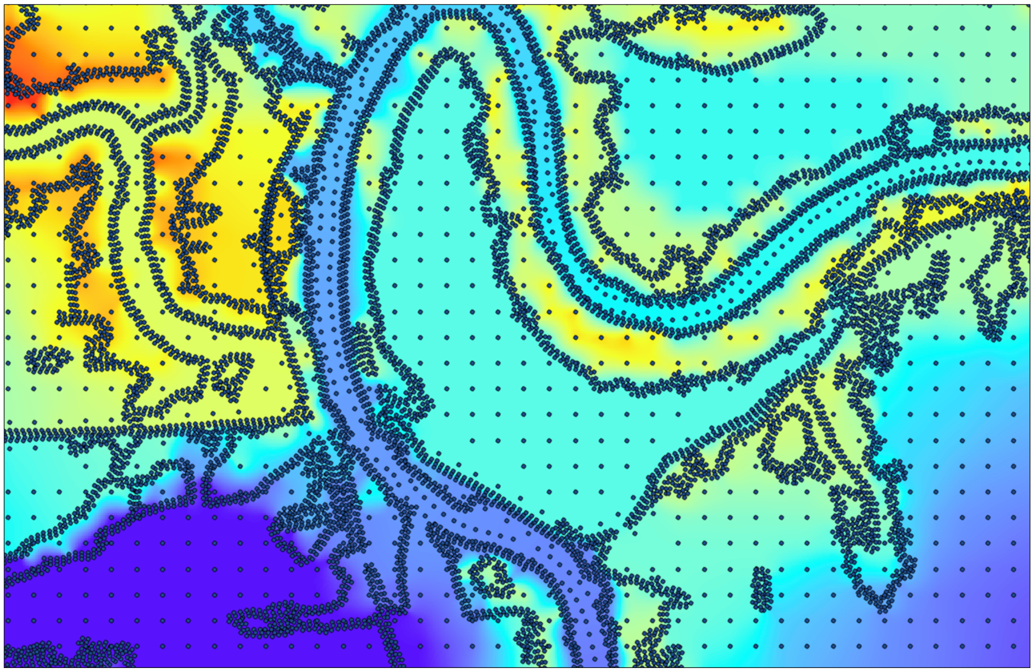

Figure 16: 2D BLE Model Points to Water Surface Elevation TIN

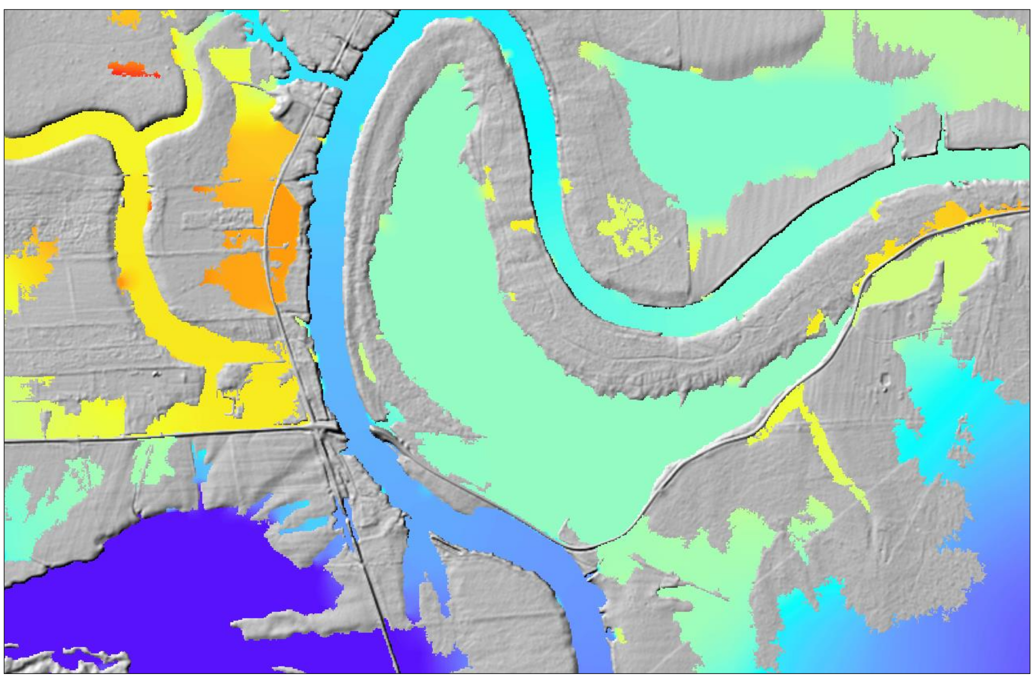

Figure 17: Water Surface Elevation TIN to Grid

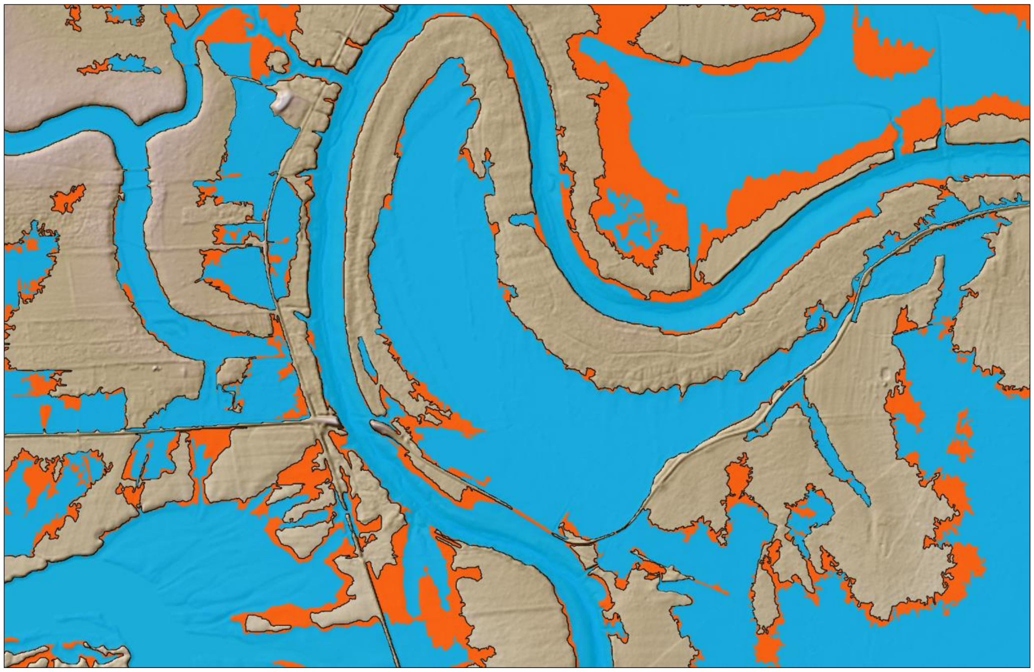

Figure 18: Water Surface Elevation Grid to Mapping Products

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 (706.9 miles) in the Lavaca Watershed were classified in CNMS with validation status of “UNVERIFIED” (167.1 miles) or “VALID” (539.8 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 Lavaca Watershed, the effective Zone A topographic data did not use LiDAR data and LiDAR is now available; therefore, all reaches fail the A1 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.

For all Zone A streams within the Lavaca Watershed, regression equations were not used for any effective studies and, therefore, pass the A2 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 streams within the Lavaca Watershed are classified as rural and, therefore, pass the A3 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	Fail	LiDAR was not used and LiDAR sources are available.
A2 – Hydrology	Pass	Regression equations not used in effective study
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 streams within the Lavaca Watershed are not 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						
Lavaca Watershed	All Streams	42,420	4,268	38,152	90%	PASS	
Beard Branch-Lavaca River	121001010305	1,098	120	978	89%	Pass	6.2
Big Brushy Creek	121001010204	2,701	312	2,389	88%	Pass	6.1
Boggy Creek-Rocky Creek	121001010105	2,354	198	2,156	92%	Pass	4.8
Chicolete Creek	121001010304	1,581	103	1,478	93%	Pass	3.3
Grafe Branch-Lavaca River	121001010201	1,660	239	1,421	86%	Pass	9.9
Kelley Creek-Clarks Creek	121001010202	3,383	359	3,024	89%	Pass	5.3
Knopp Branch-Lavaca River	121001010401	861	45	816	95%	Pass	2.6
Long Branch-Lavaca River	121001010102	1,421	176	1,245	88%	Pass	7.8
Lower Little Brushy Creek	121001010302	1,588	124	1,464	92%	Pass	3.9
North Fork Mustang Creek	121001010106	1,901	231	1,670	88%	Pass	6.3
Ponton Creek	121001010104	1,549	146	1,403	91%	Pass	6.8
Post Oak Branch-Dry Creek	121001010402	147	4	143	97%	Pass	2.2
Rickaway Branch-Lavaca River	121001010108	1,098	142	956	87%	Pass	10.3
Smothers Creek-Rocky Creek	121001010107	3,252	376	2,876	88%	Pass	8.5
South Chicolete Creek-Chicolete Creek	121001010303	2,586	180	2,406	93%	Pass	4.6
Spring Branch-Lavaca River	121001010206	3,264	386	2,878	88%	Pass	7.5
Supplejack Creek-Clarks Creek	121001010203	2,107	160	1,947	92%	Pass	3.8
Swan Lake-Lavaca River	121001010404	137	3	134	98%	Pass	2.0
Upper Little Brushy Creek	121001010301	2,870	154	2,716	95%	Pass	3.6
Waterhole Creek-Clarks Creek	121001010205	2,179	278	1,901	87%	Pass	6.4
West Campbell Branch-Lavaca River	121001010103	2,297	259	2,038	89%	Pass	8.6
Youngs Branch-Lavaca River	121001010101	2,386	273	2,113	89%	Pass	7.9

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 Lavaca Watershed has been updated as summarized in Table 16 and illustrated in Figure 19.

Table 16: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	539.8
UNVERIFIED	BEING STUDIED	167.1

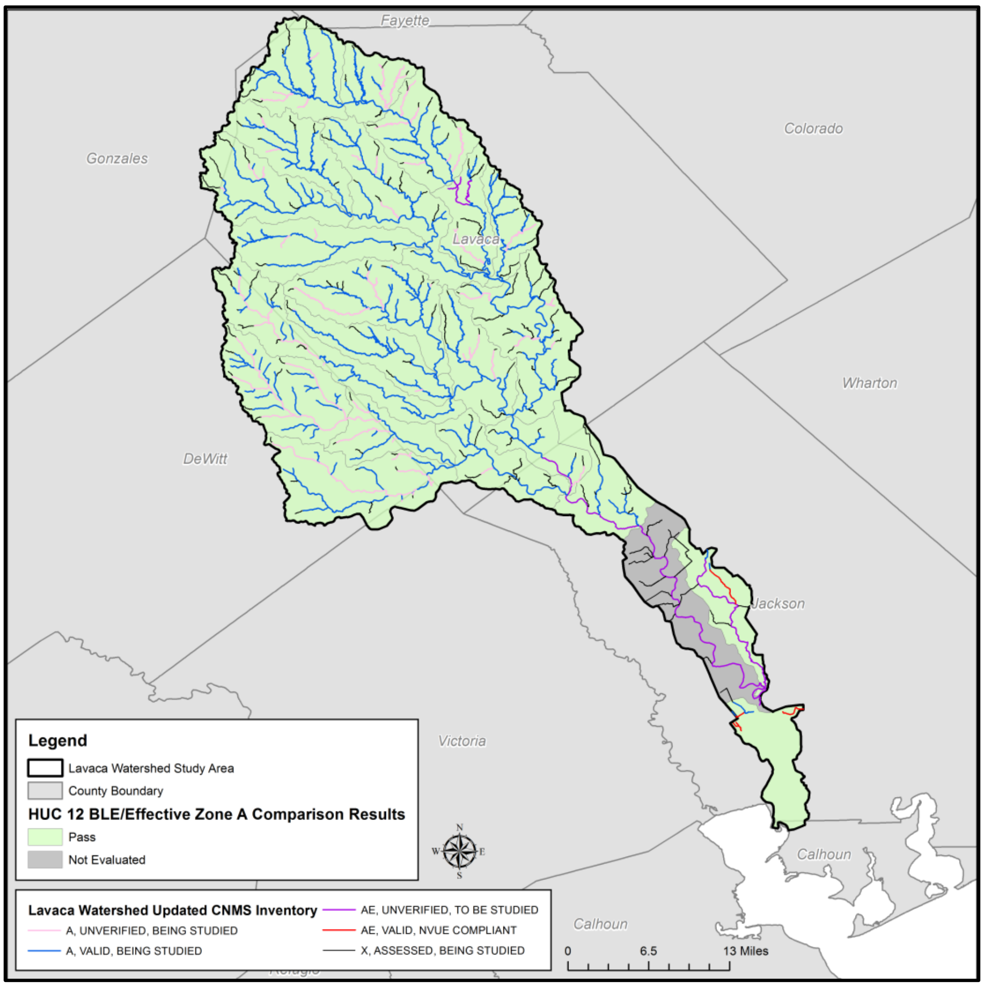

Figure 19: Lavaca Watershed CNMS Validation Results

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 20 below shows the range of the HUC-12 priority scores which can be used to initiate discussions during the Discovery phase.

Rickaway Branch-Lavaca River HUC-12 was determined to have the highest priority score and the most need while Swan Lake-Lavaca River HUC-12 had the lowest scores.

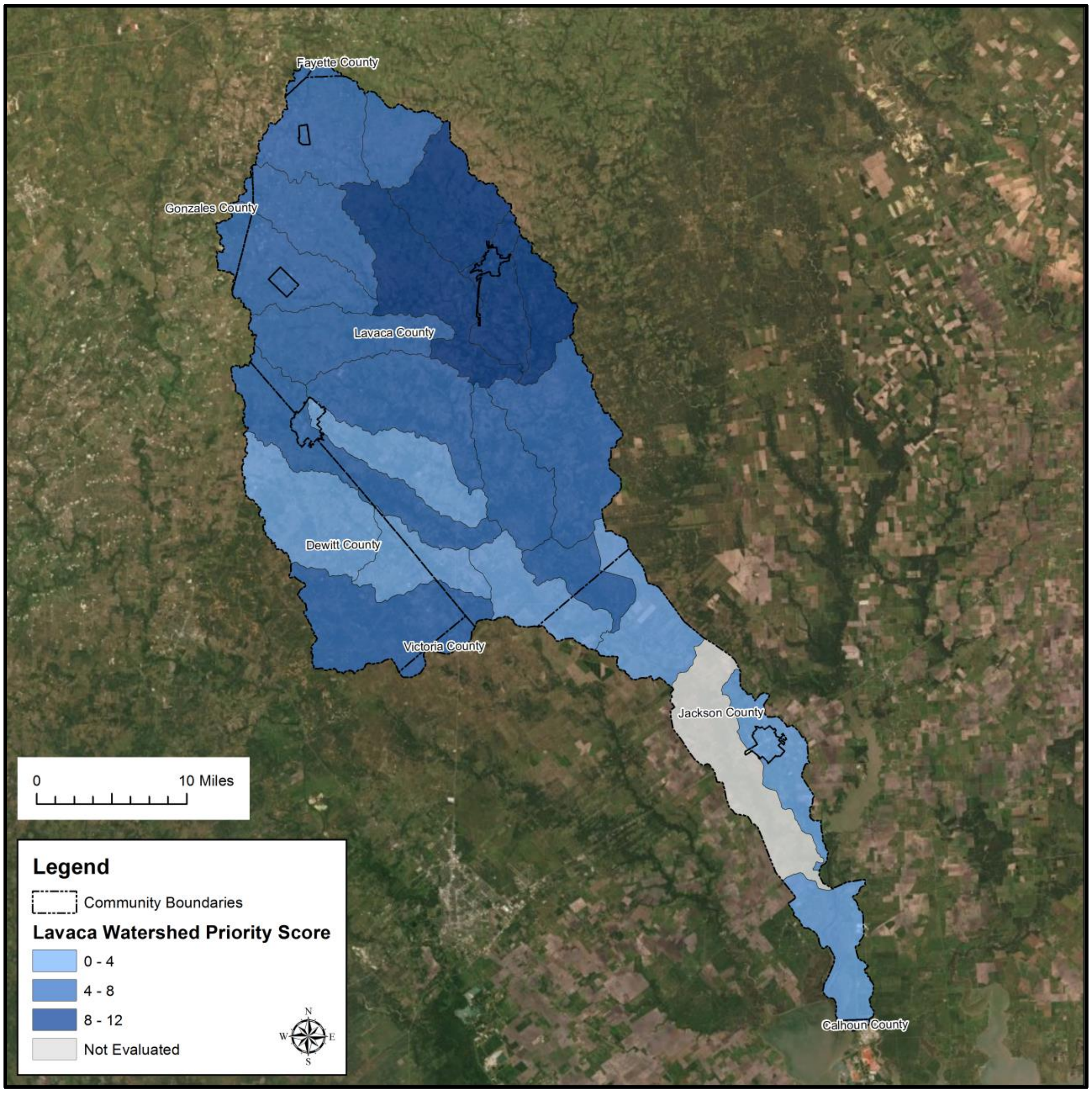

Figure 20: Ranking of Lavaca Watershed HUC-12s

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 5.0 was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 5.0 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 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 5.0 Results for 1-Percent-Annual-Chance (100 year) Scenario

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Calhoun	$76,000	$60,269,000	$88,077,000
DeWitt	$36,487,000	$416,854,000	$303,899,000
Fayette	$3,000	$9,522,000	$4,985,000
Gonzales	$108,000	$31,806,000	$26,414,000
Jackson	$89,448,000	$814,483,000	$496,905,000
Lavaca	$114,847,000	$1,890,662,000	$1,200,279,000
Victoria	$123,000	$6,715,000	$3,357,000
Total	**$241,092,000.00**	**$3,230,311,000.00**	**$2,123,916,000.00**

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Appendix A BLE Map