West Galveston 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 West Galveston Bay 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 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 (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 #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 West Galveston Bay Watershed 2D BLE project was scoped as described in the FEMA Region 6 FY19 Mapping Activity Statement No. 21. 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 West Galveston Bay Watershed footprint.

Figure 1: West Galveston Watershed

2. 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a two-dimensional (2D) hydraulic engineering analysis for the West Galveston Bay 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 two-dimensional engineering analyses by providing a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the West Galveston Bay 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 West Galveston Bay Watershed, was executed using the following steps:

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

Documentation regarding leveraged data including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables and text 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 West Galveston Bay Watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the West Galveston Bay 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), and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

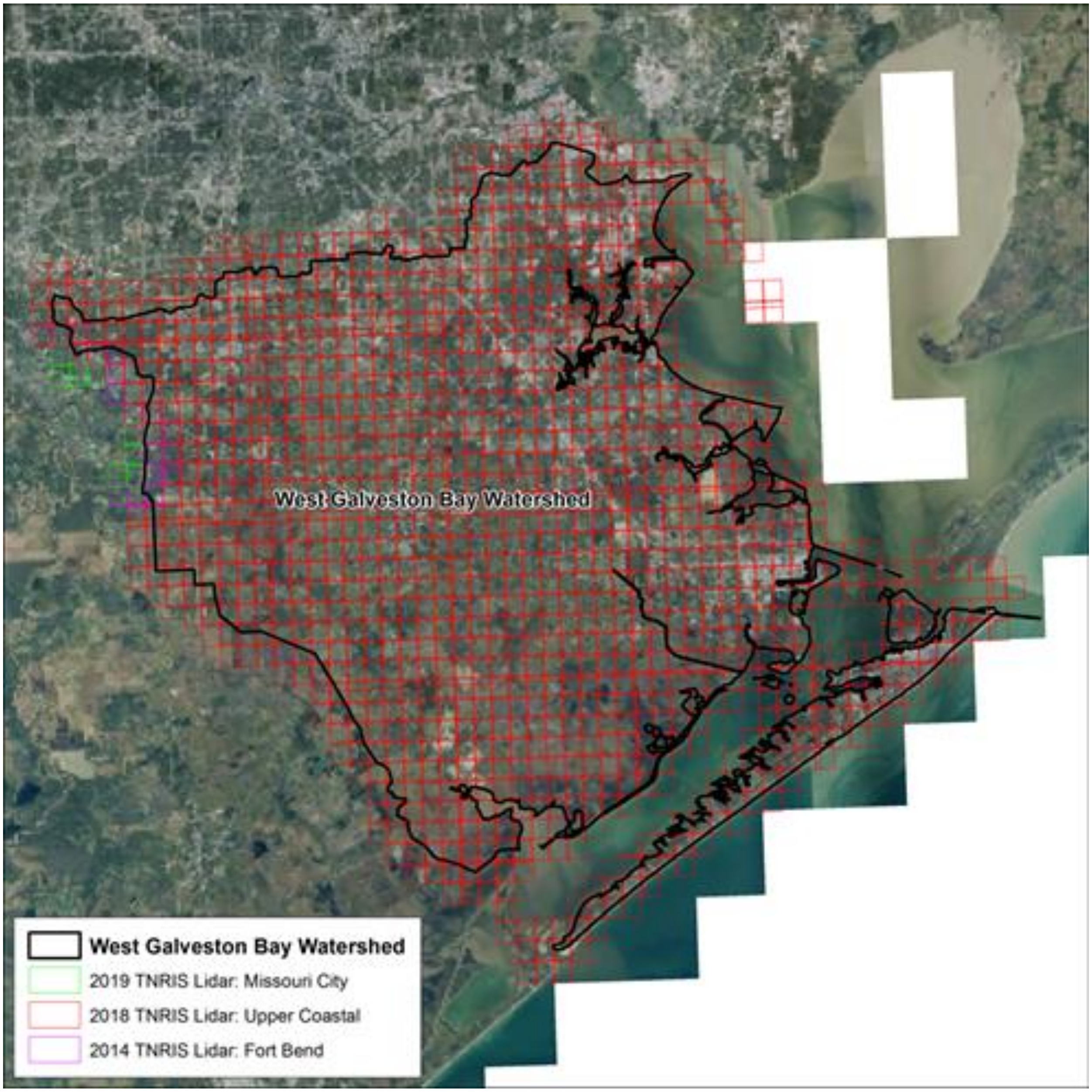

Figure 2: West Galveston Bay Watershed BLE Source Terrain Data

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)

The data collected and distributed by the Texas Natural Resources Information System (TNRIS) was identified as the best available data to leverage for the West Galveston 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 West Galveston Watershed

Year	Description	Source/Owner	Accuracy[1]	Approximate Footprint (Sq. Mi.)[2]
2019	2019 TNRIS LiDAR: Brown County and Missouri City	TNRIS/TWDB	6.5 cm	9.0
2018	2018 TNRIS LiDAR: Upper Coastal LiDAR	TNRIS/TWDB	9.4 cm	1180.9
2014	2014 TNRIS LiDAR: Fort Bend	TNRIS/TWDB	8.6 cm	5.6

[1]RMSEz reported at the 95% confidence level

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

2.1.2.1 West Galveston Bay Watershed Source Terrain Data

2019 TNRIS LiDAR: Brown County and Missouri City

This StratMap LiDAR project covers a portion of Fort Bend County around Missouri City, Texas. This project was managed by the Texas Strategic Mapping (StratMap) Program and utilized the StratMap contracts held by the Department of Information Resources (DIR). Collection took place April 15, 2019. Data was collected and processed by the Sanborn Mapping Company, LLC with third party quality assurance/quality control performed by AECOM. The StratMap contributing partner for this project was Missouri City, Texas. 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 dam safety. The RMSEz reported for the dataset was 6.5 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

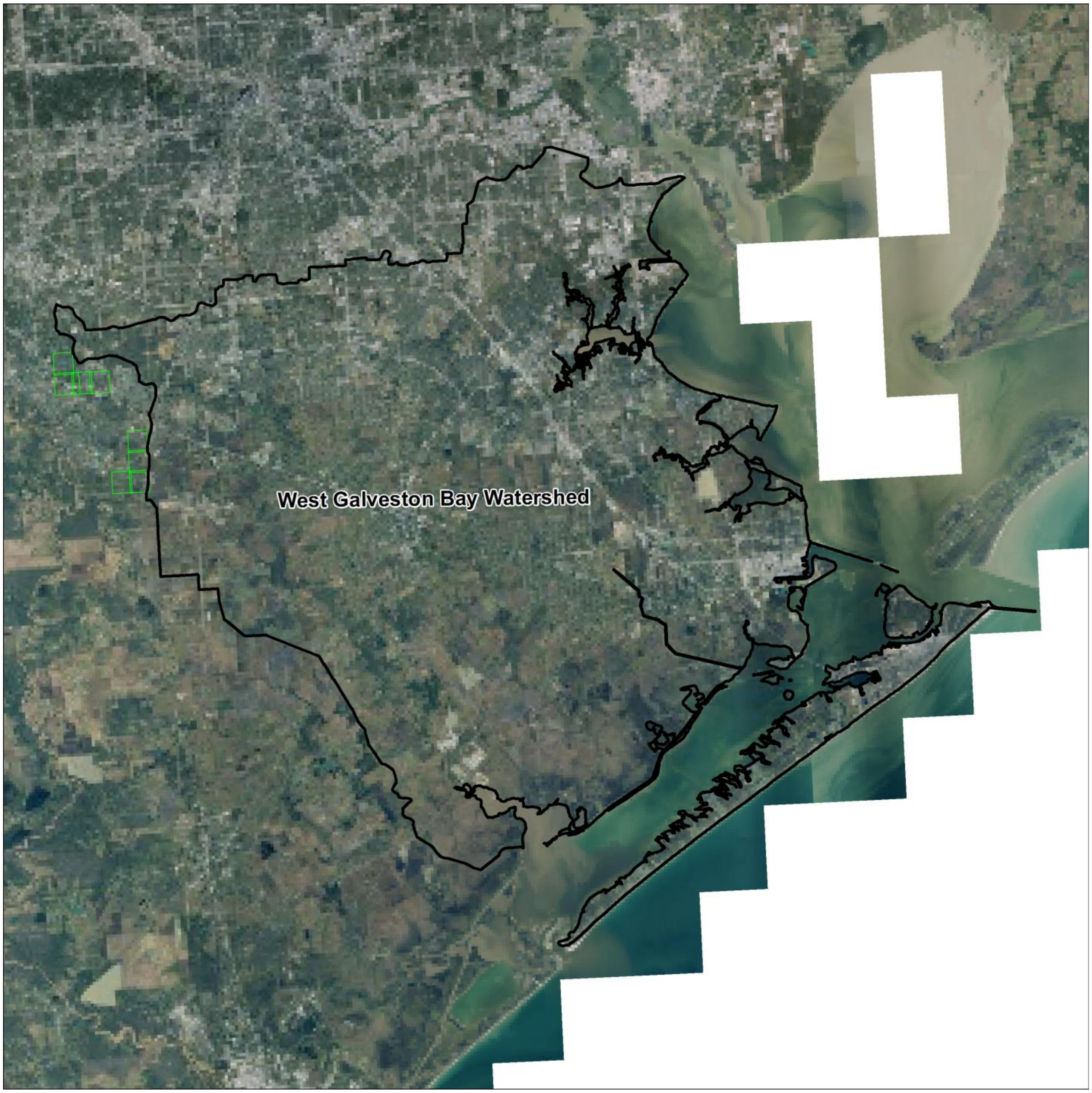

Figure 3: 2019 TNRIS LiDAR: Brown County and Missouri City

2018 TNRIS LiDAR: Upper Coastal LiDAR

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 Texas Strategic Mapping (StratMap) Contract to acquire high resolution elevation data and associated products from airborne LiDAR systems during the 2017-2018 leaf-off season. 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 TNRIS, a division of TWDB. Project partners include: H-GAC, Harris County Flood Control District (HCFCD), and the United States Geological Survey (USGS). This Coastal Texas project consists of approximately 9,758 DO4Q tiles and is located on the Texas Coast covering much of Orange to Matagorda County along with Harris County and the surrounding area. The project includes large metropolitan areas as well as coastal areas. The Urban and Coastal AOIs consist of approximately 4.045 square miles and were acquired between January 12 and March 22, 2018 utilizing both Riegl LMS-Q680i and Riegl LMS-Q780 sensors; 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 North American Datum of 1983 (NAD83, 2011) in meters and the vertical datum is the North American Vertical Datum of 1988 (NAVD88) in meters realized with GEOID12B. The RMSEz reported for the dataset was 9.4 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

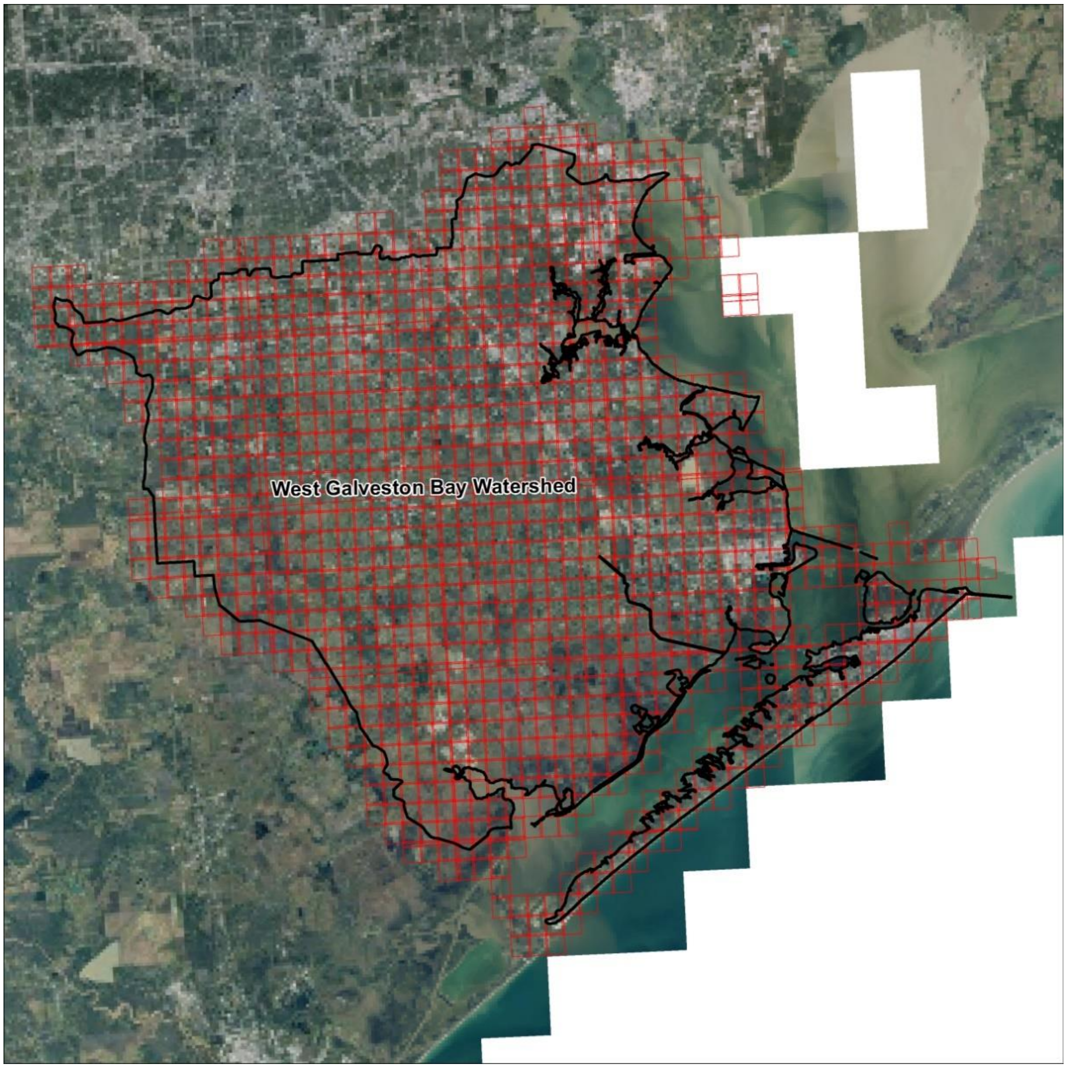

Figure 4: 2018 TNRIS LiDAR: Upper Coastal LiDAR

2014 TNRIS LiDAR: Fort Bend

This StratMap LiDAR project encompasses Fort Bend County, Texas. Fugro EarthData, Inc. captured the data from February 12-27, 2014. The data products became part of ongoing data collection by the state of Texas to support mapping and modeling of floodplains, hydrography, and terrain. This project was procured through the Council on Competitive Government's High Priority Imagery and Datasets (HPIDS) contract. The RMSEz reported for the dataset was 8.577 cm at the 95% confidence level which meets project accuracy specifications of the NSSDA.

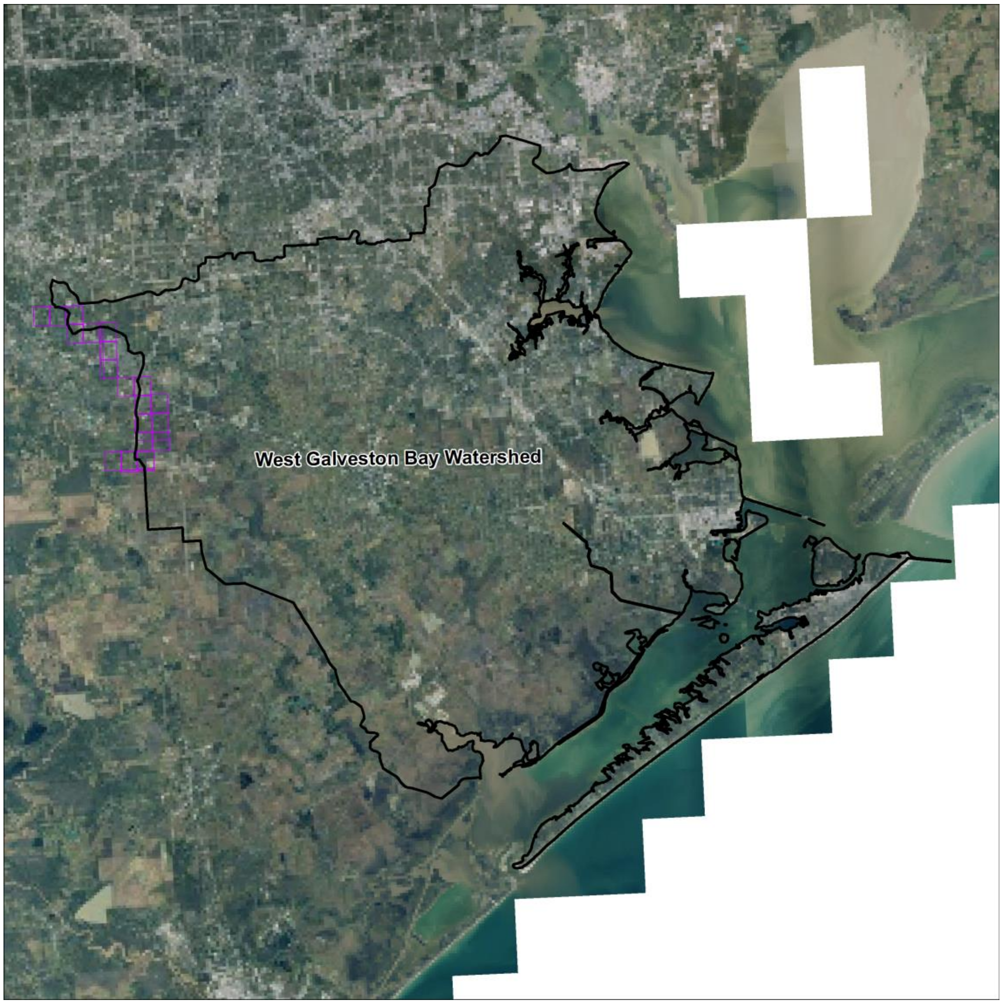

Figure 5: 2014 TNRIS LiDAR: Fort Bend

2.1.3 Data Processing

ArcGIS software was utilized in order to create a digital surface model for the West Galveston Bay 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 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. Where necessary, minor adjustments were made to represent a more accurate bare earth surface using aerial imagery. A shapefile with specific notes has been included for reference for modified locations.

2.1.4 DEM QA/QC

DEMs developed for use in the West Galveston 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 during the data development process includes, but is not limited to the following QC checks:

- Horizontal Projection Check

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

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

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

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

The final DEM data developed for the West Galveston Bay 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 Base Level Engineering (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 West Galveston Bay watershed (approximately 900 sqmi) and presence of highly populated and urbanized areas, HUC-8 was split into 4 separate HEC-RAS geometries due to computational and modeling limitations as shown in Figure 6. The HUC-8 was split into modeling areas as follows: the South West region (combination of Halls Bayou and Mustang Bayou HUC-10), South East region (Dickinson Bayou HUC-10), East region (Clear Creek HUC-10), and the Galveston Island region. The RAS5 2D computational mesh was created for the four areas using ArcGIS toolsets, which reduce the need for manual edits to mesh cells within RAS5 that result in error generation. The South West modeling area contains 1,192,923 cells, the South East contains 2,021,463 cells, the East contains 2,246,310 cells, and Galveston Island contains 533,963 cells. The entire mesh comprises 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. The RAS5 models were 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 South West (combination of Halls Bayou and Mustang Bayou HUC-10), South East (Dickinson Bayou HUC-10), East (Clear Creek HUC-10) and the Galveston Island boundaries, flow trasnfer points between models, and USGS stream gages used in the study.

Because the West Galveston Bay HUC-8 was split into four modeling areas, the outflow hydrograph from the South West model along the American Canal was used as an inflow hydrograph for the South East modeling area. Similarly, the outflow hydrograph from the South East model along Chigger Creek was used as an inflow hydrograph for the East work area. These hydrographs were extracted from the respective models using a 2D connection, and then placed as a flow hydrograph external boundary condition for the model receiving flows.

Outflow boundary conditions (from the computational 2D mesh) were used along model boundaries without an inflow boundary condition. Unique outflow boundaries were established for obvious riverine outflows, while the remaining boundaries were defined as continuous boundaries to allow drainage to adjacent basins to leave the model area freely. Normal depth was used for all non-unique outflow boundary conditions using approximate energy grade-line slopes estimated from the LiDAR terrain data.

A stage hydrograph was used for boundary conditions 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 are Galveston Railroad Bridge (8771486), San Luis Pass (8771972), Morgans point(8770613) and Galveston Pier 21(8771450). On the day it was accessed, the MHWW was 0.92, 0.92, 1.34 and 1.10 respectively. Due to multiple gage stations and model areas the data from Galveston Railroad bridge was used for the South West model area. Similarly, for the South East and East model areas the average of Galveston Railroad bridge and Morgans Point stations was used. For Galveston Island the two gages present on it (i.e San Luis Pass and Galveston Pier 21) were used.

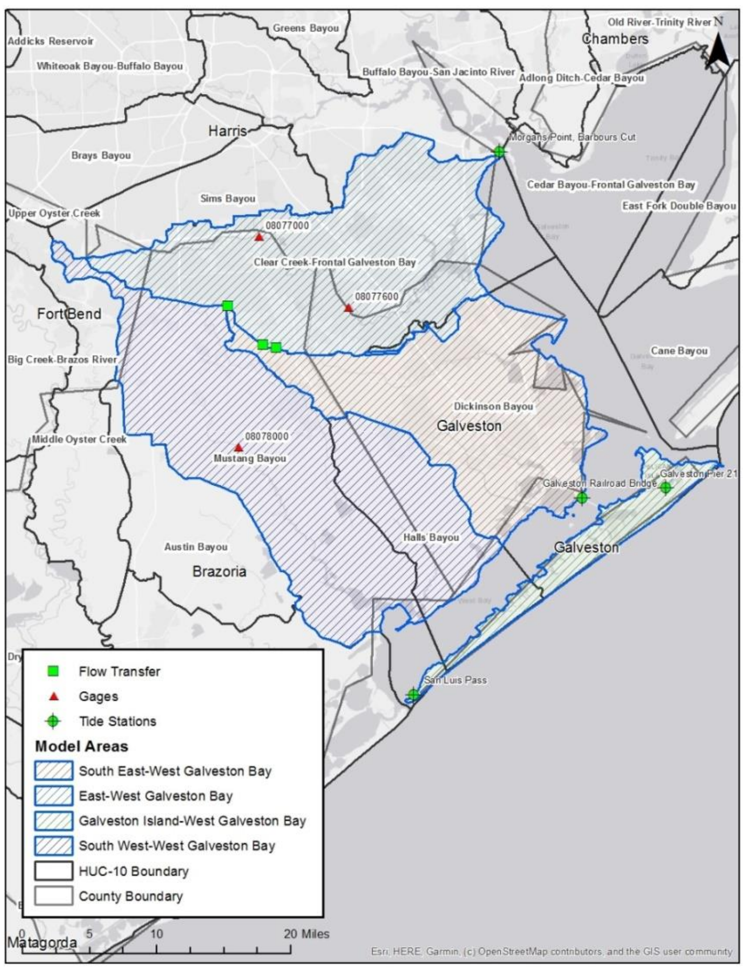

Figure 6: RAS5 2D Computational Mesh and Boundary Conditions and USGS Peak Streamflow Gages

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 all the four model areas. Excess precipitation for the 2D meshes were 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, as discussed in Section 0. Models are compared to known USGS peak flows to ensure accurate results. USGS stream gages with less than 10 years of record were not considered for hydrological analysis or for calibration. The gages considered for analysis in this study are listed in Table 3. Gage 08077000 stopped recording data in 1994 and it was not utilized because of the gage data was approximately 27 years old. Since then the land cover and development (structural, dams, canals, diversions etc) have changed in the region, which is evident by comparing 2001 NLCD and 2016 NLCD land cover. Due to these reasons, this gage is no longer a true representation of present conditions.

Table 3: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
08077600	Clear Ck nr Friendswood, TX	122	1997-2020
08078000	Chocolate Bayou nr Alvin, TX	87	1959-2020
08077000	Clear Ck nr Pearland, TX	38	1944-1994

For the two gages with more than 10 years of continuous gage data, BLE-calculated 100-yr peak discharge (Q) and water surface elevation (WSEL) will be compared with 100-yr gage data. The 100-yr peak discharge gage data along with upper and lower bound values are presented in Table 4. The gage analysis method for this project follows *Scientific Investigations Report 2009-5087(SIR2009): Regression Equations for Estimation of Annual Peak-Streamflow Frequency for Undeveloped Watersheds in Texas Using an L-Moment-Based, Press-Minimized, Residual-Adjusted Approach*. The gage data uses the L-moment method to validate 100-year flows and to estimate the upper/lower bound of the flows using the standard deviation.

The 100-yr WSEL for each gage was estimated using USGS rating curves, along with the upper and lower bound limits. If the rating curve did not reach peak discharge, it was extrapolated using either the power or the fitted equation. The final WSEL value was selected using the lowest R^2 value for that particular rating curve. The results of the stream discharge analysis, along with the +/- standard errors of estimate, are listed in Table 4.

Table 4: USGS Peak Streamflow Results

Gage ID	Flooding Source and Location	1% Peak Q (cfs)	1%- Standard Error Peak Q	1%+ Standard Error Peak Q
08077600	Clear Ck nr Friendswood, TX	43,507	27,135	59.879
08078000	Chocolate Bayou nr Alvin, TX	13,085	8,189	17,981
08077000	Clear Ck nr Pearland, TX	2,236	1,421	3,051

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% 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% plus and minus events are defined to be one standard deviation above and below the 1% event. It should be noted that the standard errors for the 1% rainfall depth were based on the depth used post-areal reduction.

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 5.

Table 5: Land Use-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

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% 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% (S_{10}) and 90% (S_{90}) 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% plus and minus events. First, ARC III (corresponding to S10) and ARC I (corresponding to S90) CN values can be estimated from a 1% 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% plus and minus S values can be estimated by:

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

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

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

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

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

Since the 1% plus and minus events represent plus and minus one standard deviation of a 1% event, CNs used in a rainfall-runoff simulation for modeling 1% 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 for the four hydrological models.

Table 6: Rainfall-Runoff Curve Numbers

Sub-basin Description	CN (initial)	CN (verified)	CN 1% Minus	CN 1% Plus
South West	85.31	90	82.3	94.6
South East	87.22	83	71.6	90.5
East	87.74	87.74	79.08	93.19
Galveston Island	89.88	86.42	77.14	92.39

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including curve numbers for defining rainfall. 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 7 provides the precipitation totals applied to the model including areal reduction.

Table 7: Precipitation Totals estimated in HEC-HMS (post ARF)

Percent Annual Chance Precipitation Depths (in.)							
Sub-Basin Description	1%	0.2%	2%	4%	10%	1% Plus	1% Minus
South West	15.93	23.94	13.20	10.83	8.22	19.26	12.61
South East	16.34	24.75	13.61	11.23	8.56	19.90	12.79
East	16.13	24.25	13.40	11.12	8.40	19.68	12.59
Galveston Island	16.26	24.72	13.31	10.93	8.22	19.73	12.79

Table 8 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 8: Total Excess Precipitation Applied to 2D Mesh

Percent Annual Chance Precipitation Depths (in.)							
Sub-Basin Description	1%	0.2%	2%	4%	10%	1% Plus	1% Minus
South West	14.67	22.66	11.96	9.61	7.02	18.59	10.35
South East	14.12	22.45	11.42	9.1	6.52	18.69	9.02
East	14.57	22.65	11.86	9.6	6.92	18.83	9.89
Galveston Island	14.51	22.93	11.59	9.25	6.6	18.77	9.81

Figure 7 through Figure 10 show the excess precipitation hyetograph used for the four models in West Galveston Bay. 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, but with varying maximum excess precipitation values.

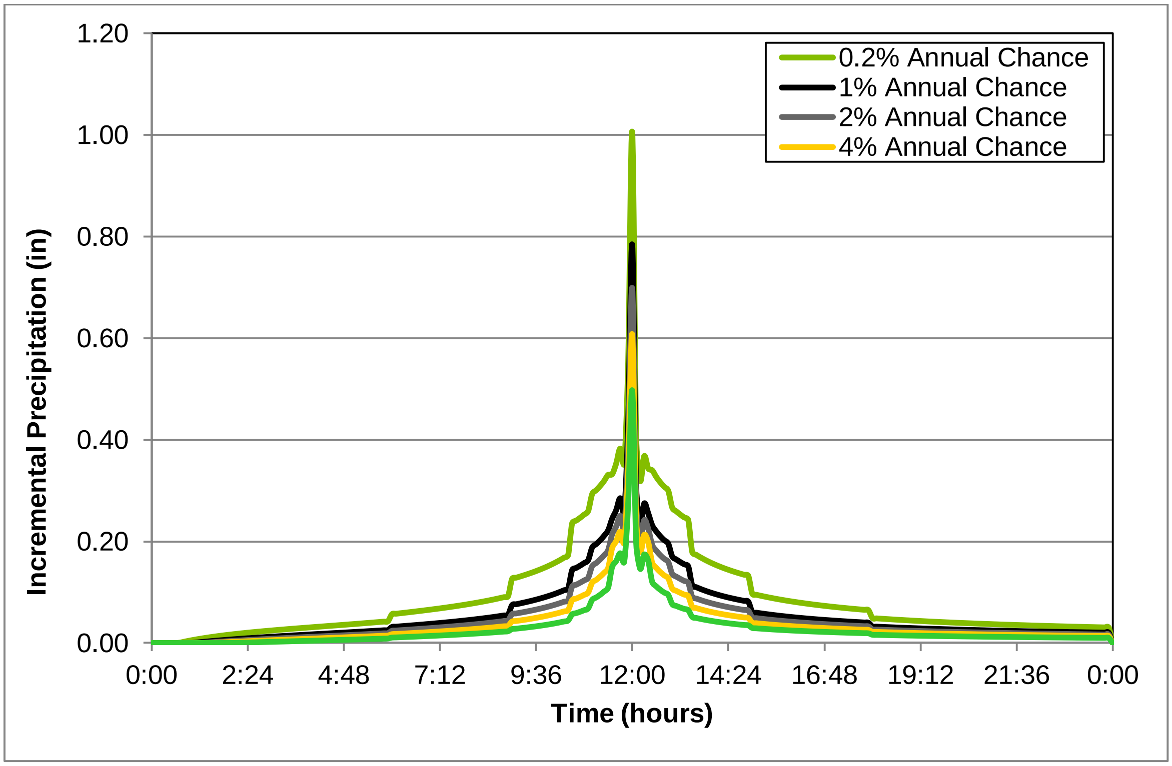

Figure 7: : Excess Precipitation Hyetographs for South West Model Area - West Galveston Bay

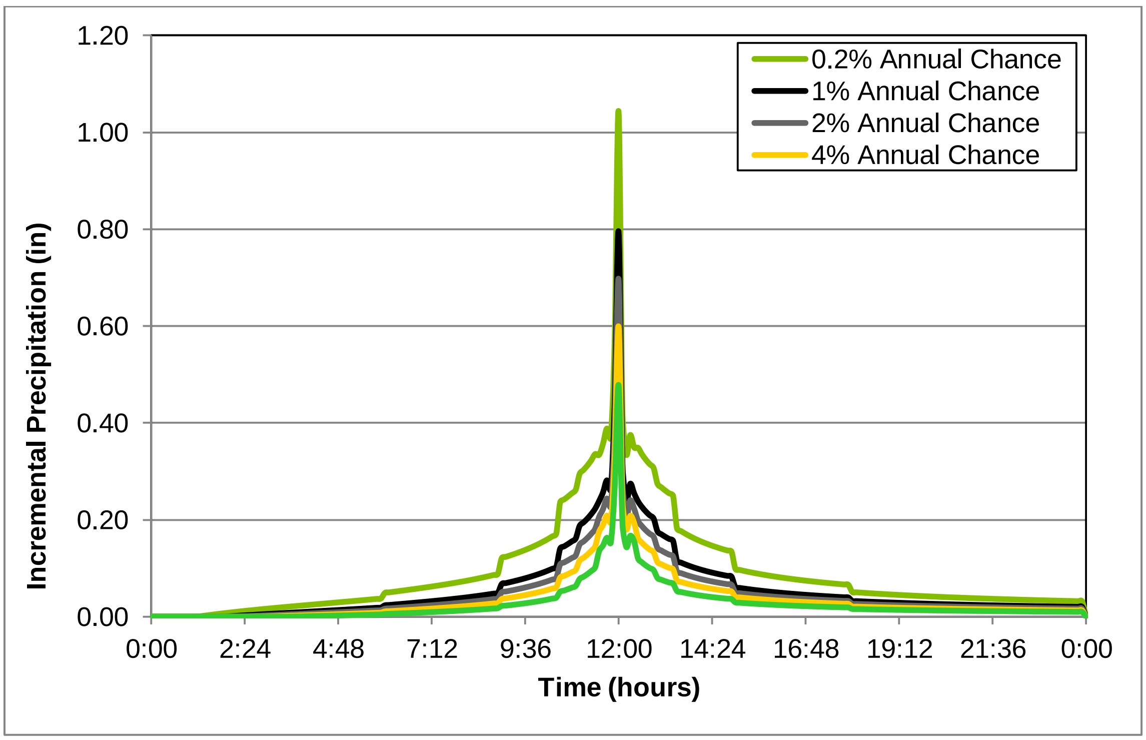

Figure 8: Excess Precipitation Hyetographs for South East Model Area - West Galveston Bay

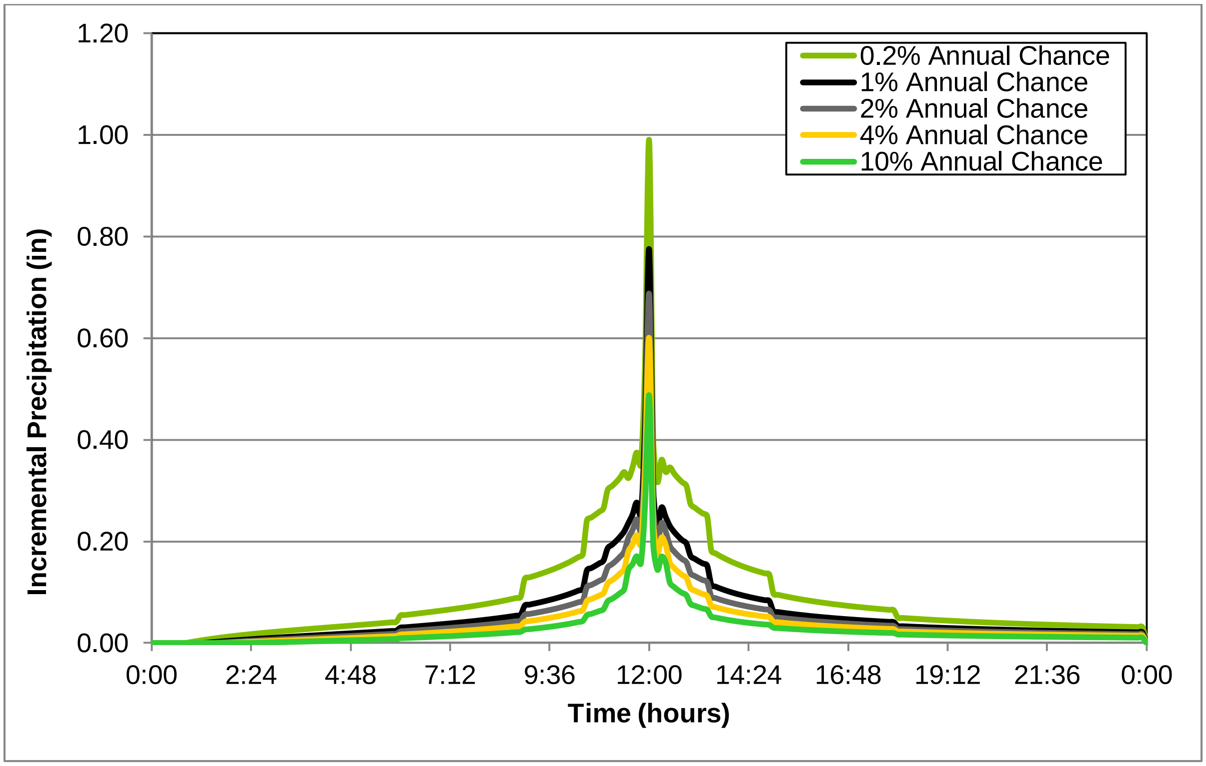

Figure 9: Excess Precipitation Hyetographs for East Model Area - West Galveston Bay

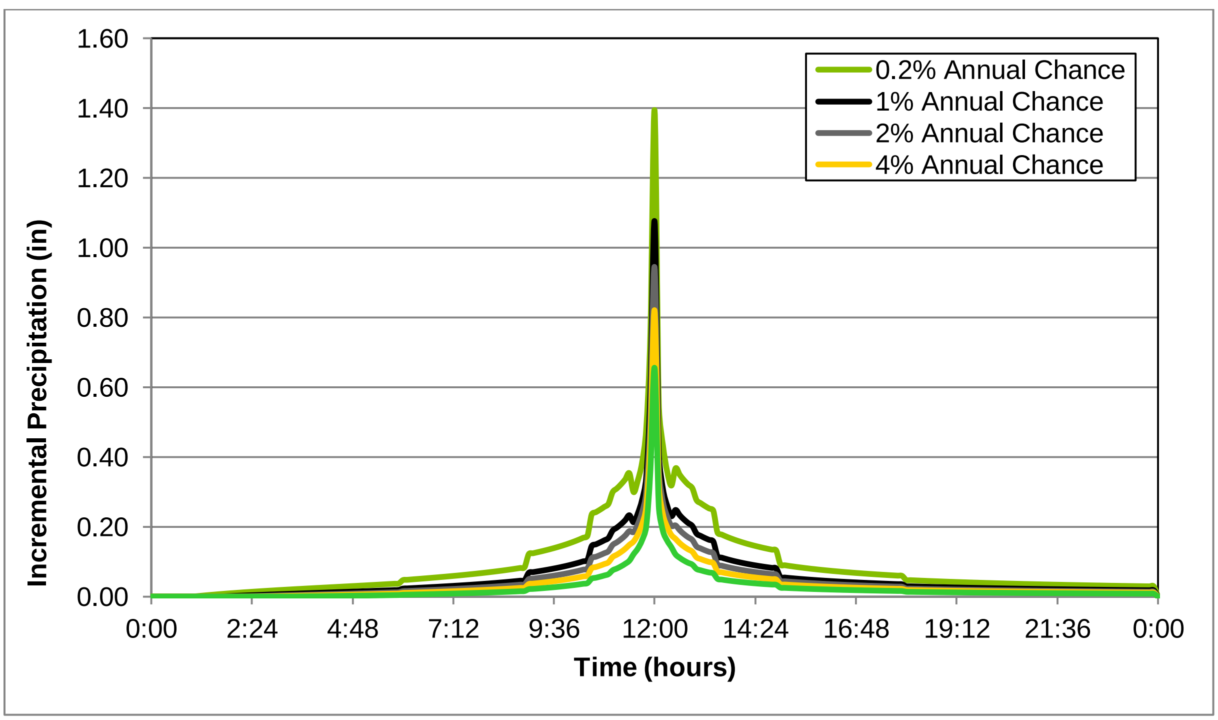

Figure 10: Excess Precipitation Hyetographs for South East Model Area - West Galveston Bay

2.2.3.2 Inflow Hydrograph Boundary Conditions

Flow from the Mustang Creek in the South West model was used as an inflow into the South East model. The inflow hydrograph was derived by utilizing the results of the HEC-RAS model for South West directly upstream. This method is used to ensure that all contributing drainage area and flow is represented accurately and seamlessly throughout each model. By using upstream model results as inflow hydrographs to the downstream model.

The inflow hydrograph was extracted from the South West model using a 2D connection, as shown in the figure below.

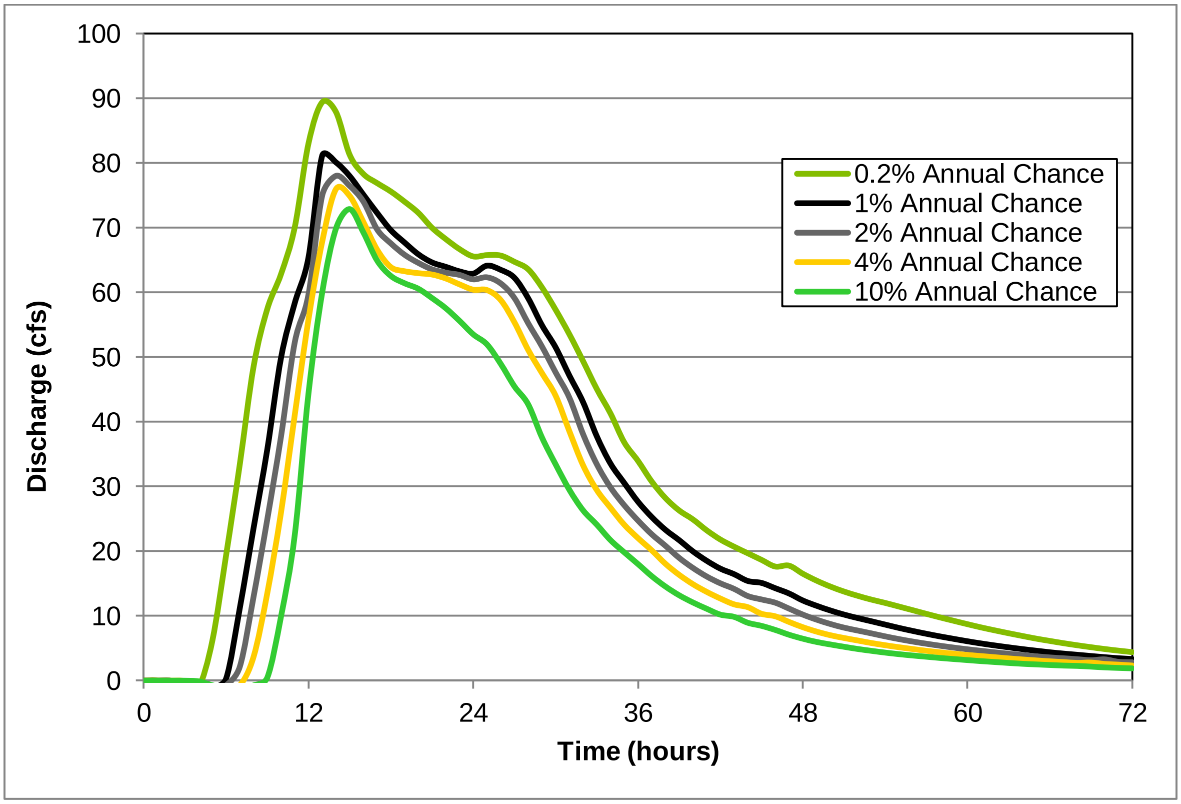

Figure 11: Inflow Hydrograph from South West Model Area - West Galveson Bay

In similar manner as above the flow from the Chigger Creek Tributary 1 and 2 in the South East model were used as an inflow into the East model. The inflow hydrograph was derived by utilizing the results of the HEC-RAS model for East directly upstream, extracted from the South East model using a 2D connection, and shown in the figures below

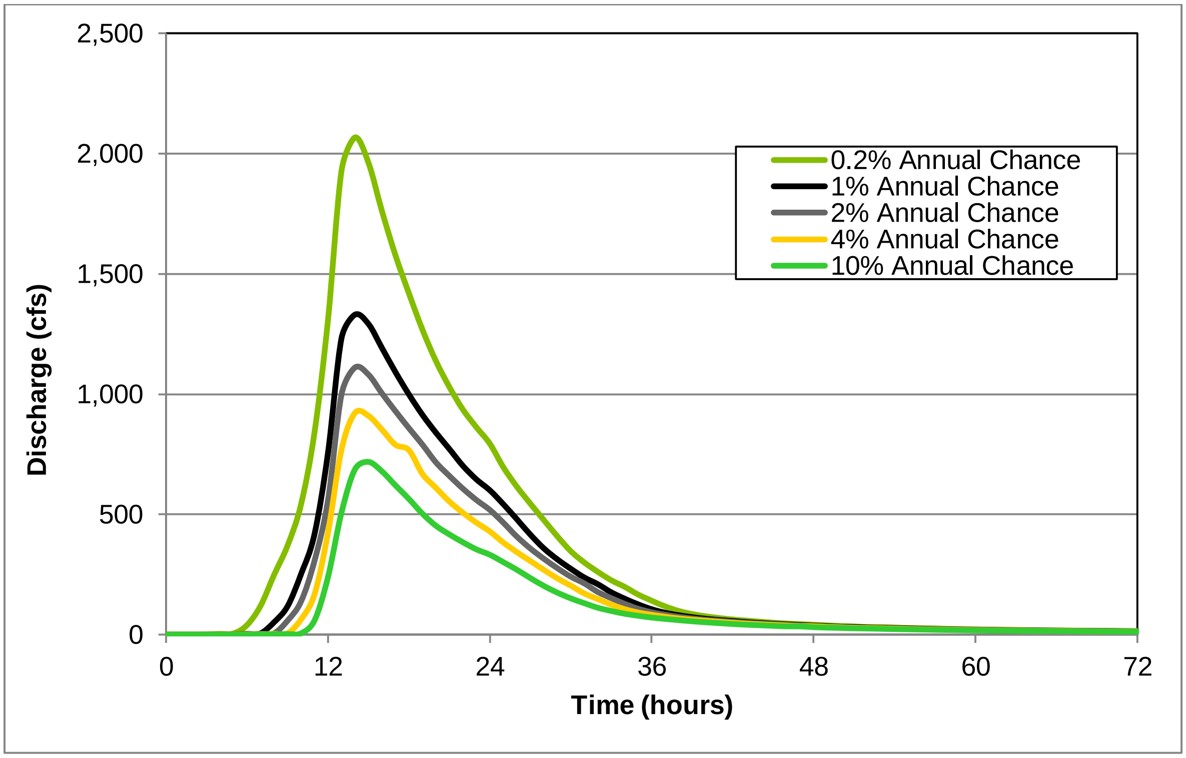

Figure 12: Inflow Hydrograph 1 from South East Model Area - West Galveson Bay

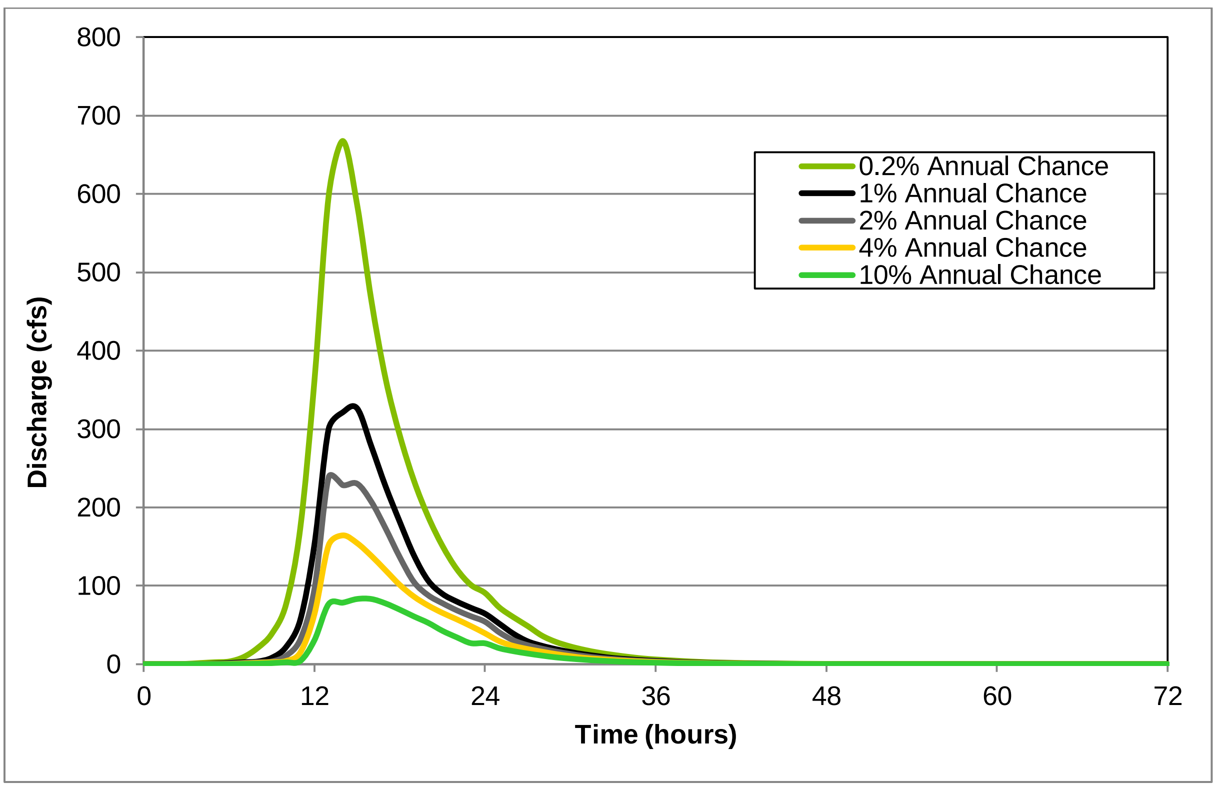

Figure 13: Inflow Hydrograph 2 from South East Model Area - West Galveson Bay

In order to achieve a seamless flood hazard result at a transition location, the water surface elevation and inundation tie-ins between models must be made as close as possible. A 1,000-foot buffer was applied to each 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 model areas 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 roughness coefficients, 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 9: 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 9 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	HCFCD modeling Guidelines
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 14.

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.

All publicly owned dams, according to the 2018 National Inventory of Dams, were modeled with breaklines to provide protection. This method allows water to flow out of the spillway, if it reaches that elevation. 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 stream centerline was enforced with 100 foot cell spacing in order to align cells along the stream line and capture more detail along the one square mile stream network.

In order to represent the prominent features, only accredited levees were included in the study and are represented as breaklines with 50-ft cell spacing. Accredited levee systems included the Texas City Hurricane Flood Protection levee system in Galveston County. Top of levee per the terrain DEM is enforeced as a breakline in the South East RAS model.

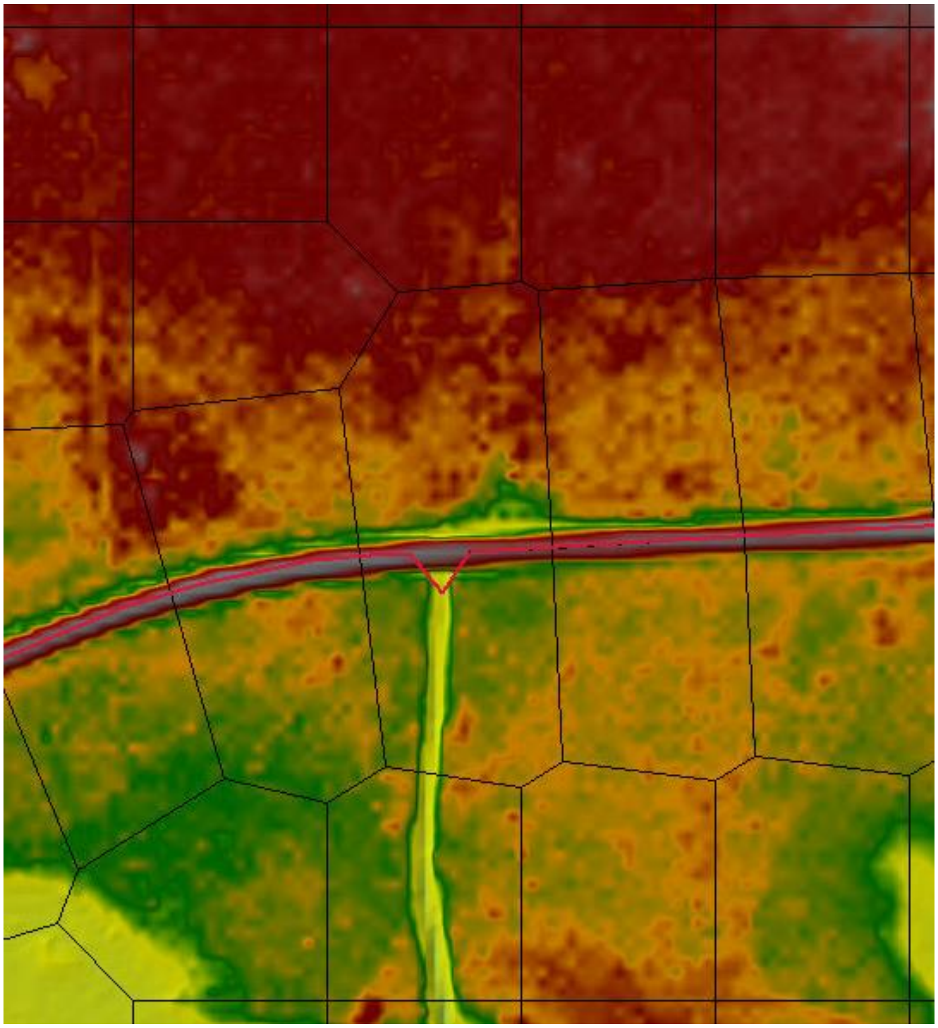

Figure 14: V-notch Breakline Approach at Bridge Crossing

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. The tables below show the communities contained within West Galveston Bay watershed that were modeled with refinement regions as well as the square mileage of the refinement region.

Table 10: Communities with 2D Mesh Refinement in South West Model Area - West Galveston Bay

Community Name	Area(mi^2)
Alvin city	12.04
Arcola city	1.14
Fifth Street CDP	0.05
Fresno CDP	4.29
Hillcrest village	0.43
Hitchcock city	30.98
Houston city	0.33

Table 10 continued: Communities with 2D Mesh Refinement in South West Model Area - West Galveston Bay

Community Name	Area(mi2)
Iowa Colony village	7.32
Liverpool city	0.76
Manvel city	22.47
Missouri City city	3.53
Pearland city	0.52
Santa Fe city	3.26
Stafford city	0.01

Table 11: Communities with 2D Mesh Refinement in South East Model Area - West Galveston Bay

Community Name	Area(mi^2)
Alvin city	5.33
Bacliff CDP	2.67
Bayou Vista city	0.45
Dickinson city	10.20
Friendswood city	1.06
Hitchcock city	36.12
Kemah city	0.34
La Marque city	14.26
League City city	23.89
Manvel city	1.05
Pearland city	0.01
San Leon CDP	4.77
Santa Fe city	15.04
Texas City city	66.59
Tiki Island village	0.64

Table 12: Communities with 2D Mesh Refinement East Model Area - West Galveston Bay

Community Name	Area(mi^2)
Alvin city	0.56
Brookside Village city	2.07
Clear Lake Shores city	0.45
Deer Park city	6.60
Dickinson city	0.01
El Lago city	0.63
Fresno CDP	0.13
Friendswood city	20.10
Houston city	52.09
Kemah city	1.78
La Porte city	13.90
League City city	29.50

Table 12 continued: : Communities with 2D Mesh Refinement East Model Area - West Galveston Bay

Community Name	Area(mi^2)
Manvel city	0.19
Morgan's Point city	0.62
Nassau Bay city	1.26
Pasadena city	21.13
Pearland city	47.05
Seabrook city	5.68
Shoreacres city	0.92
Taylor Lake Village city	1.11
Webster city	6.40

Table 13: Communities with 2D Mesh Refinement in Galveston Island Model Area – West Galveston Bay

Community Name	Area(mi^2)
Galveston city	46.89
Jamaica Beach city	0.69

2.2.5 Quality Control

The results of 2D BLE results were independently assured to meet quality standards of the project. Standard checklists compling 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, inflow hydrographs, flood events, areal reduction factor and human error.
- Hydraulic QC – included checks for RAS geometries, 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 West Galveston Bay 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 14: Effective and Model BFE Comparison

Location Description	Effective BFE (feet)	Model BFE (feet)	Difference (feet)
Armand Bayou at confluence with Spring Gully	15.3	14.7	0.6
Clear Creek at confluence with A111-000-000	14.5	15.4	-0.9
Gum Bayou at Farm Road 517	15.5	9.5	6.0
Marchand Bayou at State Route 519	14.2	10.4	3.8
Dickinson Bayou at confluence with Benson Bayou	14.0	14.3	-0.3
Dickinson Bayou at I-45	14.2	14.9	-0.7
Mustang Bayou approx. 13.42mi US of mouth	33.3	31.4	1.9

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% annual chance event. Discharges at gages were compared to discharges in the 2D models at the exact same locations. Some gage locations also have USGS published rating curves. If a published rating curve was available, water surface elevation from the model was compared to the calculated 1% 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 Brazoria County Flood Insurance Study (Effective December 2020), Galveston County Flood Insurance Study (Effective August 2019) and Harris County Flood Insurance Study (Effective November 2019). 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:

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

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

Two USGS gages that fall within the boundary of West Galveston Bay watershed were utilized for calibration purposes.The 1% modeling peak discharge values compared to USGS gages are on the lower side particularly compared to gage 08077600. It is likely that the peak discharge values vary because of the lack structural data (storm sewers, bridges and culverts etc) and is heavily urbanized. Additional effective data was used for secondary calibration to supplement the USGS gage analysis results. Adjustments to curve number and 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. Final results following model calibration at the calibration locations are presented in Table 15.

Table 15: Calibration Results

Calibration Location	Source	Method Used in Original Study	Reference			HEC-RAS 5.0.7 (2D)
			Lower Limit	1%	Upper Limit	
USGS Gage 08077600	USGS		27,135	43,507	59,879	25,752
USGS Gage 08078000	USGS		8,189	13,085	17,981	9,536
Mustang Bayou 13.42mi	Brazoria County FIS	HEC-1	2,930	5,850	11,670	3,349
Upstream of Confluence West Fork Chocolate Bayou/ Chocolate Bayou	Brazoria County FIS	USGS Report 77-110 methodologies	1,870	3,734	7,449	2,197
Gum Bayou - Farm Road 517	Galveston County FIS	HEC-1	1,503	3,000	5,985	4,775
Marchand Bayou-State Route 519	Galveston County FIS	HEC-1	951	1,900	3,790	2,128
Dickinson Bayou -Benson Bayou	Galveston County FIS	HEC-1	6,012	12,000	23,940	15,741
Dickinson Bayou - Interstate-45	Galveston County FIS	HEC-1	2,965	5,920	11,810	12,487
Confluence Armand Bayou/Spring Gully	Harris County FIS	HEC-1	6,652	13,278	26,489	11,286
Confluence Clear Creek/A111-000-000	Harris County FIS	HEC-1	11,993	23,940	47,760	35,828

Figure 15 shows the final results of the calibration locations compared to modeled flows throughout the West Galveston Bay watershed along with error bars created using the difference between 1% and 1%+ discharges and 1% and 1%- discharges as minimum and maximum values. Ten 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.

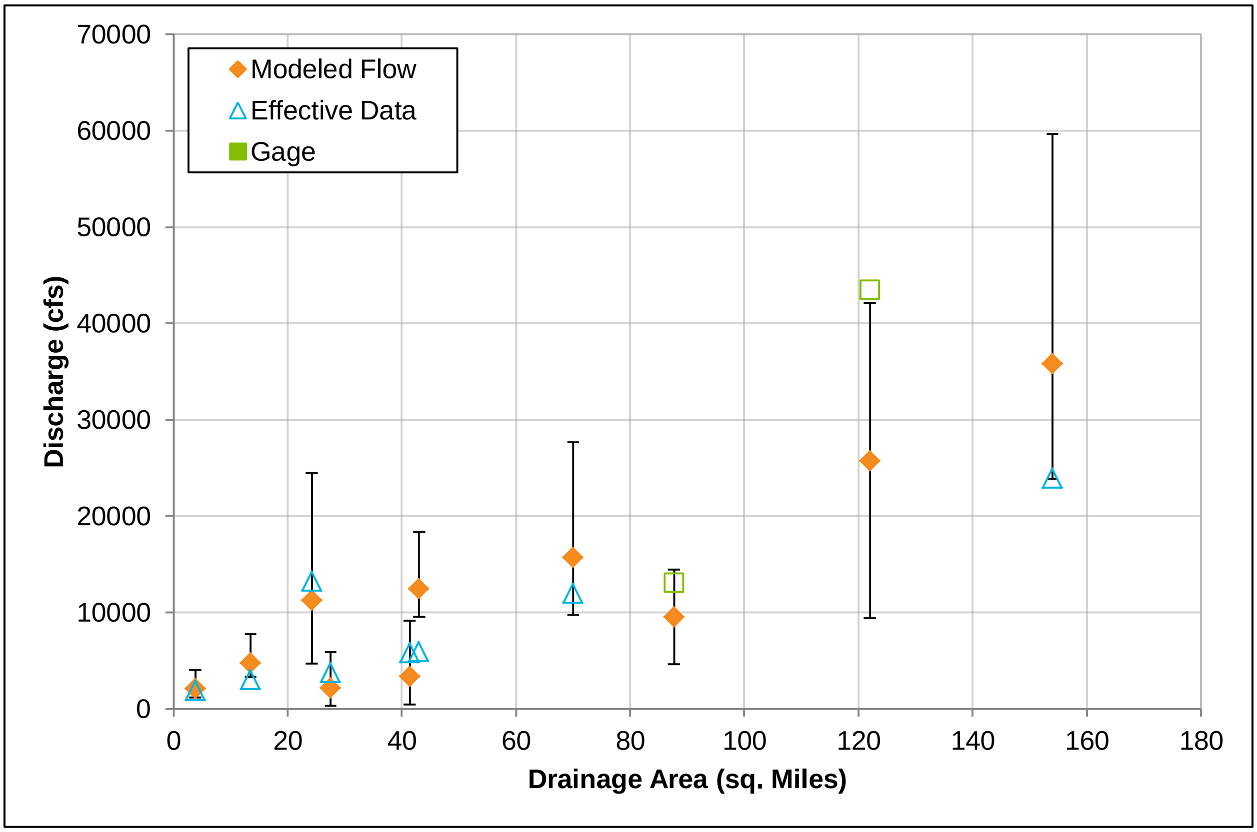

Figure 15: Calibration Comparison

3.2 Challenges

A significant challenge for the West Galveston Bay watershed was the presence of high population density zones in the HUC-8 basin which significantly increased the total number of cells. In order to create this model without creating runtime or cell number issues, it was decided that the watershed would be split into four working models. Due to the urban environment, it was a challenge to calibrate all points, considering this model doesn't account for roadways, bridges, dams and urban stormwater structures. The West Galveston Bay watershed also contains many boardwalks and roads in scoped area and due to the project scope, structure data was not included in this analysis. Another major challenge included the proximity to the coast and size of each HEC-RAS models.

Due to absence of gages and streams along the Galveston Island, coastal transects from the FIS report were used to compare the water surface elevation for the purpose of calibrating the model.

However, West Galveston Bay watershed modeling provide 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 thereby increasing the model runtime. Both accredited and non-accredited levees required close attention to the area to ensure all levees were modeled correctly, enforing the accredited levees but making sure that water can pass through the unaccredited.

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.

Due to the size of the HEC-RAS model, point source Atlas 14 rainfall data was used.For detailed modeling and further improvements smaller sized model is recommended which will have less rainfall and curve number variability. 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 in coastal areas should reduce the overall inundation using statistical analysis of flood hazard depths and areas. For the Austin Oyster watershed, the following parameters were applied to remove or reduce floodplain inundation:

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

Mapping for the 10% annual chance was mapped as well in a similar manner in 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% boundary exceeded the 1% boundary, those areas have been removed.

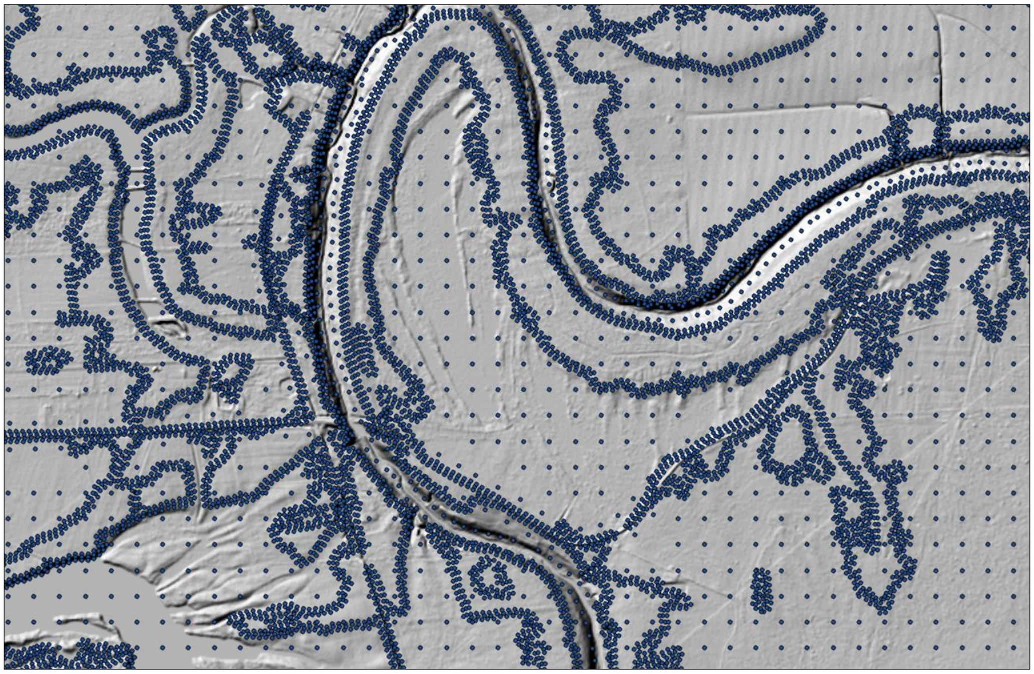

Figure 16: 2D BLE Model Points for Mapping Workflow

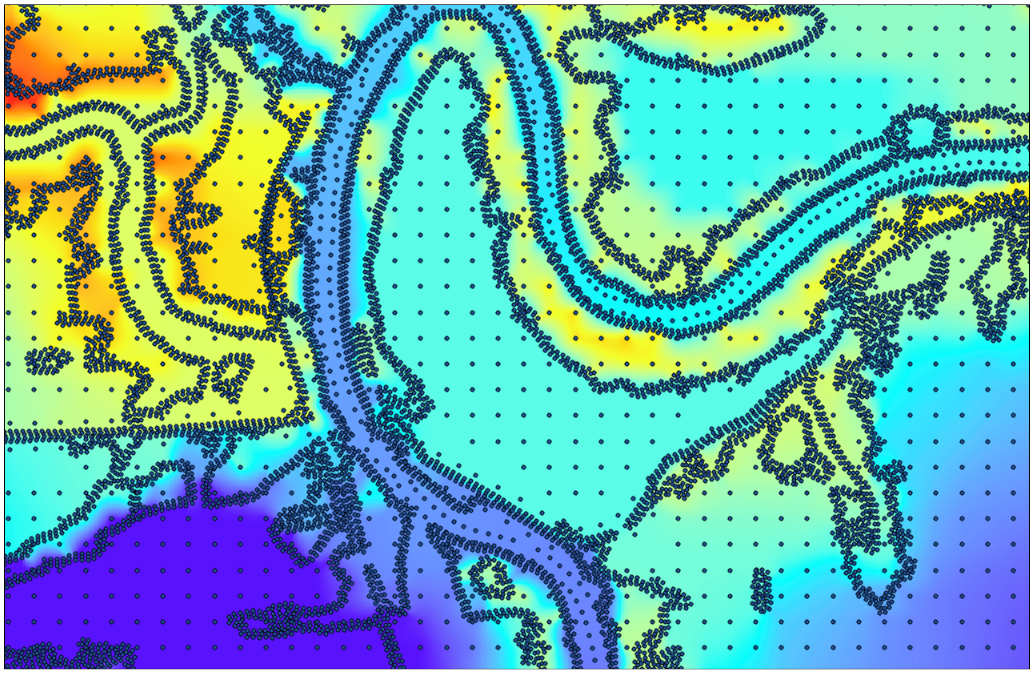

Figure 17: 2D BLE Model Points to Water Surface Elevation TIN

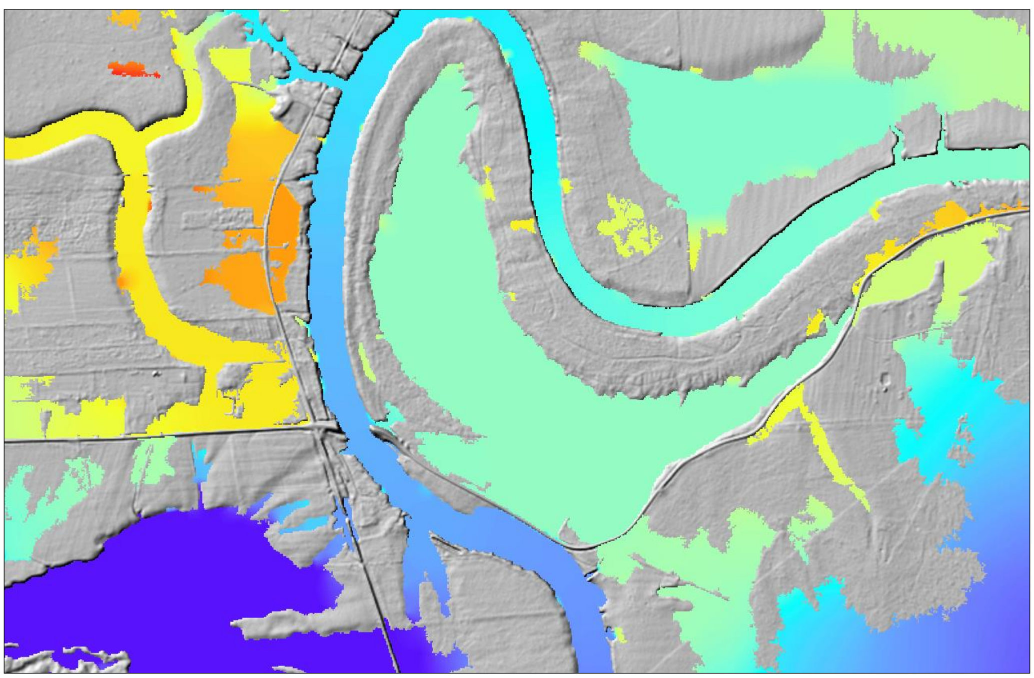

Figure 18: Water Surface Elevation TIN to Grid

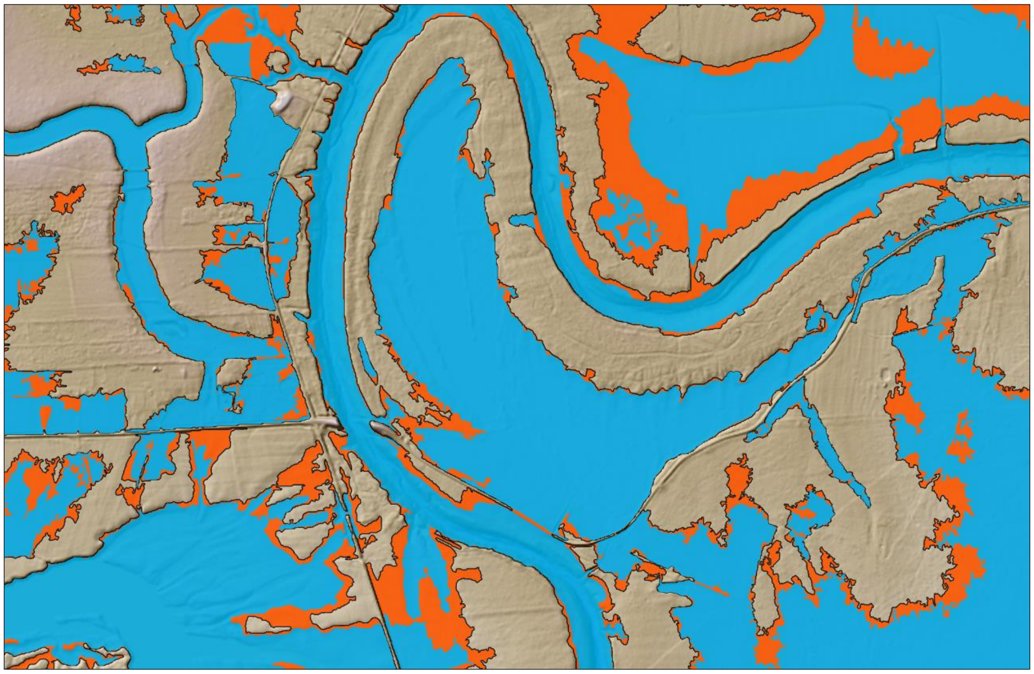

Figure 19: Water Surface Elevation Grid to Mapping Products

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% 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% annual chance inundation not mapped as BLE SFHA is retained in an additional 1% 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 (62.4 miles) in the West Galveston Watershed were classified in CNMS with validation status of “UNVERIFIED” (57.5 miles) or “VALID” (4.9 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 Intial 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 Austin Oyster Watershed, the effective Zone A topographic data consisted of LiDAR data. The LiDAR sources used in this BLE study are not considered significant improvements from the effective zone A topographic sources; therefore, all reaches pass 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.

For Zone A streams within Brazoria County, regression equations were not used for any effective studies and, therefore, pass this assessment check. For zone A streams within Fort Bend County, 2001 regression equations were utilized. New regression equations were published for the area in 2009 (SIR 2009-5087), creating a significant change in discharge. A2 fails for all reaches in Fort Bend County as a result.

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. Most Zone A studies within the watershed are classified as rural and, therefore, pass this check. There are several reaches in Fort Bend County that are classified as urban and that have experienced a significant increase % urban area. As a result, these reaches fail this check.

All of the initial assessment results are shown in Table 16.

Table 16: Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Pass	LiDAR sources available are not a significant improvement from effective topography.
A2 – Hydrology	Pass/Fail	Regression equations not used in effective study/New equations have been published since those used in effective study
A3 – Development	Pass/Fail	Watershed does not meet urban threshold/Urban watershed has experienced significant increase in urban area

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. Streams in Brazoria County are not model-backed and fail this check. Streams in Fort Bend County, are model-backed studies and, therefore, pass 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: +/- 2.5 - 5 feet (one-half contour interval of effective topographic source).
- Horizontal Tolerance: +/- 75 feet (standard horizontal tolerance for BLE comparison testing).

Comparison results for thse streams were grouped at the HUC-12 level and are summarized in Table 17 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 17: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
West Galveston Watershed	All Streams	18,442	7,186	11,256	84%	FAIL	
Clear Creek-Frontal Galveston Bay	120402040100	1,352	533	819	61%	FAIL	41.8
Dickinson Bayou	120402040200	2,293	690	1,603	70%	FAIL	29.6
Mustang Bayou	120402040400	339	109	230	68%	FAIL	22.9

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 Austin Oyster Watershed has been updated as summarized in Table 18 and illustrated in Figure 20.

Table 18: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	4.9
UNVERIFIED	BEING STUDIED	57.5

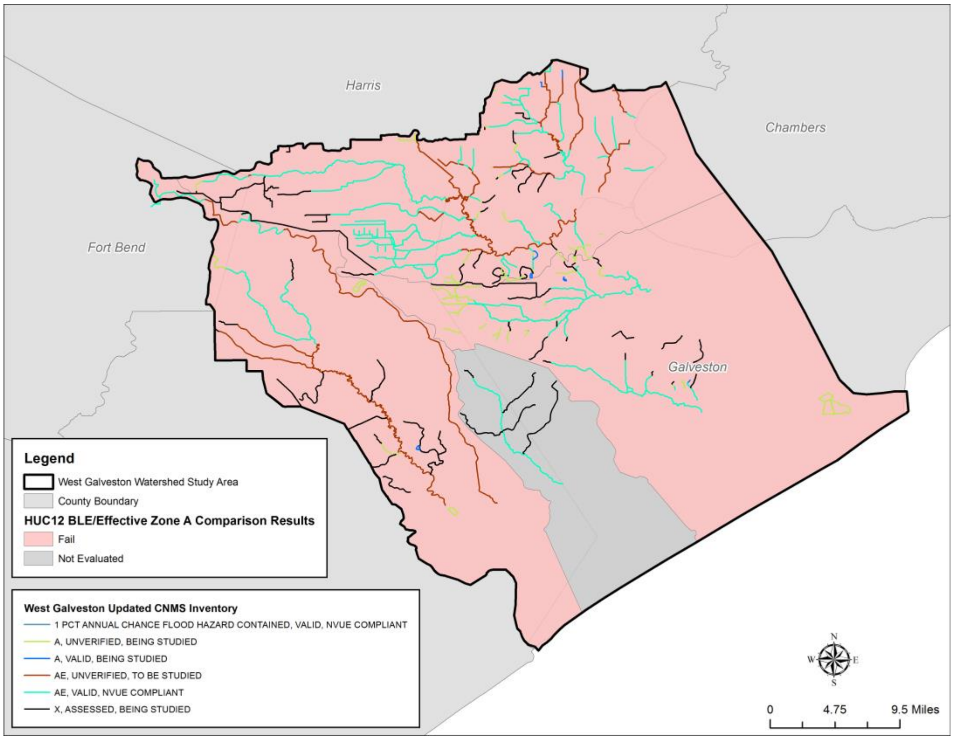

Figure 20: West Galveston Watershed CNMS Validation Results

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 21below shows the range of the HUC-12 priority scores which can be used to initiate discussions during the Discovery phase.

Clear Creek-Frontal Galveston Bay HUC-12 was determined to have the highest priority score and the most need while Mustang Bayou HUC-12 had the lowest scores.

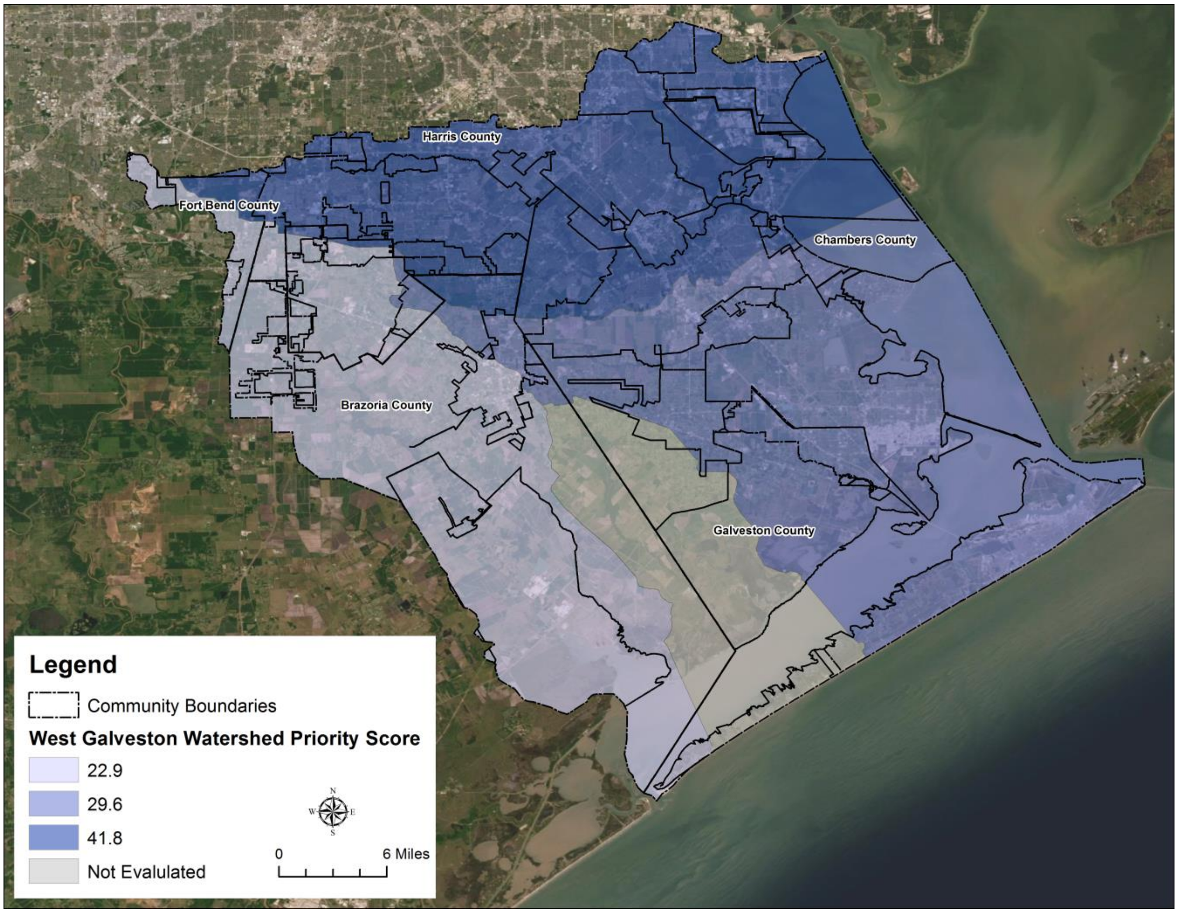

Figure 21: Ranking of West Galveston Watershed HUC-12s

4.3 Flood Risk Analysis

A flood risk analysis was performed for this project. The updated 1% annual chance and 0.2% 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 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 19.

Table 19: 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
Brazoria	59,770,000	1,821,6195,000	10,368,151,000
Fort Bend	0	2,825,205,000	1,600,442,000
Galveston	1,722,828,000	33,853,498,000	19,949,347,000
Harris	36,000	35,420,385,000	21,033,025,000
Total	**1,782,634,000**	**90,315,283,000**	**52,950,965,000**

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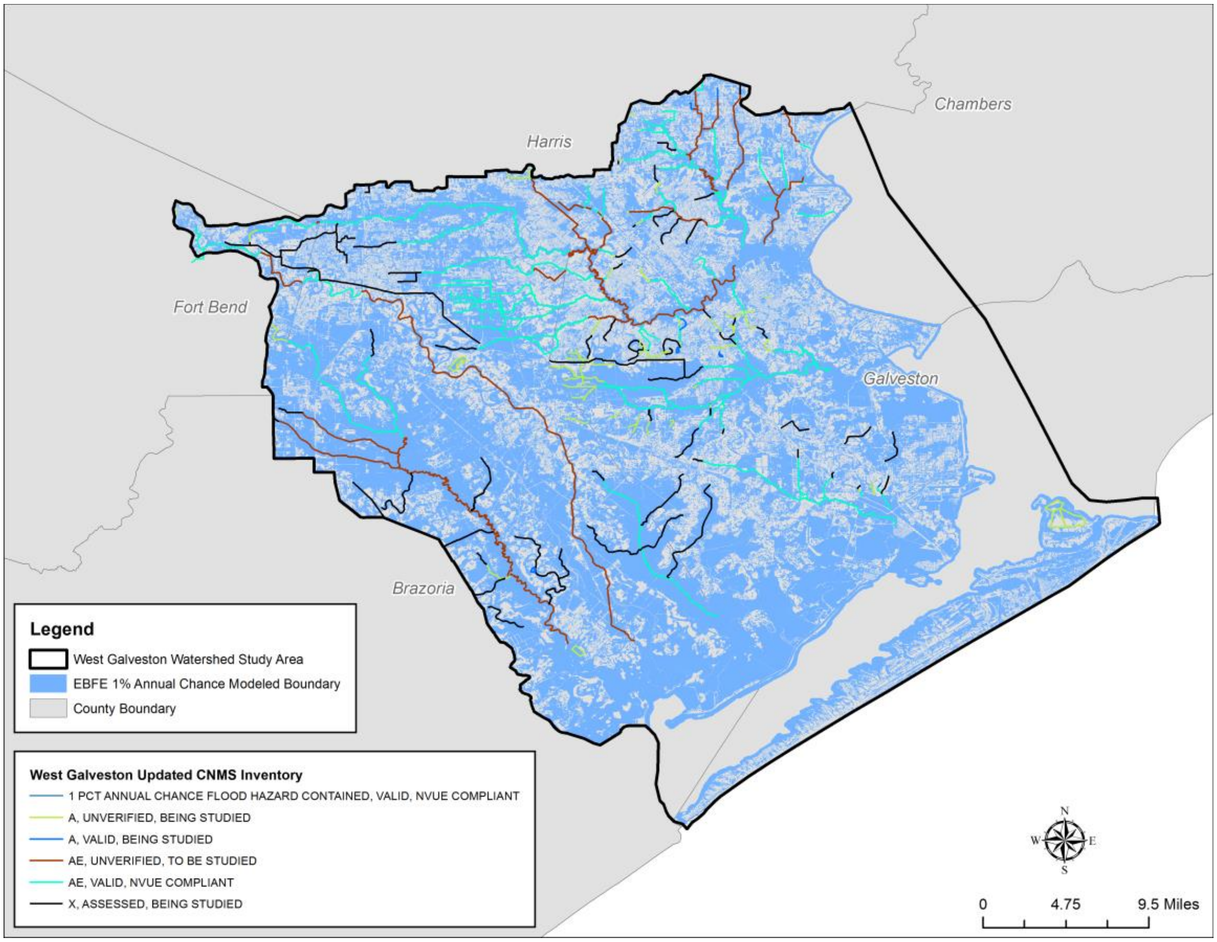
Appendix A BLE Map



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