South Corpus Christi Bay Watershed, Texas
2D Base Level Engineering Methods and Results

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FEMA Region VI
FRC 800 North Loop 288
Denton, TX 76209-3698

Submitted by:

Compass PTS JV
3101 Wilson Boulevard, Suite 900
Arlington, VA 22201

Compass PTS JV
3101 Wilson Boulevard, Suite 900
Arlington, VA 22201
T: 703.682.9100; F: 703.682.4901

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Role	Name	Phone	Title (CLIN/RMC)	Review Date	Approved Date
Project Manager	Kelsey Cayeros	(210)704-1364	Project Manager	10/20/2021	10/20/2021
Task Lead	Daniel Perry	(210)704-1353	Task Lead	10/19/2021	10/19/2021

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Name	Title/Organization	Location
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Diane Howe	FEMA Region VI Risk MAP Lead	Denton, TX

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01 Introduction

Recent innovations and efficiencies in floodplain mapping have allowed the U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) to develop a process formerly known as First Order Approximation (FOA), now labeled Base Level Engineering (BLE), which can be used to address current program challenges, including the validation of Zone A studies and the availability of flood risk data in the early stages of a Flood Risk Project. The BLE process involves using best available data and automated techniques to produce estimates of flood hazard boundaries for multiple recurrence intervals. The South Corpus Christi Bay Watershed BLE documented here was designed to use 2-dimensional (2D) modeling efforts with enhancements and calibration to develop products intended to be transitioned into regulatory data development workflows.

As described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e), once every five years, FEMA must evaluate whether the information on Flood Insurance Rate Maps (FIRMs) reflects the current risks in flood prone areas. FEMA makes this determination of flood hazard data validity by examining flood study attributes and change characteristics, as specified in the Validation Checklist of the 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.

In addition to the need for Zone A validation guidance, FEMA standards require flood risk data to be provided in the early stages of a Flood Risk Project. FEMA Program Standard Identification (SID) #29 requires that during Discovery, data must be identified that illustrates potential changes in flood elevation and mapping which may result from the proposed project scope. If available data does not clearly illustrate the likely changes, an analysis is required that estimates the likely changes. This data and any associated analyses should be shared, and results should be discussed with stakeholders.

An important goal of the BLE process is the scalability of the results. Scalability means that the results of a BLE should not only be used for CNMS evaluations of Zone A studies but can also be leveraged throughout the Risk MAP program. The large volume of data resulting from a BLE can be updated as needed and used for the eventual production of regulatory and non-regulatory products, outreach and risk communication, and MT-1 processing. Leveraging this data outside the Risk MAP program may also be valuable to external stakeholders.

FEMA Region VI (Region) contracted Compass to perform a BLE analysis for the South Corpus Christi HUC-8 Watershed (12110202) in South Texas to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHA). This report documents the BLE process, products, and results for this watershed. **Figure 1** depicts the South Corpus Christi Bay Watershed footprint in Nueces county.

Figure 1: South Corpus Christi Bay Watershed

02 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2-dimensional (2D) hydraulic engineering analysis for the South Corpus Christi 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 these Texas 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 South Corpus Christi Bay BLE project by leveraging available high-resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the entire State of Texas. The 10-foot DEM developed to support the 2D BLE modeling and analysis, within the South Corpus Christi Bay Watershed, was executed using the following steps:

1. Available elevation data for the project area were inventoried and collected and listed in **Table 2**.
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 detailed in 2.1.4.

Documentation regarding leveraged data including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables and text below. All vertical accuracy specifications were obtained from the metadata or survey reports provided with the leverage datasets. All available metadata, survey reports, and other leverage documentation are included in the FEMA Data Capture Technical Reference compliant submittal content for the South Corpus Christi Bay Watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the South Corpus Christi Bay BLE project footprint.

Figure 2 depicts the datasets identified for leveraged across the project area. FEMA, NOAA, USGS, and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

Figure 2: South Corpus Christi 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)**

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

Table 2: Source Topographic Data Available for the South Corpus Christi Bay Watershed

Year	Description	Data Type	RMSE	Source/Owner
2018	USGS South Texas LiDAR	Airborne LiDAR	10 cm	USGS

2.1.2.1 South Corpus Christi Bay Watershed Source Terrain Data

The source elevation data for the South Corpus Christi Bay Watershed are DEMs derived from the 2018 South Texas USGS LiDAR. 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**. The 2018 USGS South Texas LiDAR was collected with a nominal pulse spacing of 0.7 meters. The data was tested to meet 19.6 cm vertical accuracy at 95% confidence level (RMSE * 1.96).

2.1.3 Data Development Methodology

The source topographic data were processed for an area covering the South Corpus Christi Bay Watershed and contributing drainage areas for the South Corpus Christi Bay BLE modeling efforts. The topographic data for South Corpus Christi Bay Watershed was projected horizontally, as needed, to North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS) Texas South in feet (4205). All topographic data were adjusted vertically, as needed, to NAVD88 in feet. Compass used a combination of ArcGIS and other software tools to apply any vertical datum shifts and\or any horizontal projection transformations to the topographic data.

2.1.4 DEM QA/QC

DEMs developed for use in the South Corpus Christi Bay Watershed BLE analysis were developed and independent 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

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

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

Quality assurance was accomplished through quality control checks 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.

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

2.2 2D BLE Methods

The following sections describe the 2D computational mesh and program setting considerations, followed by discussion and tabulation of hydrologic and hydraulic engineering methods and model inputs.

2.2.1 2D Computational Mesh and Settings

The HEC-RAS 2D computational mesh defines the extents of the 2D flow and can affect the accuracy of the 2D calculations. A denser mesh may provide more accurate results, but it can dramatically increase computation times. The 2D mesh for the model was set as evenly spaced cells at 200 feet. The mesh was further refined by placing breaklines along roads, berms, ridges, and other high ground that can influence the flow.

To ensure the entire South Corpus Christi Bay Watershed was represented, an initial 1,000-foot buffer extension was added to the HUC boundary for the model mesh limits. Further refinements of the mesh included incorporating portions of the Baffin Bay and North Laguna Madre watershed in order to better capture the several interactions between adjacent watersheds.

The HEC-RAS 2D computational mesh was created for South Corpus Christi Bay Watershed based on HUC boundaries using ArcGIS toolsets, such as smoothing and simplification routines; ultimately, significantly reducing the need for manual edits to mesh cells within HEC-RAS that happen to generate errors. The 2D mesh for South Corpus Christi Bay East consists of nearly 315,000 cells at a 200-foot nominal mesh cell size; there are factors that could result in either larger or smaller cell sizes including proximity to the edge of the 2D mesh or the presence of breaklines. A 30-second time step was used in the HEC-RAS model, applying the Diffusion Wave (simplified Full Momentum) equations. This timestep was selected to improve unstable courant values that were present at higher timestep intervals.

2.2.2 Model and Boundary Condition Setup

Using HEC-RAS rain-on-grid modeling requires establishing a 2D computational mesh boundary, and often requires defining inflow boundary conditions in addition to excess precipitation applied to the mesh. For the South Corpus Christi Bay basin, no inflow hydrographs from neighboring HUCs were necessary. An outflow hydrograph was obtained from the South Corpus Christi Bay model and applied as an inflow to the Baffin Bay watershed. **Figure 3** shows the 2D computational mesh for the South Corpus Christi Bay basin, along with USGS peak streamflow gages pertinent to the study. **Figure 4** shows the outflow boundary condition locations for the South Corpus Christi Bay basin which were provided for Baffin Bay.

The development of the outflow hydrograph and excess precipitation hyetographs for the 2D mesh, are described in the following Section 2.2.3.

Outflow boundary conditions (from the computational 2D mesh) were utilized along basin boundaries. For the outflow into Baffin Bay, a unique outflow boundary was established for obvious riverine outflows, while the remaining boundaries were defined as continuous boundaries to allow drainage from adjacent basins to leave the model area freely. The free flow outfall allows for water along boundaries to be tracked to determine if significant flow is leaving the studied watershed. Normal depth was used for all non-unique outflow boundary conditions using approximate energy grade-line slopes estimated from the LiDAR terrain data. Coastal boundary conditions were placed using a Stage Hydrograph with a High-High Water Mark of 1.5 ft as determined by the NOAA Tides and Currents dataset.

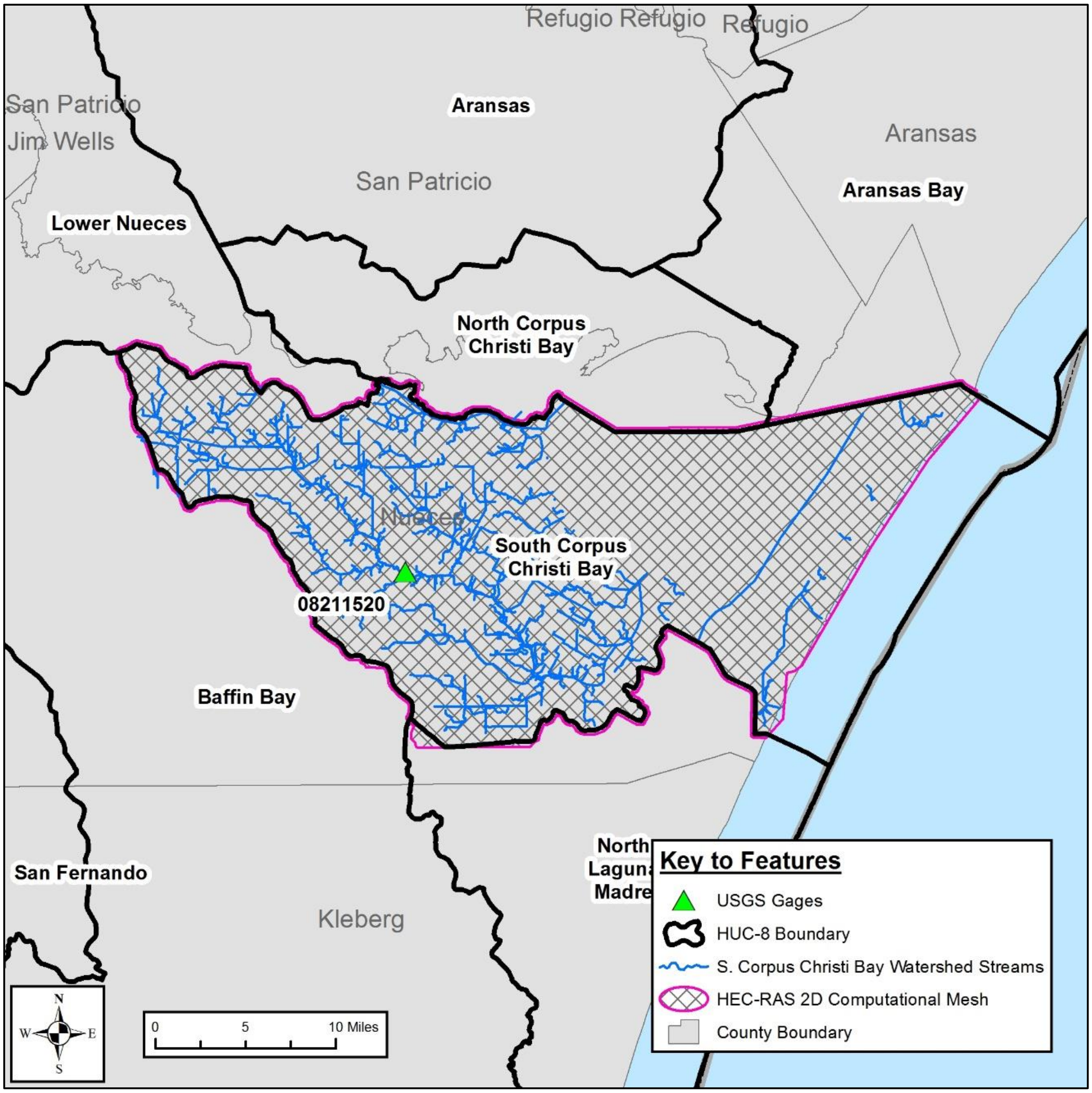

Figure 3: HEC-RAS 2D Computational Mesh and USGS Peak Streamflow Gages

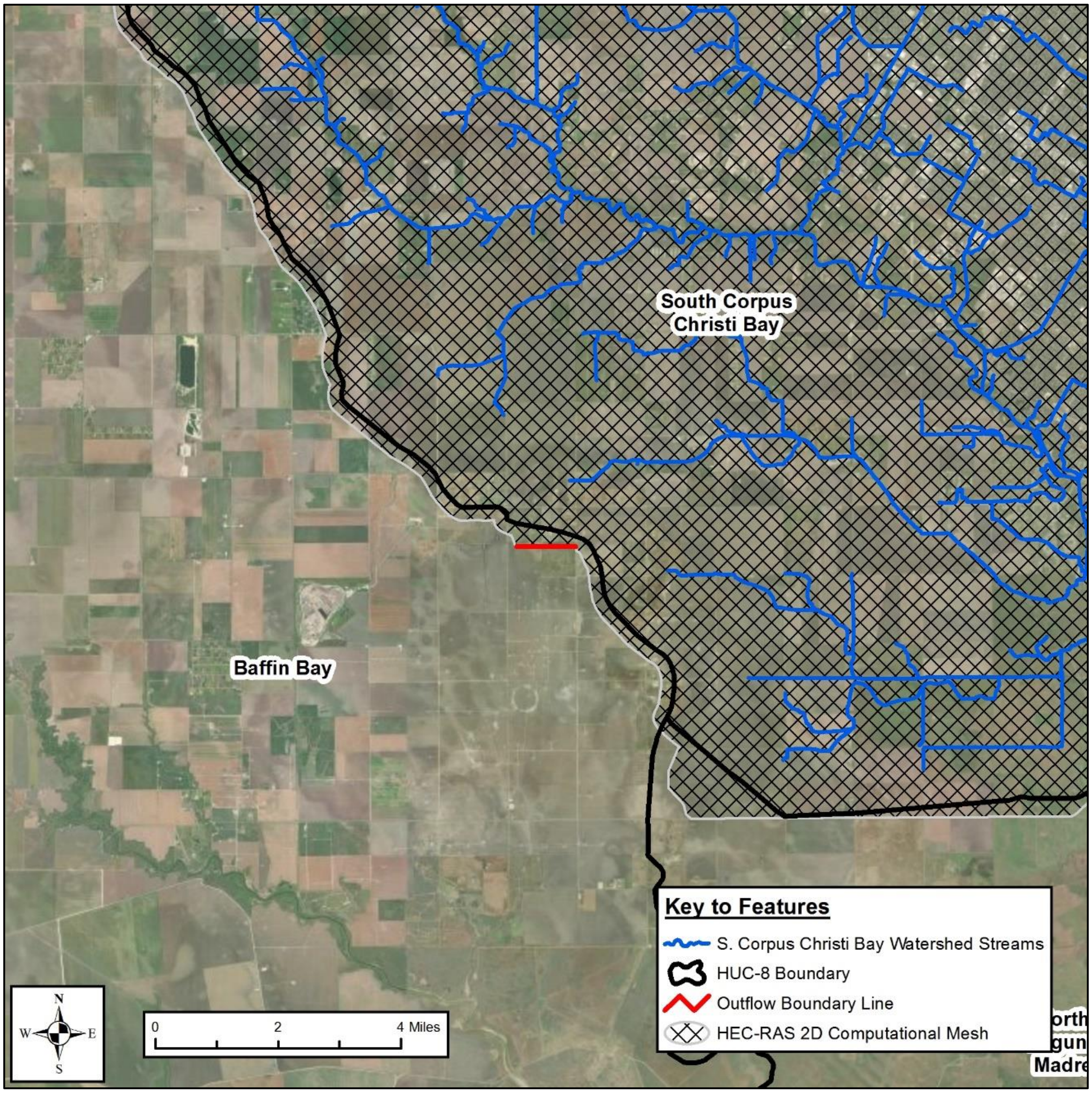

Figure 4: HEC-RAS 2D Computational Mesh and Outflow Boundary Line for South Corpus Christi Bay into Baffin Bay

2.2.3 Hydrology

Precipitation data for this study were referenced from NOAA's Precipitation Frequency Data Server, and appropriate values for all sub-basin elements were determined considering spatial variation and a representative total for each particular sub-basin. Excess precipitation for the 2D mesh was developed as described in Section 2.2.3.1. No inflow boundary conditions were necessary for South Corpus Christi Bay. USGS streamflow gage data were leveraged to estimate peak flows for gages within each work area for calibration purposes, as discussed in Section 2.3.1.1.

The HEC-HMS version 4.6 model was used solely for the development of excess precipitation hyetographs which were applied to the 2D mesh.

Precipitation frequency data published in NOAA Atlas 14, Volume 11 Version 2.0 (NOAA, 2018) were used for this Study. These data were obtained from NOAA's Precipitation Frequency Data Server (PFDS) (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html). The 10-, 4-, 2-, 1-, and 0.2-percent annual chance 24-hour precipitation depths for all sub-basin elements were determined by area-weighted intersection of gridded PFDS data with sub-basins. Excess precipitation for the 2D mesh was developed as described in Section 2.2.3.1. The gages utilized for this study are presented in **Table 3**.

Table 3: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
08211520	Oso Ck at Corpus Christi, TX	90.3	1973 - 2020

Annual chance peak flows were calculated at each gage using USGS Bulletin 17B methodology. The 92% confidence interval was used to determine the 1% plus and minus chance events. Calculated discharges for the 1%, 1% plus, and 1% minus events are presented in **Table 4** for each gage utilized in this study.

Table 4: USGS Peak Streamflow Gage Analysis Results

Gage ID	Flooding Source and Location	1% Peak Q (cfs)	1%- Peak Q (cfs)	1%+ Peak Q (cfs)
08211520	Oso Ck at Corpus Christi, TX	10,890	8,645	14,620

2.2.3.1 Excess Precipitation for 2D Computational Mesh

HEC-HMS version 4.6 was used to apply the SCS Curve Number method to calculate losses and define excess precipitation for each watershed. Temporal distributions of point rainfall totals were defined using 24-hour, SCS Type II storm distributions. The plus and minus standard error for the 1-percent annual chance precipitation depths were determined as the upper and lower 84% confidence limits on the nominal 1-percent depth, assuming a normal distribution of the logarithms for the precipitation depths.

In addition to recurrence interval precipitation estimates, NOAA Atlas 14 provides 90% confidence intervals of reported precipitation values. On a normal distribution curve, 90% confidence intervals (i.e. the upper and lower 95% confidence limits) correspond to +/- 1.645 standard deviations. The 1% plus and minus events are defined to be one standard deviation above and below the 1% event. 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**. The CN Matrix was developed from the United States Department of Agriculture (USDA) *Urban Hydrology for Small Watershed Technical Release-55* (1986) procedures. A range of CN values were developed based on Good (minimum), Fair (mean), and Poor (maximum) values obtained from Table 2-2a – 2-2d of the TR-55 document. These matrices were then used to develop Minimum, Median, and Maximum CN values to be input into HEC-HMS, along with the Original CN values shown below. The excess precipitation was obtained from HMS for each CN value and input into the hydraulic model for an iterative validation analysis. The validation process is described more in Section 2.3.1.1.

Table 5: Land Use-Soils-CN Matrix for Computing Initial Curve Numbers

LU_GridCode	NLCD LU Description	Hydrologic Soil Group			
		A	B	C	D
11	Open Water	99	99	99	99
21	Developed Open Space	49	69	79	84
22	Developed Low Intensity	57	72	81	86
23	Developed Medium Intensity	61	75	83	87
24	Developed High Intensity	77	85	90	92
31	Barren Land	49	69	79	84
41	Deciduous Forest	36	60	73	79
42	Evergreen Forest	36	60	73	79
43	Mixed Forest	36	60	73	79
52	Shrub Scrub	35	56	70	77
71	Herbaceous	55	71	81	89
81	Hay Pasture	49	69	79	84
82	Cultivated Crops	61	73	81	84
90	Woody Wetlands	55	71	81	89
95	Emergent Herbaceous Wetlands	55	71	81	89

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 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 log normally 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 I (corresponding to S10) and ARC III (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:

$$\log(\mathrm{S10}) = \mathrm{mean}(\log \mathrm{S}) + 1.282\ \mathrm{std.dev.}(\log \mathrm{S})$$
$$\log(\mathrm{S90}) = \mathrm{mean}(\log \mathrm{S}) - 1.282\ \mathrm{std.dev.}(\log \mathrm{S})$$
$$1\ \mathrm{std.dev.}(\log \mathrm{S}) = (\log \mathrm{S10} - \log \mathrm{S90}) \,/\, (1.282 * 2)$$

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.

Lag Times for sub-basins were determined using the SCS Lag Equation, as well as engineering judgement. **Table 6** below shows the Curve Numbers and Lag Time values used in this study.

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

Sub-basin Description	CN	CN 1% Minus	CN 1% Plus	Tlag (min)
South Corpus Christi Bay	85.0	74.49	91.67	1,539

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including Curve Numbers for defining rainfall losses and Lag Time for transforming the runoff temporally. No routing was considered in the rainfall-runoff modeling. NRCS Type II storm distributions were used for defining temporal distributions of point rainfall totals. Default areal reduction factor (ARF) values for BLE studies were obtained through Area-Depth curves for the 24-hour storm, from *Technical Paper No. 40, Rainfall Frequency Atlas of the United States* (1961). An Areal Reduction Factor (ARF) of 0.91 was used on all recurrence interval total precipitation depths in order to determine the effective precipitation for the sub-basin representing the 2D mesh. **Table 7** provides the precipitation totals used for determining excess precipitation.

Table 7: Precipitation Totals for HEC-RAS 2D Computational Mesh (post ARF)

Sub-basin Description	Percent Annual Chance Precipitation Total (in)						
	10	4	2	1	0.2	1% Minus	1% Plus
South Corpus Christi Bay	6.75	8.66	10.29	12.13	17.25	9.62	14.64

Figure 5 shows the hyetographs applied to the 2D computational mesh.

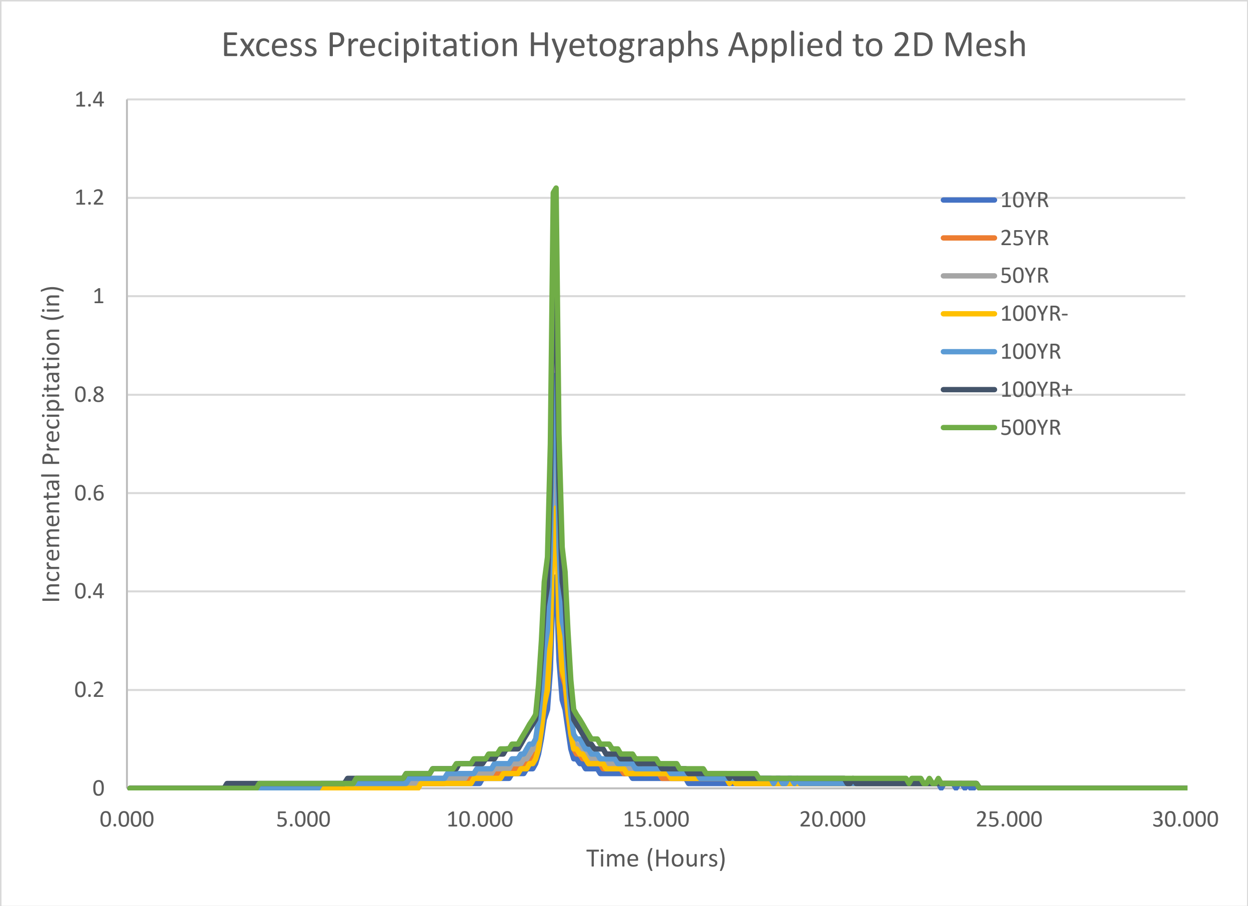

Figure 5: Precipitation Hyetographs (post ARF) applied to the Computational Mesh

2.2.3.2 Rainfall-Runoff Hydrograph Boundary Conditions

The outflow hydrographs in **Figure 6**, developed from rainfall-runoff modeling, were used as inflow boundary conditions for the neighboring Baffin Bay HUC10 2D computational mesh. These hydrographs were extracted from the South Corpus Christi Bay computational mesh at the location of a major contributing spill area to Baffin Bay shown in **Figure 4**. This data was then incorporated into the Baffin Bay 2D BLE model and the model adjusted to be within 0.5 feet of the adjoining floodplain water surface elevation.

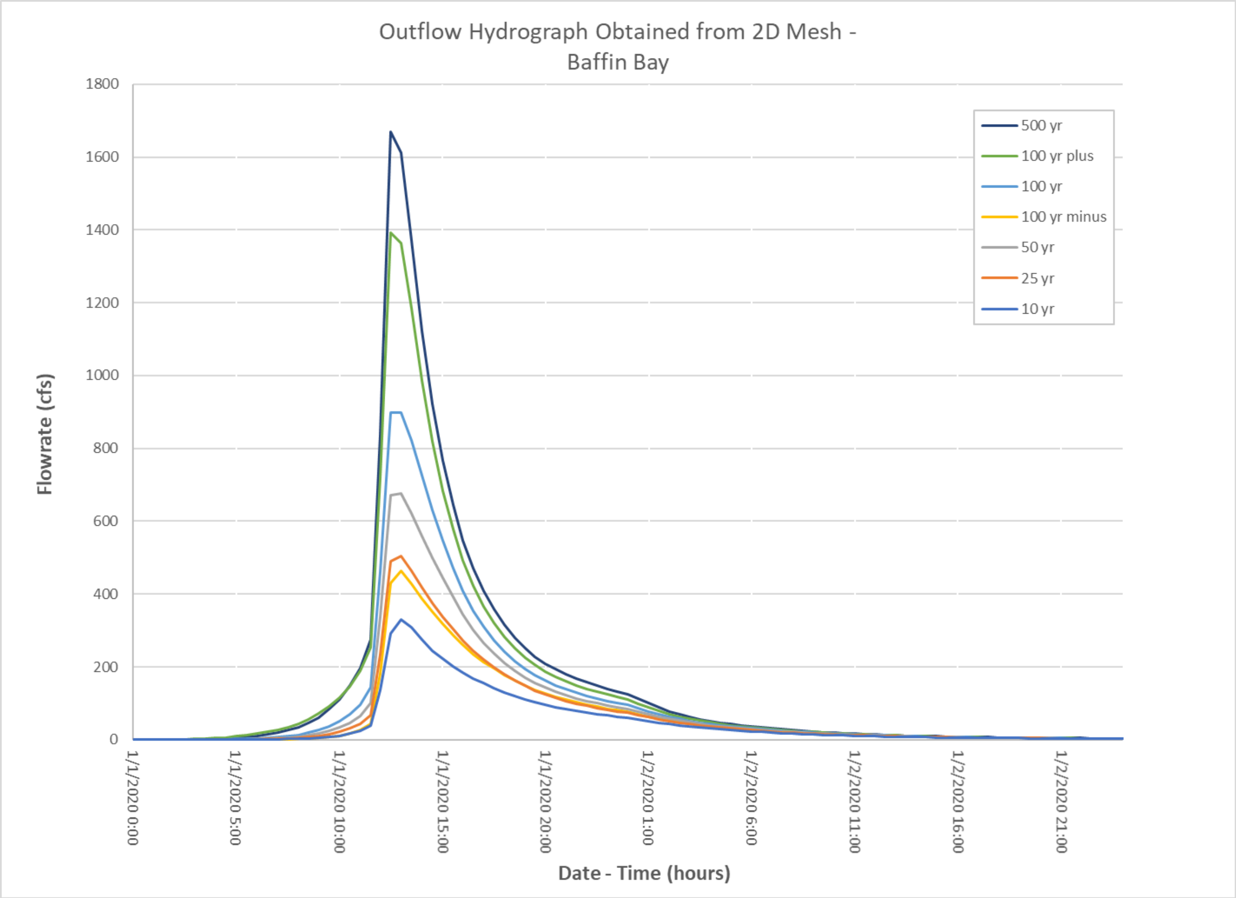

Figure 6: South Corpus Christi Basin Outflow Hydrographs into Baffin Bay

2.2.4 Hydraulics

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

2.2.4.1 Roughness Coefficients

A Manning's n roughness coverage was developed for the 2D computational mesh using typical values for roughness for given NLCD land classifications. In several areas, the channel section land use indicated a Manning's n-value inappropriate for channel conveyance; because of this, a 200-foot buffer zone was created around each stream centerline to create a main channel roughness zone. The channel roughness zone was given a Manning's n value of 0.045 based on the normal values per the HEC-RAS User's Manual.

Table 8 below shows a typical land use-roughness matrix used in defining the roughness coverage for the study area.

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

NLCD Classification	Validated[2]	Minimum	Normal	Maximum	Source
Open Water	**0.03**	0.025	0.03	0.033	Chow 1959
Developed, Open Space	**0.04**	0.01	0.013	0.016	Calenda, et al. 2005
Developed, Low Intensity	**0.06**	0.038	0.05	0.063	Calenda, et al. 2005
Developed, Medium Intensity	**0.08**	0.056	0.075	0.094	Calenda, et al. 2005
Developed, High Intensity	**0.12**	0.075	0.1	0.125	Calenda, et al. 2005
Barren Land	**0.03**	0.025	0.03	0.035	Chow 1959
Deciduous Forest	**0.12**	0.1	0.12	0.16	Chow 1959
Evergreen Forest	**0.12**	0.1	0.12	0.16	Chow 1959
Mixed Forest	**0.12**	0.1	0.12	0.16	Chow 1959
Scrub/Shrub	**0.06**	0.035	0.05	0.07	Chow 1959
Grassland/Herbaceous	**0.05**	0.025	0.03	0.035	Chow 1959
Pasture/Hay	**0.04**	0.03	0.04	0.05	Chow 1959
Cultivated Crops	**0.04**	0.025	0.035	0.045	Chow 1959
Woody Wetlands	**0.1**	0.08	0.1	0.12	Chow 1959
Emergent Herbaceous Wetland	**0.08**	0.075	0.1	0.15	Chow 1959
Main Channel[1]	**0.045**		0.045		HEC-RAS User's Manual

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

[2]Final selected values based on validation efforts. Values adjusted to accomplish validation goals as described in **Section 2.3.1.1.**

2.2.4.2 Breaklines

Breaklines align grid cell faces and were used within the 2D mesh area to define prominent features including, road embankments and hydraulic structures as well as stream centerlines. Road embankments were identified in ArcGIS and imported into HEC-RAS as breaklines to ensure that water was not routed past roads until it was deep enough to overtop the road. Similarly, bridge/culvert crossings that were not processed out of the terrain data were modeled by offsetting breaklines adjacent to the road embankment to align grid cells around the embankment and allow water to be routed across the embankment without creating artificial backwater. This approach was used for most hydraulic structures because it could be implemented in ArcGIS on a large scale with much less effort than alternative methods. An example of the offset breakline approach is shown below.

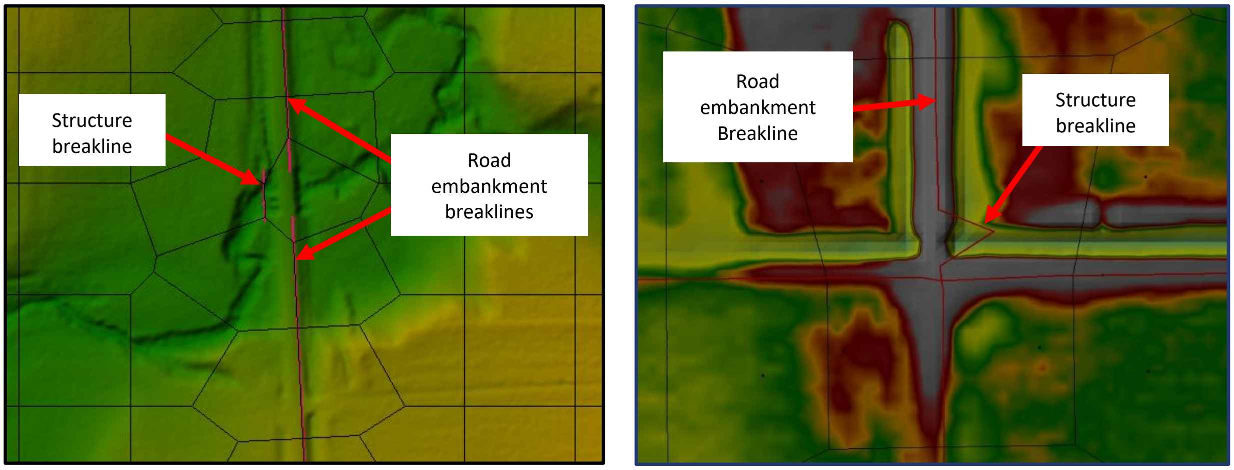

Figure 7: Offset and V-notch Breakline Approach at Bridge Crossing

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. The stream centerlines were input as breaklines to ensure cells lined up perpendicular to the stream and to capture stream conveyance. The study area included multiple accredited levee systems. To represent the prominent features, breaklines were utilized for the Corpus Christi Levee System and Corpus Christi Flood Protection System sections within the HUC.

Initial conditions were not used in the South Corpus Christi Bay 2D BLE model.

2.3 Model Results

The 2D BLE results for the study produced an SFHA that compared reasonably well with the effective SFHA in most cases and provides additional estimated SFHA in areas that do not currently have an SFHA mapped. **Table 9** shows a comparison of some the effective WSEL data with the model results. While the results provide context for flood risk communication as part of the Discovery process, and are scalable, the results require further analysis to be used for regulatory purposes. The validity of the 2D BLE results should be verified through community work map meetings before being applied to a regulatory product.

Table 9: Effective and Model WSEL Comparison

Stream	Effective XS Station[1]	Effective WSEL (feet)	Model WSEL (feet)	Difference (feet)
Airport Drainage Ditch	SS 1375	33.90	34.24	-0.34
Drainage Creek	SS 9804	30.70	30.85	0.15
Ditch F	SS 31382	79.75	80.29	0.54
Oso Creek	SS 123000	55.74	56.09	0.35
	SS 12506	11.6	12.58	0.98
Oso Creek Tributary 5	SS 19375	23.55	23.64	0.09
Oso Creek Tributary 10	SS 16659	35.27	35.57	0.30
Robstown Flow path	SS 2481	71.98	72.96	0.98

[1]Obtained from Preliminary Nueces County FIS Published 8/13/2020

2.3.1.1 Calibration & Sensitivity Analysis

Known USGS gages within the model area with more than 20-years of flow record were used for calibration and validation of the 1% annual chance event. Peak flows within the model were compared with a Bulletin 17B Analysis of the gage data using PeakFQ. Results of the flow comparisons are presented in **Table 10**.

Table 10: 1% Annual Chance Reasonability Comparisons

Flooding Source	USGS Gage Used for Verification	HEC-RAS 5.0.7 (2D)		Gage Analysis Results	
		WSEL (ft)	Discharge (cfs)	WSEL (ft) [1]	Discharge (cfs)[2]
Oso Creek	08211520	28.79	10,672	28.55	10,890

[1] Water surface elevation is approximate based on Power Function TWRI – A10 input data and adjusted to NAVD 88 Datum.
[2]Discharge value is result of Bulletin 17B Analysis of gage data using PeakFQ

Due to the lack of observed flows over 6,000 cubic feet per second and inconsistent water surface elevations when compared to peak flows, the Power function method was used to determine Water Surface Elevations at the gage. This method is based on *Techniques of Water-Resources Investigations of the United States Geological Survey Chapter A10: Discharge Rating at Gaging Stations* (TWRI 3-A10). The 50-year Peak FQ Discharge and WSEL value were also calculated and used as another verification method for further confidence, results are shown in **Table 11** below.

Table 11: 2% Annual Chance Reasonability Comparisons

Flooding Source	USGS Gage Used for Verification	HEC-RAS 5.0.7 (2D)		Gage Analysis Results[1]	
		WSEL (ft)	Discharge (cfs)	WSEL (ft)	Discharge (cfs)
Oso Creek	08211520	28.10	9,444	27.8	9,364

[1] Water surface elevation and Discharge is approximate based on PeakFQ input data and adjusted to NAVD 88 Datum.

To determine which factors were significantly impacting the model results, a sensitivity analysis was run to evaluate the impact of six parameters including Curve Numbers, Manning's roughness values, breaklines, hydrologic losses, initial conditions, and boundary conditions.

Roughness values were adjusted by increasing and decreasing all n-values to the maximum and minimum values provided in Section 2.2.4.1. CN values were adjusted to Minimum, Median, and Maximum CN values as discussed in 2.2.3.1. It was determined that enforced breaklines at major roads and centerlines were needed and are discussed further in Section 2.2.4.2. No changes were made to the precipitation. **Table 12** summarizes the results of each run at each of the USGS gages. The original parameters were shown to have the most accurate WSELs and discharges when compared to Oso Creek Gage and Power Function extrapolation, which was based on period of record data.

Table 12: Sensitivity Analysis Results at USGS Gage 08211520

Iteration[1]	Manning's N Zones	Breaklines[1]	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
1	Original Land Use	No Breaklines	Excess Precipitation	Dry/10 min	Stage Hydrograph and Normal Depth	29,916	29.21
2[2]	Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	10,672	28.79
3	N Min	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	12,196	28.76
4	N Max	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	3,862	29.86
5	CN Max; Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	13,321	29.51
6	CN Max; N Min	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	17,693	29.18

Iteration[1]	Manning's N Zones	Breaklines[1]	Hydrologic Losses	Initial Conditions/ Computational Interval	Boundary Conditions	Peak Flow (cfs)	Peak Elevation (ft)
7	CN Max; N Max	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	7,648	30.30
8	CN Min; Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	10,057	29.02
9	CN Min; N Min	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	13,190	28.72
10	CN Min; N Max	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	15,272	29.82
11	CN Median; Original Land Use	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	10,571	29.08
12	CN Median; N Min	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	13,929	28.77
13	CN Median; N Max	Major Roads w/Centerlines Enforced	Excess Precipitation	Dry / 30 second	Stage Hydrograph and Normal Depth	4,165	29.87
					Gage Analysis:	10,890[3]	28.55

[1] All iterations included breaklines for roads and centerlines.
[2] Parameters from Iteration 2 were used for the final model, however additional computational mesh was implemented flowing the results of the sensitivity analysis.
[3] Water surface elevation is approximate based on Power Function TWRI – A10 input data.

2.4 Challenges

Major challenges included a lack of peak streamflow records at the outlet and lack of streamflow gages within the HUC area, though sufficient data was available to provide confidence in the results. WSELs were within half a foot for the single USGS gage in the HUC when compared to the Power Function WSEL for the 100-year storm event and the Peak FQ WSEL for the 50-year storm event. When compared to Effective WSEL data, the model WSELs varied throughout the HUC, with some areas being over 1 ft difference. Priority was given to gage validation due to availability of historical peak streamflow data over Effective WSELs.

There were a few areas where Baffin Bay and North Laguna Madre spill in and out the model boundary into South Corpus Christi. Most of the spill areas were identified as minor HUC boundary refinements. Normal depth boundary conditions were adjusted slightly in these areas to produce seamless boundaries between North Laguna Madre and adjacent HUCs. An outflow hydrograph for South Corpus Christi into Baffin Bay was extracted from the HEC-RAS BLE model for all events. These flow hydrographs were entered as boundary condition for Baffin Bay. This resulted in similar water surface elevations at the boundary and a seamless floodplain for the area.

As part of our coordination efforts with the Texas Water Development Board, a FEMA CTP partner, we used a mapping clean-up process recommended by the TWDB. The South Corpus Christi Bay HUC8 is located in a coastal region of Texas. The TWDB recommended a threshold for mapping clean-up for this HUC8 which removes 0.33 feet of depth and then 0.33 acres of disconnected areas. Holes within a floodplain are filled up to 0.33 acres as well.

Structures have not been added to the BLE model despite evidence of cross structures which allow the streams to convey water through numerous structures. In these locations, the model may be overestimating the water surface elevation upstream of the road until the road is overtopped and underestimating the water surface elevation downstream of the road.

2.5 Recommendations

This study provides significant information useful for flood identification and communication among those affected. The study is highly scalable, and stakeholder input and further analysis would enhance the product and inform implementation of regulatory flood hazard areas. In addition, the validity of the 2D BLE results should be verified through community work map meetings before being applied as a regulatory product.

03 Floodplain Mapping and Effective Zone A Validation

The following sections provide a synopsis of how raw modeled depths were translated into SFHAs. In addition to developing a new SFHA, the BLE model data was leveraged to validate the effective zone A studies within the project footprint. The results of the validation effort can be found below in section 3.2.

3.1 Special Flood Hazard Area

3.1.1 Model Outputs

The floodplains are derived from the raw modeled depth grids using the maximum value. These depth grids are exported from HEC-RAS as TIFF format rasters with an interpolated rendering that slope values at the center and along the faces/edges of the computational mesh cells. Using GIS, the TIFF rasters are post processed into 1% SFHA and 0.2% shaded X polygons.

3.1.2 Methodology

The use of 2D modeling methods results in water surface elevation values at every cell in the model's computational mesh. In order to represent the desired model results and eliminate extraneous disconnected cells, post processing of the depth grids is required. For the purposes of the South Corpus Christi Bay BLE project, floodplain mapping delineation was completed using connected raster cells at the extent of the CNMS mapped and unmapped features in the project footprint with raster depths greater than 0.5 feet. Converting the raster data to polygon features enabled an intersection of modeled results to the CNMS and effective zones to create the SFHA and 0.2% shaded X features. Because the new mapping, based on gridded engineering, retains the blocky shape of a raster, a simplification process was applied using GIS to smooth the boundaries. These processes remove unnecessary points, bends, and angles while preserving the natural shape of the polygon. Furthermore, small voids, or "holes" inside of the floodplain were aggregated with the larger surrounding polygons to merge them and make the floodplain complete. Mapping polygons were cleaned against the criteria of being larger than 2 acres. For example, if flooding polygons were disconnected from a flooding source and less than two acres, the polygon was removed from the SFHA. Flood polygon less than 2 acres that intersected a flooding source were assessed individually. These edits adhere to traditional and approved floodplain mapping approaches.

In addition to the SFHA, all other flooding associated with the 1% and 0.2% raw results were retained as "on the shelf" data that may be leveraged for future needs and analysis.

3.1.3 Flood Hazard Area Layer

Special Flood Hazard Areas, as noted above, were developed to the extent of the CNMS features or up to 1 square mile drainage area and effective zone A study locations. The Regional CNMS database, National Flood Hazard Layer, and paper inventory were used as reference data to ensure extent of the BLE results represents appropriate flooding extent.

The 0.2% flood areas were produced using the same methods as the 1% SFHA. After both layers were developed, a union of the two products was performed to develop the deliverable format EBFE_FLD_HAZ_AR.

3.2 Validation of Effective Zone A SFHA

The following summarizes the results of the CNMS validation assessments for the effective Zone A studies in the South Corpus Christi Bay Watershed.

3.2.1 Initial Assessment A1 – Significant Topography Update Check

The significant topography update check determines whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. For the study area in the South Corpus Christi Bay Watershed the effective Zone A topographic data source leveraged contours from USGS 24K map products except for in Caldwell Parish where LiDAR was used. The topographic data source for the BLE was derived from LiDAR flown for the state of Texas from 2004 to 2008. This elevation data represents a significant improvement from the effective Zone A topographic source for all reaches and were, therefore, set to FAIL this check.

3.2.2 Initial Assessment A2 – Check for Significant Hydrology Changes

The significant hydrology changes check determines whether new regression equations have become available from the USGS since the date of the effective Zone A study. If newer regression equations exist for the area of interest, then an engineer must determine whether these regression equations would significantly affect the 1-percent-annual-chance flow. It is unknown if regression methods were used in the effective studies, therefore, this element was set to PASS for all reaches within the study area.

3.2.3 Initial Assessment A3 – Check for Significant Development

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

Table 13 presents the summarized results of checks A1 through A3.

Table 13: A1-A3 Validation Results

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

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

Zone A studies that pass all initial assessment checks described above may be categorized as "Valid" in the CNMS Inventory only if the effective Zone A study is supported by modeling or sound engineering judgment and all regulatory products are in agreement. If the effective Zone A study passes all initial assessment checks, but is not supported by modeling, or if the original engineering method used is unsupported or undocumented, a comparison of the BLE results and effective Zone A's is performed. Due to lack of documentation of the original engineering methods in the South Corpus Christi Bay Watershed, check A4 has been marked as FAIL for the majority of the reaches in the study area except for those in Vernon Parish. The reaches in Vernon Parish were studied in 2010 and are assumed to be model backed.

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

The effective Zone A comparison was performed at the full extent of the South Corpus Christi Bay Watershed. The validation of the effective Zone A boundaries using 2D flood hazard products differ from the standard 1D methods due to the lack of cross sections and their use with standard FBS methodology. For this 2D study, the effective A zone boundaries were compiled using the National Flood Hazard Layer and Core Logic effective digital uplift product. These data were dissolved to one continuous A-zone layer, which then had points placed along its perimeter every 500 feet.

For each test point, a 75-foot buffer was created. Using this buffer, the minimum and maximum values of the DEM were extracted, as a proxy for the effective base flood elevation. The minimum value of the 1% minus raster, and the maximum value of the 1% plus raster are also extracted. These 1% plus maximum and 1% minus minimum values are products of the new 2D BLE study and act as the vertical tolerance. The test point passes if the DEM maximum value is less than or equal to the 1% plus maximum value and the DEM minimum value is greater than or equal to the 1% minus minimum value. This can be visualized as a short 75-foot radius cylinder, with a height of 1% plus maximum – 1% minus minimum. This test verifies that at least one point from the ground surface (i.e. proxy BFE) falls both vertically and horizontally within this range.

3.2.6 Validation Results

All 895.9 total miles of available CNMS features representing the effective Zone A studies were categorized as VALID – BEING STUDIED or UNVERIFIED – BEING STUDIED. Total miles in each of these categories are summarized in **Table 14** and illustrated in **Figure 8** below.

Table 15 summarizes the validation results based on the individual HUC 12 watersheds within South Corpus Christi Bay Watershed.

Table 14: Aggregated Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	796.8
UNVERIFIED	BEING STUDIED	99.1

Table 15: HUC 12 Zone A Validation Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>90%)	Priority Score
Watershed Name	Watershed Number						
South Corpus Christi Bay	All Streams	655	175	480	73.3%	FAIL	
City of Robstown	121102020101	59	3	56	94.9%	PASS	2.5
West Oso Creek-Oso Creek	121102020102	261	55	206	78.9%	FAIL	11.5
Corpus Christi International Airport-Oso Creek	121102020103	233	111	122	52.4%	FAIL	27.8
Dean Airport-Oso Creek	121102020105	86	0	86	100%	PASS	0.0
Oso Creek-Frontal Oso Bay	121102020106	16	6	10	62.5%	FAIL	36.7

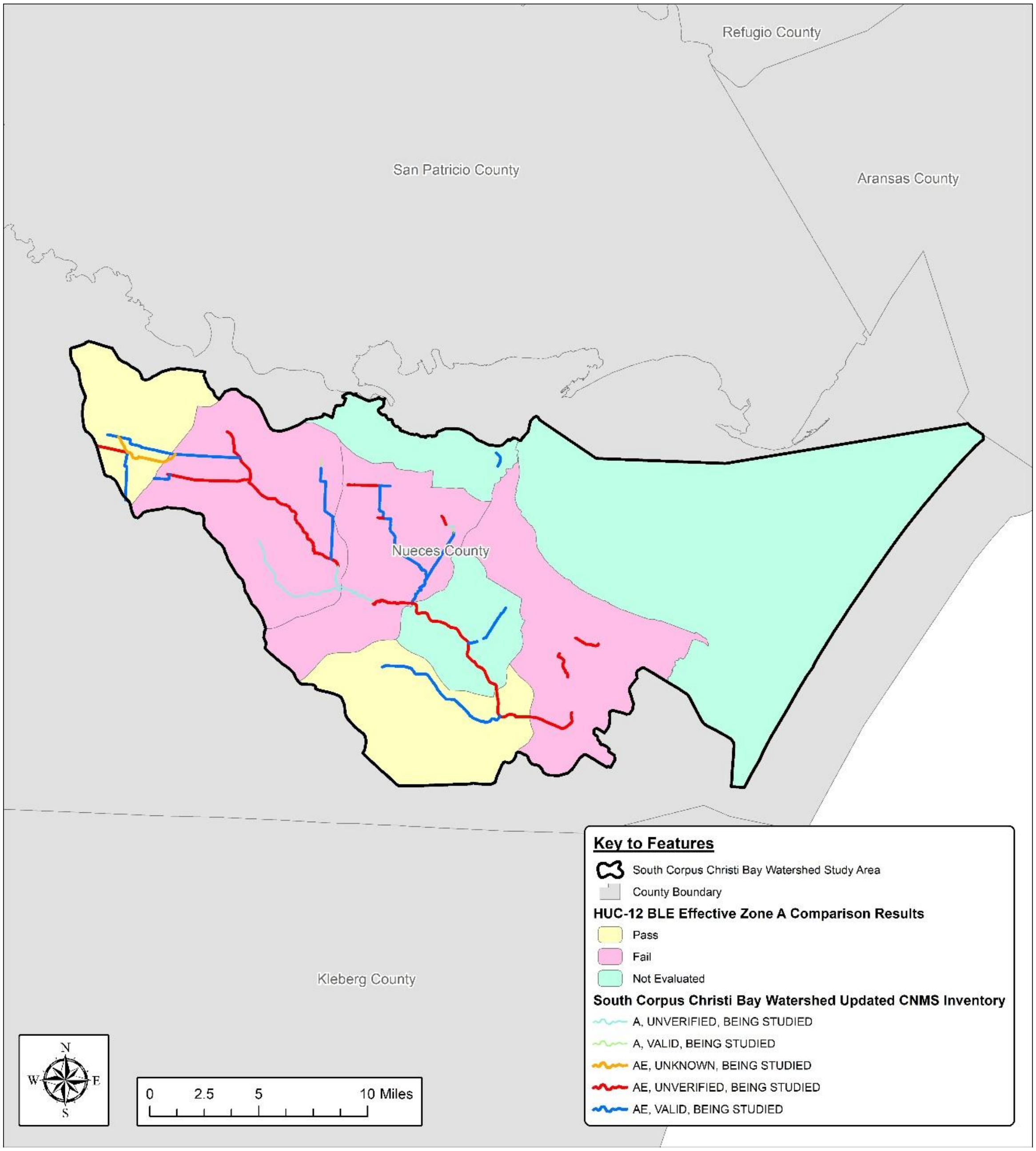

Figure 8: South Corpus Christi Bay Watershed CNMS Validation Results

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 9** below shows the range of the South Corpus Christi Bay HUC-12 priority scores which can be used to initiate discussions during the Discovery phase. Oso Creek-Frontal Corpus Christi Bay HUC-12 was determined to have the highest priority score and the most need while Dean Airport-Oso Creek and City of Robstown HUC-12s have the lowest score.

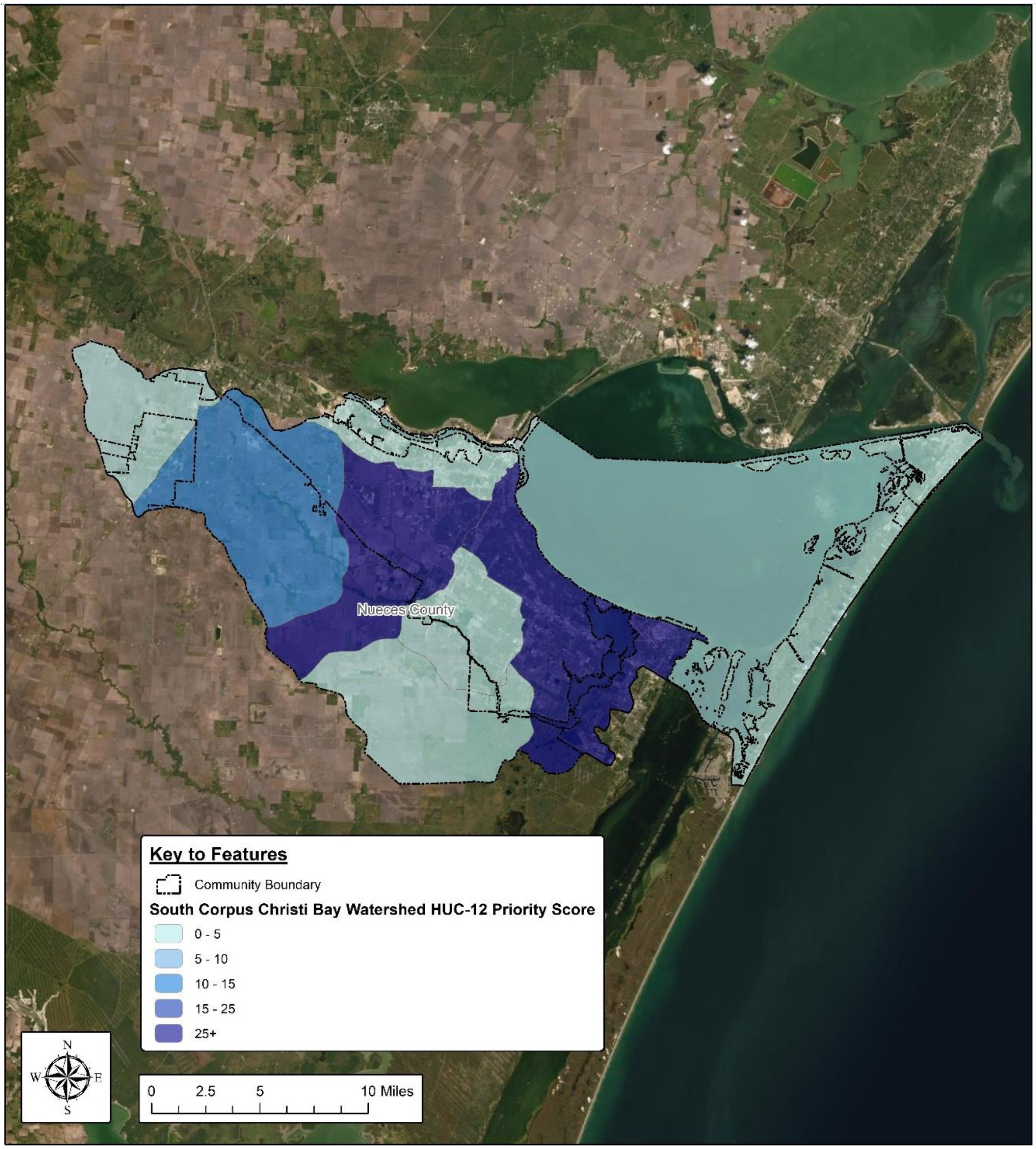

Figure 9: Ranking of South Corpus Christi Bay Watershed HUC-12s

3.3 Flood Risk Analysis

A flood risk analysis was performed for this project. The updated 1-percent annual chance depth grid was used to calculate the potential flood losses. The loss results are stored in the S_FRAC_AR spatial file within the FRD geodatabase. All results are reported in whole dollar values.

Hazus version 5.0 (SP02) was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 5.0 (SP02) uses dasymetric census blocks. Dasymetric mapping removes undeveloped areas (such as areas covered by other bodies of water, wetlands, or forests) from the census blocks, changing their shape and reducing their size in these areas. For more information on dasymetric data visit FEMA's Media Library for the Hazus-MH Data Inventories: Dasymetric vs. Homogenous, or Hazus 3.0 Dasymetric Data Overview.

Hazus analysis was performed by parish within the project watershed extends for each return period to ensure proper model processing. A summary of results per parish for the 100-year scenarios are shown in **Table 16**.

Table 16: Hazus 5.0 (SP02) Results for 1-percent-annual-chance (100 year) scenario for South Corpus Christi Bay Watershed, Texas

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Nueces	$5,234,301,000	$28,341,035,000	$18,190,958,000
Total	$5,234,301,000	$28,341,035,000	$18,190,958,000

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