Bayou Teche Watershed, Louisiana: 2D Base Level Engineering Methods and Results

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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 Bayou Teche 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.

In an effort to increase and enhance the flood risk products in Louisiana, FEMA Region VI contracted the Compass PTS JV to perform BLE for the Bayou Teche Watershed. This report documents the BLE process, products, and results for this watershed. Figure 1 depicts the Bayou Teche Watershed footprint. Figure 2 depicts the Bayou Teche Watershed HEC-RAS 2D model areas.

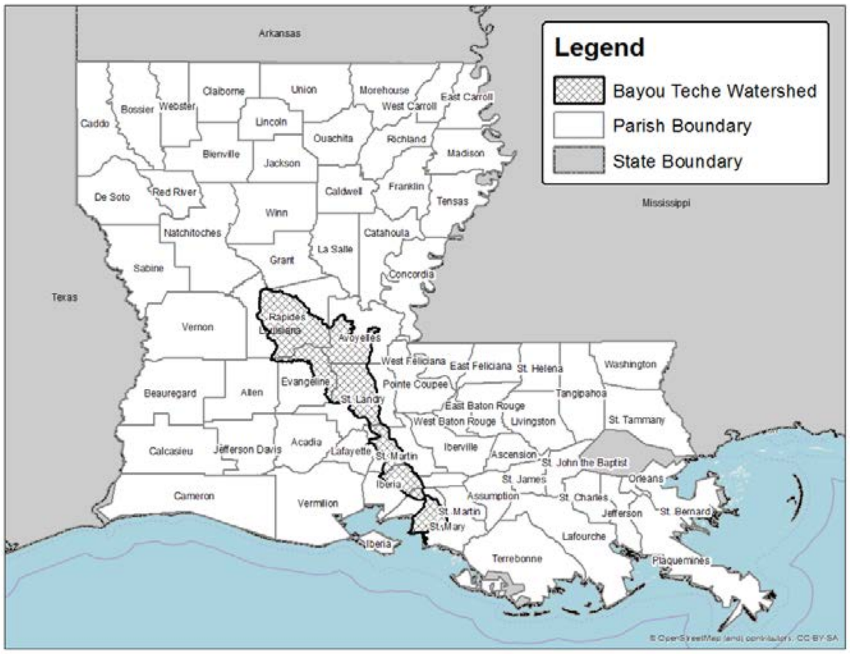

Figure 1: Bayou Teche Watershed

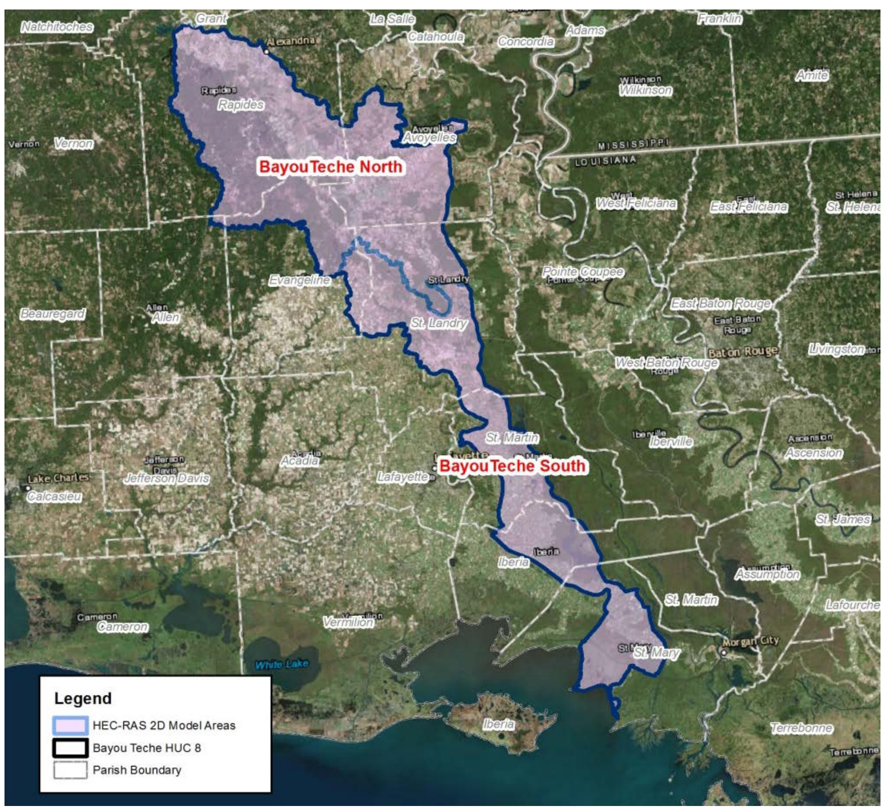

Figure 2: Bayou Teche Watershed HEC-RAS 2D Model Areas

02 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2-dimensional (2D) hydraulic engineering analysis for the Bayou Teche Watershed. Inputs such as elevation data, hydrology from rain-on-grid hydrographs, and hydraulic analyses and variables are defined herein.

2.1 Topographic Data

A high resolution Digital Elevation Model (DEM) is a fundamental component for two-dimensional engineering analyses which provides a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the Bayou Teche BLE project by leveraging available high resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the entire State of Louisiana. The 10 foot DEM used to support the 2D BLE modeling and analysis, within the Bayou Teche Watershed, was developed using the following steps:

1. Available elevation data for the project area were inventoried and collected.
2. 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 leverage data including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables and text within this section. All vertical accuracy specifications were obtained from the metadata or survey reports provided with the elevation datasets. All available metadata, survey reports, and other documentation are included in the FEMA Data Capture Technical Reference compliant submittal for the Bayou Teche Watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the Bayou Teche BLE project footprint. Figure 3 depicts the elevation datasets identified across the project area. FEMA, NOAA, USGS, and other State and Federal agencies were queried to build an inventory with the most current available data sources.

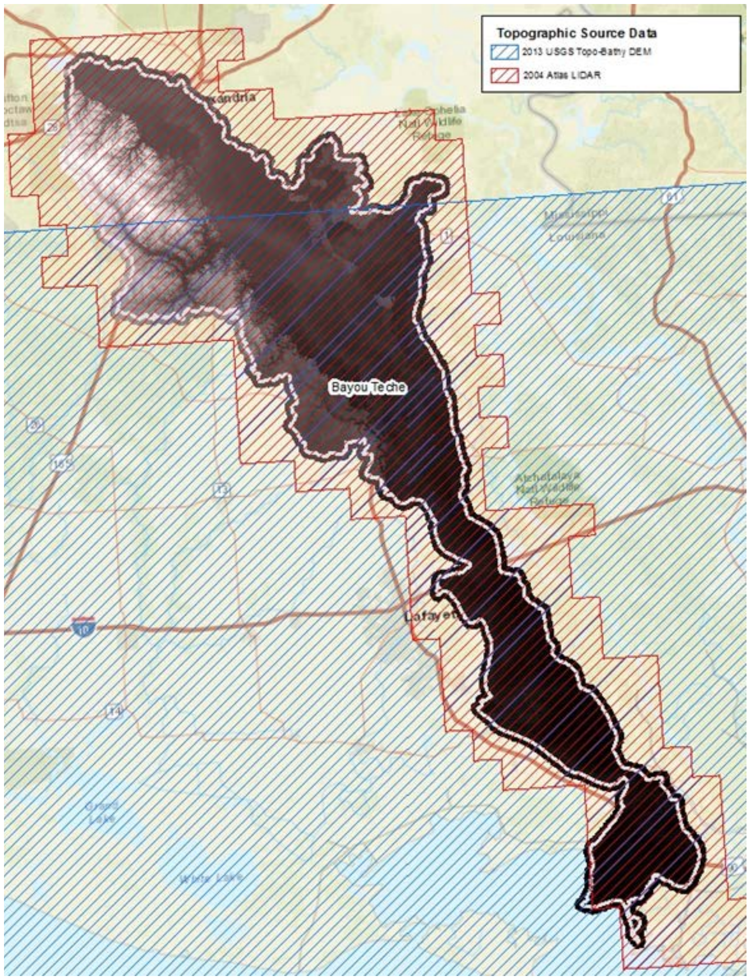

Figure 3: Bayou Teche Watershed BLE Source Terrain

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 elevation data ensured each dataset meets FEMA accuracy requirements for topographic data. Decisions to include or exclude a dataset (or a portion of it) were based on the following general criteria coupled with engineering judgment:

- FEMA vertical accuracy standards met (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 Bayou Teche 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 Bayou Teche Watershed

Year	Description	Data Type	RMSE	Source/Owner
2013	USGS Topo-Bathy DEM	Airborne LiDAR supplemented with bathymetric elevation data	18.28 cm	NGOM/USGS
2004	Louisiana Statewide LIDAR	Airborne LiDAR	15 – 30 cm	LOSCO/LOEP

2.1.2.1 Bayou Teche Watershed Source Terrain Data

The primary source elevation data for the Bayou Teche Watershed are DEMs derived from the Louisiana Statewide LiDAR collection. 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. Table 2 above lists the source data used to compile the engineering DEM for the Bayou Teche Watershed. Figure 3 depicts the extent of the data defined in Table 2 while Figure 4 shows the DEM used to conduct this analysis.

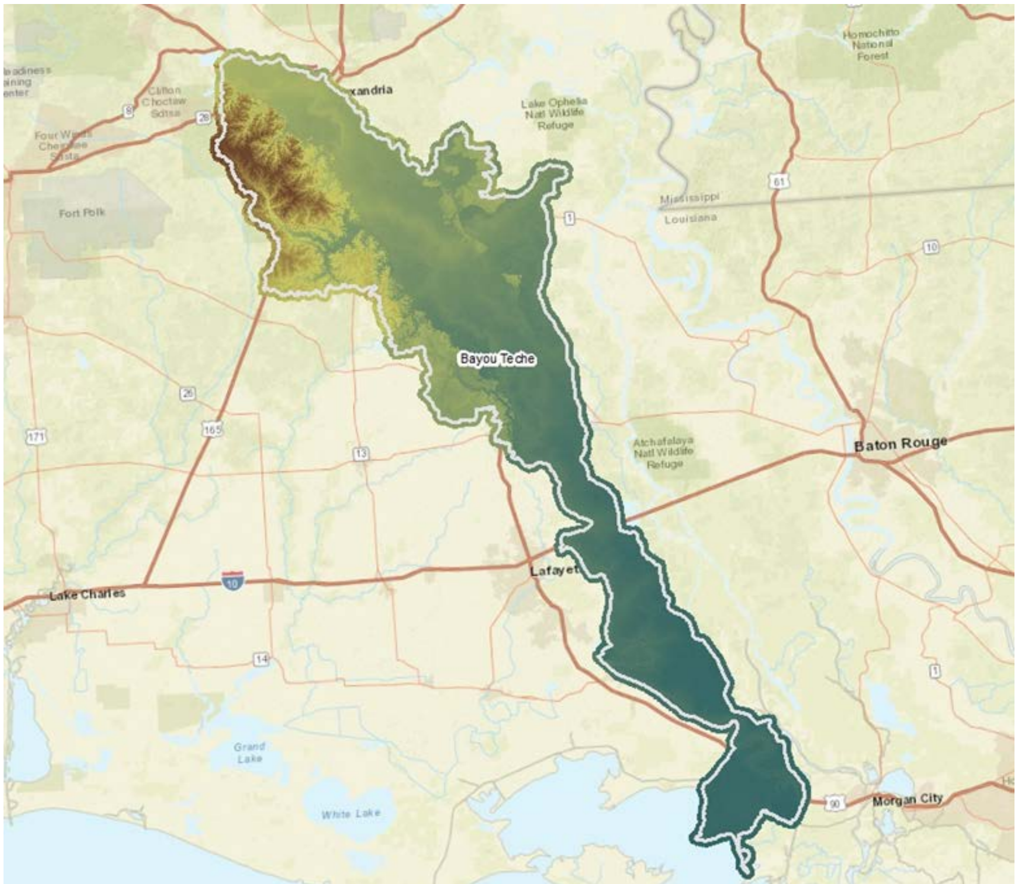

Figure 4: Bayou Teche Watershed BLE DEM

2.1.2.1.1 2013 USGS Topo-Bathy DEM

The U.S. Geological Survey's (USGS) Coastal and Marine Geology Program (CMGP) and the National Geospatial Program (NGP) collaborated with the Coastal Protection and Restoration Authority of Louisiana (CPRA) and a number of other federal and state agencies to create a comprehensive topo bathymetric elevation model for the Northern Gulf of Mexico (NGOM). The new dataset consists of a detailed and highly accurate elevation model incorporating the best available multi-source topographic and bathymetric elevation data for the Northern Gulf of Mexico (NGOM). The NGOM topobathymetric elevation model integrates over 400 different data sources including topographic and bathymetric LiDAR point clouds, hydrographic surveys, side-scan sonar surveys, and multibeam surveys obtained from USGS, NOAA, the State of Louisiana, the U.S. Army Corps of Engineers, FEMA, and other agencies. The LiDAR and bathymetry surveys were sorted and prioritized based on survey date, accuracy, spatial distribution, and point density to develop a model based on the best available elevation data. Because bathymetric data is typically referenced to tidal datums (such as Mean High Water or Mean Sea Level), all tidally-referenced heights were transformed into orthometric heights that are normally used for mapping elevation on land (based on the North American Vertical Datum of 1988). The spatial resolution is 3 meters and extends from the Florida/Alabama border on the east to the Louisiana/Louisiana border on the west. The temporal range of the input topography and bathymetry is 1888 to 2013. The RMSEz reported for the dataset was 18.28 cm at the 95% confidence level which meet project accuracy specifications of the National Standard for Spatial Data Accuracy (NSSDA). Figure 3 shows the Bayou Teche Watershed extent of the 2013 USGS Topo-bathy DEM data leveraged for this study.

2.1.2.1.2 2004 Louisiana Statewide LIDAR

Beginning in 2000, Louisiana's statewide LIDAR project was initiated in response to the high per capita and repetitive flood loss rates experienced by the FEMA, National Flood Insurance Program and the private insurance industry in the state. LIDAR derived, high-resolution topographic information has been accepted by FEMA as a low cost means to update inaccurate and out of date flood maps. The state sponsor for the project, thus far, has been the Louisiana Oil Spill Coordinators Office (LOSCO), which has managed the project and arranged for state match through legislative action. Oil spill contingency planning and response issues plague all Louisiana parishes requiring critical high resolution topographic information. The Louisiana Office of Emergency Preparedness (OEP) has recently assumed administrative control of the project, largely because of OEP's direct, official connection with FEMA. The LIDAR systems being used in the Louisiana project are accurate to 15 - 30 cm RMSE, depending upon land cover, and will support contours of 1-2 foot vertical map accuracy standards. These accuracies meet FEMA standards for floodplain reevaluation studies and map modernization programs designed to update the Flood Insurance Rate Maps (FIRM). Figure 3 shows the Bayou Teche Watershed extent of the 2004 Louisiana Statewide LIDAR data leveraged for this study.

2.1.3 Data Development Methodology

The source topographic data were processed for an area covering the Bayou Teche Watershed and contributing drainage areas for the Bayou Teche BLE modeling efforts. The topographic data for Bayou Teche was projected horizontally, as needed, to North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS) Louisiana South in feet (1702-SPC83). 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 Bayou Teche 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 both a topographic data development team and the engineering team. Quality assurance during the data development process included, but was 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 process included, but was not limited to the following QC checks:

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

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

The final DEM data developed for Bayou Teche are assured to meet FEMA standards and present a representative surface developed from leverage elevation data for the purposes of this BLE project.

2.2 2D BLE Methods

The following sections describe the 2D computational mesh and hydraulic modeling program settings and considerations, followed by discussion and tabulation of hydrologic and hydraulic engineering methods and model inputs. For this study, HEC-RAS 5.0.3 (RAS 5) was used for hydraulic calculations.

2.2.1 2D Computational Mesh and Settings

The 2D computational mesh was created for Bayou Teche Watershed using ArcGIS tools, significantly reducing the need for manual edits to mesh cells within RAS 5. This mesh was divided into two work areas, Bayou Teche North (BTN) and Bayou Teche South (BTS), producing a total of 1,554,581 cells and 666 internal breaklines. It is generally recommended that a 2D mesh should be limited to approximately one million cells, as exceeding this number can cause significant computational issues, often resulting in memory overflow errors. Determining a mesh cell size is a balancing act; the number of cells, along with the simulation time interval, dictates in large part the run time, as well as the modeling and mapping accuracy. Therefore, a 200 foot nominal mesh cell size was selected for Bayou Teche. Supported by a 10 foot terrain raster, this size was sufficient to accurately represent large streams within the study area. Computation time intervals ranged from 1 to 4 minutes in the RAS 5 model, and diffusion wave (simplified full momentum) equations were used for each simulation. The model stability, accuracy of results, and courant number were the factors considered in selecting the computational time step. Diffusion wave equations show better performance and shorter run times in large scale models, and provide similar results to full momentum equations.

2.2.2 Model and Boundary Condition Setup

Using RAS 5 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. However, for the Bayou Teche Watershed, no incoming flows from surrounding areas were included in the model. The development of excess precipitation hyetographs for the 2D mesh is described in Section 2.2.3, and these hyetographs were applied to the 2D mesh for each RAS 5 model area. Figure 5 below shows the 2D computational mesh for each work area for this project, along with USGS streamflow gages pertinent to this study.

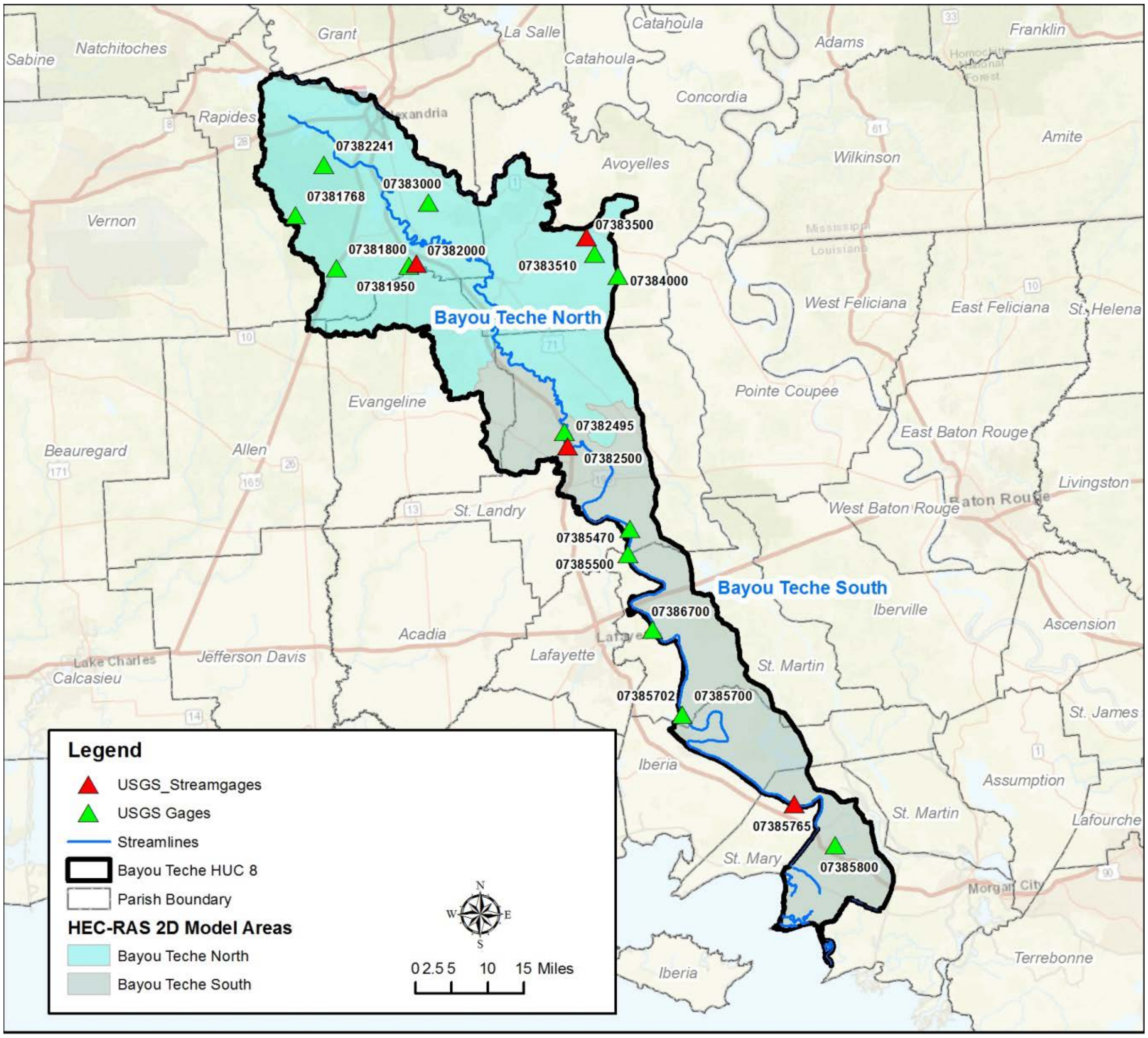

Figure 5: RAS 5 2D Computational Mesh and USGS Peak Streamflow Gages

Outflow boundary conditions (from the computational 2D mesh) were included along the 2D mesh area boundaries. Unique outflow boundaries were established for obvious riverine outflows, while longer boundaries were also defined to allow drainage to leave the model area freely and move into adjacent basins. Normal depth was used for all outflow boundary conditions using approximate energy grade-line slopes estimated from the terrain data.

2.2.3 Hydrology

Precipitation data for this study were obtained from NOAA's Precipitation Frequency Data Server using the NOAA Atlas 14 Frequency Estimates for Louisiana. Regionally appropriate temporal distributions provided by NOAA for the Southeast, Region 1 have been utilized (see Figure 6). Per guidance from NOAA, for a 24-Hour duration the majority of storms for this region occur in the first quartile (see Table 3). The 50% cumulative total precipitation will be used for Region 1 since it represents the median temporal distribution.

Table 3: Total Number of Precipitation Cases and Number (and Percent) of cases in each Quartile for Selected Durations

Duration	Region	All Cases	1st Quartile Cases	2nd Quartile Cases	3rd Quartile Cases	4th Quartile Cases
6-hour	1	9,142	3,050 (33%)	2,829 (31%)	2,087 (23%)	1,176 (13%)
	2	1,231	748 (35%)	698 (33%)	426 (20%)	259 (12%)
12-hour	1	9,631	3,519 (37%)	2,476 (26%)	2,203 (23%)	1,433 (15%)
	2	2,189	826 (38%)	550 (25%)	463 (21%)	350 (16%)
24-hour	1	9,325	3,316 (36%)	2,278 (24%)	2,171 (23%)	1,560 (17%)
	2	2,218	764 (34%)	476 (21%)	505 (23%)	473 (21%)
96-hour	1	8,908	3,696 (41%)	1,962 (22%)	1,653 (19%)	1,597 (18%)
	2	2,113	747 (35%)	504 (24%)	414 (20%)	448 (21%)

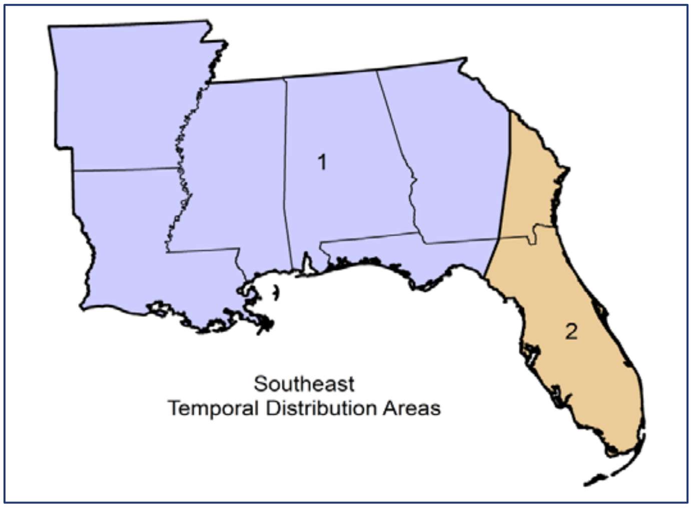

Figure 6: NOAA Atlas 14 Volume 9 - Southeast Temporal Distribution Areas

2.2.3.1 Excess Precipitation for 2D Computational Mesh

HEC-HMS (version 4.2) was used to apply the SCS Curve Number method to calculate losses and define excess precipitation for each model 2D mesh area. Regionally appropriate temporal distributions defined by NOAA Atlas 14, Volume 9, Region 1 were defined using a 24-hour duration. The 1% plus and minus storm event precipitation values were found by using a 68% confidence interval on the baseline 1% event. Table 4 displays the total precipitation for each model, and Table 5 presents a summary of the areal reduction factors applied to each model.

Table 4: Model Area Total Precipitation Depths for each Percent Annual Chance Event

Model Area	Percent Annual Chance Precipitation Total (in)						
	10	4	2	1	0.2	1% Minus	1% Plus
BTN	4.51	6.34	7.81	9.68	14.61	7.28	14.42
BTS	7.2	9	10.53	12.19	16.62	10.56	14.16

Table 5: Summary of Areal Reduction Factors

Model Area	Area (mi^2)	Areal Reduction Factor (ARF)
BTN	1,339.2	0.9098
BTS	847.2	0.9098

Initial Curve Numbers (CNs), i.e. obtained prior to calibration, were computed by using GIS to intersect the 2011 National Land Cover Dataset (NLCD) with NRCS soils data based on the matrix presented in Table 6.

Table 6: Landuse-Soils-CN Matrix for Computing Initial Curve Numbers

Land Use (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

Antecedent Runoff Condition (ARC) II CNs were used for all baseline recurrence interval storm events, while ARC III CN's were used for the 1% plus event and ARC 1.5 CN's were used for the 1% minus event. Table 7 provides the initial CNs used for determining excess precipitation.

Table 7: Curve Numbers Input into HMS Models

Sub-basin Description	CN (initial)	CN (verified)	CN 1% Minus	CN 1% Plus
Bayou Teche North Mesh	75.4	82.94	71.54	90.46
Bayou Teche South Mesh	83.4	85.00	74.50	91.70

The following figures shows the final excess precipitation hyetographs applied to the 2D computational mesh. Note that CNs were modified during the calibration process and the excess precipitation hyetographs were recalculated, as discussed in Section 2.2.5.1.

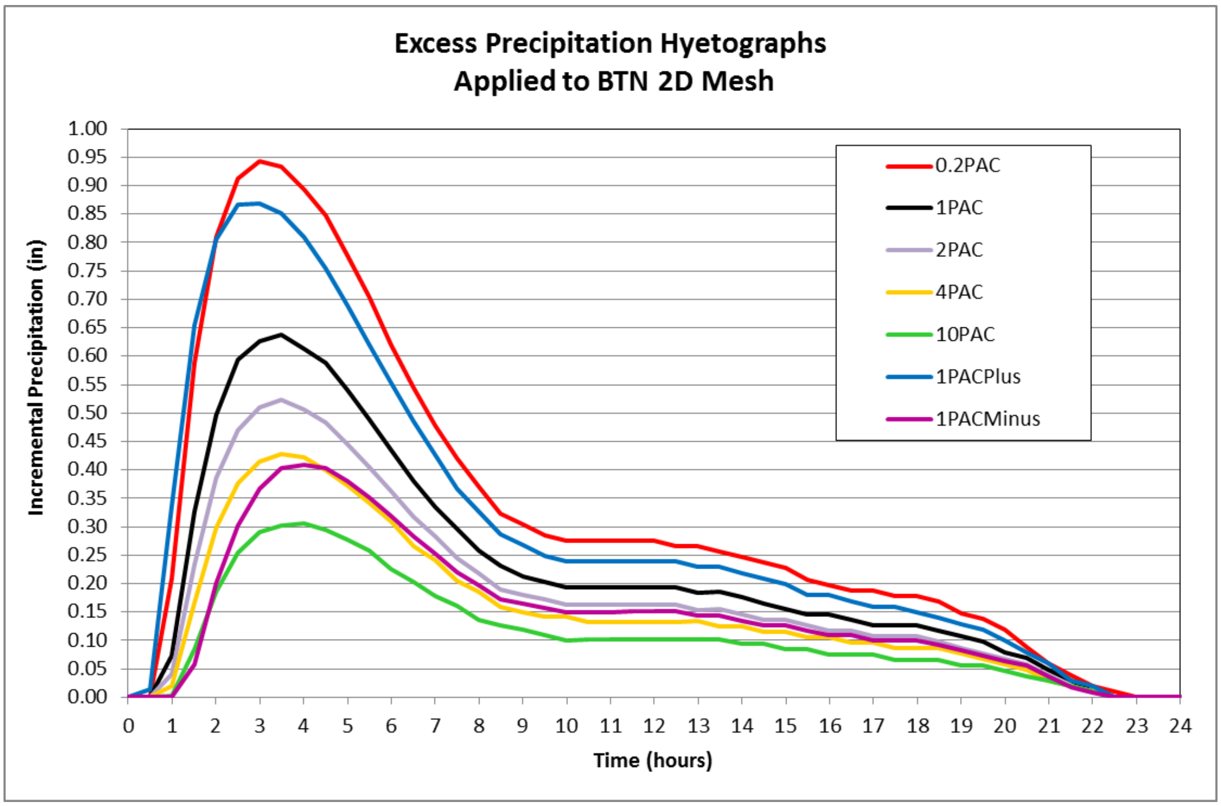

Figure 7: Excess Precipitation Hyetographs Applied to the Computational Mesh for BTN

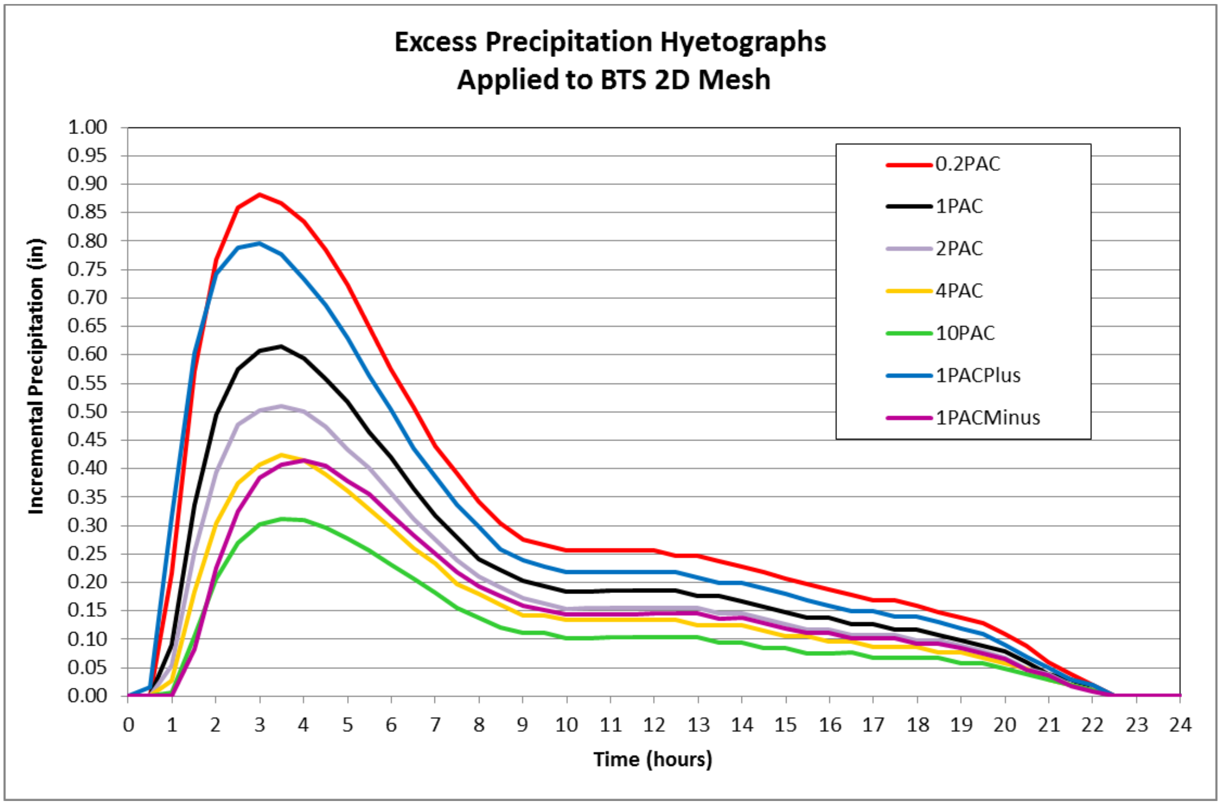

Figure 8: Excess Precipitation Hyetographs Applied to the Computational Mesh for BTS

2.2.4 Hydraulics

This section describes remaining hydraulic modeling considerations, including the implementation of Manning's roughness, breaklines, and hydraulic structures within the study area.

2.2.4.1 Roughness Coefficients

Manning's n roughness coverage was developed using typical values of roughness for given NLCD land classifications. Table 8 shows the landuse-roughness matrix used in defining the roughness coverage for the study area.

Table 8: NLCD 2011-Manning's N Roughness Matrix

NLCD Classification	Minimum	Normal	Maximum	Source
Open Water	0.025	0.03	0.033	Chow 1959
Developed, Open Space	0.01	0.013	0.016	Calenda, et al. 2005
Developed, Low Intensity	0.038	0.05	0.063	Calenda, et al. 2005
Developed, Medium Intensity	0.056	0.075	0.094	Calenda, et al. 2005
Developed, High Intensity	0.075	0.1	0.125	Calenda, et al. 2005
Barren Land	0.025	0.03	0.035	Chow 1959
Deciduous Forest	0.1	0.12	0.16	Chow 1959

NLCD Classification	Minimum	Normal	Maximum	Source
Evergreen Forest	0.1	0.12	0.16	Chow 1959
Mixed Forest	0.1	0.12	0.16	Chow 1959
Scrub/Shrub	0.035	0.05	0.07	Chow 1959
Grassland/Herbaceous	0.025	0.03	0.035	Chow 1959
Pasture/Hay	0.03	0.04	0.05	Chow 1959
Cultivated Crops	0.025	0.035	0.045	Chow 1959
Woody Wetlands	0.08	0.1	0.12	Chow 1959
Emergent Herbaceous Wetland	0.075	0.1	0.15	Chow 1959

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 embankments were defined in GIS and imported into RAS 5 as breaklines to ensure that water was not routed past roads without passing through a structure 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 GIS on a large scale with much less effort than alternative methods. An example of the offset breakline approach is provided in Figure 9.

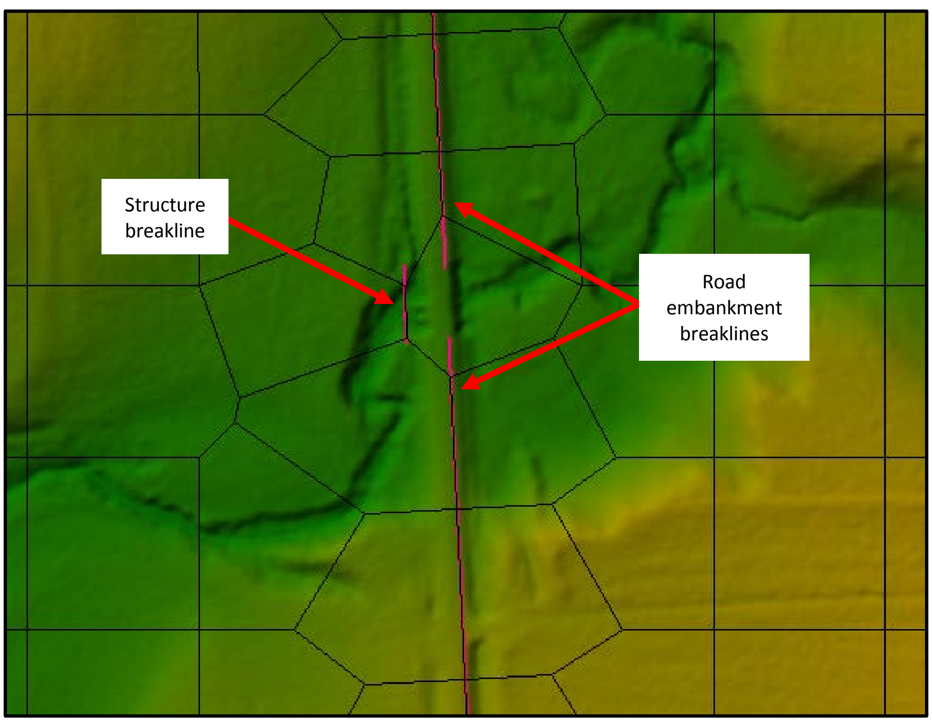

Figure 9: Offset Breakline Approach at Bridge Crossing

2.2.4.3 Internal Hydraulic Structures

Internal structures were utilized to define some prominent hydraulic structures and at locations where flow hydrographs needed to be extracted for calibration or flow transfer to an adjacent model. Internal structures at bridge or culvert crossings were input based on estimated parameters measured from aerial imagery (e.g., culvert diameter, culvert length, weir width, etc.). To extract flow hydrographs "dummy" weirs were input with a profile equivalent to the underlying terrain, zero width, and a weir coefficient of 0.2 to minimize impacts to the hydraulics.

2.2.5 Model Results

The 2D BLE results for the study produced a Special Flood Hazard Area (SFHA) that compared reasonably well with the effective SFHA, and provides additional estimated SFHA in areas that do not currently have an SFHA mapped. While the results are scalable and provide context for flood risk communication as part of the Discovery process, it is recommended they be verified through community work map meetings before being applied to a regulatory product.

2.2.5.1 Calibration

Known USGS gages within the model area with more than 20-years of flow record were used for calibration of the 1% annual chance event. Annual chance peak flows were calculated at each gage using USGS Bulletin 17B methodology. Figure 5 shows the USGS gage locations used for model calibration. The 68% confidence interval was used to determine the 1%-plus and minus chance events. Calibration was performed based on water surface elevations (WSEs) derived from published and estimated rating curves which were based on the discharges previously mentioned. WSEs were used to calibrate the models, rather than discharges, because USGS stream gages directly measure stage and not discharge. Calculated discharges for the 1%, 1%-plus, and 1%-minus events are presented in Table 9 for each gage utilized in this study.

Hydrograph timing adjustments were made until simulated flows closely matched the calculated peak flows. Final results following model calibration are also presented in Table 9.

Table 9: USGS Gage Calibration Location Results

RAS 5 Model Area	Flooding Source	USGS Gages used for Verification	Bulletin 17B Flow Frequency Results			2D RAS 1% (cfs)	2D RAS 1% (feet)
			1% (feet)	1% Minus (feet)	1% Plus (feet)		
BTN	Bayou Cocodire near Clearwater, LA	07382000[1]	63.35	63.06	63.68	13,641	63.25
	Bayou Des Glaises Diversion Channel at Moreauville, LA	07383500	45.05	44.31	45.97	1,917	45.58
BTS	Bayou Courtableau at Washington, LA	07382500	32.52	31.90	33.28	4,210	32.62
	Bayou Teche at Adeline Bridge nr Jeanerette, LA	07385765	6.24	5.48	7.38	738	6.68

[1] USGS published rating curve

2.3 Challenges

Challenges experienced during this analysis are outlined below.

- The most challenging problem encountered during the BLE process was tying in the water surface elevations at the boundary between the different 2D mesh areas.

  Initially, normal slope boundaries that reflected the underlying terrain were used as the outflow boundary conditions for the BTN model, while the BTS model maintained a flow hydrograph boundary through each model iteration. There were five major flow-transfer locations between the BTN and BTS models.

  - For the first iteration, three of the flow transfer locations did not have matching WSEs or flooding extents between the BTN and BTS models.
  - For the second iteration, the normal slope boundary conditions were changed in the BTN model to rating curve boundary conditions, and the rating curves were developed from flow-stage data at the transfer locations in the BTS model. This second iteration improved the tie-in results, but the model also showed instability, with water volume accounting errors. Several attempts were made to improve model stability by decreasing the computational time interval, refining and improving the rating curve outflow boundary conditions, and adjusting the transfer locations slightly.
  - For the third iteration, a new basin break line was drawn to try to find better tie-in locations, however the new break line did not improve the tie-in issue between the models.
  - For the fourth iteration, normal depth boundary conditions with the original basin break lines were used. One of the outlet normal depth settings already met the lower limit of 10^{-5} for HEC-RAS 5.0.3. This iteration showed the least model instability, and also had the lowest simulation time.

- The BTN model area represents approximately 1,339 mi^2 and had a 200 foot nominal cell size. This means that the BTN model cell number count approached the practical computational limits of HEC-RAS 5.0.3. Therefore, the BTN model showed stability issues, and model crashes and errors in the hydrographs were common during simulations. To reduce the number of crashes and errors, cell volume filter tolerances were adjusted slightly.

- Due to the presence of Lake Fausse Pointe in the BTS model the simulation times had to be adjusted for the low flow events because of the detention effects of Lake Fausse Pointe.

- The lack of sufficient gage data proved to be a challenge in the process of verifying the model results. Our primary goal was to calibrate the models based on stage data provided by USGS stream gages since stages are directly measured. However, only one gage in the Bayou Teche basin had published rating curve data.

2.4 Recommendations

This study provides significant information useful for flood identification and communication. The study is highly scalable, and stakeholder input and further analysis could enhance end products and the transformation to regulatory flood hazard areas. Additionally, the results presented in this report and the accompanying FEMA data capture technical reference format flood hazard results should be presented and further evaluated through Flood Risk Review meetings.

Future projects of similar scope could use larger nominal cell sizes (up to 500 feet) and model a HUC-8 watershed as one 2D area. A higher maximum allowable nominal cell size coupled with more detailed breaklines in flood-prone areas would allow for more accurate model results, as well as faster run times. Additionally, the lower total cell count would have a lower potential to cause model stability issues.

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 were derived from the raw modeled depth grids using the maximum value. These depth grids were exported from HEC-RAS as TIFF format rasters with an interpolated rendering of slope values at the center and along the faces/edges of the computational mesh cells. Using GIS, the TIFF rasters were 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 was required. For the purposes of the Bayou Teche 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. Converting the raster data to polygon features enabled an intersection of modeled results with 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. 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 analyses.

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 Bayou Teche 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 most of the study area the effective Zone A topographic data source is unknown, but most likely would have leveraged contours from USGS 24K map products. The exceptions to this are the St. Landry and St. Martin Parishes. The effective approximate studies in these counties were adjusted to new topography in 2008. The topographic data source for the BLE was derived from LiDAR flown for the state of Louisiana in 2004. This elevation data leveraged in the BLE represents a significant improvement from the USGS 24K map products.

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. Regression equations were not used to develop these effective Zone As. Therefore, this check does not affect 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. 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 the Bayou Teche study area was completed by evaluating percentage of urban change at the HUC-12 level. None of the HUC-12 polygons within the study area met the threshold of 15% or more urban cover.

Table 10 presents the summarized results of checks A1 through A3.

Table 10: A1-A3 Validation Results

Assessment Checks	Pass / Fail	Notes
A1 – Topography	Fail/Pass	2004 LiDAR is significantly better than the assumed effective USGS topo source. Studies within St Landry and St. Martin Parishes were adjusted to newest topo source.
A2 – Hydrology	Fail	Regression was not used for effective studies
A3 – Development	Pass	Less than 15% of study area is under urban cover

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 Bayou Teche Watershed, check A4 for streams within this watershed have been marked as Fail in the CNMS database.

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 Bayou Teche 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 Zone A boundaries were compiled using a combination of data from the National Flood Hazard Layer and the CoreLogic digital uplift product. The effective Zone A boundaries were tested at points along the effective SFHA boundary. The test points were intersected with the ground DEM and 1% Plus and Minus results from the study. DEM elevations represent the effective elevation of the boundary and a "confidence band" created by the 1% Plus and 1% Minus elevation is used to determine if the DEM value is within the "confidence band" range. Additionally, a vertical tolerance was applied that represents one half of the assumed effective topographic data source contour interval. For this study, effective data sources like USGS topographic maps, referenced a contour interval of 5 feet. A vertical tolerance with an additional 2.5 feet tolerance was applied to the 1% Plus and 1% Minus value to determine whether each point is within the allowable tolerance along the effective SFHA. If the test point was within the range, it passed. If the test point was outside the range, it failed. This test verifies that there is at least one point that falls both vertically and horizontally within this range.

Effective Zone A SFHA is considered UNVERIFIED if less than 90% of the validation points pass the A5 check. Table 11 aggregates the mileage of the flooding sources for VALID and UNVERIFIED.

Table 11: Bayou Teche Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	NVUE COMPLIANT	272.6
UNVERIFIED	TO BE STUDIED	905.9

3.2.6 Validation Results

The validation assessments and results comparing the BLE with the effective Zone A flood hazard boundaries have been aggregated to the HUC - 12 level. Table 12 and Figure 10 summarizes validation results for each HUC - 12 within Bayou Teche Watershed.

Table 12: HUC-8 Zone A Validation Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>90%)	Priority Score
Watershed Name	Watershed Number						
Bayou Teche	08080102	229,869	65,026	164,870	72%	Fail	
Barber Creek-Spring Creek	080801020302	1,099	671	428	39%	Fail	16.3
Bayou Berard Canal-Catahoula Coulee	080801020703	4,673	883	3,790	81%	Fail	17.0
Bayou Bertrand-Bayou Rapides	080801020102	6,890	2,087	4,803	70%	Fail	25.0
Bayou Boeuf	080801020502	4,670	1,611	3,059	66%	Fail	29.4
Bayou Boeuf-Bayou Wauksha	080801020509	4,361	470	3,891	89%	Fail	6.5
Bayou Boeuf-Cocodrie Diversion Channel	080801020503	4,144	1,517	2,627	63%	Fail	29.3
Bayou Boeuf-Turner Canal	080801020504	2,804	521	2,283	81%	Fail	15.1
Bayou Carlin-Frontal Cote Blanche Bay	080801020901	760	271	489	64%	FAIL	33.5
Bayou Carron-Bayou Little Teche	080801020604	5,608	866	4,742	85%	Fail	12.8
Bayou Chicot-Lake Chicot	080801020507	8,215	308	7,907	96%	Pass	1.5
Bayou Choctaw	080801020106	5,121	2,976	2,145	42%	Fail	30.6
Bayou Choupique-Bayou Jack	080801020403	11,052	4,078	6,974	63%	Fail	33.9
Bayou Clear-Bayou Boeuf	080801020203	3,016	1,320	1,696	56%	Fail	10.9
Bayou Cocodrie	080801020601	4,051	1,587	2,464	61%	Fail	20.2
Bayou Cocodrie-Bayou Rapides	080801020101	2,279	877	1,402	62%	Fail	14.2
Bayou Cocodrie-Elm Bayou	080801020308	5,443	1,452	3,991	73%	Fail	21.0
Bayou Courtableau-Bayou Toulouse	080801020605	1,818	621	1,197	66%	Fail	26.7
Bayou Des Glaises-Bayou Roseau Drainage Canal	080801020402	5,415	2,447	2,968	55%	Fail	32.4
Bayou Du Portage-Coulee Du Portage	080801020801	2,951	607	2,344	79%	Fail	18.5
Bayou Grand Encore-Bayou Du Lac	080801020401	2,967	1,440	1,527	51%	Fail	36.6
Bayou Grand Louis-Bayou Carron	080801020603	2,345	916	1,429	61%	Fail	23.6
Bayou Huffpower-Bayou Rouge	080801020508	4,145	915	3,230	78%	Fail	15.6
Bayou Latanier-Bayou Rapides	080801020104	3,166	1,071	2,095	66%	Fail	30.4
Bayou Petite Passe	080801020602	898	224	674	75%	Fail	7.8
Bayou Portage	080801020701	4,151	1,051	3,100	75%	Fail	22.6
Bayou Portage-Coulee Portage	080801020702	2,340	485	1,855	79%	Fail	18.7
Bayou Robert-Bayou Boeuf	080801020204	7,279	2,147	5,132	71%	Fail	15.9
Bayou Rouge-Spring Bayou	080801020404	13,217	4,842	8,375	63%	Fail	30.3

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>90%)	Priority Score
Watershed Name	Watershed Number						
Bayou Teche	080801020705	7,237	1,741	5,496	76%	Fail	21.7
Bayou Teche-Bayou Gerimond	080801020607	3,970	655	3,315	84%	Fail	10.4
Bayou Veillon-Coulee Coteau Holmes	080801020704	753	50	703	93%	Pass	6.0
Bayou Wauksha	080801020511	4,909	1,193	3,716	76%	Fail	14.1
Billy Bayou-Frontal Intercoastal Waterway	080801020902	424	170	254	60%	Fail	36.1
Black Lake-Bayou Cocodrie	080801020506	1,360	168	1,192	88%	Fail	7.5
Chatlin Lake Canal-Bayou Du Lac	080801020107	5,517	2,731	2,786	50%	Fail	23.3
Dry Bayou-Bayou Petite Prairie	080801020510	7,066	1,795	5,271	75%	Fail	23.0
Hurricane Creek	080801020304	2	2	0	0%	Fail	80.0
Hynson Bayou-Bayou Rapides	080801020103	3,303	656	2,647	80%	Fail	18.1
Indian Creek-Indian Creek Reservoir	080801020501	2,632	649	1,983	75%	Pass	11.7
Kincaid Reservoir-Bayou Boeuf	080801020201	2,943	1,071	1,872	64%	Fail	11.4
Lake Fausse Pointe	080801020803	1,153	42	1,111	96%	Pass	3.3
Langs Branch-Bayou Cocodrie	080801020305	3,857	370	3,487	90%	Pass	19.6
Little Spring Creek	080801020303	863	320	543	63%	Pass	32.2
Loreauville Canal-Bayou Teche	080801020804	10,410	3,393	7,017	67%	Fail	29.8
Middle Bayou-Bayou Boeuf	080801020202	2,463	1,021	1,442	59%	Fail	20.8
Mountain Bayou Lake-Bayou Cocodrie	080801020505	8,126	247	7,879	97%	Pass	0.8
Rattlesnake Bayou-Chatlin Lake Canal	080801020105	1,722	632	1,090	63%	Fail	34.4
Slow Bayou-Bayou Courtableau	080801020606	4,090	965	3,125	76%	Fail	19.8
Spring Creek	080801020301	2,537	1,525	1,012	40%	Fail	15.0
Spring Creek-Cocodrie Lake	080801020307	9,420	2,726	6,694	71%	Fail	23.5
Tete Bayou	080801020802	3,285	422	2,863	87%	Fail	12.2
Turkey Creek-Caney Bayou	080801020306	6,345	288	6,057	95%	Pass	2.0
Yellow Bayou-Bayou Teche	080801020904	7,750	2,904	4,846	63%	Fail	33.2
Yokely Bayou-Frontal Intercoastal Waterway	080801020903	2,854	1,029	1,852	65%	Fail	28.8

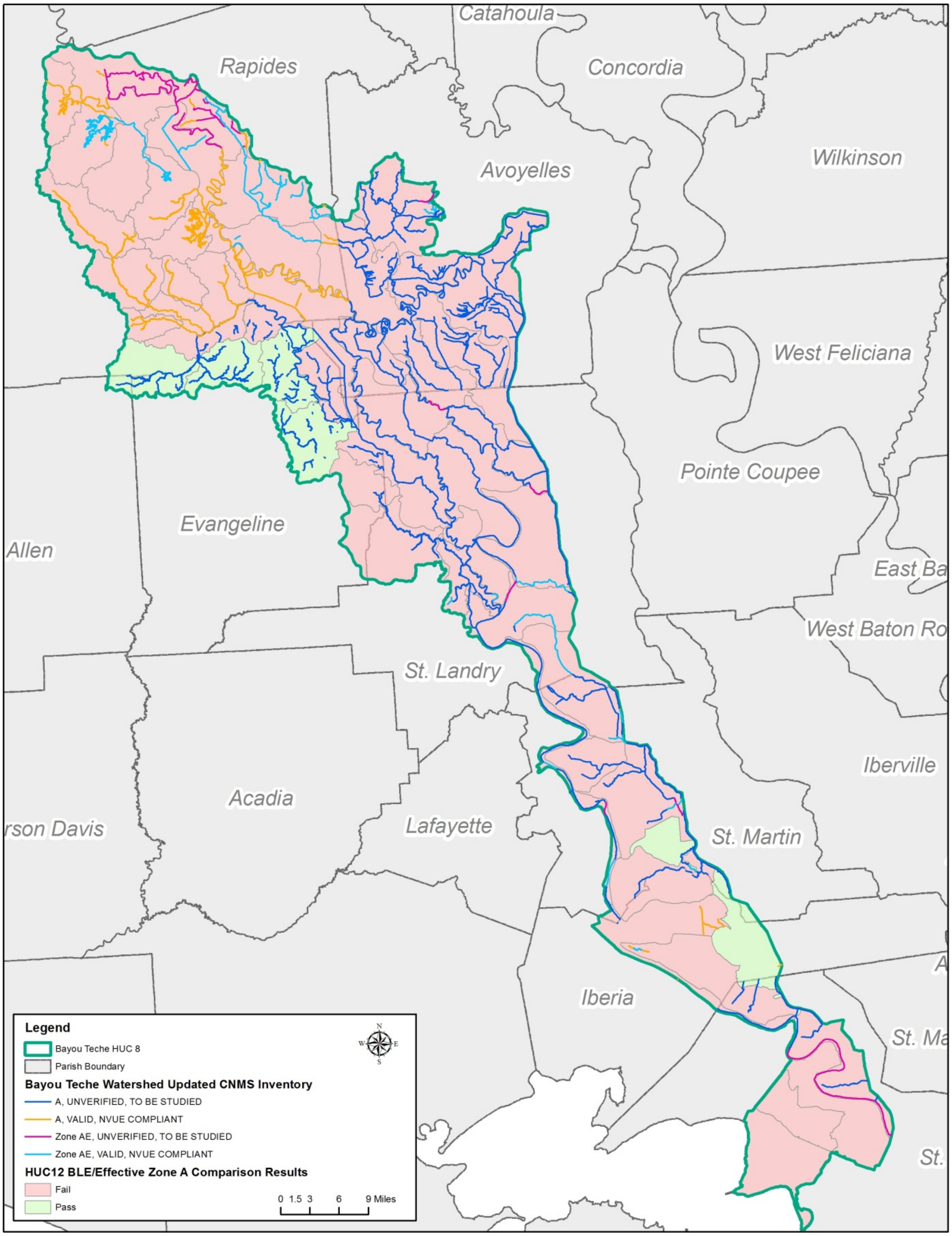

Figure 10: Bayou Teche Watershed CNMS Validation Results

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 in order to determine the priority score. Figure 11 below shows the range of the Bayou Teche HUC-8 priority scores which can be used to initiate discussions during the Discovery phase. Hurricane Creek HUC-12 was determined to have the highest priority score and the most need while Mountain Bayou Lake-Bayou Cocodrie HUC-12 has the lowest score.

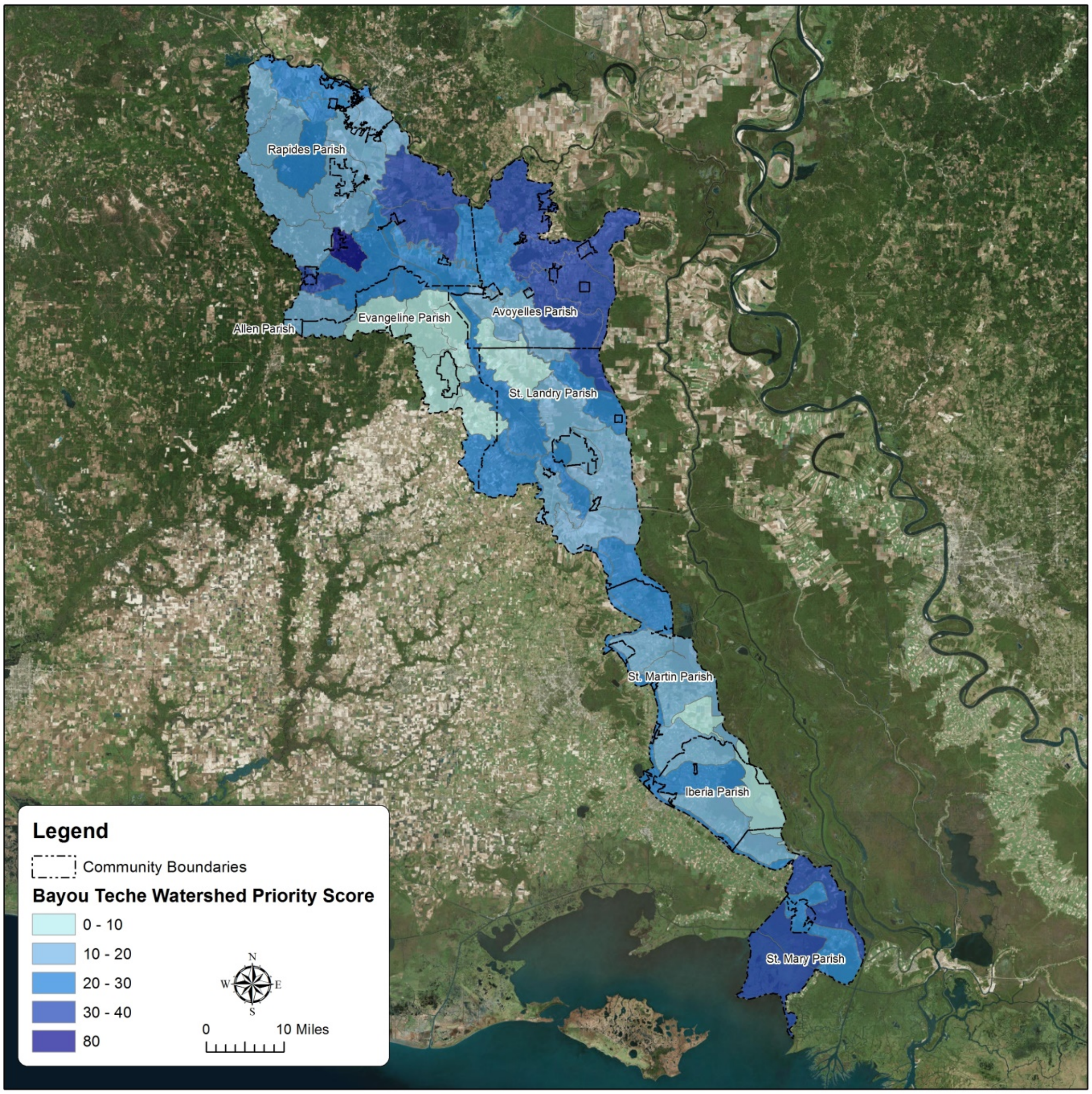

Figure 11: Ranking of Bayou Teche Watershed HUC-12s

3.3 Flood Risk Analysis

A flood risk analysis was performed for this project. The updated 1-percent annual chance grid (known as the 'refined' grid) was used to perform the flood risk analysis to produce the flood losses. The refined grid loss results are stored in the L_RA_Results table.

Hazus version 4.2 was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 4.2 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.

04 References

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Appendix A BLE Map