Region 6 Neches River Watershed – Middle Neches (HUC8 - 12020002)

MIP Case Number 16-09-0654S Deliverable

Base Level Engineering Analysis

FEMA IDIQ Contract: HSFE60-15-D-0005
Task Order #: HSFE09-15-J-0001

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STARR II Strategic Alliance for Risk Reduction

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

List of Acronyms

BFE	Base Flood Elevation
BLE	Base Level Engineering
CNMS	Coordinated Needs Management Strategy
DEM	Digital Elevation Model
DWR	Department of Water Resources
FEMA	Federal Emergency Management Agency
LiDAR	Light Detection and Ranging
LSAE	Large Scale Automated Engineering
NAD	North American Datum of 1983 ‘
NBI	National Bridge Inventory
NED	National Elevation Dataset
NHD	National Hydrography Dataset
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RSC	Regional Service Center
STARR	Strategic Alliance for Risk Reduction
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator

1. Scope

Base Level Engineering (BLE) has been completed to support flood risk analysis for Neches River Basin and its 7HUC8s.

The BLE analysis included the acquisition and processing of topographic data, development of hydrologic and hydraulic data, and conducting an A5 validation check for a Coordinated Needs Management Strategy (CNMS) (FEMA 2016) as summarized below. The flow chart in Appendix 2 outlines the hydrologic and hydraulic analysis process.

- Topographic processing included the resampling of available LiDAR data in the Neches River Watershed.
- Hydrologic data consisted of preparing a stream network, delineation of watersheds, development of gridded input parameters and peak flows from rural regression equations, and gage analysis for the HUC-8 watersheds.
- Basin-wide Base Level Engineering (BLE) Hydraulics and Floodplain Mapping –11,230 miles are based on NHD 100K and 24K near communities with population more than 1,000
- Seamless floodplain coverage of 10-percent, 1-percent and 0.2-percent annual chance floodplains
- A shapefile with the CNMS lines attributed with the results of the A5 validation check. The shapefile will be provided to the Region VI Regional Service Center (RSC) to update the CNMS database as appropriate.

The 7 HUC8 watersheds are shown in **Error! Reference source not found.**. This report provides an overview of methodology utilized for the Neches River watersheds, however focuses on details specific to the Middle Neches River Watershed (HUC 8 Number 12020002).

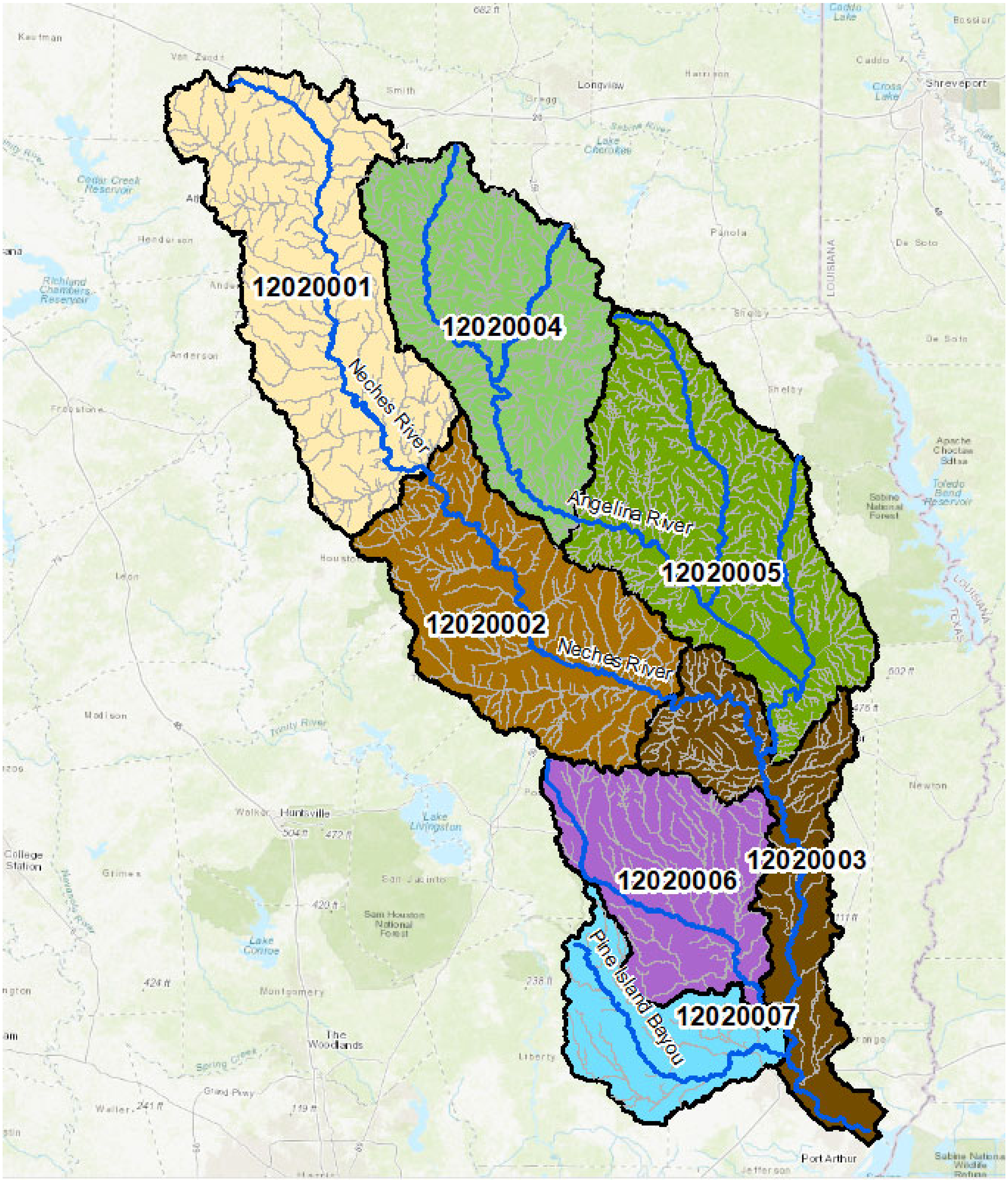

Figure 1:Neches River Basin HUC8 Watersheds

2. Topographic Processing

LiDAR for the Neches River watershed was provided by the Federal Emergency Management Agency (FEMA) Region VI (2018). Extents of the LiDAR topography are shown in **Error! Reference source not found.**. Bare Earth Digital Elevation Models (DEM) were provided as raster image (.img) files with a horizontal datum of NAD83 (2011), a vertical datum of North American Vertical Datum of 1988 (NAVD88), coordinate system Bureau of Land Management (BLM) Zone 15 N, horizontal and vertical units in U.S. Survey Feet, and 2-foot cell sizes. While the raster images were resampled, all other datums, coordinate systems, and units were the same as the original DEM files provided.

The raster images were mosaicked and resampled to 10-foot cell size vector images using bilinear resampling methods. Contours from the resampled vector images were created using 2-foot and 10-foot spacing. During processing, the grids were tiled to allow for faster hydraulic computations and floodplain delineation, resulting in the creation of a topographic index file of the images. The topographic contours were reviewed to ensure that the resampled images were acceptable for use in hydraulic modeling.

During hydraulic analysis, viewing extensive contour vectors in GIS can cause extreme lag and delay. The contour vector data was converted to images, then to image catalogs to allow for seamless and rapid viewing of the topographic data within the study area. Rasters were created for the 2-foot and 10-foot contours, and corresponding labels were also generated. The processed DEM, and the contour rasters, are included in the electronic deliverables. The contour raster image catalogs are accessed by adding DBF files within GIS software.

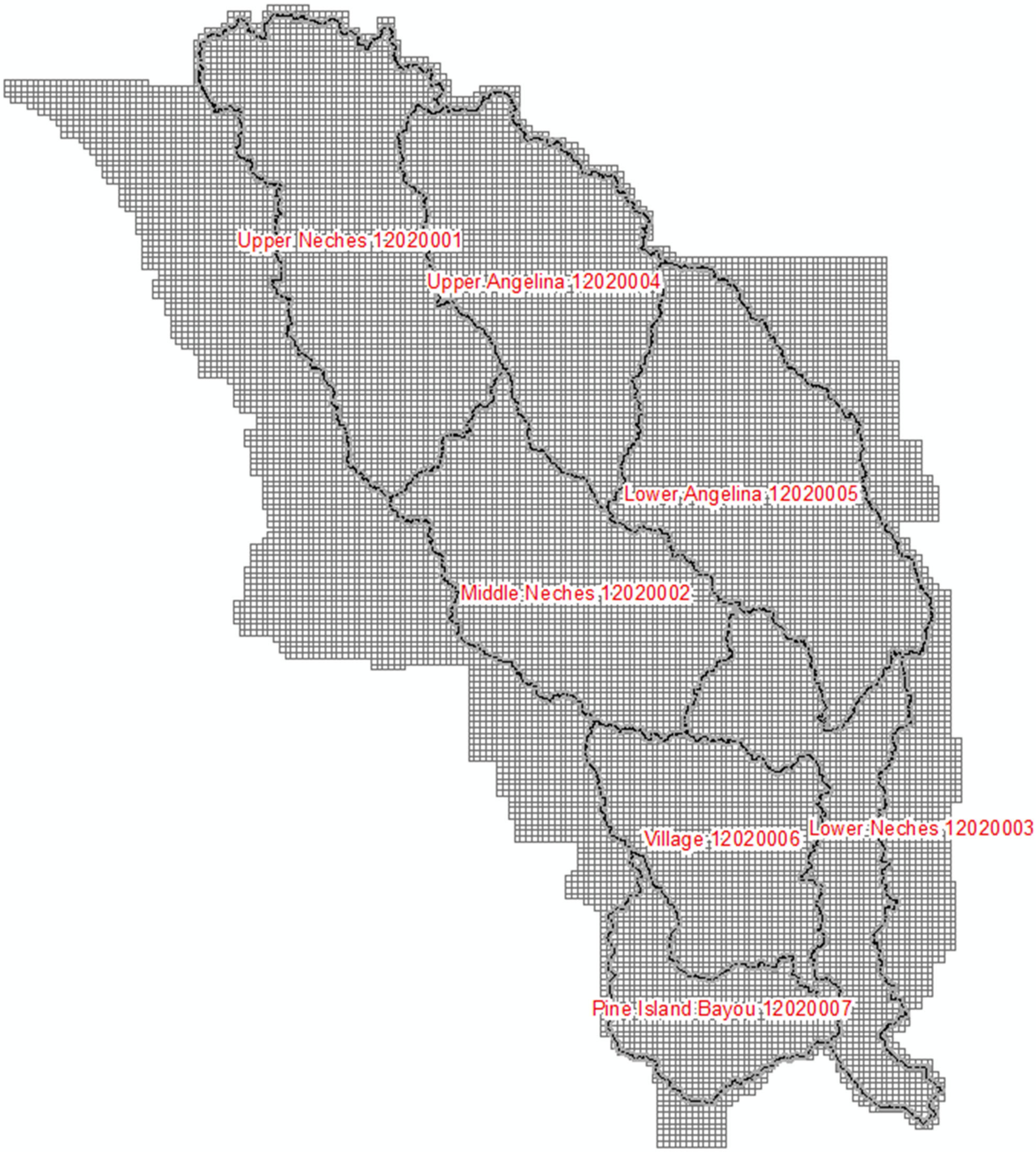

Figure 2: Neches River Basin LiDAR availability

3. Development of Hydrologic Data

STARR II's hydrology process is summarized in a work flow chart and is included as part of Appendix A. Following sections provide details of the hydrology process.

The study area was divided into three watersheds for the hydrologic analysis (see Table 1 and Figure 1). These watersheds were extended beyond the study streams in order to capture the upstream drainage areas.

Peak flows for the 10%, 4%, 2%, 1%, 1% plus, 1% minus, and 0.2% events were computed utilizing the published USGS regression equations (Asquith and Roussel, 2009). For each watershed, a grid was generated for each of the regression parameters and each of the flow events described above. Each grid cell has a value for the drainage area and other regression parameters associated with the basin draining to that cell. Due to limited data and to be conservative, the effects of regulation on the flow rates were not included in this analysis.

The primary steps for the development of hydrologic data include:

1. Prepare stream network, hydrologic network, and delineate watersheds
2. Develop gridded input parameters and peak flows from the rural regression equations

The details for each of these steps are included in the following sections.

The study area consisted of 7 HUC 8 watersheds, including 23 HUC10 watersheds and there are 4 mainstems that cover these watersheds.

Table 1: List of Main Streams and HUC10s

Mainstem	description
Neches River	Main stem crossing HUCs 0101, 0103, 0104, 0105, 0106, 0107, 0201, 0202, 0203, 0205, 0301, 0302, 0303, 0304
Angelina River	Main stem crossing HUCs 0302, 0402, 0404, 0405, 0406, 0407, 0501, 0502, 0506, 0509, 0510
Big Sandy-Village Creeks	Main stem crossing HUCs 0601, 0602, 0604
Pine Island Bayou	Main stem crossing HUCs 0701, 0702, 0703

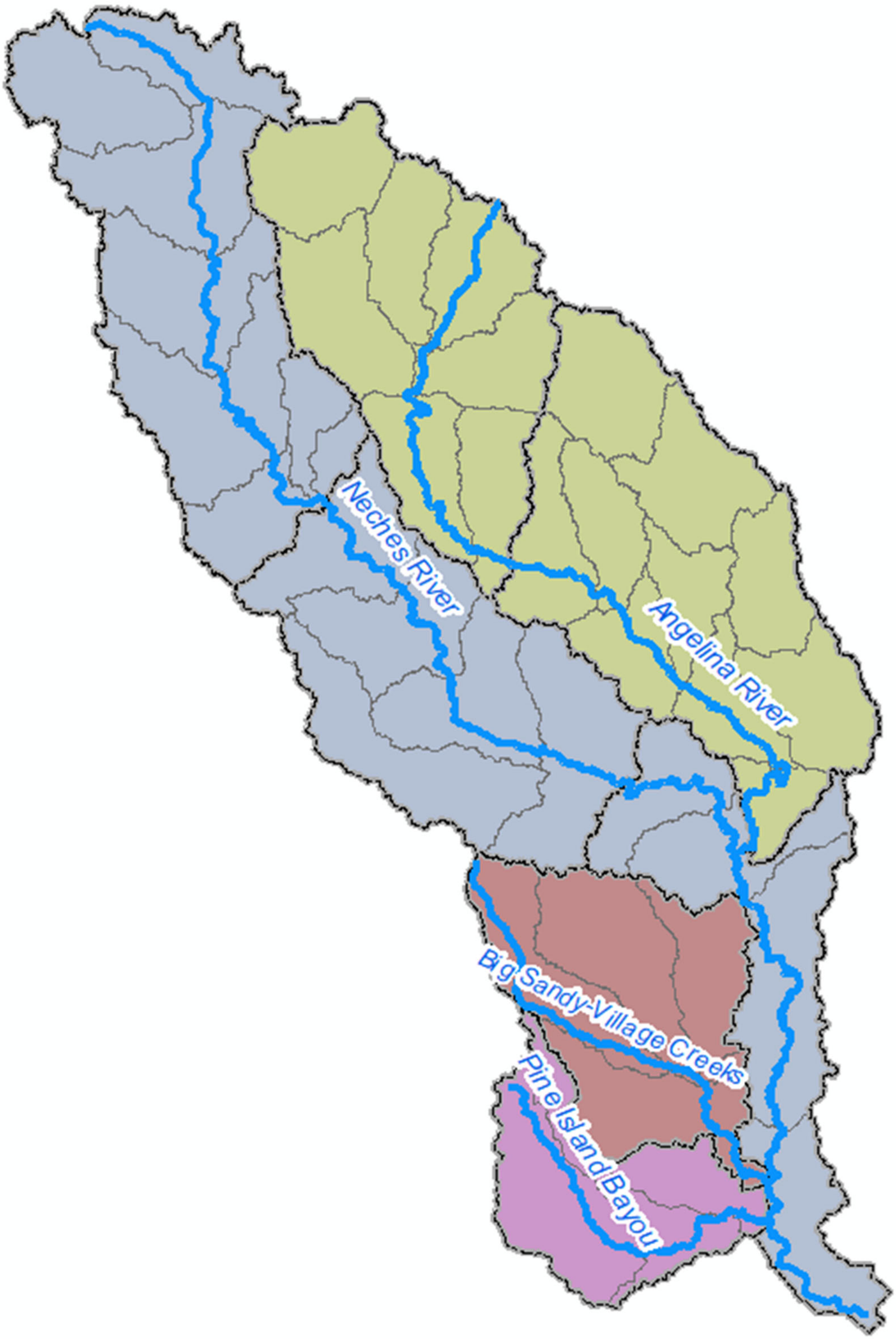

Figure 3: Neches River main stream HUC10 Basins

3.1 Stream Network Preparation and Watershed Delineation

The stream network was derived from the NHD high-definition flow lines for the watershed and used as a basis for stream centerlines and to develop hydrologic flow paths and drainage basins. The NHD lines are currently available at
ftp://nhdftp.usgs.gov/DataSets/Staged/SubRegions/FileGDB/HighResolution/.

These features are frequently updated, and the versions used for the project were from about May to August 2014.

The steps used to develop the stream network, delineate watersheds, and compute drainage areas are listed below:

1. Initially, the approximate contributing basins for those reaches for which hydraulic models are required were identified using NHD Plus (http://www.horizon-systems.com/nhdplus/) flow direction grids and watersheds derived from them. USGS stream gage locations that have drainage area information attached were also used to identify or confirm the size of contributing basins and to identify large streams with contributing flow outside the basin. No large streams with contributing flow outside the basin were identified.

2. A 30-meter DEM topography sets for the approximate contributing basin was created. These DEMs were extracted from National Elevation Dataset 1/3 arcsecond (about 10 meter) rasters, downloaded from ftp://rockyftp.cr.usgs.gov/vdelivery/Datasets/Staged/Elevation/13/GridFloat. The National Elevation Dataset (NED) 1/3 data as it existed around mid-2014 was used. These were mosaiced as needed and re-projected into USGS Albers North American Datum of 1983 (NAD 83), 30-meter grids to cover the candidate contributing basin. The sampling method during re-projection was bilinear resampling. Note that this DEM is used only to develop hydrologic parameters and will not be used for hydraulic modeling.

3. All NHD high-definition lines that intersected the contributing basins were extracted and the lines classified as coastlines, if any, were deleted.

4. The NHD lines were joined to create the stream network with higher priority given to longer lengths.

5. The stream network was reviewed and modified as follows:

   - Split flow locations were reviewed, and the primary flow path identified. The alternate flow paths were deleted from the network.
   - NHD lines classified as canals, underground conduits, and pipelines were removed from the network if they did not correspond to "natural" flow paths or scoped streams (CNMS lines).
   - Streamlines were added where there was no NHD flowline associated with a CNMS line.

6. All streamlines within 50 meters of CNMS lines were reviewed. At locations where the two alignments were noticeably different; the aerial photography and topography were reviewed to determine the correct alignment and the NHD flow line modified if appropriate.

7. The NHD stream network was then used as the basis for the "burn" layer. In the burn process, DEM cells that crossed burn lines were modified to have lower elevations.

8. There were no sinks in the watersheds. So, the DEM was filled to remove depressions so that there were continuous flow paths to the basin outlets.

9. A flow direction grid was created from the filled DEM, where each cell points to the next downstream cell.

10. Watershed delineation was performed (i.e., flowlines and basins are created from the flow direction grids). Basins were delineated up to a threshold of 0.1 square miles, and hydrologic flowlines were also created up the 0.1 square miles of drainage area, which is the threshold recommended for hydrologic computations.

11. The following quality checks were performed:

    a. Delineated watersheds and flow lines were examined for consistency with the expected flow paths for the basin. The flow directions and alignments between the NHD stream network and the hydrologic network were checked. Differences were highlighted with automated tools. Generally, differences occurred when two burn lines were too close together and the flow direction grid was incorrect. At these locations, the stream line was not burned into the DEM in order to correct the direction.

    b. A drainage area grid was computed along the flow paths and checked against stream gage drainage areas. If the flowlines or basins appeared to be in error, then the NHD stream network was modified.

    c. If modifications were made, the fill / flow direction / watershed delineation steps were repeated and drainage areas recalculated, and the flagged locations checked again.

During the review process, it was noted that the direction of a majority of the CNMS lines was reversed compared to the actual flow path and topography.

The delivered spatial files are described in the table 2 below. All files listed below are projected in USGS Albers NAD 1983.

Table 2: Spatial files delivered for stream network preparation and watershed delineation

File Name	Type	Description
NEC_DA_poly.shp	polygon	Single polygon depicting the hydrologic study area
NEC_nhd.shp	polyline	All NHD high-definition flow lines in the study area
NEC_topo.bil	grid	Mosaiced 30-meter USGS DEM covering the contributing drainage area
NEC_burn_reaches.shp	polyline	Connected stream network derived from modified NHD flow lines.
NEC_fd.bil	grid	Flow direction grid
NEC_fa.bil	grid	Flow accumulation grid
NEC_sqmi.tif	grid	Contributing drainage area (in square miles) for all drainage areas of 0.1 square mile or greater
NEC_basinpolys_0.1.shp	polygon	Basins delineated up to a threshold of 0.1 square mile of drainage area

File Name	Type	Description
NEC_basinpaths_0.1_join.shp	polyline	Hydrologic flow paths up to 0.1 square mile of drainage area. Each path has a unique streamid similar to stream order that was used to name the streams in the hydraulic models and determine where flows can be extracted from the flow grids
NEC_basinpolys_1.shp	polygon	Basins delineated up to a threshold of 1 square mile of drainage area
NEC_basinpaths_1_join.shp	polyline	Hydrologic flow paths up to 1 square mile of drainage area
NEC_basinpolys_5.shp	polygon	Basins delineated up to a threshold of 5 square mile of drainage area
NEC_basinpaths_5_join.shp	polyline	Hydrologic flow paths up to 5 square mile of drainage area
NEC_basinpolys_10.shp	polygon	Basins delineated up to a threshold of 10 square miles of drainage area
NEC_basinpaths_10_join.shp	polyline	Hydrologic flow paths up to 10 square miles of drainage area
NEC_basinpolys_50.shp	polygon	Basins delineated up to a threshold of 50 square miles of drainage area
NEC_basinpaths_50_join.shp	polyline	Hydrologic flow paths up to 50 square miles of drainage area
NEC_basinpolys_100.shp	polygon	Basins delineated up to a threshold of 100 square miles of drainage area
NEC_basinpaths_100_join.shp	polyline	Hydrologic flow paths up to 100 square miles of drainage area
NEC_streamids.tif	grid	Grid with the streamids of the 0.1 square mile hydrologic flow paths used to name the streams in the hydraulics models and determine where flows should be extracted from the flow grids

3.2 Peak Flows Computed from Rural Regression Equations

Peak flows for the 10%, 4%, 2%, 1%, 1% plus, 1% minus, and 0.2% events were computed utilizing the published USGS regression equations (Asquith and Roussel, 2009).

The contributing drainage area (“A”) and mean annual precipitation (“P”) dimensionless main channel slope (“S”) were the basin characteristics used to estimate the flows. Flow grids were developed for each flow event and the input parameters described above were developed for drainage areas of 0.1 square mile or greater. The most recent regression equations include a factor called OmegaEM parameter that represents a generalized terrain and climate index for regionalization of peak-streamflow frequency. These factors were obtained from the same USGS report and were applied accordingly to the study area.

The mean annual precipitation (1971 - 2000) gridded spatial data was obtained from the PRISM Climate Group at Oregon State University. The original dataset is included as part of the supplemental data. The precipitation values were converted to inches, clipped to the study area, and re-projected to USGS Albers NAD 83. A grid of the area-weighted basin average precipitation was created for all the drainage areas of 0.1 square mile or greater. The lower and upper values in the regression analysis were 30.34 and 36.18 inches, respectively. All basin averaged precipitation values were within this range for the study area.

The main channel slope, feet per mile, is the slope of the stream between points that are 10 percent (E_{10}) and 85 (E_{85}) percent of the distance along the channel from the basin outlet to the basin divide (*DD*). The USGS 30-meter DEM, the flow accumulation, and flow direction grids were used to derive the grids for the elevations in meters and the distance to the divide in meters. The following equation was used to compute the main slope grid in feet per mile:

$$\text{CSL10\_85fm} = \left(\frac{E_{85} - E_{10}}{0.75 \cdot DD}\right) \cdot 5280$$

The lower and upper limits of the slope in the regression analysis were 1.21 and 371 feet per mile, respectively. The computed flows are sensitive to the channel slope and unreasonable flows tend to be computed when slopes are outside of the range used in the regression analysis. Therefore, when the channel slope was less than 1.21 feet per mile, 1.21 feet per mile was used in place of the computed value; and similarly, when the channel slope exceeded 371 feet per mile, 371 feet per mile was used in place of the computed values.

The regression equations used to compute the gridded unregulated peak flows for the 10%, 4%, 2%, 1%, and 0.2% chance exceedances for basins with drainage areas of 0.1 square mile shown below:

Regression equation
$Q_2 = P^{1.398} S^{0.270} \times 10^{[0.776\Omega + 50.98 - 50.30 A^{-0.0058}]}$
$Q_5 = P^{1.308} S^{0.372} \times 10^{[0.885\Omega + 16.62 - 15.32 A^{-0.0215}]}$
$Q_{10} = P^{1.203} S^{0.403} \times 10^{[0.918\Omega + 13.62 - 11.97 A^{-0.0289}]}$
$Q_{25} = P^{1.140} S^{0.446} \times 10^{[0.945\Omega + 11.79 - 9.819 A^{-0.0374}]}$
$Q_{50} = P^{1.105} S^{0.476} \times 10^{[0.961\Omega + 11.17 - 8.997 A^{-0.0424}]}$
$Q_{100} = P^{1.071} S^{0.507} \times 10^{[0.969\Omega + 10.82 - 8.448 A^{-0.0467}]}$
$Q_{200} = P^{1.034} S^{0.531} \times 10^{[0.975\Omega + 10.61 - 8.058 A^{-0.0504}]}$
$Q_{250} = P^{1.021} S^{0.541} \times 10^{[0.977\Omega + 10.56 - 7.943 A^{-0.0516}]}$
$Q_{500} = P^{0.988} S^{0.569} \times 10^{[0.976\Omega + 10.40 - 7.605 A^{-0.0554}]}$

The average standard error of prediction for the 1% chance exceedance 35.72%. The 1% plus and 1% minus gridded flows were computed using the standard error of prediction as shown in the equations below:

$$Q_{1\%plus} = Q_{1\%} \cdot (1.3572)$$

$$Q1\%minus = \frac{Q_{1\%}}{1.3572}$$

The delivered spatial files are described in the table below. All files listed below are projected in USGS Albers NAD 1983.

Table 3: Regression Equation Input Parameter Calculations

File Name	Type	Description
NEC_sqmi.tif	grid	Contributing drainage area in square miles for all drainage areas of 0.1 square mile or greater
NEC_precip.bil	grid	PRISM precipitation grid clipped to the contributing drainage area, re-projected to USGS Albers NAD83, adjusted to 30-meter grid cells, and converted to inches
NEC_basinavgprecip_final.tif	grid	Area-weighted basin average precipitation for all drainage areas of 0.1 square mile or greater clipped to the associated regression region upper and lower limits
NEC_basinavgomega.tif	Grid	Parameter to represent generalized terrain and climate index for regionalization of peak streamflow frequency.

File Name	Type	Description
NEC_elevat100pcup.tif	grid	Elevations in meters of the channels at the basin divide (Edivide) for all drainage areas of 0.1 square mile or greater
NEC_disttodivide_mtrs.tif	Grid	Distance along the channel from the basin outlet to the divide in meters (DD)
NEC_chanslope_final.tif	grid	Dimensionless main channel slope (S) clipped to the upper and lower regression limits for all drainage areas of 0.1 square miles or greater
NEC_Q10_eqs_only.tif	grid	Regression equation peak streamflows with 10-percent chance exceedance for all drainage areas of 0.1 square miles or greater
NEC_Q25_eqs_only.tif	grid	Regression equation streamflows with 4-percent chance exceedance for all drainage areas of 0.1 square miles or greater
NEC_Q50_eqs_only.tif	grid	Regression equation streamflows with 2-percent chance exceedance for all drainage areas of 0.1 square miles or greater
NEC_Q100_eqs_only.tif	grid	Regression equation streamflows with 1-percent chance exceedance for all drainage areas of 0.1 square miles or greater
NEC_Q100_minus1_eqs_only.tif	**grid**	Regression equation 1-percent minus peak stream flows
NEC_Q100_plus1_eqs_only.tif	grid	Regression equation 1-percent plus peak stream flows
NEC_Q500_eqs_only.tif	grid	Regression equation peak streamflows with 0.2-percent chance exceedance for all drainage areas of 0.1 square miles or greater

3.3 Gage Analysis for High Drainage Areas and FIS adjustments to Regression flows.

The regression equations are not valid for drainage areas greater than 2,500 square miles. Flows were adjusted using gage data on Neches River, Angelina River, Ayish Bayou, Attoyac River, Mud Creek, Pine Island Bayou, and Village Creek as described below.

For each of these gages, PeakFQ was used to calculate the 10-, 25-, 50-, 100-, and 500-year discharges of each gage based on the observed yearly peak flows as well as the associated 1% plus and minus flows. A weighted least-squares regression was then performed, where the explanatory variable was the log of the drainage area, and the dependent variable was the log of the discharge.

The drainage areas used in the regression were those provided by the USGS for each gage, in square miles, and the 100-year discharges were those calculated by PeakFQ in cubic feet per second. The weight of each gage for the weighted least-squares regression was the number of valid years in the peak flow record, according to PeakFQ. Thus, a gage with 90 years of the flow record received ten times the weight, in the regression, compared to a gage with 9 years of flow record.

Using the outputs of PeakFQ, the standard error of each 100-year discharge calculation was estimated. This resulted in the 100-year minus one standard error discharge, and 100-year plus one standard error discharge for each gage. For the gage set selected for a particular reach, a weighted least-squared regression was performed on the 100-year minus one standard error flows, and another regression on the 100-year plus one standard error flows holding the slope constant at the value determined for the 100-year regression described above.

Also, regression flows were compared with FIS flows where available and the regression flows were adjusted to effective FIS flows where regression equation has resulted in lower flows.

The flows were adjusted to FIS flows

The flows computed in this stage are the FINAL flows that are used in the hydraulic modeling.

Table 4: Flow adjustments identified at HUC10

HEC-RAS Model ID	Miles	Flooding Source	Flow Used	HUC10
13960	1.286	Cedar Creek	FIS	1202000203
13952	4.871	Cedar Creek	FIS	1202000203
13961	0.276	Cedar Creek	FIS	1202000203
13972	2.555	Cedar Creek South Tributary	FIS	1202000203
13903	5.620	Hurricane Creek	FIS	1202000203
1390302	3.288	Hurricane Creek	FIS	1202000203
13925	1.601	Hurricane Creek East Tributary (East)	FIS	1202000203
13912	1.839	Hurricane Creek East Tributary (North)	FIS	1202000203
13934	1.537	Hurricane Creek East Tributary (South)	FIS	1202000203
13931	0.626	Hurricane Creek East Tributary (South)	FIS	1202000203
13920	2.479	Hurricane Creek West Tributary	FIS	1202000203
13918	1.558	Unnamed Tributary 1 to Hurricane Creek	FIS	1202000203
1393102	1.740	Unnamed Tributary 4 to Hurricane Creek	FIS	1202000203
14320	10.457	White Oak Creek	FIS	1202000203
1432003	10.457	White Oak Creek d/s of FIS	FIS	1202000203
1432002	10.457	White Oak Creek u/s FIS	FIS	1202000203
15110	2.064	Biloxi Creek North Tributary	FIS	1202000205
15131	2.338	Biloxi Creek South Tributary	FIS	1202000205
15175	6.438	One Eye Creek	FIS	1202000205

Table 5: Spatial files and related data delivered for the final peak flows

File Name	Type	Description
NEC_Q10_final.tif	grid	Final peak flows for the 10% event adjusted for high drainage areas
NEC_Q25_final.tif	grid	Final peak flows for the 4% event adjusted for high drainage areas
NEC_Q50_final.tif	grid	Final peak flows for the 2% event adjusted for high drainage areas
NEC_Q100_final.tif	grid	Final peak flows for the1% event adjusted for high drainage areas
NEC_Q100_minus1_final.tif	grid	Final 1% minus peak flows adjusted for high drainage areas
NEC_Q100_plus1_final.tif	grid	Final 1% plus peak flows adjusted for high drainage areas
NEC_Q500_final.tif	grid	Final peak flows for the 0.2% event adjusted for high drainage areas

3.4 Digital Data Structure

Digital data delivered as part of the hydrology task is organized in the following structure

1. Stream_Hydrologic_Network: This folder contains data produced during stream network preparation and watershed delineation and are listed in Table 1.

3. Peak_Flows_From_Regression_Equations: This folder contains data before any adjustments to the Flow Retarding Structures within the project area are applied and includes regression equations input parameter calculations (drainage area, average annual precipitation and average slope) and 10%, 4%, 2%, 1%, 1% -, 1% + and 0.2% annual chance exceedance flows. All files included in this folder are listed in Table 3.

4. Final_Peak_Flows: This folder contains the final 10%, 4%, 2%, 1%, 1% -, 1% + and 0.2% annual chance exceedance flows adjusted for high drainage area and regulation by large dams along with gage location data, regulated streams. All files included in this folder are listed in Table 4.

4. Hydraulic Analysis

For the hydraulic analysis, the study area was divided into four (4) HUC-10 watersheds as shown in Figure below. A separate analysis has been performed on Neches River, Angelina River, Big Sandy-Village Creeks and Pine Island Bayou main stems. Each of these main stems cross multiple HUC-10s in the study area.

Steady flow HEC-RAS models were developed for the 10%, 4%, 2% 1%, 1% minus, 1% plus, and 0.2% flood events. Model geometry and mapping were developed automatically using GIS tools and scripts and then refined as needed. Some common modeling practices not considered in this analysis are inclusion of bridges, culverts, or levees or split flow analysis.

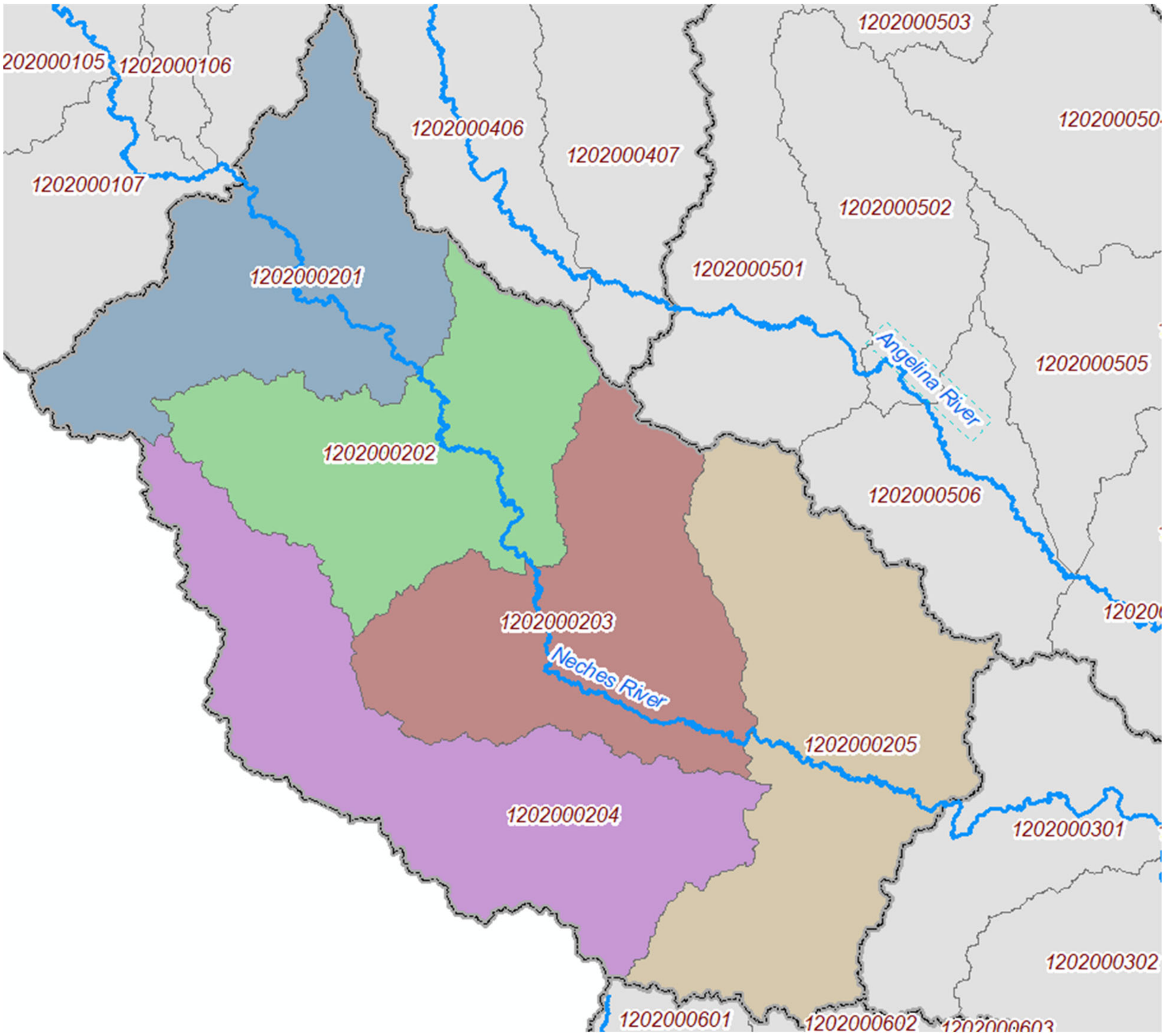

Figure 4: Middle Neches HUC8 watershed study area

The NHD high-definition streamlines were used to create the initial hydraulic centerlines for the models. These lines were then reviewed and modified to more closely follow the thalweg of the stream. A single conveyance area was used for each cross-section, e.g. bank stations were set at the outer limits of the cross-section. This method has been found to give good results, especially when Manning's n-values are set based on land-use coverage.

No supercritical flows were permitted in the models, so the lowest possible water surface elevation for any cross-section was critical depth.

After automated models were developed, the floodplains and cross-sections were visually reviewed. Cross sections with unusual changes in hydraulic parameters (water surface and energy grade slopes, water surface elevations, and velocity) were examined. In numerous cases cross-sections were deleted or modified, to improve the quality of the hydraulic model.

Floodplains (10% 1% and 0.2% events) and water surface grids (1% and 0.2% events) were processed once the models were finalized.

4.1 Discharges

Discharges for the 10%, 4%, 2%, 1%, 1% plus, 1% minus, and 0.2% events were derived from the final flow grids and imported into HEC-RAS using automated tools such that the corresponding computed USGS rural regression discharge was assigned at each cross-section.

4.2 Boundary Conditions

The downstream boundary condition for almost all models was set at critical depth. For areas of interest, where the streamline did not terminate at a confluence with another river, the reach was extended by about 3,200 feet downstream, to allow the water surface to stabilize, so that the area of interest was already outside the influence of the downstream limit of the model. Through confluences in most situations reaches were also extended downstream to parallel the main channel that they join. In the model extensions downstream of confluences the discharge applied was not increased to represent the increased discharge computed for the main channel, instead the highest computed discharge upstream of the confluence is used. This process allows for a smooth transition in water surface elevation and thus floodplains between tributaries and main channels.

Typically, “normal” depth is used for hydraulic models for the downstream boundary. However, the use of normal depth requires an estimate of the “normal slope,” which depends on the method used to estimate it. Fully automated methods to estimate the normal slope for large numbers of reaches are not completely reliable, in particular there is a risk that the slope may be estimated too low, which can cause a significant and unrealistic backwater condition at the start of the model, which may perpetuate for a long distance upstream. When critical depth is used, the models will typically stabilize to a “normal” depth within just a few cross-sections.

The only place where the model results should be used in this stabilization region would be when the downstream end of a reach was in the confluence with another modeled stream. For most confluences, the downstream main channel was modeled also. Typically, the higher water surface elevation (backwater) of the main channel would govern when the water surface grids and floodplains are merged, negating any inaccuracies associated with the critical depth boundary condition on the tributary stream.

4.3 Stream Centerlines

The burn reaches derived from the NHD high-definition lines were used as the basis for the stream centerlines. Rough models with closely spaced cross sections were developed with these lines using a low flow rate. Based on the results and the terrain, an automated process was used to locate the thalweg and then smooth the lines based on a splining operation.

The splined streamlines were reviewed and editing manually based on 2 ft contours where needed to ensure the streamlines were located as close to thalweg as possible.

4.4 Cross Sections

Automated processes were used to create the cross sections with input parameters defining cross sections spacing and width. Cross section spacing was typically 100-150 feet spacing for headwater upstream steep slope, 250 feet for medium slope and 500-1000 feet spacing for downstream flat slope. The spacing and width may vary along a stream based on the terrain and 1% and 0.2% flood extents. Cross section geometries were obtained by overlaying the cross section on the LiDAR topography.

All cross sections were reviewed and manually edited where needed to ensure the following: cross sections alignment should be perpendicular to the flow; cross sections should contain 500yr floodplain and floodplain continuity; All cross sections were reviewed and manually edited where needed to ensure the following: cross sections alignment should be perpendicular to the flow; cross sections should contain 500yr floodplain and floodplain continuity;

A series of checks was performed to look for unusual changes in water surface elevation, slope, or velocity between cross-sections for the water surface profile of the 1% annual chance exceedance event. Places flagged as exhibiting unusual behavior were examined,
and cross-sections were sometimes modified (or deleted) in these areas. Some cross sections were added where needed in steep areas to ensure that the streamline was wet. This process resulted in the final cross-sections location and orientation, however the cross-section extent or width was kept such that the containment for a 500-year event is achieved.

Bounding cross sections were placed at hydraulically significant roadways and inline structures and at high points where weir flow occurs. If roadway is not elevated and performed as weir, cross sections should be added on top of road the capture the effects of high ground.

At inline reservoirs, cross sections were generally placed at the toe and at the upstream face at the emergency spillway elevation. Based on engineering judgement, locational cross sections were place along the length of the emergency spillway at some locations.

4.5 Ineffective Areas

Normal ineffective flow limits were added as appropriate to account for contraction and expansion that occurs within the floodplain at roadway crossings, inline structures and non-conveyance areas. Ineffective flow lines are primarily placed based on 100yr floodplain; however, they are adjusted in some locations based on 10yr (such as locating proper high ground along the channel for better 10yr floodplain) and some locations are ineffective based on a 500yr floodplain contraction expansion locations.

4.6 Channel Banks and Overbank Flow paths

The bank stations were set at the outer limits of the cross-section and thus using a single conveyance for each cross section. The overbank flow paths were not created for this analysis. Overbank reach lengths are assumed to be the same as channel reach lengths.

4.7 Manning's n Values

Manning's n values were assigned to each class in the National Land Cover Database 2011 (NLCD, http://www.mrlc.gov/nlcd11_data.php). The correspondence between land use codes and the Manning's n-values are provided in Appendix B. For each model cross section, the n-value was computed by compositing the land cover Manning's n values along the cross section using the Lotter

Method (Chow, 1959, p. 136-137), which included an estimate of the 1% plus water surface elevation so the wetted extents could be used to perform the compositing. The compositing was done by each cross-section using the 1% plus discharges and estimated wetted extents. These composite n-values were then used for all other event simulations, including the 10% for which shorter cross sections are used to limit conveyance to the smallest overall width that may provide containment. For areas Manning's n not specified, a default n-value of 0.04 will be assigned for the cross sections for model use.

4.8 Expansion and Contraction

Default contraction and expansion coefficients (0.1 and 0.3) were used.

4.9 Bridges and Culverts

No bridges and culverts were modeled. However, bounding cross sections were added on upstream and downstream side of hydraulically significant roadway crossings using NBI bridge data as well as best available aerial imagery.

4.10 Special Issues

Polygons identifying locations of special issues including locations that do not meet one-dimensional modeling assumptions, potential breakout flows, containment losses etc. are included in the deliverables.

Flow was not decreased due to model breakouts, nor were models modified to take them into account. To prevent the channel from drying out, ineffective flow areas were generally used to confine the flow to most perched channels resulting in conservative floodplains and water surface elevations.

4.11 Floodplain and Water Surface Elevation Grids

Floodplains were generated for the 1%, 10% and 0.2% annual chance exceedance events for the hydraulic model reaches. These floodplains were utilized to determine if the hydraulic model results looked reasonable, and if the models needed adjustment. A GIS shapefile of streamlines was provided that shows the actual reaches that were modeled.

The floodplains are based on water surfaces interpolated from the hydraulic model cross sections. In most locations where flow containment was lost at the limits of the models, backwater conditions were considered, and the floodplains adjusted with an automated post-processing step to include additional backwater areas. Figure 4 shows backwater that was added beyond the limits of the hydraulic model. Figure 5 shows an example of backwater that required additional area because the water surface elevations extend upstream beyond the upstream limits of most models.

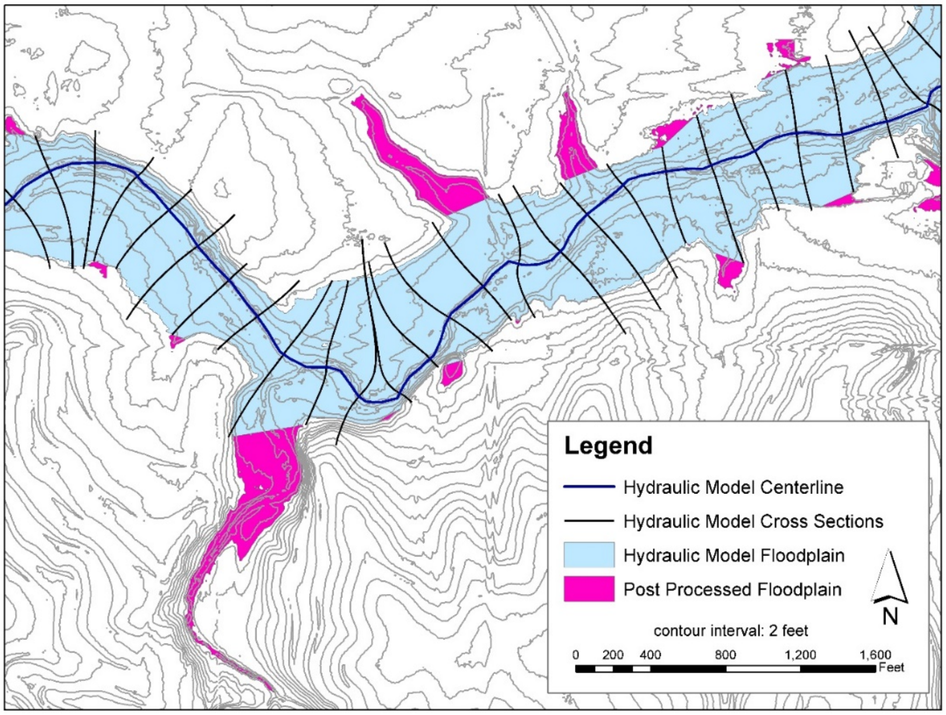

Figure 5:Post processed floodplain to add backwater areas along a modeled reach that would be flooded but were

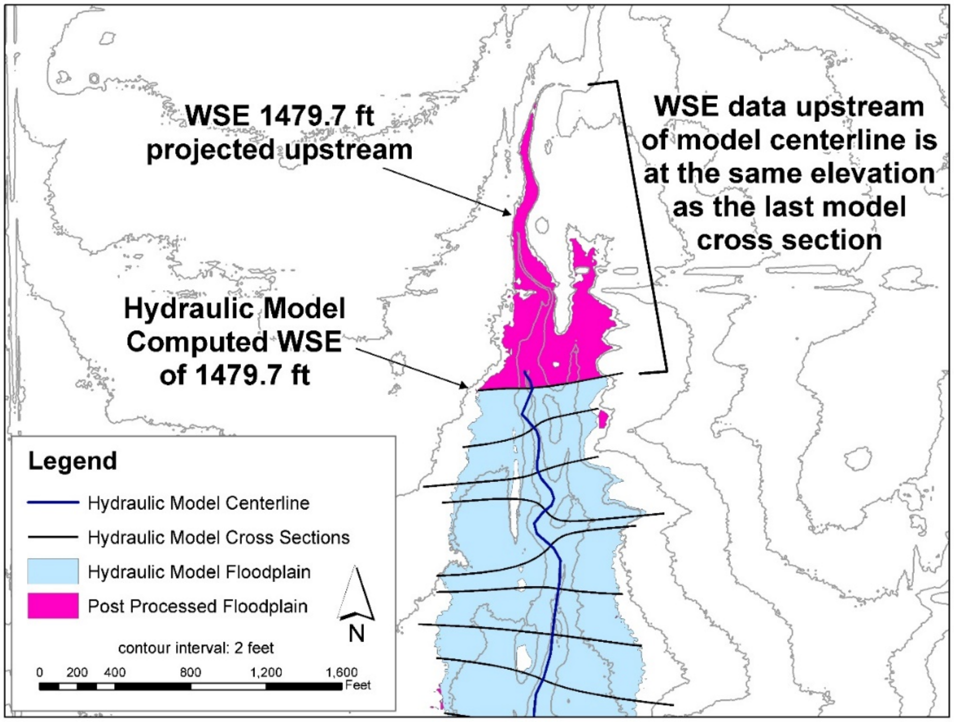

Figure 6:The post processing of floodplains also adds backwater areas upstream of the hydraulic model, these areas have the projected water surface from the most upstream cross section.

For locations where the models overlap, e.g. at confluences, the highest water surface elevation across all models dominates and results in the largest delineated floodplain by definition.

Dams and reservoirs are accounted for by simply placing a model cross section along the upstream face of the dam at the same elevation as the emergency spillway.

4.12 Quality Review

STARR II conducted a detailed review of the data utilized for this analysis at task level as part of STARR II Quality Management Plan (QMP). As part of QMP framework, STARR II maintains a consistent quality checklists and folder structure. Individual checklists and Technical review form are provided in Appendix C. Review comments and their resolution are documented in spatial files based on a set of questions documented in Appendix D.

4.13 Deliverables

The HEC-RAS models have been created for the following flood profiles: 10%-, 4%-, 2%-, 1%-, and 0.2%-annual-chance events. Two additional profiles the 1%-plus and 1%-minus have been created, that alter the 1%-annual-chance profiles based on the standard error reported for applicable regression equations.

For all these profiles the same HEC-RAS geometries are used.

Under the Hydraulic_Models folder, all the HEC-RAS models are grouped based on the HUC10 boundaries along with Mainstem. Each HUC10 folder contains individual hydraulic models for each stream within that HUC10. The Streamline_Model_Index spatial file provides the location of the streams and their corresponding model number. See Figure 6 below for the HUC10 folder structure.

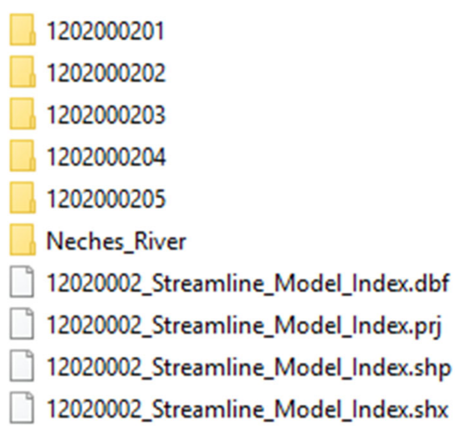

Figure 7: HUC10 folder structure

For all events an identical file and folder structure has been established and provided in the supplemental folder.

Inside each folder, for a given event, there are folders for each individual reach.

5. Flood Risk Products and Dataset

The Flood Risk Database (FRD) is the key product that will support all other flood risk products and datasets. It is a database of non-regulatory flood risk data which contains the digital data used to prepare the Flood Risk Report (FRR) and Flood Risk Map (FRM), as well as other ancillary data generated during Base Level Engineering analysis.

As part of this project, Multi-Frequency Depth Grid and Water Surface Grids are produced. For BLE study areas, it is required to produce 1% and 0.2% annual chance profiles. All depth and water surface grids (rasters) within the FRD are floating point with data rounded to the nearest tenth of a unit (i.e., 0.1 feet, 0.1 feet/second, or 0.1%) and have the same spatial reference, origin, resolution and rotation as one another. All elevation data in depth and water surface elevation raster, are reference the North American Vertical Datum of 1988 (NAVD88) with units of US Survey Feet.

6. CNMS Validation

Under Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e), FEMA is to revise and update all floodplain areas and flood risk zones identified, delineated, or established, based on an analysis of all-natural hazards affecting flood risks on a five-year cycle. To accomplish this goal, the Coordinated Needs Management Strategy (CNMS) establishes criteria by which to evaluate flood hazard studies and stores the study validation results and validation status in a database. Further, progress towards this goal is measured through the New, Valid, and Updated Engineering (NVUE) program metric.

As part of this project, CNMS validation of 640 miles was completed, which included 16 miles of detailed study miles and 624 miles of approximate study miles. Detailed studies were subjected to the complete validation processes as documented in the CNMS User's Guide Version 6.0 (FEMA, November 2016), which includes the review of 17 separate elements of a study's input data. The approximate studies were reviewed first for the A1 through A4 checks based on the November 2016 procedures. Base Level Engineering analysis (A5 check) was completed for those studies that failed at least one of the A1 through A4 checks.

6.1 Detailed Validation

Detailed study validation resulted in a x % revalidation rate calculated by mileage for all detailed miles that were part of this project. The following critical and secondary checks were evaluated based on the latest FEMA CNMS guidance.

- Critical Checks
  - (C1) Major change in gage record since effective analysis that includes major flood events
  - (C2) Updated and effective peak discharges differ significantly
  - (C3) Model methodology no longer appropriate
  - (C4) Addition/removal of a major flood control structure
  - (C5) Current channel reconfiguration outside effective SFHA
  - (C6) Five or more new or removed hydraulic structures that impact BFEs
  - (C7) Significant channel fill or scour

- Secondary Checks
  - (S1) Use of rural regression equations in urbanized areas
  - (S2) Repetitive losses outside the SFHA
  - (S3) Increase in impervious area in the sub-basin of more than 50 percent

- (S4) One to four new or removed hydraulic structures that impact BFEs
- (S5) Channel improvements / Shoreline changes
- (S6) Availability of better topography/bathymetry
- (S7) Changes to vegetation or land use
- (S9) Significant storms with High Water Marks
- (S10) New regression equations

6.2 Approximate Study Validation

The Zone A validation process begins with an assessment of three checks (A1-A3) which serve as an initial screening to efficiently categorize some Zone A studies as “Valid” or “Unverified” in the CNMS Inventory. Additional assessments include checking if the effective Zone A study is backed by technical data (A4) and the comparison of the effective Zone A study against a Refined Zone A Engineering study (A5). For the purposes of these Zone A validation assessment procedures, either Large Scale Automated Engineering (LSAE) or Base Level Engineering (BLE) are appropriate sources for a Refined Zone A Engineering study. For regulatory FIRM production work, only Base Level Engineering would be appropriate. The following checks were evaluated based on the latest FEMA CNMS guidance.

- (A1) Check for Significant Topography Updates
- (A2) Check for Significant Hydrology Changes
- (A3) Check for Significant Development in the Watershed
- (A4) Check if Study was backed by Technical Data
- (A5) Comparison of Refined Zone A Engineering and Effective Zone A

6.3 A5 Check

An A5 check was completed for A zone CNMS lines that fall entirely within the extents of LiDAR based topography. There are two alternative comparison methods that could be used for validation, the “basic method” and “width-based method.” The basic method is simpler but tends to lead to lower passing rates for wider reaches. The width-based method is more complex and can only be used for 1D models. Either approach could be used for an entire study. The width-based method was used in this study.

6.4 Validation Procedure

This BLE effective Zone A comparison approach uses the 1% plus and 1% minus flood profiles data inputs described below. Data inputs:

- BLE cross-section GIS layer attributed with the 1% plus WSE, or a water surface raster or TIN interpolated from the 1% plus cross sections, or a water surface raster or TIN created otherwise from model results.
- BLE cross-section GIS layer attributed with the 1% minus WSE, or a water surface raster of TIN interpolated from the 1% plus cross sections, or a water surface raster or TIN created otherwise from model results.
- Effective Zone A floodplain boundary
- BLE topographic data

- Vertical tolerance—one half contour interval of the USGS 24K quadrangle. For example, if the contour interval on the quadrangle is 20 feet, the vertical tolerance is 10 feet in the region of that quadrangle.

The steps are described below:

1. Obtain sampling points on the Effective Zone A floodplain boundary. Each sampling point would require new topography in the vicinity of each point, as well as corresponding water surface elevations from the 1% plus and 1% minus models. The sample points and the water surface elevations were obtained from evenly spaced points around the boundary of the effective floodplain (both exterior and interior boundaries, e.g. islands). The points were generally spaced at a maximum of 200 feet apart but can be closer. The BLE 1% plus and 1% minus water surface elevations were then assigned to the point by using an interpolated water surface elevation from the BLE models, either at the point itself (from interpolated or otherwise modeled water surface features) or optionally, if the point is outside one or both of the LSAE floodplains, from a nearby representative point when an interpolated water surface is available, and which corresponds to approximately the same river station as the sampling point.

2. Check if 1% plus WSE >= 1% minus WSE, in very rare cases this might not be true. In these rare cases, switch the two water surface elevations in the following steps (e.g. always use the higher WSE when the 1% plus WSE is referenced), and use the lower WSE when the 1% minus WSE is referenced in the steps below.

3. For each validation point, determine the 1% plus and 1% minus active floodplain widths (active means excluding ineffective flow areas). If the validation points were obtained using the cross-section approach, the active floodplains widths should be taken from that model's cross section. This width will be used even if the cross section is in the backwater of another model. If the validation points were obtained by evenly spaced points along the effective floodplain boundary, the validation point may already be associated with a particular reach and cross-section station number that was used to obtain the 1% plus and 1% minus water surface elevations (before consideration of backwater). If the reach and station has not been assigned, it can be assigned at this point; however, consistency with the location that was used to obtain the modeled water surface (before considering any backwater) would be needed. Normally the point would be assigned to a station which is between cross sections. The active top widths from the upstream and downstream cross sections should be interpolated (for both the 1% plus and 1% minus models), to assign 1% plus and 1% minus floodplain widths. The interpolated active top width could be calculated using the following formula:

   Interpolated topwidth=

   $$\frac{\text{(dist. to u/s section) x (d/s active top width)+ (dist.to d/s section) x (u/s active top width)}}{\text{distance between bounding sections}}$$

   Where dist. or distance means "distance determined by river station", d/s means "downstream", and u/s means "upstream".

4. Determine which modeled top width is the "final topwidth". Determine the maximum topographic elevation within a 37.5-foot radius from the validation point. If this elevation is less than the 1% minus WSE, this means that the point is well inside the 1% minus floodplain. If this is the case, then let "final topwidth" equal the 1% minus interpolated active topwidth calculated previously. If the maximum elevation is greater than or equal to the 1% minus interpolated active topwidth, let "final topwidth" equal the 1% plus interpolated topwidth calculated previously. Inputs include minimum and maximum topographic elevations within a 37.5-foot radius of the validation points.

Output is the determination whether the "final topwidth" should be from the 1% plus or the 1% minus active topwidth.

5. Use Table to determine and inner and outer radius values. Inputs include "final topwidth" from the previous step (first column of the table). Outputs include the radius of inner circle, radius of outer circle (second and third columns of the table).

Table 5: Inner and Outer Radius Values

Final topwidth condition	Inner radius, feet	Outer radius, feet
topwidth <= 100	25	37.5
100 < topwidth <=200	37	50
200 < topwidth <= 400	50	75
400 < topwidth <=600	75	100
600 < topwidth <= 900	100	150
900 < topwidth <= 1200	150	200
1,200 < topwidth	200	300

6. Perform inner-radius horizontal check on the point. Check if either of these conditions hold:

    a. Maximum topography elevation within the inner radius < 1% minus water surface elevation

    b. Minimum topography elevation within the inner radius > 1% plus water surface elevation

    If either condition is true, the point fails the inner radius horizontal check and proceed to next step. If both conditions are false, the point passes the inner radius horizontal check (and has also previously passed the FBS-like check), the point receives a score of 1 and scoring for the point is complete. If the point does not meet these conditions proceed to the next step. Inputs include minimum and maximum water surface elevation using inner circle, 1% plus water surface elevation, 1% minus water surface elevation. Outputs include score determination of 1 or continue to next steps.

7. Perform outer-radius horizontal check on point. If the point failed the inner horizontal check in the previous step, a horizontal check using the outer radius is needed. Check if either of these conditions are true:

    a. Maximum topography elevation in the outer radius < 1% minus water surface elevation

    b. Minimum topography elevation in the outer radius > 1% plus water surface elevation

    If either condition is true, then the point fails the check using the outer radius and receives a score of zero. If both conditions are false, then the point passed the outer horizontal check and receives a score of 0.5 (e.g. partial credit). Inputs include minimum and maximum water surface elevation using outer circle, 1% plus water surface elevation, 1% minus water surface elevation. Outputs include score determination of 0.5 or zero.

8. After all points have been score, proceed to the grouping phase. Once all points have been assigned a score of 0 or 1 (or possibly 0.5 if the width-based has been used) they must be grouped. The groups consist of geographic regions which encompass the points, and the effective floodplains being evaluated. The groups may be based on HUC-12 areas or refined down to the reach level. At least 20 points should be in each group. The pass percentage is computed for each group using the points located in that group. The total score of all point in

each group are divided by the number of points in the group and expressed as a percentage. The streams located in the group are assigned that pass percentage. Each stream is categorized as "Valid" or "Unverified" based on the risk class in which it is primarily located (see Table below).

Table 6: Floodplain Boundary Standards Pass Thresholds based on Risk Class

Risk Class	Characteristics	Total score as percentage of the total points for Stream Reaches to be called "Valid"
A	High population and densities in the floodplain and/or large amount of anticipated growth	95%
B	Medium population and densities in the floodplain and/or modest anticipated growth	90%
C	Low population and densities in the floodplain and little or no anticipated growth	85%

7. Base Level Engineering Deliverables

As described in the Regional BLE Submittal Guidance, dated January 2019, following datasets are included in the FRD as shown in the table below. Appendix E of this report provides additional details about Base Level Engineering Database.

Category	File Name	File	Description
Base Dataset	S_Pol_AR	Polygon	Political/Community Layer
	S_HUC_AR	Polygon	HUC8 Basin
EBFE Dataset	SUBBASINS	Polygon	Hydrologic sub-basin delineations
	XS	Line	1-D Hydraulic Cross-Sections
	BFE	Line	2-D Base Flood Elevations
	WTR_LN	Line	Stream Centerline
	WTR_AR	Polygon	Water Bodies
	DTL_STUD_LN	Line	Stream Centerline – Detailed Study on FIRM
	DTL_STUD_AR	Polygon	Bounding Area – Detailed Study on FIRM
	FLD_HAZ_AR	Polygon	Seamless 1% and 0.2% floodplains included
	TENPCT_FP	Polygon	Seamless 10% floodplain
Mit_Haz Datasets	S_AOMI_PT	Point	Location of structures where information may refine H&H analysis
	S_AOMI_AR	Polygon	Areas of mitigation that provide targets for future mitigation action
	S_FRAC_AR	Polygon	Census Blocks within HUC8 with loss analysis results
CNMS Dataset	S_Studies_Ln	Line	CNMS validation status for streams included on current FIRMs
	S_UnMapped_Ln	Line	CNMS stream centerlines for streams not currently included on the FIRM
Grids	BLE_WSE1PCT	Raster	Water Surface Elevation Grid – 1% annual chance
	BLE_WSE0_2PCT	Raster	Water Surface Elevation Grid – 0.2% annual chance

	BLE_DEP01PCT	Raster	Flood Depth Grid – 1% annual chance
	BLE_DEP0_2PCT	Raster	Flood Depth Grid – 0.2% annual chance

8. References

FEMA, 2016, *Coordinated Needs Management Strategy (CNMS) Technical Reference – CNMS User's Guide.*

Gotvald, A.J., Barth, N.A., Veilleux, A.G., and Parrett, C., 2012, *Methods for Determining Magnitude and Frequency of Floods in California, Based on Data through Water Year 2006,* U.S. Geological Survey Scientific Investigations Report 2012-5113.

NHD Plus (http://www.horizon-systems.com/nhdplus/

National Elevation Dataset (NED) 1/3 arcsecond (about 10 meter) rasters, downloaded from ftp://rockyftp.cr.usgs.gov/vdelivery/Datasets/Staged/Elevation/13/GridFloat

PRISM (http://www.prism.oregonstate.edu/).

National Land Cover Database 2011 (NLCD, http://www.mrlc.gov/nlcd11_data.php)

Appendix A
BLE Hydrologic and Hydraulic Analysis Process Flowchart

Appendix B
Manning's n Values by NLCD 2011 Land Use Code

Appendix C

Hydraulic and Floodplain Quality Review Questions

Appendix D
Base Level Engineering Database Preparation