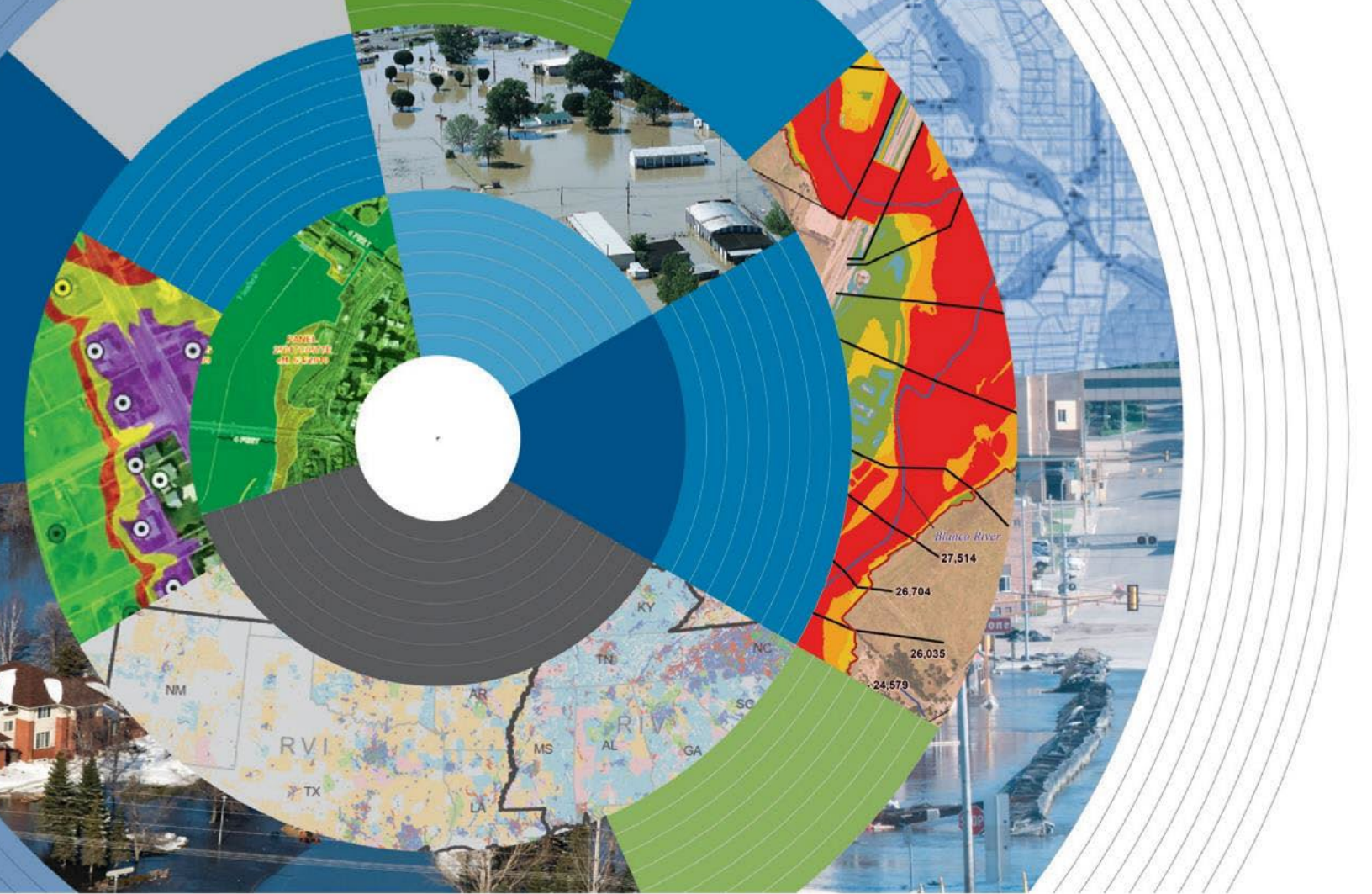




Base Level Engineering Report

Nueces Headwaters (12110101)

CASE NUMBER: 22-06-0047S

Texas Water
Development Board



September 28, 2023

Engineered by Stantec Consulting
Services Inc. - Texas Registered
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1.1	August 2023	Final Deliverable to TWDB (CNMS removed pending completion)	Stantec
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Acronyms

AAL	Average Annualized Loss
AOMI	Area of Mitigation Interest
BFE	Base Flood Elevation
BLE	Base Level Engineering
CN	Curve Number
CNMS	Coordinated Needs Management Strategy
DEM	Digital Elevation Map
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HAZUS	Hazards United States
HC	Hydraulic Connector
HEC	Hydraulic Engineering Center
H&H	Hydrology and Hydraulics
LiDAR	Light Detection and Ranging
NAVD	North American Vertical Datum
NFHL	National Flood Hazard Layer
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
RAS	River Analysis System
SCS	Soil Conservation Service
SFHA	Special Flood Hazard Area
SSURGO	Soils Survey Geographic Database
TNRIS	Texas Natural Resource Information Systems
TWDB	Texas Water Development Board
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSEL	Water Surface Elevation
QA/QC	Quality Assurance/Quality Control

Executive Summary

The Texas Water Development Board's (TWDB) statewide floodplain modeling and mapping project is part of the TWDB's effort to understand and evaluate regional flood risks to drive statewide efforts in the creation of effective flood mitigation strategies in Texas. Stantec Consulting Services Inc. (Stantec) is working with TWDB to develop base level engineering (BLE) floodplain modeling and mapping studies with a multi-year contract that will include two-dimensional (2D) riverine model development, floodplain and flood hazard mapping, and Coordinated Needs Management Strategy (CNMS) data development for FEMA Region 6. This report summarizes the BLE hydrologic and hydraulic (H&H) analyses performed by Stantec for the Nueces Headwaters watershed, as part of Task Order #1 under Contract No. 2101792546. A summary of the study parameters and results for Nueces Headwaters watershed is provided in Table 0-1 and Table 0-2.

Table 0-1: Summary of Stream Miles

Source	Stream Miles
Current Inventory – CNMS (S_Studies_Ln)	597 mi
New Study Streams – CNMS (S_Unmapped_Ln) Informed by NHD 1:100	296 mi
Total (BLE) Stream Miles	893 mi

Table 0-2: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment	Total Miles
VALID	NVUE COMPLIANT	0	0	0
UNKNOWN	DEFERRED, TO BE ASSESSED AND TO BE STUDIED	0	0	0
UNVERIFIED	TO BE STUDIED	597	597	597

TWDB contracted Stantec under Task Order #1 to complete a BLE analysis for six, HUC8-scale watersheds in the Nueces and Frio River Basins, west of San Antonio, in the Edward's Aquifer region:

- Nueces Headwaters - # 12110101
- Upper Nueces - #12110103
- Turkey - #12110104
- Middles Nueces - #12110105
- Upper Frio - #12110106
- Hondo - #12110107

Results of this study affect the counties of Edwards, Kinney, Real, Uvalde, Zavala, Maverick, Medina, Frio, Dimmit, La Salle, McMullen, Webb, Duval and Live Oak. The BLE Analysis under this Task Order was Divided into five tasks covered in this report:

- Task 1 – Terrain Development (Section 2)
- Task 2 – Hydrologic and Hydraulic Analysis (Section 3 and 4)
- Task 3 – Floodplain Mapping (Section 6)

- Task 4 – HAZUS Estimation (Level 2)
- Task 5 – CNMS (Section 7)

1 Introduction and Project Scope

The Texas Water Development Board (TWDB) contracted Stantec under Task Order #1 to complete a Base Level Engineering (BLE) analysis for six, HUC8-scale watersheds in the Nueces and Frio River Basins, west of San Antonio, in the Edward's Aquifer region:

- Nueces Headwaters - # 12110101
- Upper Nueces - #12110103
- Turkey - #12110104
- Middles Nueces - #12110105
- Upper Frio - #12110106
- Hondo - #12110107

Results of this study affect the counties of Edwards, Kinney, Real, Uvalde, Zavala, Maverick, Medina, Frio, Dimmit, La Salle, McMullen, Webb, Duval and Live Oak.

The BLE process involves using best available data and incorporating automated techniques with traditional hydrologic and hydraulic model development procedures to produce regulatory quality flood hazard boundaries for the 1-percent-annual-chance event as well as estimates of flood hazard boundaries for multiple recurrence intervals. The BLE analysis under this Task Order was divided into six tasks, most of which are covered in this report:

- Task 1 – Terrain Development (Section 2)
- Task 2 – Hydrologic and Hydraulic Analysis (Section 3 and 4)
- Task 3 – Floodplain Mapping (Section 6)
- Task 4 – HAZUS Estimation (Level 2)
- Task 5 – CNMS (Section 7)
- Task 6 – Project Management (includes community outreach)

A breakdown of each task is summarized in Table 1-1.

Table 1-1. BLE Task Configuration

Task ID	Task	Task Phase ID	Task Phase
1	Terrain Data Development	1.1	Phase1: Seamless HUC8 DEM
		1.2	Phase2: Streams and sub-watersheds
		1.3	Phase3: Incremental deliverables, report, internal QA/QC
		1.4	Phase4: Independent QA/QC (Respond/Resolve comments only)
2	Hydrology and Hydraulic Analyses	2.1	Phase1: Draft HEC-RAS Model
		2.2	Phase2: Model Adjustments/Calibration
		2.3	Phase3: Multi-frequency Runs

Task ID	Task	Task Phase ID	Task Phase
		2.4	Phase4: Incremental deliverables, report, internal QA/QC
		2.5	Phase5: Independent QA/QC (Respond/Resolve comments only)
3	Floodplain Mapping & Grids	3.1	Phase1: Mapping/Grid products and Geodatabase
		3.2	Phase2: Incremental deliverables, report, internal QA/QC
		3.3	Phase3: Independent QA/QC (Respond/Resolve comments only)
4	Hazus Estimation (Level2)	4.1	Phase1: Loss Estimation and Geodatabase
		4.2	Phase2: Incremental deliverables, report, internal QA/QC
		4.3	Phase3: Independent QA/QC (Respond/Resolve comments only)
5	CNMS	5.1	Phase1: Round1 CNMS
		5.2	Phase2: Independent QA/QC (Respond/Resolve comments only)
		5.3	Phase3: Round2 CNMS
		5.4	Phase4: Independent QA/QC (Respond/Resolve comments only)
6	Project Management	6.1	Project Kickoff & Community Outreach
		6.2	TWDB Coordination/Invoicing/Reporting
		6.3	FEMA/USGS Coordination and Project Closeout

The BLE results from this study may be used for eventual production of regulatory and non-regulatory products. This report describes the BLE analysis performed for Nueces Headwaters watershed (Figure 1-1) which includes coverage of portions of Edwards, Real, and Uvalde counties.

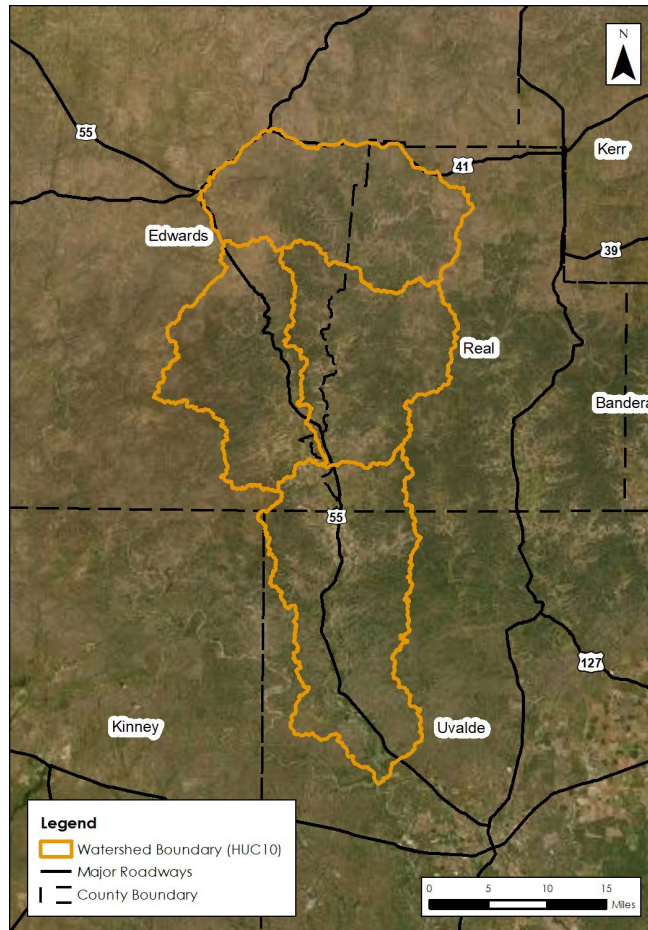


Figure 1-1. Nueces Headwaters (12110101)– HUC10 Basins

The Base Level Engineering assessment for the Nueces Headwaters watershed prepared cursory engineering analysis for approximately 844 miles of stream reaches with a minimum drainage area tolerance of one square mile; the stream selection was not based number of effective Zone A stream miles. The following sections will summarize the BLE process and will discuss the results along with their recommended use.

2 Topographic and Watershed Data

2.1 Terrain Data Development

The primary data source for Nueces Headwaters Watershed was the Lower Colorado San Bernard Lidar project (2018) obtained from the Texas Natural Resource Information System (TNRIS). The individual Digital Elevation Model (DEM) tiles from the data source(s) were used to create one seamless DEM mosaic for the Nueces Headwaters Watershed. This HUC8 watershed was entirely covered by one data source.

The final seamless DEM was developed by cataloging the tiles and then mosaicking them into one DEM while maintaining UTM Zone 14 meters NAVD88 meters and raster cell size 1 meter by 1 meter; this was done for each individual data source applicable to the project watershed. The full DEM was then projected into the NAD83 Texas South Central FIPS 4204 (US Foot) horizontal projected coordinate system and clipped to a buffer (minimum of 500 feet.) based on the NHD HUC8 boundary. The raster elevation values from the clipped output were converted from meters to feet.

Table 2-1: LiDAR Data Sources

LiDAR Collection Name	County ¹	Age/Year	Accuracy ²	Source & Contact	Approximate Footprint (Sq Mi) ³
Lower Colorado San Bernard 2018	Edwards, Kinney, Real, and Uvalde	02/2018 – 04/2018	Horizontal: +/- 42.8cm at 95% confidence level Vertical: NVA: 4.5cm RMSEz NVA (DEM): 4.9cm RMSEz VVA (DEM): 17cm 95 th Percentile	Texas Natural Resources Information System (TNRIS)	17,942

¹Counties listed are only those applicable to current project watershed.

²Accuracy derived from original Lidar project report.

³Area reported reflects coverage of entire lidar project beyond the current project watershed.

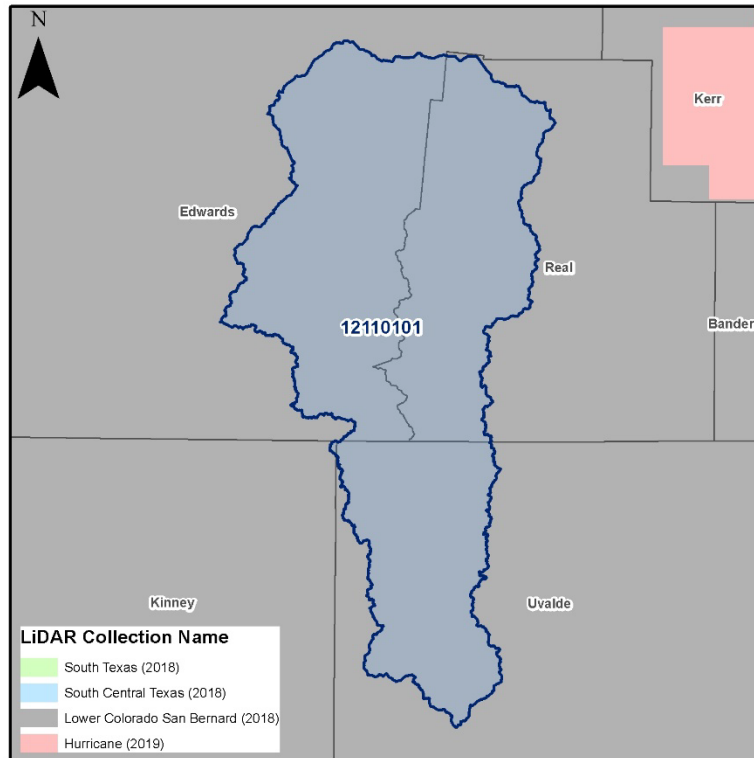


Figure 2-1. Extent and coverage of LiDAR Data as it relates to the project watershed.

2.2 Final Seamless DEM

The final DEM covers the project watershed, has been re-projected into the local State Plane (NAD83) horizontal coordinate system, and has raster elevation values adjusted from meters to feet.

Projection: NAD83 Texas South Central FIPS 4204 (US Foot)

Linear: US Feet

Horizontal Datum: NAD83

Vertical Datum: NAVD88

Vertical Units: US Survey Feet

Raster Information:

Pixel Depth: 32 bit

Number of Bands: 1

Cell Size: 3.28083333, 3.2808333 (feet)

Format: TIFF

2.3 Watershed Data Development

The primary data source for this phase was the seamless DEM described in the previous section. The seamless DEM was the basis for subsequent processing using the Arc Hydro toolset. The Arc Hydro processing steps outlined below create output that creates the Arc Hydro data model for this watershed.

1. Fill Sinks
2. Flow Direction
3. Flow Accumulation
4. Stream Definition (1 square mile threshold used)
5. Stream Segmentation
6. Catchment Grid Delineation
7. Catchment Polygon Processing
8. Drainage Line Processing
9. Adjoint Catchment Processing

2.4 Final Arc Hydro Data Model

The final watershed data is composed of an Arc Hydro data model and hydrography data. The Arc Hydro data model contains vector, raster, and tabular data outputs from Arc Hydro processing tools. The hydrography data contains streams that represent a drainage area of at least 1 square mile, updated HUC8 watershed boundary, and a comparison between the NHD HUC8 watershed boundary and the projection watershed delineation.

2.4.1 Arc Hydro Data Model (Geodatabase and Rasters)

- Geodatabase (.gdb)
 - ArcHydro (feature dataset)
 - Adjoint Catchment – An adjoint catchment is the total upstream area (if any) draining into a single catchment.
 - Catchment – Polygon feature class out of the catchment grid.
 - DrainageLine – Streamline line feature class derived from stream link grid.
 - APUNIQUEID – A table created and managed through Arc Hydro tools; contains the last hydro identifier assigned to a new feature within the geodatabase.
- Rasters (.tif)
 - Catchment Grid (Cat) – Drainage areas for segments in the stream link grid or sinks in the sink link grid.
 - Flow Accumulation Grid (Fac) – Created from the flow direction grid; each cell value represents the total quantity of upstream cells draining to that cell.
 - Flow Direction Grid (Fdr) – Represents the direction of flow from a given cell; 8 different directional values are possible based on the eight-direction (D8) flow model.
 - Fill Sinks Grid (Fil) – Gridded DEM with sinks or depressions removed.
 - Stream Grid (Str) – A stream grid with cells from a flow accumulation grid that exceed a user defined cell count and/or area threshold.
 - Stream Link Grid (StrLnk) – A stream grid with unique values for every link between two stream junctions.

2.4.2 Hydrography Data (Geodatabase)

- Drainage Lines – Drainage lines from the Arc Hydro data modeling within the study HUC8.
- Watershed – A watershed delineation developed through Arc Hydro and based on the elevations within the Seamless DEM created in Task 1 Phase 1.
- Watershed Comparison – A comparison of the watershed feature and the NHD WBD HUC8 boundary

3 Hydrology

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) Version 6.2 has the capability to utilize spatially varying precipitation, improving the hydrologic representation of the study area. Gridded precipitation data from NOAA Atlas 14 were added to HEC-RAS model using the Unsteady Flow Boundary Conditions editor, from the Meteorological Data tab. The gridded precipitation data was temporally distributed using the NOAA Atlas 14 Volume 11, Region 2, 1st quartile, 50% event hyetographs (Figure 3-1) to create 6-minute, 24-hour duration time series of gridded precipitation (Figure 3-2). Rasters of these hyetographs were generated on a HUC-8 level and converted to DSS files for import into HEC-RAS.

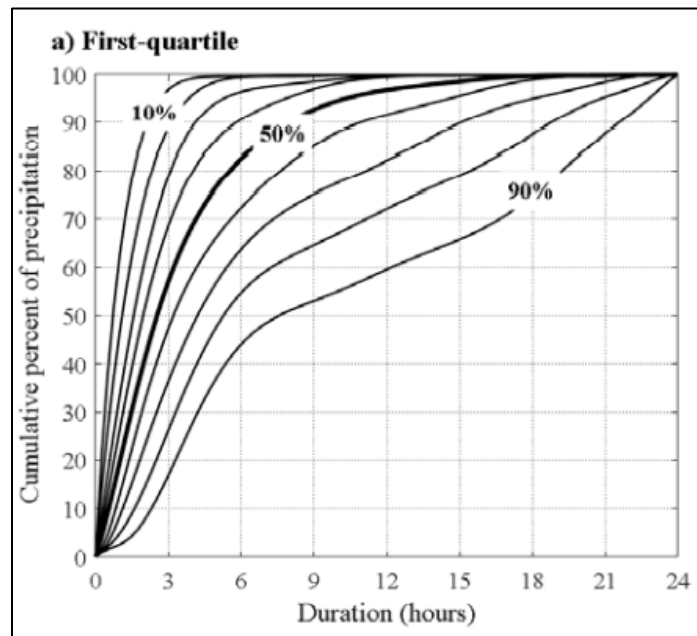


Figure 3-1: Example of temporal distribution curves for first-quartile events with 24-hour duration. Taken from NOAA Atlas 14 Volume 11. Accessed 12/13/2021.

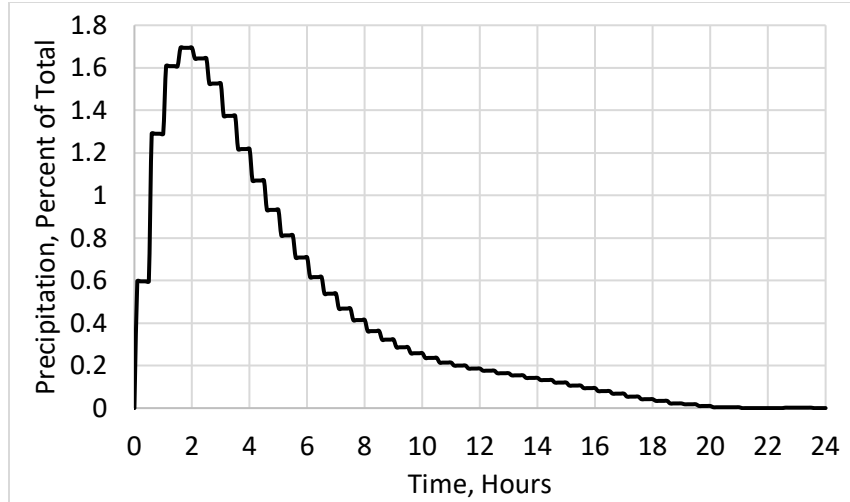


Figure 3-2: Incremental unit hyetograph used to create timeseries of precipitation rasters.

3.1 Precipitation-Frequency Estimates

Precipitation-frequency estimates for this study were obtained from NOAA Atlas 14 in Geographic Information system (GIS) compatible format (NOAA 2017). Specifically, precipitation depths for 10-year, 25-year, 50-year, 100-year, 500-year, 100-year plus and 100-year minus recurrence intervals were used for this study. These data are provided as 1/12-degree spatial-resolution raster data clipped to the state of Texas boundary and were subsequently cropped to cover the extent of the Nueces Headwaters watershed. The 1%-plus and 1%-minus storm events are not directly provided by Atlas 14 but were calculated using Atlas 14-provided the 90% confidence interval around the baseline 1% event. The plus and minus events represent the 68% confidence interval, and assuming a normal distribution, can be calculated as follows:

$$\hat{\sigma} = \frac{X_{95} - X_{05}}{Z_{95} - Z_{05}} \quad (1)$$

$$CI_{68} = (X - \hat{\sigma}, X + \hat{\sigma}) \quad (2)$$

In equation 1, $\hat{\sigma}$ represents the standard deviation of an assumed normal distribution around the NOAA Atlas 14 frequency estimates; X_{95} and X_{05} represent the upper and lower estimates of the 90% confidence interval, respectively; and Z_{95} and Z_{05} represent the corresponding z-scores of the upper and lower estimates, respectively (i.e., $Z_{95} = 1.645$; $Z_{05} = -1.645$). In equation 2, the 68% confidence interval is approximated by applying one standard deviation above and below the baseline 1-in-100 (1%) annual-chance event. Figure 3-3 shows a map of the baseline 1-in-100 (1%) annual-chance event rainfall totals for Nueces Headwaters watershed.

The NOAA Atlas 14 precipitation-frequency grids only provide total depth. To utilize the grids within HEC-RAS, they must be temporally disaggregated across the provided events duration. To accomplish this, the NOAA Atlas 14 Volume 11, Region 2, 1st quartile 50% event distribution was applied at each grid cell for the duration of the event to create a 6-minute event time series (Figure 3-32). The first quartile event shape was selected because it represents the shape of 49% of historical events for Region 2 (Table 3-1, Figure 3-3). The 50% event represents the median temporal distribution for all first quartile events, meaning that 50% of the analyzed events had either more intense or less intense distributions (Figure

3-3). The 50% event was selected as a balanced option, not too conservative but also not erroneously overestimating the floodplain, which is the most representative of historical storms for this region. The use of spatially varying precipitation was used to capture the heterogeneity of event magnitude across an individual HUC08 (Figure 3-4). Accurately representing this spatial variability will ultimately provide a more accurate product.

An aerial reduction factor was not applied to this HUC8 study for Nueces Headwaters watershed. Rather, the spatial rainfall grid as detailed above, was applied to the terrain grid and the focus was placed on calibration to individual gages.

An overview of the precipitation dataset development can be found in Appendix B – Supplemental Hydrology Data.

Table 3-1: Total number of precipitation cases and number (and Percent) of cases in each Atlas 14 Quartile for Selected Durations for Interior Highlands (1), Central Plains (2), and Gulf Coast (3) regions.

Duration	Region	All Cases	1 st Quartile Cases	2 nd Quartile Cases	3 rd Quartile Cases	4 th Quartile Cases
6-hour	1	1,530	916 (60%)	353 (23%)	174 (11%)	87 (6%)
	2	6,206	2,574 (41%)	2,002 (32%)	1,073 (17%)	557 (9%)
	3	2,331	735 (32%)	806 (35%)	525 (23%)	265 (11%)
12-hour	1	1,559	983 (63%)	277 (18%)	190 (12%)	109 (7%)
	2	6,318	3,124 (49%)	1,570 (25%)	1,029 (16%)	595 (9%)
	3	2,306	883 (38%)	656 (28%)	477 (21%)	290 (13%)
24-hour	1	1,516	892 (59%)	223 (15%)	188 (12%)	213 (14%)
	2	6,153	3,027 (49%)	1,196 (19%)	1,099 (18%)	831 (14%)
	3	2,243	866 (39%)	507 (23%)	472 (21%)	398 (18%)
96-hour	1	1,409	656 (47%)	290 (21%)	262 (19%)	201 (14%)
	2	5,886	2,753 (47%)	1,283 (22 %)	1,001 (17%)	849 (14%)
	3	2,093	894 (43%)	443 (21%)	399 (19%)	357 (17%)

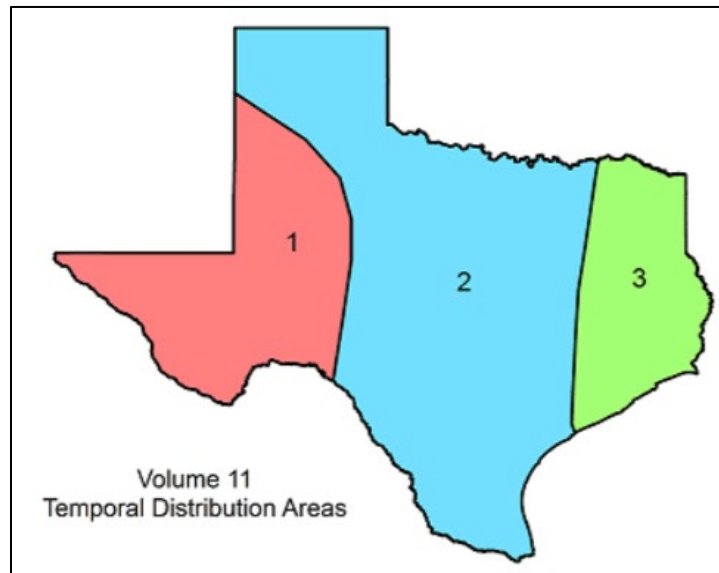


Figure 3-3: NOAA Atlas 14 Volume 11 – Texas Temporal Distribution Areas: Interior Highlands (1), Central Plains (2), and Gulf Coast (3) regions.

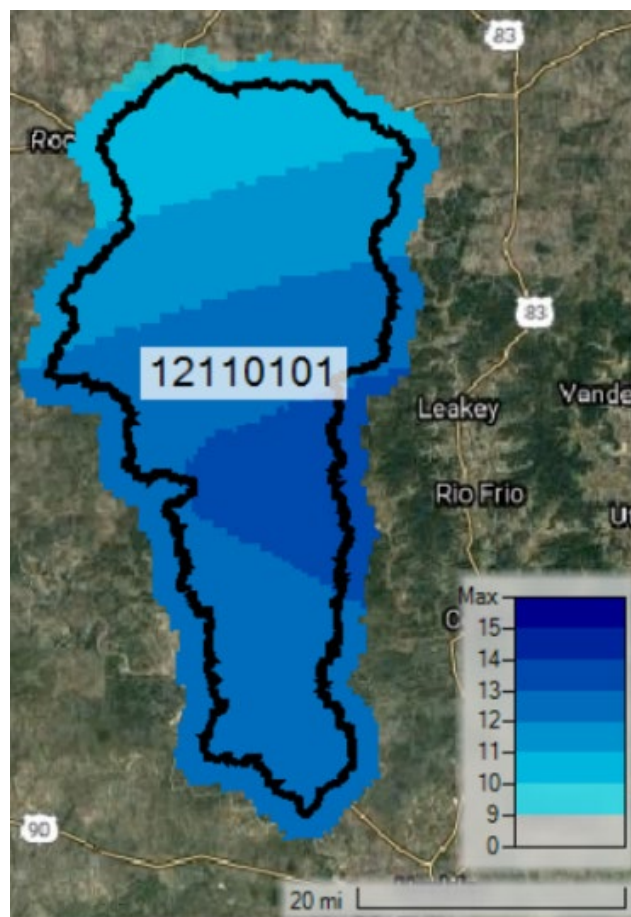


Figure 3-4. Total precipitation (inches) for baseline 1% event across HUC8 Nueces Headwaters watershed

3.2 Infiltration Parameters

The infiltration layer containing attributes for Soil Conservation Survey (SCS; now the Natural Resources Conservation Survey (NRCS)) curve numbers (CN), abstraction ratio, and minimum infiltration rate (Table 3-2) was developed in ArcGIS using the National Land Cover Database (NLCD) and NRCS soil data from the USGS Soils Survey Geographic Database (SSURGO) (SSURGO 2020; MRCL 2019). The overall technical development process for the base CN data is described in a process flow chart included in Appendix B – Supplemental Hydrology Data.

Table 3-2. SCS Hydrologic Soil Groups and Infiltration Parameters (Source: USACE 2021)

Hydrologic Soil Group	Range of Loss Rates (in./hour) (SCS 1986)	Base Model Loss Rates (in./hour) *
A – deep sand, deep loess, aggregated silts	0.30 – 0.45	0.30
B – shallow loess, sandy lam	0.15 – 0.30	0.23
C – clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay	0.05 – 0.15	0.10
D – Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00 – 0.05	0.05

*Base minimum infiltration rate chosen based on engineering judgement per regional experience

A land-use – soils – CN table (Table 3-3) was used to determine initial CN values for the study area. The selected CN values agree with CN ranges presented in *USDA Urban Hydrology for Small Watersheds* (TR-55) and tend toward the higher end of the established ranges for hydrologic conditions (“Poor, Fair, Good”). The higher CN values were chosen and applied in this study because this generally resulted in less parameter adjustment when validating models to USGS gage flows.

The CN matrix was applied in conjunction with an initial loss rate (Table 3-2) and initial abstraction ratio to create a base infiltration layer processed in each hydraulic model. Initial abstraction for the base layer was set to an abstraction ratio of 0.2 based on HEC-RAS 2D user’s manual (USACE 2021). The base infiltration layer was processed in HEC-RAS RASMapper to create a spatially distributed raster dataset of the infiltration parameters.

Further validation adjustment of base infiltration parameters (CN, abstraction ratio, loss rate) occurred on a per-model basis depending on available historical flow data at USGS gage stations and is discussed in Section 4.6.

Table 3-3. Land use -Soils -CN Matrix for Computing Initial Curve Numbers

LU_GridCode	NLCD LU Description	Hydrologic Soil Group				TR-55 Land Use Cover Type
		A	B	C	D	
11	Open Water	100	100	100	100	-
21	Developed Open Space	49	69	79	84	Open Space – Fair Condition (grass cover 50 – 75%)

LU_GridCode	NLCD LU Description	Hydrologic Soil Group				TR-55 Land Use Cover Type
		A	B	C	D	
22	Developed Low Intensity	77	86	91	94	<i>Newly graded areas</i>
23	Developed Medium Intensity	89	92	94	95	<i>Urban Districts – commercial and business</i>
24	Developed High Intensity	98	98	98	98	<i>Impervious areas: paved</i>
31	Barren Land	77	86	91	94	<i>Fallow – bare soil</i>
41	Deciduous Forest	32*	48	57	63	<i>Oak- aspen – fair hydrologic condition *Woods – grass combination, good hydrologic condition</i>
42	Evergreen Forest	39*	58	73	80	<i>Pinyon – juniper – fair hydrologic condition *Pasture – good hydrologic condition</i>
43	Mixed Forest	46	60	68	74	<i>Woods/ Woods – grass combination – hydrologic condition ranging poor - good</i>
52	Shrub Scrub	49	69	79	84	<i>Pasture, grassland, or range – fair hydrologic condition</i>
71	Herbaceous	64	71	81	89	<i>Herbaceous – fair hydrologic condition</i>
81	Hay Pasture	49	69	79	84	<i>Pasture, grassland, or range – fair hydrologic condition</i>
82	Cultivated Crops	71	80	87	90	<i>Row Crops – poor hydrologic condition</i>
90	Woody Wetlands	88	89	90	91	<i>Within range of impervious cover (wetlands), herbaceous and woods.</i>
95	Emergent Herbaceous Wetlands	89	90	91	92	<i>Within range of impervious cover (wetlands), herbaceous and woods.</i>

*All values derived from tables 2-2a -d in USDA Urban Hydrology for Small Watersheds (TR-55) unless indicated.
Note: values for emergent and woody wetlands are not explicitly defined in TR-55. Values listed are derived from Appendix table 4b in TR-55.*

3.3 Hydrologic Calibration

Hydrologic parameters were revised on a case-to-case basis as a result of hydraulic model comparison of the 1-in-100 (1%) annual-chance comparison to historic USGS gage data on an individual model (HUC10) scale. See section 4.6 for more details.

4 Hydraulics

The hydraulic approach for the Nueces Headwaters watershed's BLE analysis consisted of developing HUC10-scale two-dimensional (2D) hydraulic models with the Hydrologic Engineering Center's River Analysis System (HEC-RAS) program version 6.2. Hydraulic routing was performed with an unsteady-state analysis by applying NOAA Atlas 14 spatially varying rainfall data to the final model mesh, which is comprised of the terrain model (described in section 2.1) and the hydrologic inputs (described in section 3). The models were refined based on USGS historic gages records to simulate predictions of WSEL and inundation extent during the 10%, 4%, 2%, 1%, +1%, -1% and 0.2% annual-chance events.

The Nueces Headwaters watershed consisted of four HUC10 catchments resulting in the creation of four, HUC10-scale models:

- East Prong Nueces River - 1211010101
- Pulliam Creek - 1211010102
- Headwaters Nueces River - 1211010103
- Montell Creek-Nueces River - 1211010104

The HUC10 models were coupled through outflow and inflow boundary conditions for calibration and derivation of a unified floodplain which is described in Section 4.5. Each HUC10 model was developed for consistency applying the same parameters and procedures described in this chapter. Unique variances from these procedures are noted and described in sections 4.2 to 4.4 as applicable to each model.

4.1 2D Computational Mesh and Settings

The base computational mesh for the models in the Nueces Headwaters watershed was developed at a 200ft x 200ft (40,000 ft²) grid cell size. Breaklines and refinement regions were implemented to create higher mesh resolution for channels with contributing area of at least 1 square mile and in areas of significant terrain elevation change, both of which are described in the following section. ESRI's ArchHydro GIS extension was used to develop drainage catchments for the entire HUC8 using the finalized terrain. The HUC10 model perimeters, originally defined by the HUC10 watershed boundaries, were adjusted to reflect the drainage catchments. The total number of mesh elements and average cell size varied per HUC10 model; spatial parameters of each HUC10 model are summarized in Table 4-1.

Table 4-1. HUC10 Mesh Parameters

HUC10 Model Name and Number	Size of Study Area (mi ²)	Number of Mesh Elements (grid cells)	Average cell size (ft ²)
East Prong Nueces River (1211010101)	199.80	167,984	33,637
Pulliam Creek (1211010102)	175.35	149,544	32,651
Headwaters Nueces River (1211010103)	182.84	255,495	31,480

HUC10 Model Name and Number	Size of Study Area (mi ²)	Number of Mesh Elements (grid cells)	Average cell size (ft ²)
Montell Creek-Nueces River (1211010104)	258.67	191,910	31,427s

4.1.1 Model Computational Settings

Models were run using the Diffusion Wave equation set for 2D flow at a 30-second computation interval for each frequency event discussed in this report. Diffusion Wave computational method was selected rather than the Shallow Water equations due to hydraulic structures, such as bridges, culverts and dams, not being modeled in detail as part of this BLE study. The Full Momentum equation is typically selected to better account for energy losses in and around structures (USACE 2021). More information on the application of Diffusion Wave Equations versus the Shallow Water equations can be found in the HEC-RAS version 6.2 2D user's manual.

A 30-second computational timestep was determined from a sensitivity analysis for Courant conditions and model computational time. A time step of 30 seconds was deemed appropriate as it limited Courant numbers to less than 5 in the models tested while maintaining a reasonable run-time for base models. The model computational timestep was adjusted as necessary, based on each frequency simulation, to limit Courant values to approximately 2 for final model simulations. The default 2D flow options were applied for the multi-frequency runs as shown in Figure 4-1.

General | 2D Flow Options | 1D/2D Options | Advanced Time Step Control | 1D Mixed Flow Options

☐ Use Coriolis Effects (not used with Diffusion Wave equation)

Parameter	(Default)	1211010104
1 Theta (0.6-1.0)	1	1
2 Theta Warmup (0.6-1.0)	1	1
3 Water Surface Tolerance [max=0.2](ft)	0.01	0.01
4 Volume Tolerance (ft)	0.01	0.01
5 Maximum Iterations	20	20
6 Equation Set	Diffusion Wave	Diffusion Wave
7 Initial Conditions Time (hrs)	0	0
8 Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1
9 Number of Time Slices (Integer Value)	1	1
10 Turbulence Model	None	None
11 Longitudinal Mixing Coefficient	0.3	0.3
12 Transverse Mixing Coefficient	0.1	0.1
13 Smagorinsky Coefficient	0.05	0.05
14 Boundary Condition Volume Check	☐	☐
15 Latitude for Coriolis (-90 to 90)		
16 Solver Cores	All Available	All Available
17 Matrix Solver	PARDISO (Direct)	PARDISO (Direct)
18 Convergence Tolerance		
19 Minimum Iterations	0	0
20 Maximum Iterations	0	0
21 Restart Iteration	10	10
22 Relaxation Factor	1.3	1.3
23 SOR Preconditioner Iterations	10	10

OK Cancel Defaults ...

Figure 4-1. HEC-RAS Unsteady Computation Options and Tolerances

4.2 Breaklines and Refinement Regions

Breaklines and refinement regions were enforced in the model mesh at half the base cell resolution. Refinement regions for smaller tributaries were enforced at higher resolution (minimum cell size of 50 ft x 50 ft) on a case-by-case basis per engineering judgement. The spatial properties of breaklines and refinement regions for each Nueces Headwaters model are summarized in Table 4-2. The development of these features is described in the following sections.

Table 4-2. Summary of Mesh Refinement Features for Nueces Headwaters

HUC10 Model Name and Number	Breaklines (linear ft)	Total area of Refinement Regions (acres)
East Prong Nueces River (1211010101)	178,062	5,060
Pulliam Creek (1211010102)	142,288	5,806
Headwaters Nueces River (1211010103)	222,530	8,055

HUC10 Model Name and Number	Breaklines (linear ft)	Total area of Refinement Regions (acres)
Montell Creek-Nueces River (1211010104)	180,396	11,331

4.2.1 Breaklines

Breaklines were enforced in the models' computational meshes for state and federal roadways and dams found in the National Inventory of Dams (NID). Additional breaklines were added using engineering judgement after inspection of individual models to better represent areas such as agricultural ponds, dams, embankments, or other changes in elevation found to be hydraulically significant to a model domain. Breaklines were specifically added in the main reach adjacent to urbanized areas, or individual structures, to capture channel bank geometry correctly in the mesh. An overview of the breaklines for the Nueces Headwaters is shown in Figure 4-2.

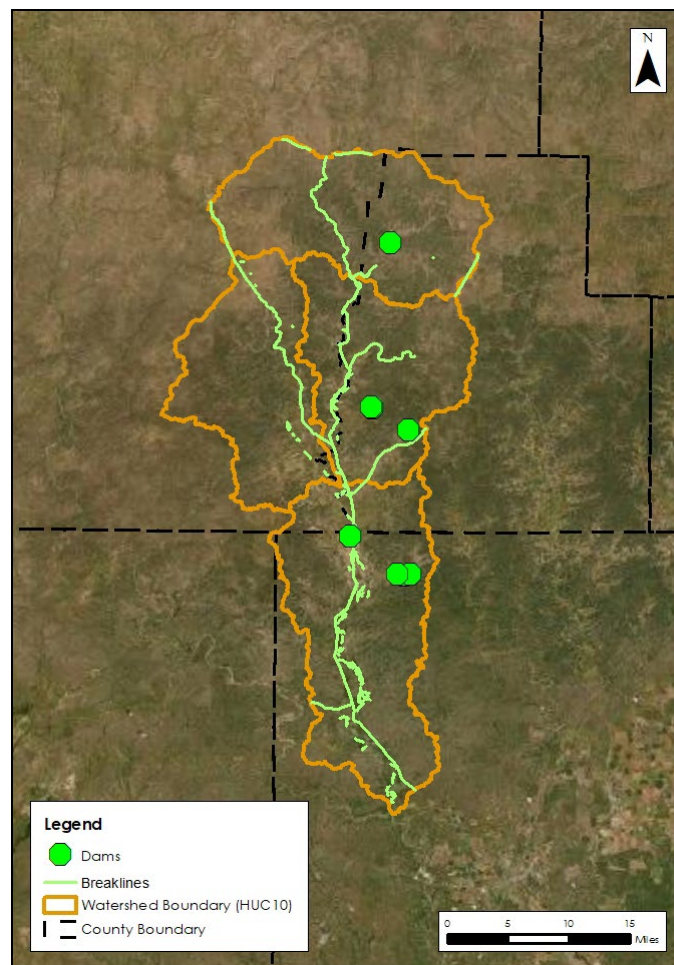


Figure 4-2. Overview of HUC8 Scale Breaklines for Nueces Headwaters

4.2.2 Mesh Refinement Regions

A mesh refinement region was enforced to provide a more detailed drainage pathway in the computational mesh. A refinement region polygon was developed for each model to represent bank full flow (Figure 4-3).

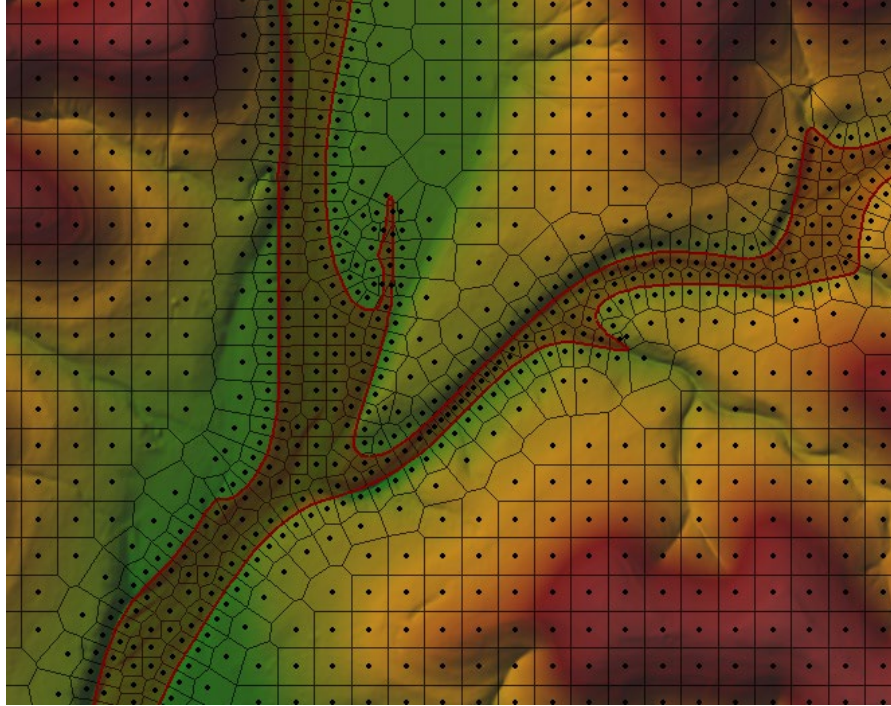


Figure 4-3. Example of Refinement Region Polygon

The polygon was developed by simulating a 2-year NOAA atlas 14 rainfall event in each model using the base 200 ft resolution mesh. The 2-year event was simulated without breaklines, infiltration, or Manning's roughness implemented in the model. The inundation boundary from the 2-year event was exported from RASMapper for post-processing and smoothing in ArcGIS. The processed polygon was then imported into the model geometry as a refinement region in the HEC-RAS geometry with 100 ft near and far cell spacing. An overview of the refinement regions for Nueces Headwaters is shown in Figure 4-4.

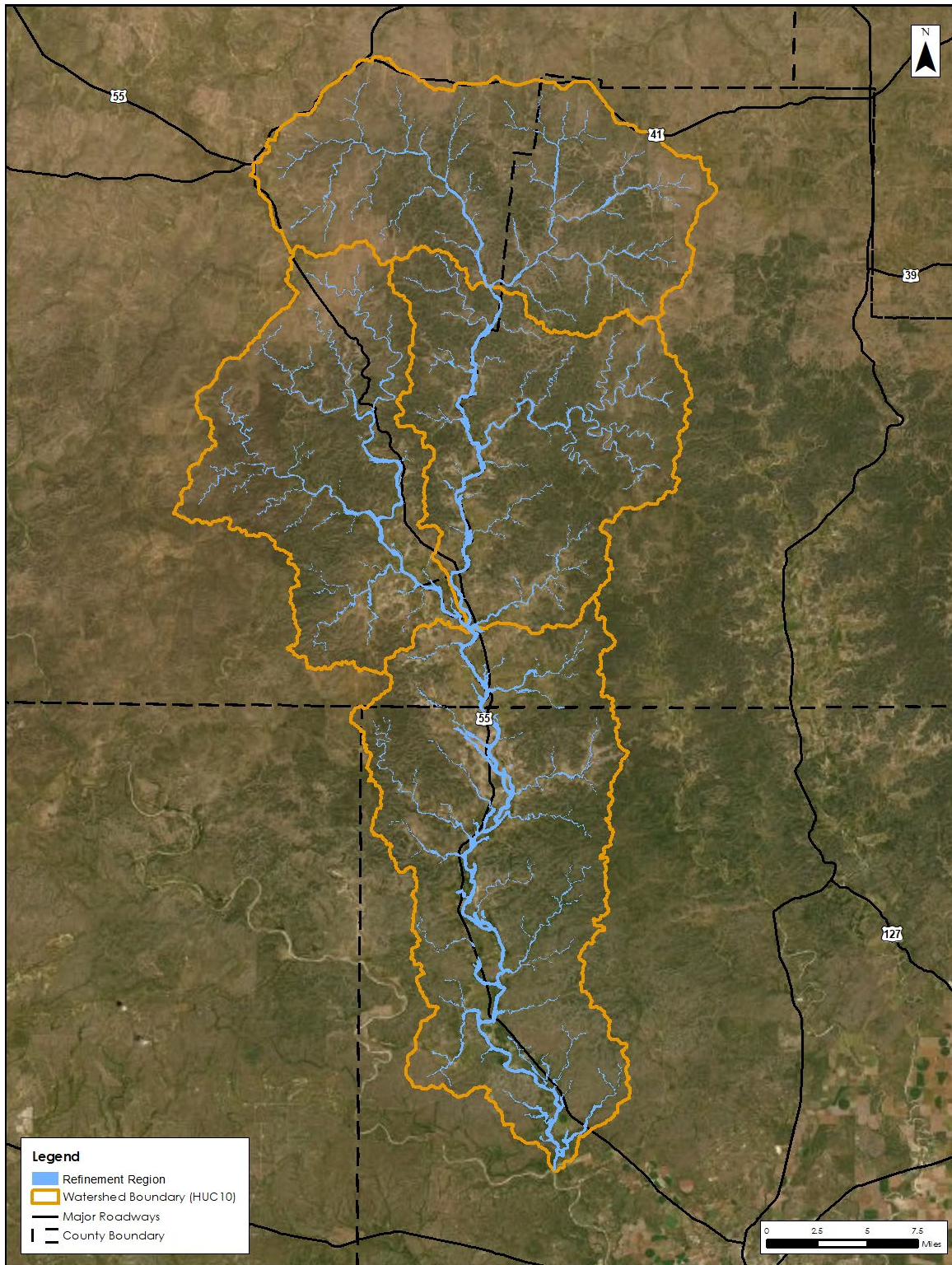


Figure 4-4. Overview of HUC8 Scale Mesh Refinement Regions for Nueces Headwaters

4.3 Manning's n Surface Roughness

The 2019 National Land Cover Database (NLCD) Land Use Classification raster was used to develop the Manning's n roughness coefficients for the study area. Manning's n selected for the Nueces Headwaters watershed are presented in Table 4-3 below. The values selected are within the range of values provided by the Texas Water Development Board's (TWDB) Base Level Engineering Guidelines (May 2022) and the HEC-RAS 2D manual (USACE 2021).

Table 4-3. Manning's N Values

Land Use Classification	TWDB BLE Guidelines (May 2022)	Nueces Headwaters Manning's Values
Open Water	0.025 – 0.050	0.040
Developed, Open Space	0.030 – 0.050	0.040
Developed, Low Intensity	0.080 – 0.120	0.100
Developed, Medium Intensity	0.060 – 0.140	0.080
Developed, High Intensity	0.120 – 0.200	0.150
Barren Land	0.023 – 0.300	0.025
Deciduous Forest	0.100 – 0.160	0.160
Evergreen Forest	0.100 – 0.160	0.160
Mixed Forest	0.100 – 0.160	0.160
Scrub/Shrub	0.070 – 0.160	0.100
Grassland/Herbaceous	0.025 – 0.050	0.035
Pasture/Hay	0.025 – 0.050	0.030
Cultivated Crops	0.025 – 0.050	0.035
Woody Wetlands	0.045 – 0.150	0.120
Emergent Herbaceous Wetland	0.050 – 0.085	0.070
Manning's n override region/channels	0.025 – 0.150	0.055

Manning's n override regions were enforced in the models to represent the channels' high-stage preferential flow paths, spatially corresponding to the channel mesh refinement regions as discussed in Section 4.2.2. Initial Manning's override n values were set based on examination of aerial imagery and engineering judgement. If necessary, channel Manning's values were modified on a per-model basis for calibration, as discussed further in Section 4.6, as applicable.

4.4 Terrain Modifications

Terrain modifications were made through the HEC-RAS layer modifications feature in RASMapper Version 6.2. Direct modifications were not made to the original terrain. A modifications layer was added to each model terrain to apply Hydraulic Connectors (HCs) which allow flow to be conveyed through structures, such as roadway culverts, that the original DEM otherwise impedes. After adding a modifications layer with all final HCs, the terrain was resampled in RASMapper to include the HC drainage pathways (Figure 4-5).

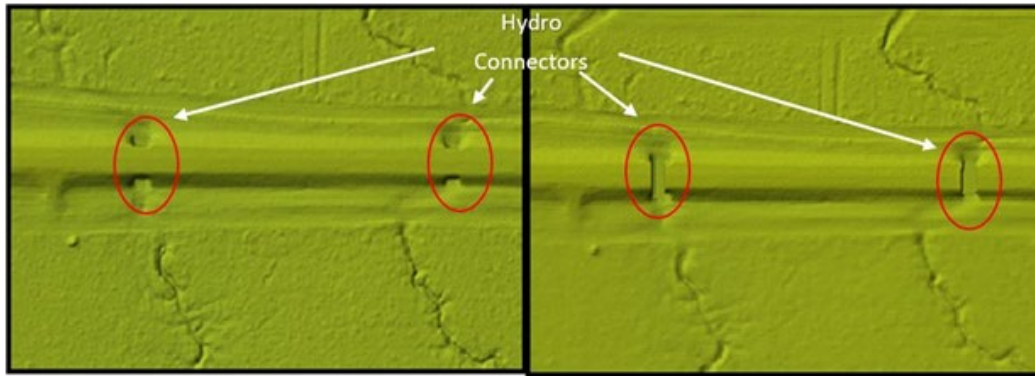


Figure 4-5. Example of localized original terrain (left) and terrain after resampling and addition of modification layer (right)

4.5 HUC10 Level Model Integration

A diagram showing inter-basin connectivity and boundary condition locations for Nueces Headwaters watershed is included in Figure 4-6. There are three locations between these models where flow is transferred to a downstream HUC10 via the main channel, and additional locations where inter-basin transfer occurs via overland sheet flow (ex: a normal depth boundary condition was added at the downstream end of 1211010104 to allow for accumulated water along the model perimeter to spill into 12110103). The HUC10 models were coupled using Storage Area (SA)/2D connectors in the upstream model to transfer flow hydraulics into receiving downstream models in the form of stage or flow inflow hydrograph boundary conditions in the downstream model.

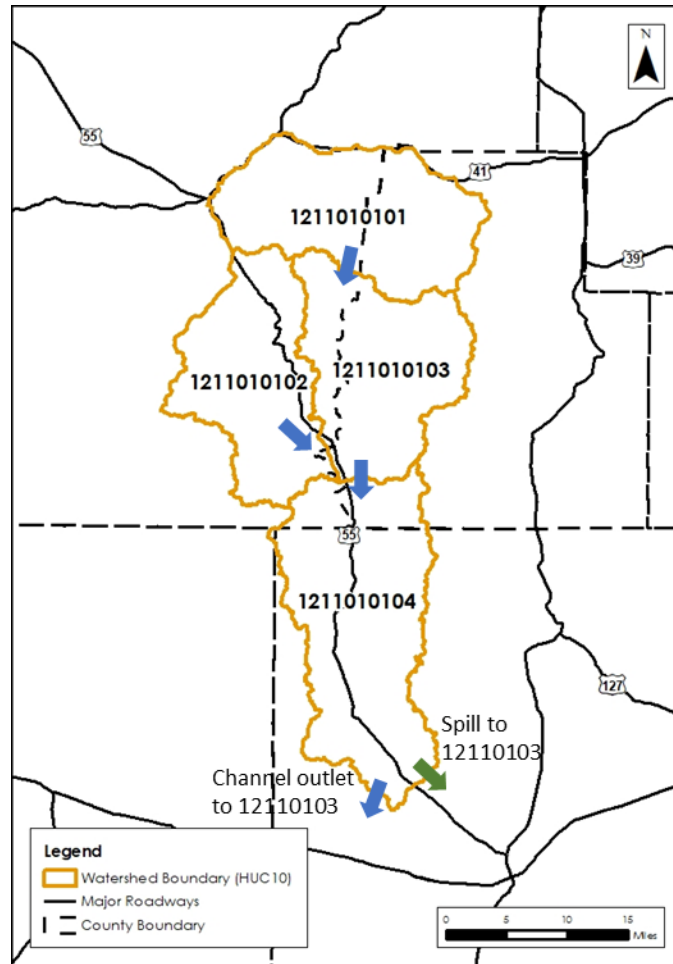


Figure 4-6. Overview of HUC8 with HUC10 Model Connectivity

The SA/2D connectors in the upstream model were placed perpendicular to channel flow a distance upstream of the channel outlet to avoid influence of the downstream normal depth boundary conditions. The upstream SA/2D location was isolated based on a normal depth sensitivity analysis where the placement distance from the downstream boundary condition was determined by the location of channel WSEL convergence for runs of varying normal depth BC values (Figure 4-7).

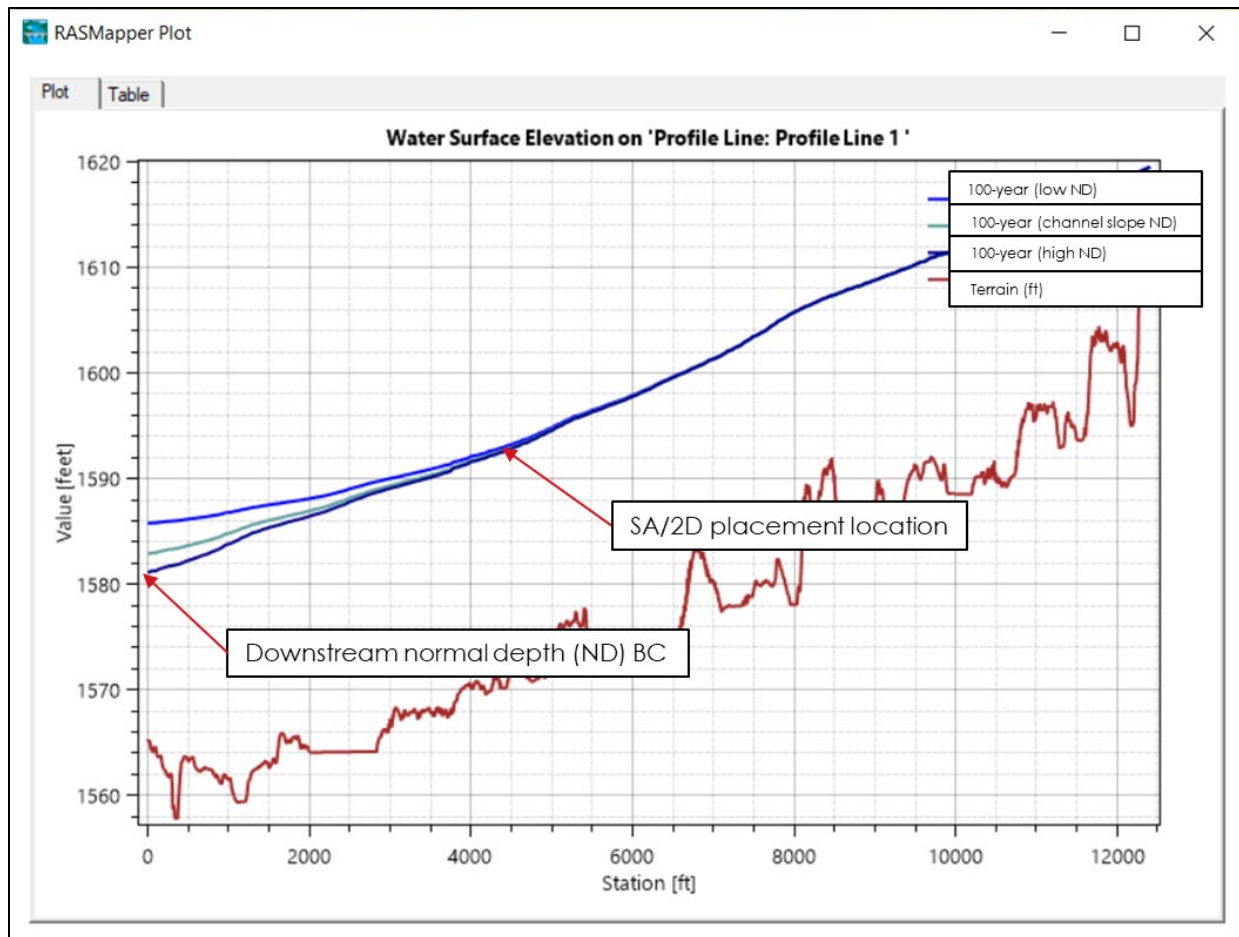


Figure 4-7. SA/2D Normal Depth sensitivity and placement example

The upstream and downstream model meshes were modified from the USGS HUC10 delineation to overlap at the location of the SA/2D connection. To optimize the hydraulic performance of the connection, the SA/2D placement varied per model based on unique features such as terrain slope, channel dimensions, instream flow obstructions (dams, railroad crossings, low water crossings etc.) and normal depth sensitivity. Therefore, model overlap size varied per model and connection location. Final model meshes for the Nueces Headwater watershed models are shown in Figure 4-8. In locations where the models overlap, the downstream model's water surface elevation and flow take precedent and are applied in the mapping products. The downstream model should be referenced for model results downstream of the SA/2D line in the upstream model (which acts as the tie-in between the downstream model) which are consistent with the mapping product.

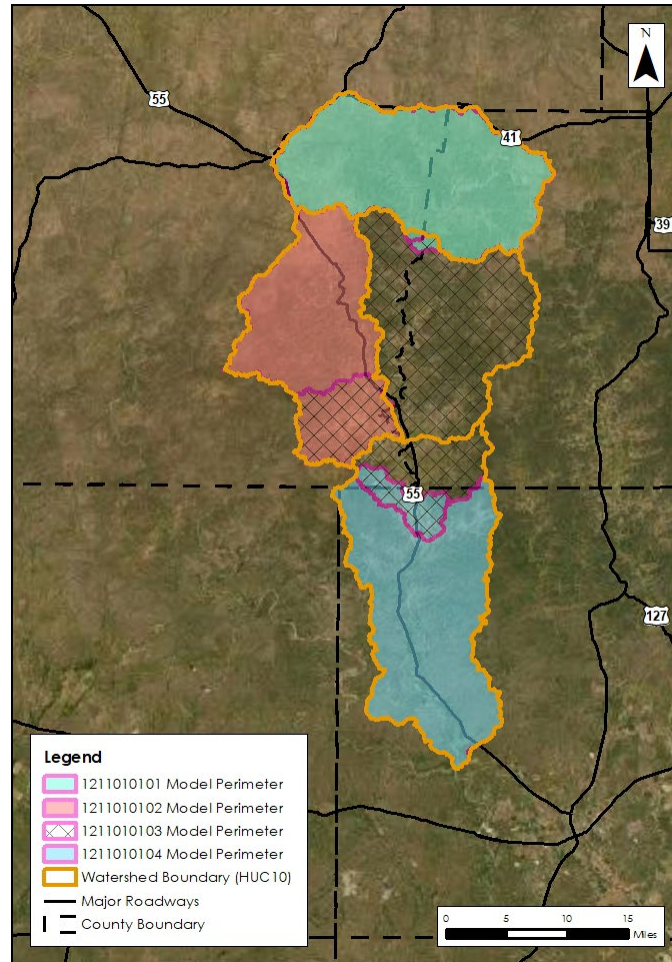


Figure 4-8. Overview of Adjusted Model Domains

The SA/2D connections were evaluated to ensure continuity of both water surface elevation and flow between upstream and downstream models, within 0.5 ft and 5%, respectively, during the 1-in-100 (1%) annual-chance event only. The continuity of water surface elevation and flow was assessed, but not calibrated to, for the other simulated annual-chance events and the corresponding results are included in the following sections. The continuity metrics for the 1% annual-chance event are summarized in

Table 4-4 for Nueces Headwaters models. Application of a stage hydrograph versus a flow hydrograph boundary condition was also evaluated independently for each connection. Flow hydrographs were found to transfer flow with greater accuracy than stage hydrographs in reaches with flat overbank terrain and low channel slope (promoting pooling), reaches with “braided” stream formations and variable terrain elevation across the floodplain cross-section, and reaches with a proximal instream flow obstructions such as an upstream dam. Flow hydrographs were applied to connect the four Nueces Headwaters HUC10 models, and to transfer flow to the downstream HUC8 (Upper Nueces). The flow hydrograph inflows were calibrated by first setting the initial Energy Grade (EG) slope of the boundary condition as the channel slope derived from the terrain, and the EG was revised iteratively to reflect

modeled EG and maintain modeled WSEL continuity between models. The continuity metrics for each model connection are summarized in

Table 4-4 and are described in more detail in the following sections.

Table 4-4. HUC10 Model Integration Summary

Upstream HUC10 Model Name and Number	Downstream HUC10 Model Name and Number	Number of SA/2D Connectors	Distance from SA/2D Connector to DS BC (ft)	100-Year Flow Difference (%)	100-Year Stage Difference (ft)
East Prong Nueces River (1211010101)	Headwaters Nueces River (1211010103)	1 (flow)	6,700	0.0	0.2
Pulliam Creek (1211010102)	Headwaters Nueces River (1211010103)	1 (flow)	32,000	0.0	0.4
Headwaters Nueces River (1211010103)	Montell Creek-Nueces River (1211010104)	1 (flow)	20,550	0.0	0.5
Montell Creek-Nueces River (1211010104)	External Indian Creek-Nueces River ¹ (1211010301)	1 (flow)	13,890	0.0	0.2
		1 (flow)	15,700	0.0	0.4

¹more information on this connection can be found in Upper Nueces BLE report (HUC 8 12110103).

4.5.1 East Prong Nueces River (1211010101) and Headwaters Nueces River (1211010103) Boundary

The downstream boundary of the East Prong Nueces River USGS HUC10 delineation model is near the confluence of two major tributary channels. The initial normal depth sensitivity test concluded that the model mesh should be extended downstream, a significant distance from the confluence, such that a singular SA/2D connector could be used to connect the models. Outflow from the East Prong Nueces River HUC10 model was sufficiently captured by a single SA/2D connector and corresponding flow hydrograph inflow BC for the Headwaters Nueces River HUC10 model. The resulting model meshes and hydraulic continuity results are summarized in Figure 4-9, Figure 4-10, and Table 4-5.

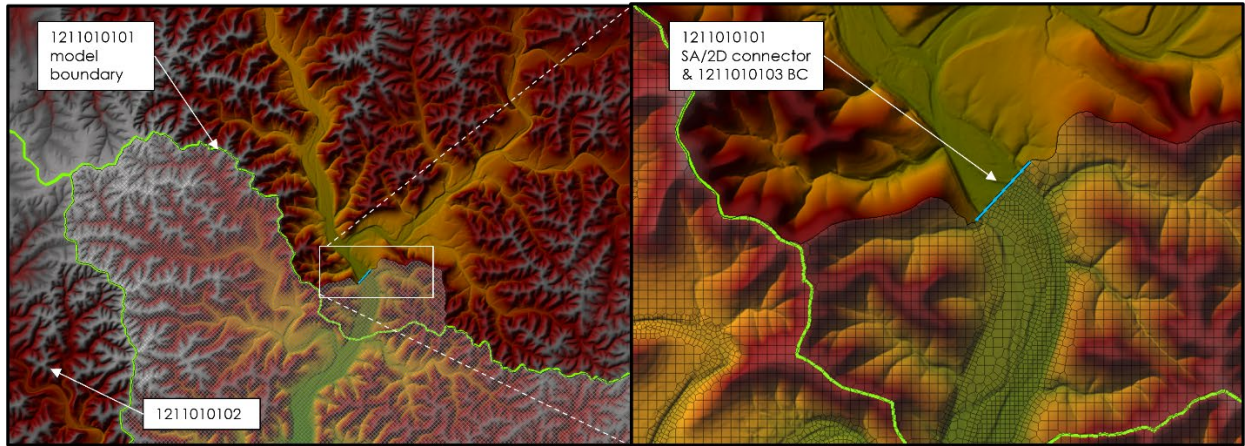


Figure 4-9. 1211010101 and 1211010103 Boundary Plan View

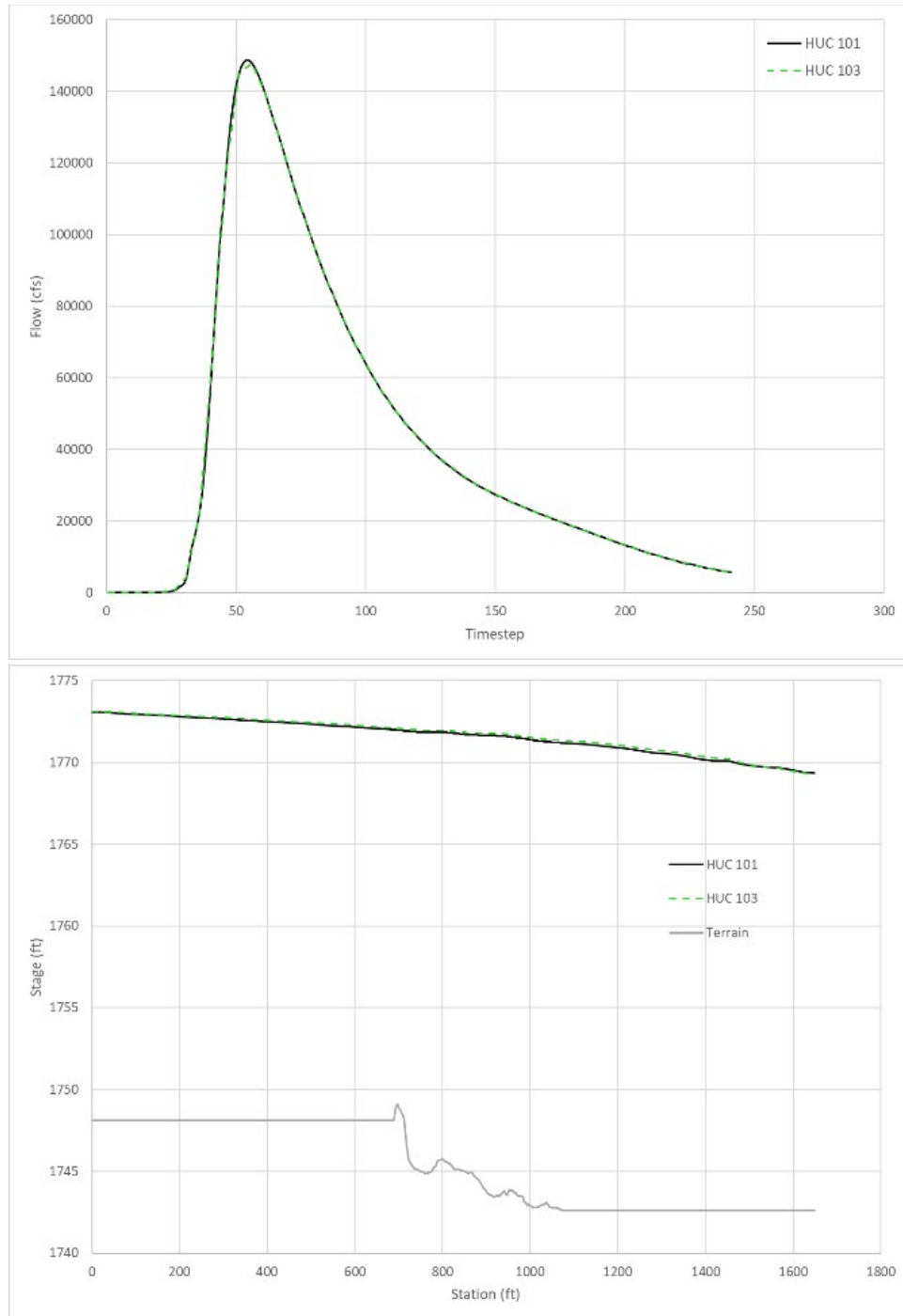


Figure 4-10. 1211010101 and 1211010103 Flow & WSEL Continuity

Table 4-5. 1211010101 and 1211010103 Continuity – all modeled events

Annual-chance Event	HUC101 (Upstream)		HUC103 (Downstream)		Absolute Difference	
	Max WSEL (ft)	Peak Flow (cfs)	Max WSEL (ft)	Peak Flow (cfs)	Max WSEL (ft)	Peak Flow (cfs)
10YR	1766.4	63,360	1766.2	63,360	0.2	0
25YR	1769.3	93,830	1769.1	93,830	0.2	0
50YR	1771.5	120,875	1771.3	120,875	0.2	0
100YR	1773.7	153,550	1773.5	153,551	0.2	0
500YR	1779.2	251,972	1779.0	251,972	0.3	0
100YR-	1770.6	109,855	1770.4	109,855	0.2	0
100YR+	1776.6	200,829	1776.4	200,829	0.2	0

4.5.2 Pulliam Creek (1211010102) and Headwaters Nueces River (1211010103) Boundary

The Pulliam Creek HUC10 area is comprised of steep hills in the upstream portion turning into a flat terrain in the downstream portion of the system. The main reach in the downstream portion of the watershed has substantial pooling due to lack of slope and flat overbanks, making it difficult to connect the models with a single SA/2D connection. The SA/2D connection was placed midway through the HUC10 just before transition to flat terrain, where the channel was well-defined and allowed for placement of a single connection for flow transfer (Figure 4-11). A flow hydrograph inflow BC was used to transfer the flow at this location from the Pulliam Creek model to the southwest portion of the Headwaters Nueces River model; the continuity between the two models is exemplified in Figure 4-11, Figure 4-12 and summarized in Table 4-6.

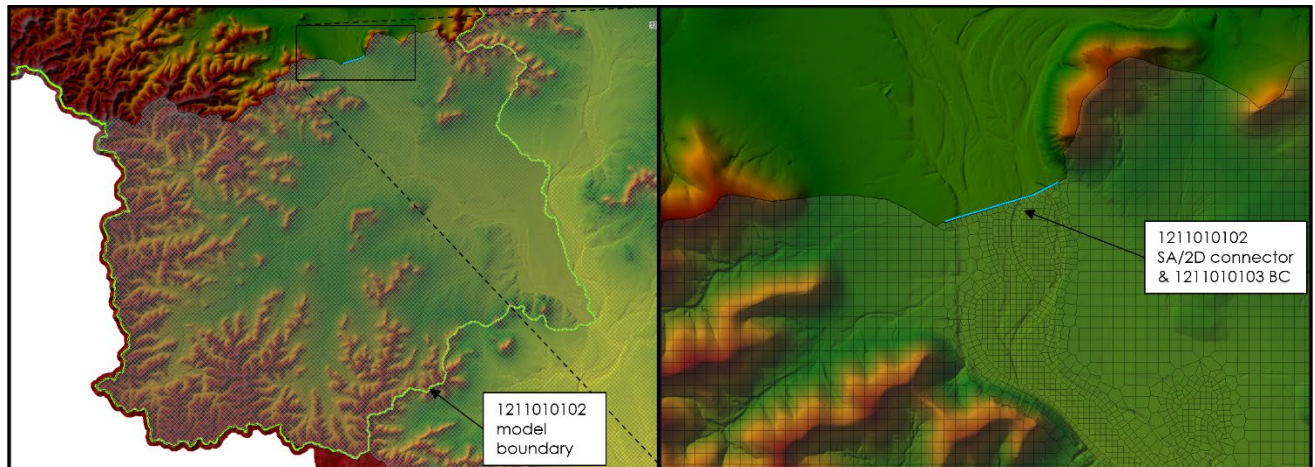


Figure 4-11. 1211010102 and 1211010103 Boundary Plan View

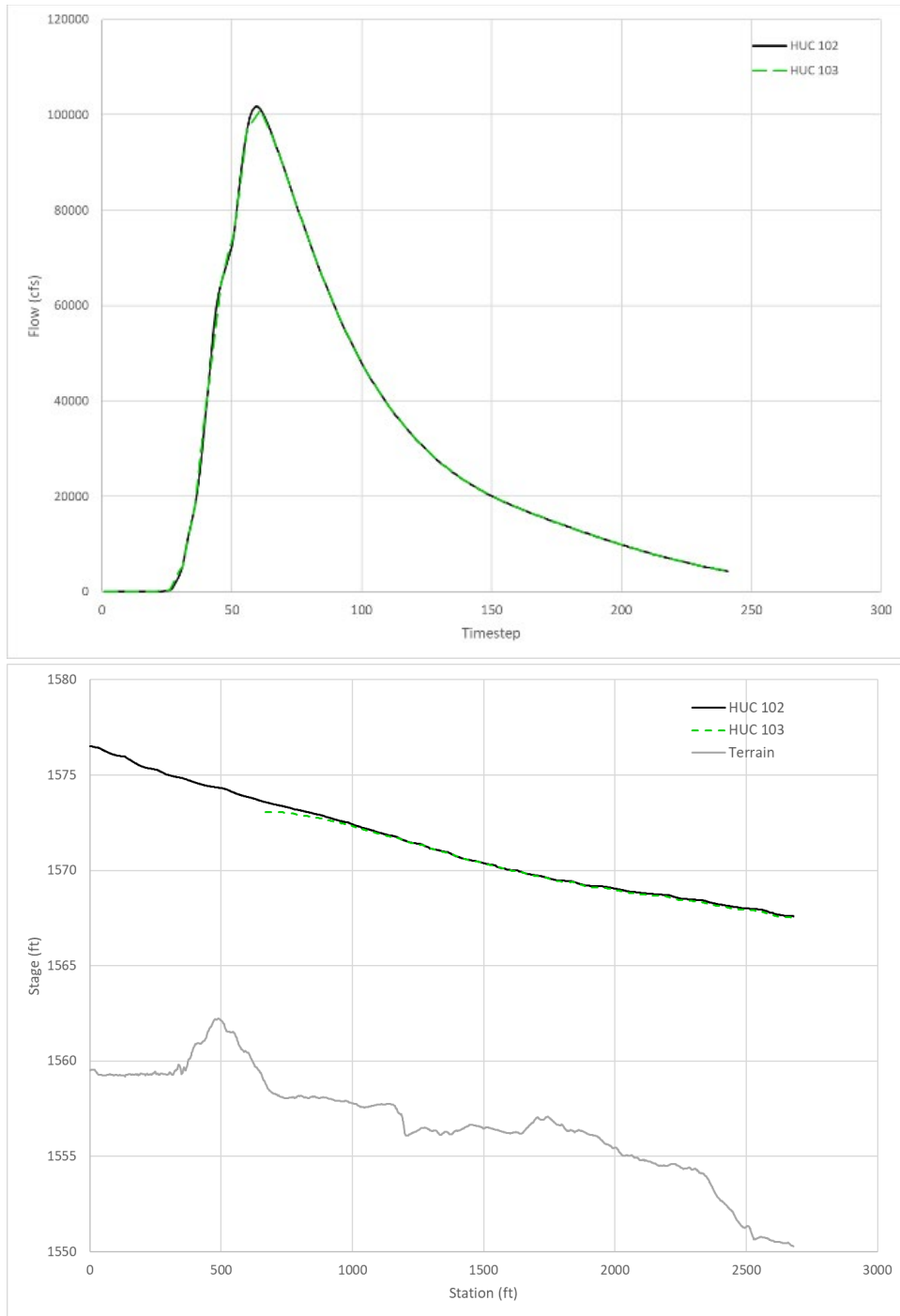


Figure 4-12. 1211010102 and 1211010103 Flow & WSEL Continuity

Table 4-6. 1211010102 and 1211010103 Continuity – all modeled events

Annual-chance Event	HUC102 (Upstream)		HUC103 (Downstream)		Absolute Difference	
	Max WSEL (ft)	Peak Flow (Cfs)	Max WSEL (ft)	Peak Flow (Cfs)	Max WSEL (ft)	Peak Flow (Cfs)
10YR	1,569.5	39,220	1,569.26	39,220	0.2	0
25YR	1,571.1	59,737	1,570.85	59,737	0.2	0
50YR	1,572.4	78,693	1,572.12	78,693	0.2	0
100YR	1,573.9	102,633	1,573.63	102,633	0.3	0
500YR	1,578.1	175,702	1,577.61	175,702	0.5	0
100YR-	1,571.9	72,234	1,571.71	72,234	0.2	0
100YR+	1,575.8	134,131	1,575.41	134,131	0.4	0

4.5.3 Headwaters Nueces River (1211010103) and Montell Creek-Nueces River (1211010104) Boundary

The USGS HUC10 delineation of the Headwaters Nueces River model was extended downstream to place a single SA/2D connector to transfer flow to the Montell Creek Nueces River model. Similar to the other upstream models, braided flow and a confluence near the original outlet of the HUC10 prevented clean transfer to the downstream model. A flow hydrograph was used as the inflow boundary condition in the Montell Creek-Nueces River model and the continuity results are summarized in Table 4-7 and shown in Figure 4-13 and Figure 4-14.

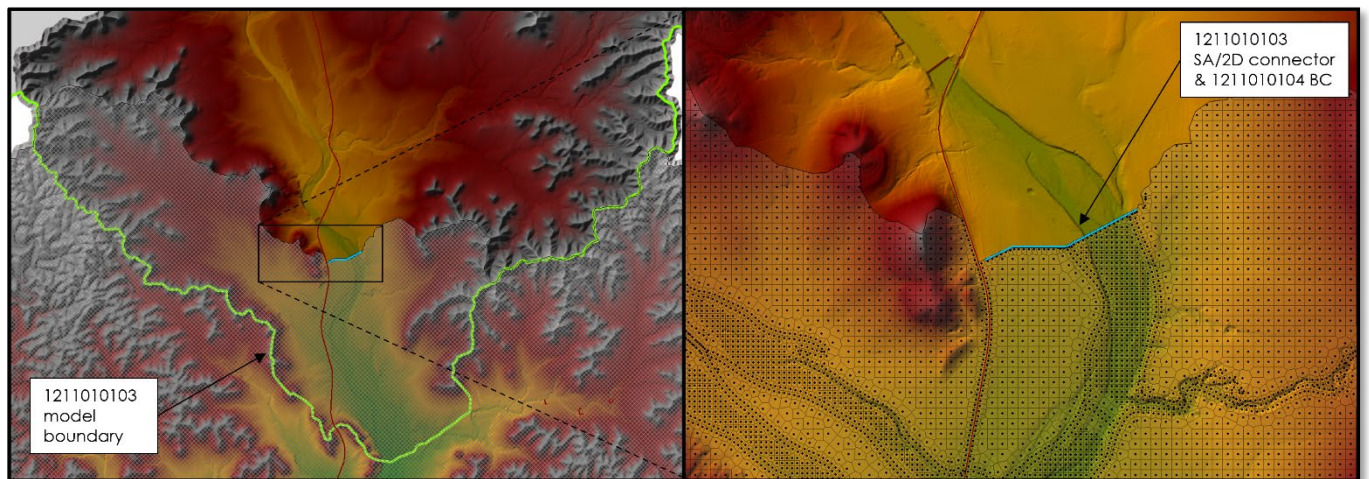


Figure 4-13. 1211010103 and 1211010104 Boundary Plan View

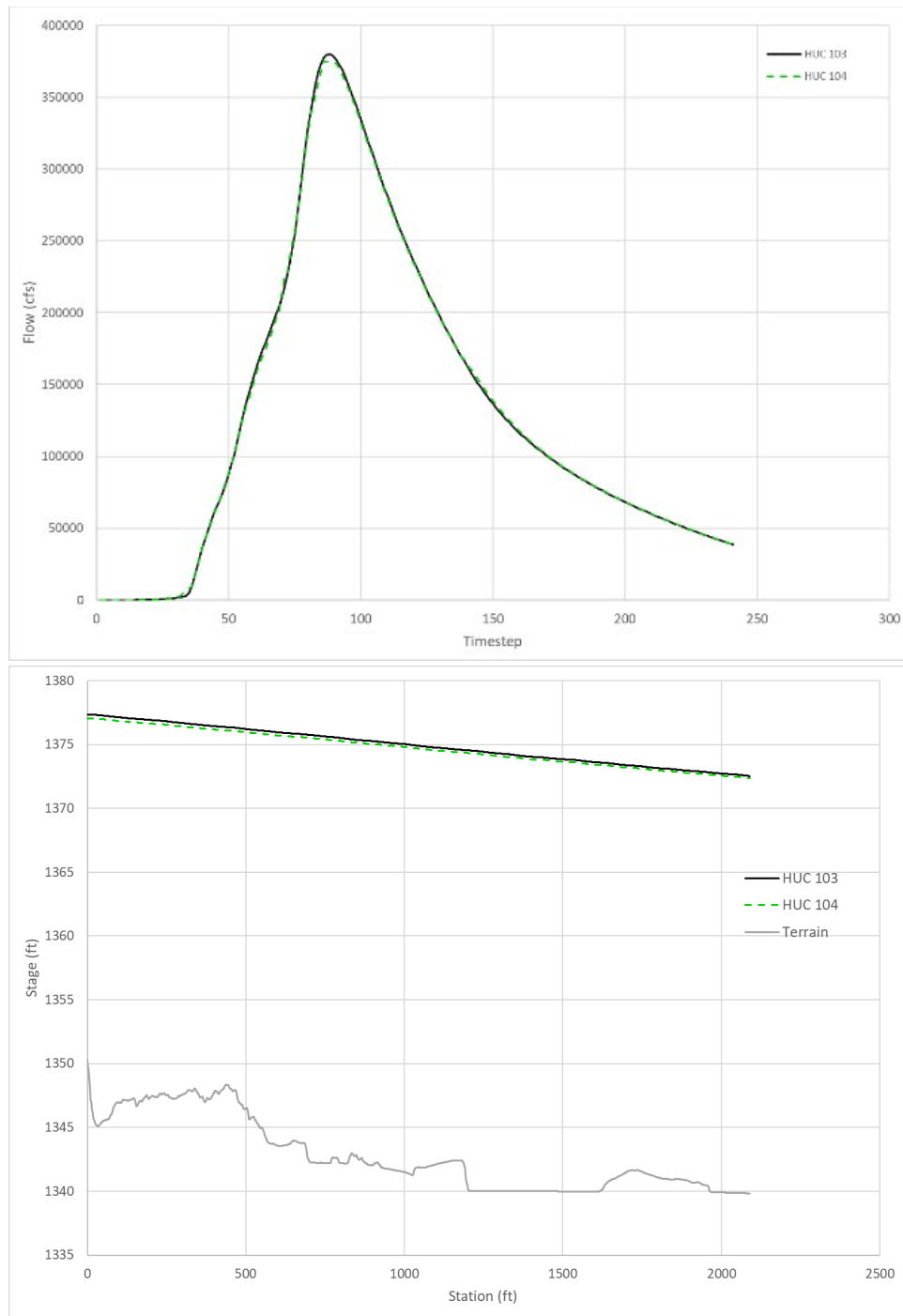


Figure 4-14. 1211010103 and 1211010104 Flow & WSEL Continuity

Table 4-7. 1211010103 and 1211010104 Continuity – all modeled events

Annual-chance Event	HUC103 (Upstream)		HUC104 (Downstream)		Absolute Difference	
	Max WSEL (ft)	Peak Flow (Cfs)	Max WSEL (ft)	Peak Flow (Cfs)	Max WSEL (ft)	Peak Flow (Cfs)
10YR	1,367.1	148,595	1,366.8	148,595	0.3	0
25YR	1,371.2	225,555	1,370.9	225,555	0.3	0
50YR	1,374.1	300,500	1,373.9	300,500	0.3	0
100YR	1,377.1	391,395	1,376.8	391,394	0.3	0
500YR*	1,383.9	663,506	1,383.1	663,507	0.8	0
100YR-	1,373.1	272,499	1,372.8	272,499	0.3	0
100YR+	1,380.5	518,831	1,380.1	518,831	0.4	0

*The 500-year mainstem connection at the SA/2D location was outside of the +/- 0.5 ft WSEL difference metric. The mapping for this interval was tied-in (+/- 0.5 ft) downstream of the SA/2D location within the overlap between model 1211010103 and 1211010104.

4.6 Calibration and Validation

Model parameter adjustment and calibration in the Task Order #1 BLE study was performed for models encompassing USGS gages with a minimum of 10 years of record. Model adjustments were based on estimates of a 1-in-100 (1%) annual-chance median peak flow values from a Bulletin 17C statistical analysis, and not considering hydrograph timing and flow volume. No model adjustments were made based on USGS regional regression estimates, but regression estimates were assessed to contextualize modeled results in watersheds lacking adequate gage records and a brief comparison is included in this section.

HUC8 watersheds in this Task Order coincide with the Edward's Aquifer recharge and contributing zone and the Carrizo-Wilcox Aquifer underlies majority of the Frio, Upper and Middle Nueces HUC8 watersheds (Figure 4-15). Coinciding with the aquifer creates a unique hydrologic rainfall-runoff response and groundwater-surface water interaction that is not reflected in the base CN derivation described in Section 3.2. Therefore, adjustment of infiltration parameters of Task Order #1 models for calibration was highly variable depending on vicinity of the model to the respective aquifers and recharge zones. Adjustment of CN's to reflect additional or enhanced infiltration in the recharge zone of the Edward's Aquifer region is a practice consistent with recent studies in Central Texas near the aquifer (URS 2016). Hydrologic losses due to the Carrizo-Wilcox influence and Karst geography in the Upper and Middle Nueces River HUC8 watersheds are well documented and being quantified by a concurrent InFRM study by USACE.

Initial modeled results for the Nueces Headwater models compared well to the Bulletin 17C gage analysis for the 100-year event and did not indicate the need to adjust infiltration parameters for

potential influence of the Edward's Aquifer. This is discussed in the following paragraphs and exemplified in the final model results.

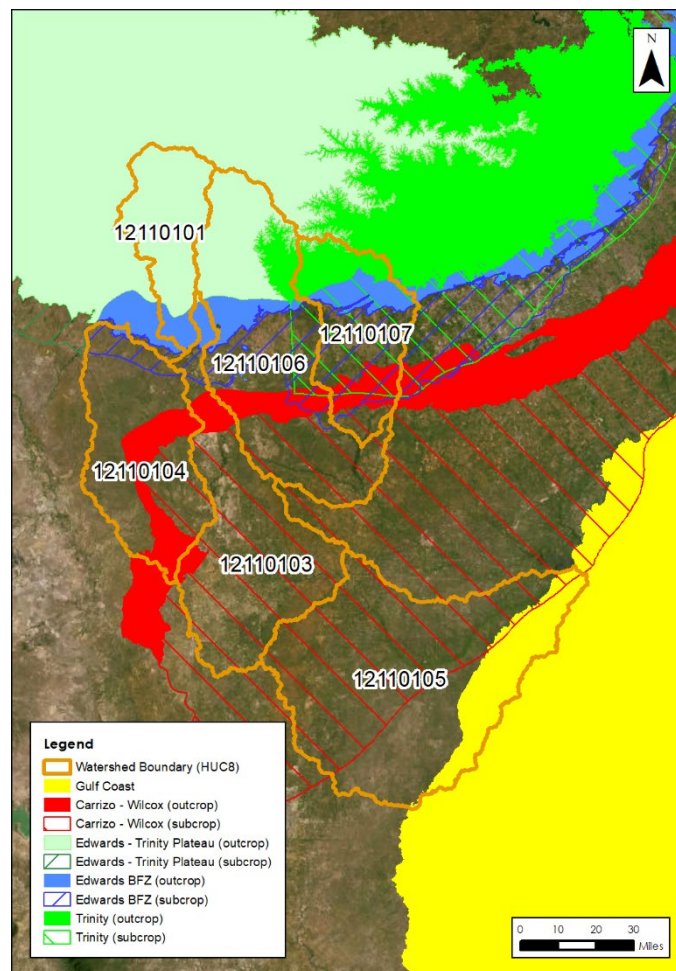


Figure 4-15. Task Order 1 HUC8 watershed overview with major aquifer zones

The Nueces Headwaters watershed has three active USGS gages (Nueces Rv nr Barksdale, TX (0818999010), Nueces Rv at CR 414 at Montell, TX (08189998), and Nueces Rv at Laguna, TX (08190000)). There is sufficient historic data for the Bulletin 17C statistical analysis at gage 08190000. Gage locations in the Nueces Headwaters watershed are shown in Figure 4-16 and calibration results are summarized in Table 4-8.

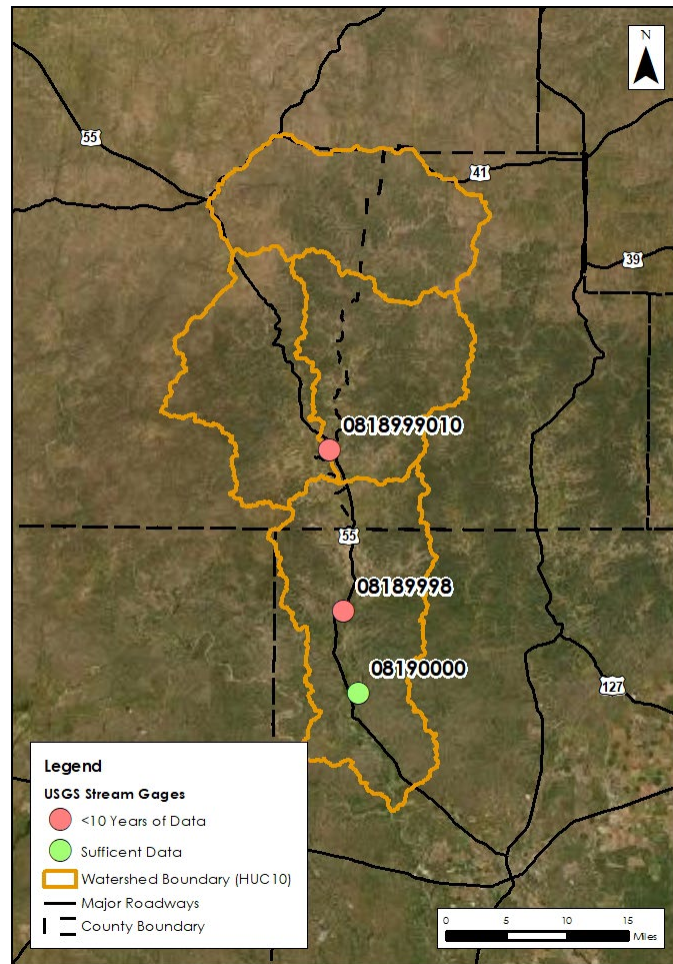


Figure 4-16. USGS Gages in Nueces Headwaters

Nueces Headwaters watershed models are shown again in Figure 4-17 with the underlying Edward's Aquifer features. The USGS gage used for calibration in this study is upstream of the recharge zone of the Edward's Aquifer in the Montell Creek-Nueces River (HUC 104) model and therefore did not reflect influence of the recharge zone (Figure 4-17). No CN adjustments for the Nueces Headwaters' HUC10 models were made based on proximity of the watershed to the aquifer.

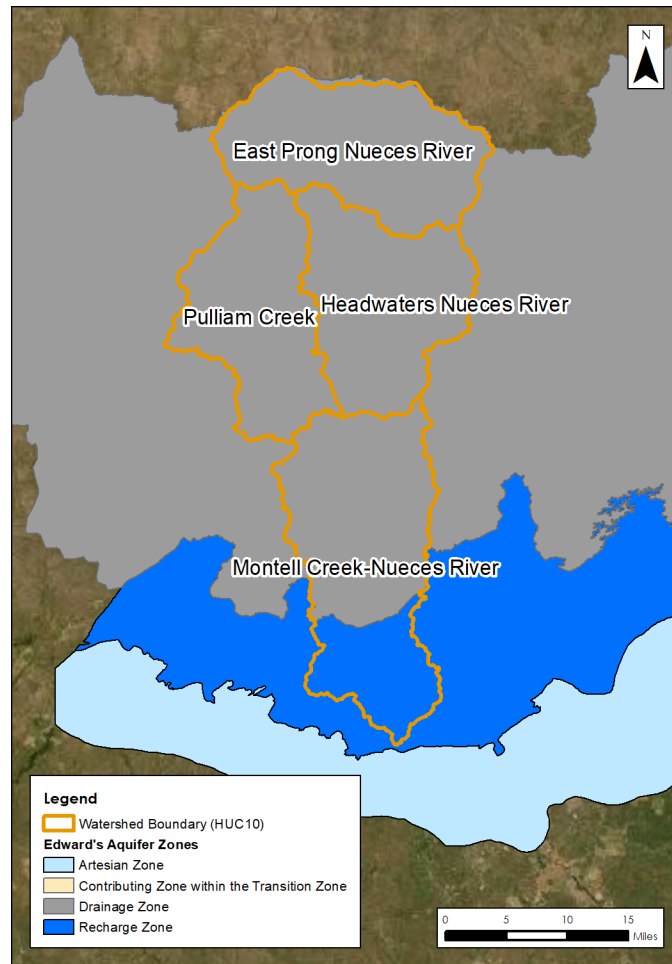


Figure 4-17. Nueces Headwater watershed HUC10 models and Edward's Aquifer zones

The initial Nueces Headwaters model results compared lower at gage 08190000 than the median Bulletin 17C estimate for the 100-year event (352,300 CFS with regional skew). The gage was installed in 1923 and is located just downstream of an S-bend on the Nueces River near Laguna, Texas. Due to the age of the gage, and with comparison to aerial imagery, it is assumed erosion has occurred on the outside bank of the bend since the USGS gage and rating curve were established (Figure 4-18). Erosion upstream of the gage has likely altered channel hydraulics which is now captured in the 2D modeling with updated LiDAR. There is no indication from USGS that the gage rating curve or streamflow recording methodology has been modified since initial gage installation in 1923. With the current model and base terrain, significant overflow is modeled at the S-bend prior to reaching the gage. This flow volume was likely maintained within the channel upon initial gage installation and would have been conveyed to pass through the gage cross-section.

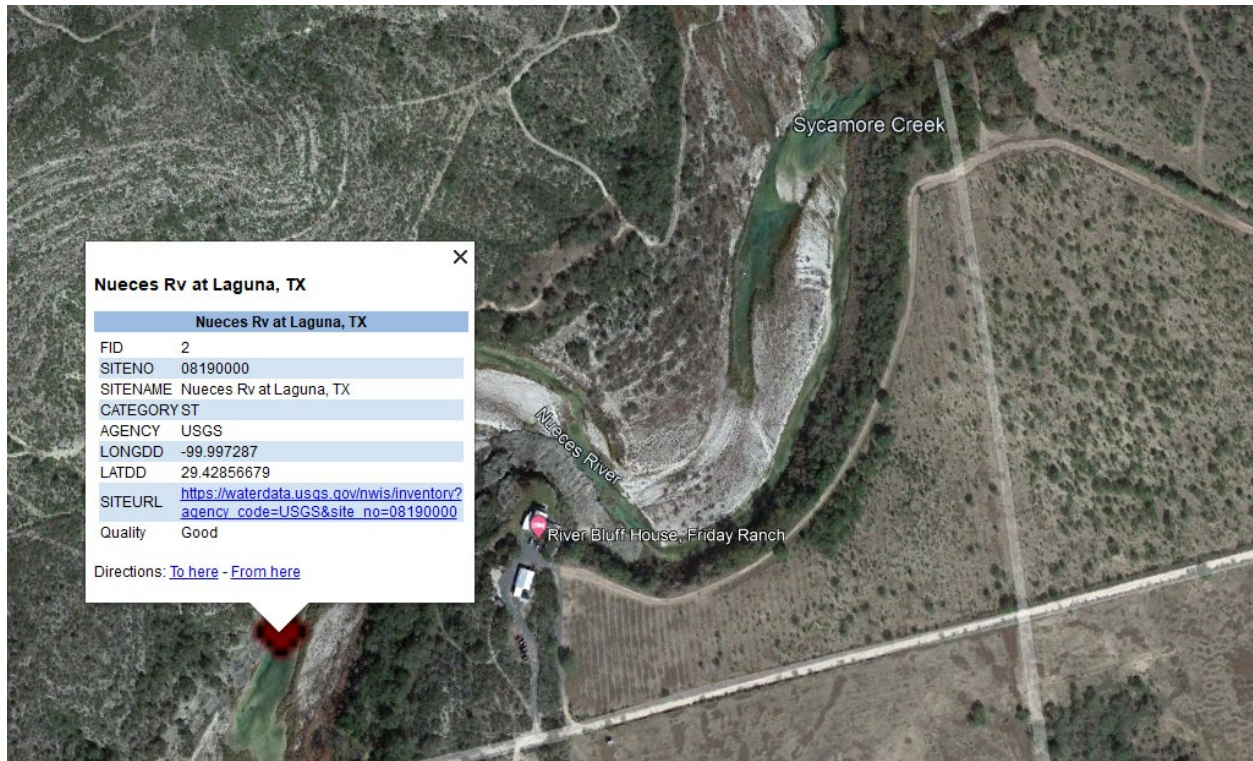


Figure 4-18. USGS gage 08190000 plan view with upstream bend

Although the initial model results were slightly lower than the median 100-year gage analysis results, base infiltration was not adjusted to increase runoff volume. As an alternative, the channel manning's values upstream of the gage and breaklines in the channel were refined to improve model conveyance and bring modeled peak flow values closer to the Bulletin 17C median 100-year peak flow estimates at the gage. A manning's calibration region was added to the model for channel manning's of 0.045 upstream of the gage and resulted in increasing peak flow at the gage slightly to 304,200 CFS for a difference of -13.65% from the historic statistical median (well within the confidence limits of the gage analysis). Final comparison of the modeled peak flow to the Bulletin 17C estimate at the gage location is summarized in Table 4-8.

Table 4-8. 1%-Annual-chance Flood Event Calibration Results Summary for Nueces Headwaters

USGS Gage	Contributing Area (Sq. Mi)	Historic Record Bulletin 17C Flood Frequency Analysis -1%- Annual Exceedance Probability Flow (CFS)			Modeled Peak Flow (1%)	Percent Difference (Modeled v. Historic median)
		Median	Lower 5% Confidence Limit	Upper 95% Confidence Limit		
08190000	737	352,300	216,600	680,400	250,600	28.86%

The model response was also compared to calculated flow estimates derived from USGS regional regression equations corresponding to the USGS gage locations in the HUC8 watershed (Table 4-9), as well as FEMA effective data where available. The modeled flows were higher than the median regression estimates but are within the upper 90% and lower 10% confidence bounds which were calculated with regional equations with Texas parameters derived from the 2009 USGS report by Asquith and Roussel (USGS 2009).

Table 4-9. 1% Annual-chance Flood Event – Modeled Peak Flow Comparison to USGS Regional Regression Estimates (equations and parameters via USGS 2009)

USGS Gage	1% AEP Peak Flows (CFS)			
	Modeled Peak Flow	Regression Estimate	Regression Estimate – 10% Lower CL	Regression Estimate – 90% Upper CL
0818999010	199,800	131,321	43,485	396,584
08189998	404,600	243,640	80,677	735,782
08190000	250,600	230,940	76,472	697,429

The modeled WSEL and floodplain extents were compared to effective FEMA data, where existing. The National Flood Hazard Layer (NFHL) regulatory data is currently only available for HUC10 12010104 in Uvalde County. The NFHL designations are Zone A and Zone X in this watershed with no published Base Flood Elevation (BFE) data. The effective NFHL was imported as a map layer in RASMapper and the inundation extent was compared to model floodplain extents. The modeled results on the mainstem of the watershed are highly correlated with the NFHL Zone A estimates in the downstream portion of the watershed. Generally, in areas of variance with the NFHL flood extents, the modeled results are narrower. This difference is likely due to a difference in precipitation application (BLE analysis v. previous studies), not modeling detailed structures in this BLE analysis, as well as the increased ability of the 2D model to simulate runoff patterns in the overbanks and low gradient area terrains.

4.7 Modeled Results

A summary of modeled HEC-RAS peak flow and WSEL results for the 10%, 1% and 0.2%-annual-chance events are summarized in Table 4-10 to Table 4-12 for USGS and NWS gages in the watershed. Of the three gages listed in the tables below, only one (USGS 08190000) had adequate data for statistical comparison (as discussed in more detail in the previous section). Modeled flow is reported at the additional two gages as they provide easily identifiable, stationary points for future comparison.

Floodplain delineation for these events is described in the following section (Chapter 6 Floodplain Delineation (10%, 1% and 0.2% events)). The hydraulic study results will be shared with the Nueces Headwaters communities during the Discovery Process.

Table 4-10. 10%-Annual-chance Modeled Flood Results Summary for Nueces Headwaters

USGS Gage Number	Gage Description	Peak Flow (CFS)	WSEL ¹ (ft)
0818999010	USGS	96,500	1,488.3
08189998	USGS	151,700	1,264.6
08190000	USGS	139,900	1,151.8

¹Note vertical datum of modeled WSEL NAVD88

Table 4-11. 1%-Annual-chance Modeled Flood Results Summary for Nueces Headwaters

USGS Gage Number	Gage Description	Peak Flow (CFS)	WSEL ¹ (ft)
0818999010	USGS	199,800	1,497.2
08189998	USGS	404,600	1,273.3
08190000 ²	USGS	250,600	1,160.7

¹Note vertical datum of modeled WSEL NAVD88

²Peak flow affected by channel overtopping upstream of gage

Table 4-12. 0.2%-Annual-chance Modeled Flood Results Summary for Nueces Headwaters

USGS Gage Number	Gage Description	Peak Flow (CFS)	WSEL ¹ (ft)
0818999010	USGS	417,200	1,503.2
08189998	USGS	692,090	1,279.2
08190000 ²	USGS	331,720	1,166.4

¹Note vertical datum of modeled WSEL NAVD88

²Peak flow affected by channel overtopping upstream of gage

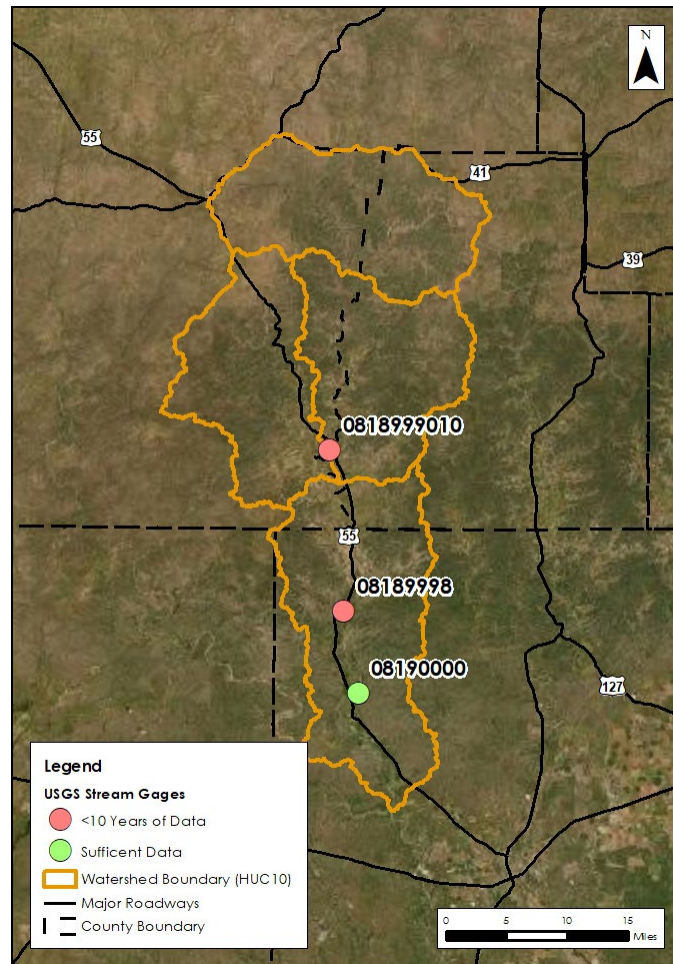


Figure 4-19. Overview of Peak Flow Comparison Locations for Nueces Headwaters

4.8 Challenges and Recommendations

The primary challenge encountered during this study was calibrating/validating modeled results due to limited existing flood hazard data, and sparse gage representation in the watershed. However, the agreement of the modeled results with the gage on the mainstem Nueces River near the HUC8 outlet, USGS gage 08190000, provided confidence in the overall HUC8 watershed model performance. Model agreement with historic flooding in tributaries, specifically the headwaters in the hill country terrain for this basin, is less certain. It is recommended to revisit these watershed models for further validation when adequate flow record is built for statistical comparison at USGS gages 0818999010 and 08189998.

The Nueces Headwaters HUC8 basin is comprised of variable topography creating unique flood responses; the headwater areas of the basin are primarily steep, rocky, Texas hill country which contributes to peaky, high-volume, high-velocity flows being passed downstream. The downstream portion of the basin begins to flatten as the steep terrain subsides to rolling hills/flat plains which then contributes to sprawling floodplains in this area as the water is slowed down exiting the hill country. The flat terrain creates challenges for 2D modeling as it inhibits a clear indication of the watershed divide. A few small, low- flow, drainage pathways continue between 2D watershed models in the downstream portion HUC8 which were difficult to tie-in between models while maintaining WSEL continuity. These

continuity issues can primarily be found in the Nueces Headwaters models at the west boundary of HUC10 1211010104, adjacent to the West Nueces (12110102) watershed and additional study may be recommended in the future for these areas (as indicated with the accompanying AOMI data). However, at present, this basin is primarily rural, and these issues do not impact cities, incorporated areas, or individual parcels.

Additional challenges include modeling surrounding major transportation infrastructure such as State Highway 55 crossing mainstem Nueces. It's recommended that flood risk surrounding major roadway crossings be revisited with detailed modeling. These HUC10 watershed models are highly scalable and provide a basis for detailed studies in the future. Additional recommendations for this study include incorporating stakeholder input in future analysis, or for BLE revisions, to enhance end products and validate flood hazard areas in higher-density urban areas along State Highway 55 and S. Ranch Rd 335 such as Montell, Camp Wood, and Barksdale.

5 Quality Control

Following the initial BLE analysis in each watershed, the flood hazard area delineations were reviewed for areas where the inundation that impacted either critical public infrastructure or private property. Revisions were made, if necessary, to reflect potential flooding risk on these properties more accurately.

Quality Assurance/Quality Control (QA/QC) review necessitated some manual editing including adding/moving computational points, breaklines, hydraulic connectors, and mesh refinement regions. The areas in or adjacent to channelized areas or significant ponding were the focus of this review.

6 Floodplain Delineation (10%, 1% and 0.2% events)

Floodplain Delineation for the Nueces Headwaters watershed was developed using the TWDB Matrix Tool, followed by running a set of ArcGIS Cartography tools against the output results from the Matrix Tool. The Matrix Tool processes the raw depth grid input data (from HEC-RAS) to remove small islands that have any of the following parameters: areas of floodplain that are less than 0.33 acres; areas of floodplain between 0.33-0.5 acres with an average depth less than 0.33 feet; or areas between 0.5 – 1 acre averaging a depth less than 0.25 feet, or between 1 – 2 acres averaging less than 0.1 feet. Lake, reservoir, and/or ponding areas of approximately 40 acres or greater were incorporated into the final mapping.

The Matrix Tool was also applied to fill the holes less than or equal to 0.33 acres in the vector floodplains. After the Matrix Tool was run, post-processing was performed to fill any additional holes still remaining by comparing to floodplain extent. For the flooding product extents to match, a 0.1ft depth was applied to the Depth Grid in areas that did not match the floodplain extent, which resulted in a 0.1ft depth low value for the datasets. The Depth Grid was then used to extract the Water Surface Elevation Grid to have 1:1 match per FEMA standards.

Additional post processing steps were applied using ArcGIS Simplifying and Smoothing tools to the 0.2% and 1% floodplain polygons. A 5-foot threshold for simplifying and 25-foot tolerance for smoothing were applied in this process. Per TWDB 2D BLE Guidance, the 10% floodplains did not go through this post processing step (TWDB 2022). This was to maintain the 10% flood extents as close to the model export as possible. Disconnected floodplain extents are maintained through the postprocess as preferred by the TWDB.

6.1 Internal Mapping Tie-ins

The hydraulic models in this task order were setup for upstream and downstream overlap in sequential models to maintain flow continuity of the mainstem between models. This overlap also provided an area to achieve a mapping tie-in within +/-0.5 ft of WSEL difference for the 10-year, 100-year and 500-year storms per FEMA Region 6 requirements. The Nueces Headwaters watershed mapping products demonstrate a 0.5ft tie-in at all mainstem model overlap locations. However, along the model perimeters where there are auxiliary flooding or spill locations, often model overlaps do not exist. In many of these instances, AOMI areas were used to identify tie-in issues that were unable to be resolved in this study due to a lack of model overlap.

Within the downstream portion of Nueces Headwaters watershed just north of the West Nueces River confluence, floodplain mapping from an Upper Nueces watershed (112110103) model was used to tie-in the Nueces Headwaters mapping products (Figure 6-1). The channel in this downstream portion of the Nueces Headwaters watershed is heavily braided and surrounded by flat terrain in the floodplain (contributing to a wide floodplain extent). The braided channels in the terrain made it difficult to achieve a 0.5 ft tie-in across the full floodplain extent at these locations. Therefore, in the area of overlap between Nueces Headwaters and Upper Nueces, a tolerance range of 0.5ft - 0.8ft was applied to tie-in the mapping data. This tolerance was applied on a pixel-to-pixel basis, as demonstrated in Figure 6-2, with only a few select pixels exceeding the 0.5 ft tolerance across the floodplain extent.

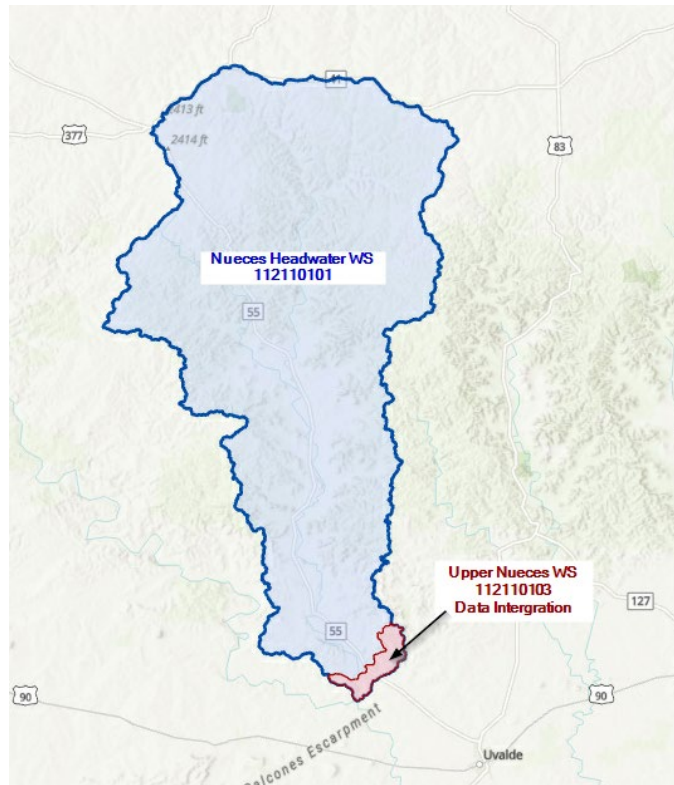


Figure 6-1. Nueces Headwaters WS mapping data integration – overlap with Upper Nueces WS

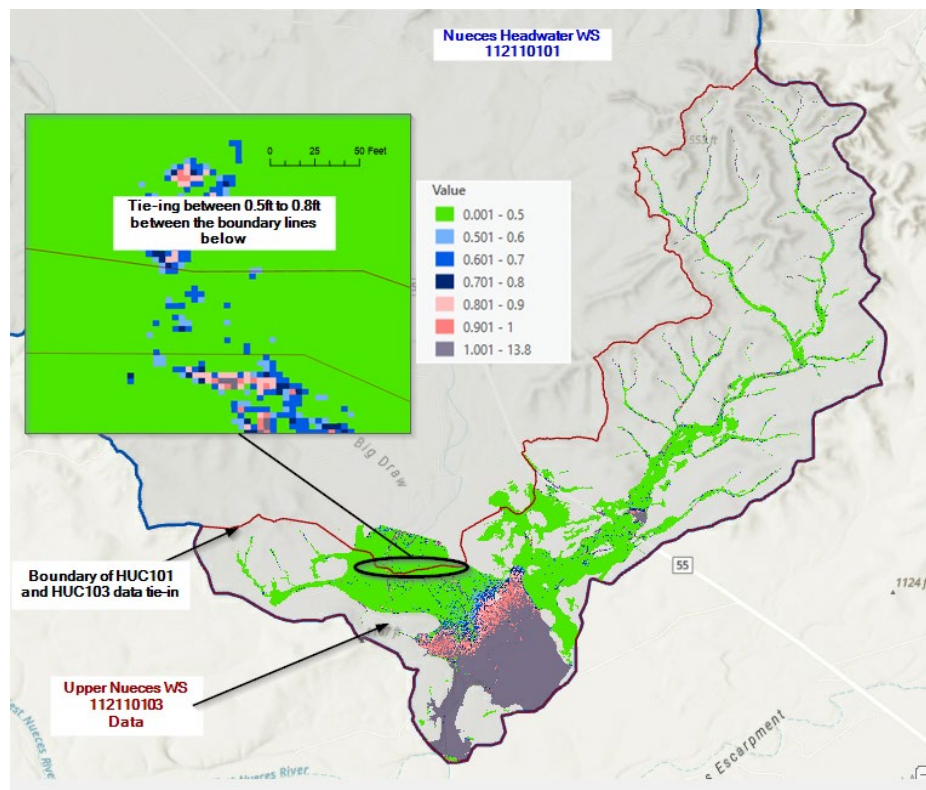


Figure 6-2. WSEL difference raster with tolerance at Nueces Headwaters – Upper Nueces overlap location

6.2 Hazus

As a part of the Base Level Engineering assessment effort, Hazus was run using version 6.0 with a resampled 10ft cell size, 1% Depth Grid. Hazus 6.0 uses parcel data to map the results but attributes data by census block number. S_FRAC_Ar was populated with the 1% Hazus results. Data that intersects the HUC8 boundary was left as is, no clipping was performed. All census/parcel data completely outside of the HUC8 boundary was removed.

6.3 Special Considerations

Unique challenges to modeling this watershed were discussed in Chapter 4. In addition, the following items should be considered in reviewing the mapping products, and for consideration in potential future studies in the watershed:

- There are no existing detailed study areas/lines (DTL_STUD_AR & DTL_STUD_LN) within Nueces Headwaters watershed, only approximate zones as provided from the National Flood Hazard Layer (NFHL) and TWDB Floodplain Quilt. These detailed features therefore were intentionally left blank in the in the FRD deliverable for this study.
- In the Nueces Headwaters watershed products, stream centerlines are contained within the 1% floodplain. However, in areas where there are road crossings and embankments, there is no streamline containment because the floodplain is not overtopping. In the areas with no floodplain containment, the length of stream centerline is less than 500 feet.
- Significant artificial depth increases at floodplain fringes occur in some areas of the Nueces Headwaters mapping products because of an artifact of RASMapper raster generation. In the sloping rendering mode, RASMapper attempts to interpolate between adjacent cells to “slope” the water surface, but in doing so, steep canyon walls or bluffs on the floodplain fringe can artificially cause the water surface to be interpolated upstream in the rendering, resulting in significant areas of inundation where inundation was not actually modeled as existing. This erroneous mapping result is referred to as “cupping”. Cupping may be resolved in future studies with assumed improvement of the RASMapper 2D rendering engine.

6.4 Results and Recommendations

The BLE results for the Nueces Headwaters produced an SFHA that compares reasonably well with the effective SFHA (if digitally available) in most cases and provides an additional estimated SFHA in areas that do not currently have an SFHA mapped. These results provide context for flood risk communication. These products should be shared with stakeholder communities during the discovery process and should be verified through community work map meetings before being applied to a regulatory product.

7 CNMS Validation of Effective Zone A Special Flood Hazard Area (SFHA)

All the Zone A studies (596.5 miles) in the Nueces Headwaters watershed were classified in CNMS with a validation status of “UNVERIFIED” and maintained a status type of “BEING STUDIED.” Zero miles of Zone A studies were classified in CNMS with a validation status of “VALID” and status type of “NVUE COMPLIANT.” The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A5 were evaluated for the CNMS inventory of Zone A studies.

7.1 Initial Assessment A1 – Significant Topography Update Check

This check involves determining whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. For the Nueces Headwaters watershed study area, the effective Zone A topographic data leveraged a variety of sources, but primarily based upon USGS 24K map products.

The effective topo used for the effective Zone A in HUC8 12110101 does not meet vertical accuracy requirements of SID 43. There is new topo available that does meet SID 43 from Texas Natural Resources Information System (TNRIS). Therefore, all effective Zone A studies in HUC8 12110101 fail A1.

7.2 Initial Assessment A2 – Check for Significant Hydrology Changes

This check involves first determining whether regression equations were used in the effective study. If they were then it was determined if 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.

Hydrology methods are unknown for the effective Zone A studies in HUC8 12110101. Therefore, all effective Zone A studies in HUC8 12110101 pass A2.

7.3 Initial Assessment A3 – Check for Significant Development

This check involves using the National Urban Change Indicator (NUCI) dataset to assess increased urbanization in the watershed of the Zone A study. If the percentage of urban area within the HUC-12 watershed containing the effective Zone A study is 15% or more, and has increased by 50% or more since the effective analysis, the study would fail this check. Although the NUCI data provide year-to-year changes in urbanization, the NLCD also is needed to establish a baseline of urban land cover for this analysis.

National Land Cover Data and National Urban Change Indicator were analyzed, and urbanization increase for HUC8 12110101 was deemed insignificant for all effective Zone A reaches. Therefore, all effective Zone A reaches pass this check.

Table 7-1: Zone A Initial Assessment Results

Assessment Check	Pass/Fail	Comments/Notes
A1 - Topography	Fail	Old topo does not meet SID 43, new topo does
A2 - Hydrology	Pass	Hydrology methods unknown

Assessment Check	Pass/Fail	Comments/Notes
A3 - Development	Pass	Urbanization increase is insignificant

7.4 Initial Assessment 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.

Effective Zone A studies in HUC8 12110101 are not model backed. Therefore, all effective Zone A reaches in HUC8 12110101 fail A4.

7.5 Initial Assessment A5 – Comparison of BLE and Effective Zone A Floodplains

The BLE /effective Zone A comparison method leverages the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach uses the 1-percent plus and 1-percent minus flood profiles and horizontal and vertical tolerances described in the First Order Approximation - Methodology, Validation, and Scalability Guidance Procedures (Version 1.5). For the comparison of BLE and effective Zone A in the study area, the following vertical and horizontal tolerances were used to conduct the modified FBS procedure. Points were sampled on the effective floodplain boundary at 200 ft intervals for comparison.

Vertical Tolerance: +/- 0.5 feet (one-half contour interval of assumed effective topographic source).

Horizontal Tolerance: +/-75 feet (standard horizontal tolerance for BLE comparison testing).

All effective Zone A studies in HUC8 12110101 failed the BLE comparison check. The National Risk Index risk deciles were grouped to represent risk classes and used to evaluate the threshold of points needed to assign a passing A5 score for each HUC12. Results are listed in Table 7-3.

7.6 CNMS Validation Results

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in Nueces Headwaters watershed study area has been updated, total miles in each of these categories are summarized in Tables 7-2 and illustrated in Figure 7-1 below.

Table 7-2: Zone A Validation Results

Validation Status	Status Type	Total Mileage
Valid	NVUE Compliant	0 miles
Unverified	Being Studied	596.5 miles

Table 7-3: BLE Comparison Results

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	HUC12 ID						
Ranger Hollow	121101010104	958	856	102	11%	>95%	Fail
Ruth Draw- Nueces River	121101010301	1968	1724	244	12%	>95%	Fail
Camp Wood Creek-Nueces River	121101010305	1046	835	211	20%	>95%	Fail
Upper Bull Head Creek	121101010302	1872	1715	157	8%	>95%	Fail
Elm Slough- Nueces River	121101010406	1501	994	507	34%	>95%	Fail
Dry Creek- Nueces River	121101010304	1874	1543	331	18%	>95%	Fail
Sycamore Creek-Nueces River	121101010404	1497	1094	403	27%	>95%	Fail
Ranch Creek- Nueces River	121101010401	1477	1118	359	24%	>95%	Fail
Lower Bull Head Creek	121101010303	1160	927	233	20%	>95%	Fail
Lake Creek- Nueces River	121101010402	1241	842	399	32%	>95%	Fail
Cedar Creek- Nueces River	121101010403	1389	1090	299	22%	>95%	Fail
French Creek- Nueces River	121101010405	1433	1023	410	29%	>95%	Fail
Upper Hackberry Creek	121101010101	1774	1471	303	17%	>95%	Fail
Lower Hackberry Creek	121101010102	1284	1123	161	13%	>95%	Fail
Lower East Prong Nueces River	121101010105	1846	1621	225	12%	>95%	Fail
Upper Pulliam Creek	121101010202	1299	1110	189	15%	>95%	Fail
Upper East Prong Nueces River	121101010103	1345	1191	154	11%	>95%	Fail
Little Hackberry Creek	121101010201	1071	925	146	14%	>95%	Fail

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	HUC12 ID						
Middle Pulliam Creek	121101010203	582	457	125	21%	>95%	Fail
Cedar Creek	121101010204	1697	1437	260	15%	>95%	Fail
Lower Pulliam Creek	121101010205	1312	968	344	26%	>95%	Fail

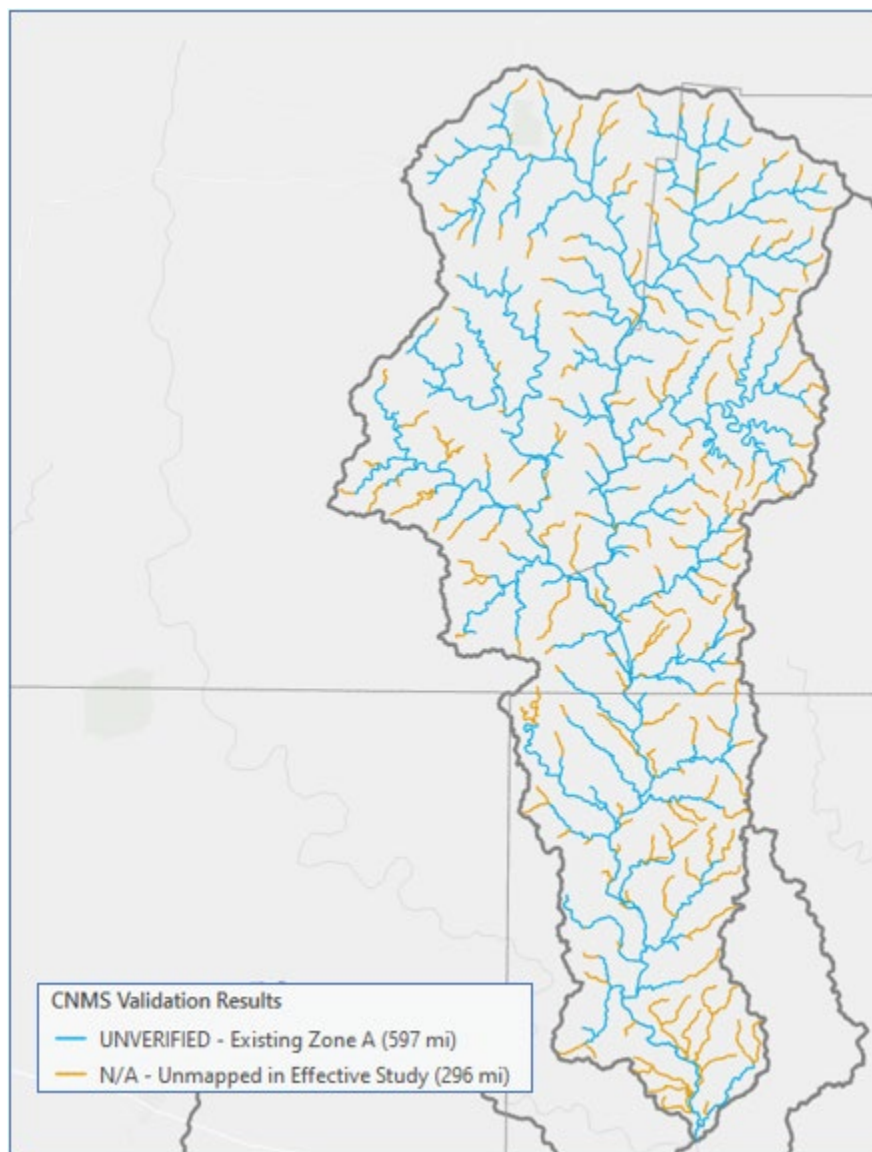


Figure 7-1. CNMS Validation Results

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Appendix A – PeakFQ Output File

```
1
Program PeakFq          U. S. GEOLOGICAL SURVEY          Seq.002.000
Version 7.3             Annual peak flow frequency analysis  Run Date / Time
10/25/2019                                     11/12/2021 16:43
```

--- PROCESSING OPTIONS ---

```
Plot option           = Graphics device
Basin char output     = None
Print option          = Yes
Debug print           = No
Input peaks listing   = Long
Input peaks format    = WATSTORE peak file
```

Input files used:

```
peaks (ascii) -
C:\Users\snarkhede\Documents\PROJECTS\TWDB\HUC
101\1211010104\08199000\1211010104_PEAK.TXT
specifications -
C:\Users\snarkhede\Documents\PROJECTS\TWDB\HUC
101\1211010104\08199000\PKFQWPSF.TMP
Output file(s):
main - C:\Users\snarkhede\Documents\PROJECTS\TWDB\HUC
101\1211010104\08199000\1211010104_PEAK.PRT
```

```
*** User responsible for assessment and interpretation of the following
analysis ***
```

1

```
Program PeakFq          U. S. GEOLOGICAL SURVEY          Seq.001.001
Version 7.3             Annual peak flow frequency analysis  Run Date / Time
10/25/2019                                     11/12/2021 16:43
```

Station - 08190000 Nueces Rv at Laguna, TX

TABLE 1 - INPUT DATA SUMMARY

Number of peaks in record	=	99
Peaks not used in analysis	=	0
Gaged peaks in analysis	=	97
Historic peaks in analysis	=	2
Beginning Year	=	1913
Ending Year	=	2020
Historical Period Length	=	108
Skew option	=	WEIGHTED
Regional skew	=	-0.458
Standard error	=	0.465
Mean Square error	=	0.216
Gage base discharge	=	0.0
User supplied high outlier threshold	=	--
User supplied PILF (LO) criterion	=	--

```

Plotting position parameter      =      0.00
Type of analysis                 EMA
PILF (LO) Test Method           MGBT
Perceptible Ranges:
  Start Year  End Year  Lower Bound  Upper Bound
      1913      2020       0.0        INF      DEFAULT
      1913      1923    160000.0        INF    HISTORIC 1

Interval Data                    =  None Specified

```

TABLE 2 - DIAGNOSTIC MESSAGE AND PILF RESULTS

```

*WCF107I-ACCEPTED GEN SKEW OUTSIDE MAP LIMITS.  -0.458  -0.400  0.800
EMA002W-CONFIDENCE INTERVALS ARE NOT EXACT IF HISTORIC PERIOD > 0

```

MULTIPLE GRUBBS-BECK TEST RESULTS

```

MULTIPLE GRUBBS-BECK PILF THRESHOLD  3360.0
NUMBER OF PILFS IDENTIFIED            29
CLASSIFICATION OF PILFS:
  NUMBER OF ZERO FLOWS                0
  NUMBER OF CENSORED FLOWS            0
  NUMBER OF GAGED PEAKS               29
    GAGED PEAKS AND CORRESPONDING P-VALUES
      78.0    (0.8374)
     106.0    (0.7258)
     124.0    (0.5664)
     156.0    (0.5114)
     158.0    (0.2878)
     161.0    (0.1333)
     175.0    (0.0692)
     183.0    (0.0267)
     206.0    (0.0146)
     242.0    (0.0111)
     248.0    (0.0030)
     251.0    (0.0006)
     276.0    (0.0002)
     304.0    (0.0001)
     406.0    (0.0002)
     558.0    (0.0014)
     617.0    (0.0009)
     660.0    (0.0004)
     694.0    (0.0001)
     769.0    (0.0001)
    1000.0    (0.0005)
    1060.0    (0.0002)
    1080.0    (0.0000)
    1470.0    (0.0007)
    1550.0    (0.0004)

```

1810.0	(0.0008)
1820.0	(0.0002)
2220.0	(0.0009)
2580.0	(0.0024)

Kendall's Tau Parameters

	TAU	P-VALUE	MEDIAN SLOPE	No. of PEAKS
GAGED PEAKS	-0.059	0.390	-17.918	97

1

Program PeakFq	U. S. GEOLOGICAL SURVEY	Seq.001.002
Version 7.3	Annual peak flow frequency analysis	Run Date / Time
10/25/2019		11/12/2021 16:43

Station - 08190000 Nueces Rv at Laguna, TX

TABLE 3 - ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	LOGARITHMIC		
	MEAN	STANDARD DEVIATION	SKEW
EMA WITHOUT REG SKEW	3.9219	0.8561	-0.643
EMA WITH REG SKEW	3.9327	0.8341	-0.526
EMA ESTIMATE OF MSE OF SKEW WITHOUT REG SKEW			0.0837
EMA ESTIMATE OF MSE OF SKEW W/GAGED PEAKS ONLY (AT-SITE)			0.0909

TABLE 4 - ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	<- EMA ESTIMATE -> WITH REG SKEW	WITHOUT REG SKEW	<- FOR EMA ESTIMATE WITH REG SKEW -> LOG VARIANCE OF EST.	<-CONFIDENCE LIMITS-> 5.0% LOWER	95.0% UPPER
0.9950	23.8	16.1	0.2961	0.7	103.3
0.9900	47.6	34.5	0.2205	2.3	168.1
0.9500	280.4	237.3	0.0896	38.9	621.6
0.9000	672.9	606.4	0.0522	148.2	1237.0
0.8000	1821.	1741.	0.0260	650.0	2842.0
0.6667	4339.	4310.	0.0138	2241.0	6199.0
0.5000	10130.	10300.	0.0085	6708.0	14000.0
0.4292	14130.	14450.	0.0075	9854.0	19470.0

0.2000	44390.	45270.	0.0074	32230.0	62680.0
0.1000	87840.	87780.	0.0090	62590.0	131000.0
0.0400	170400.	164400.	0.0124	116300.0	278800.0
0.0200	252700.	236500.	0.0163	164400.0	447300.0
0.0100	352300.	319500.	0.0213	216600.0	680400.0
0.0050	468900.	411900.	0.0276	270900.0	997200.0
0.0020	648600.	546300.	0.0380	343700.0	1588000.0

*Note: If Station Skew option is selected then EMA ESTIMATE WITH REG SKEW will display values for and be equal to EMA ESTIMATE WITHOUT REG SKEW.

1

Program PeakFq	U. S. GEOLOGICAL SURVEY	Seq.001.003
Version 7.3	Annual peak flow frequency analysis	Run Date / Time
10/25/2019		11/12/2021 16:43

Station - 08190000 Nueces Rv at Laguna, TX

Appendix B – Supplemental Hydrology Data

Stantec developed spatially varying precipitation data based on NOAA Atlas 14 (NOAA 2018). This was done by establishing the unit hyetograph that will accurately represent the specific region (SCS Type graph, balanced, Atlas 14, etc.) corresponding to the study area, and then applying that unit hyetograph to the model mesh. Each cell within the mesh receives the precipitation amount that coincides with the hyetograph at that location within the gridded precipitation raster that has been overlaid. Figure B-1 depicts the derivation process in a flowchart. Stantec believes this is more representative for local flood mapping than the historical method, which takes the mean (or some assumed representative point) of precipitation over an area for which to apply a uniform precipitation hyetograph. Please see additional example figures below, derived from the study area (Figure B.2 – B.5), which provide a backcheck of the applied spatial data.

Note: Figure B.5 was created by normalizing the cumulative precipitation values from Figure 2 and the slight variation is caused by the truncation of data in HEC-GridUtil's `ascii2dssgrid.exe`.

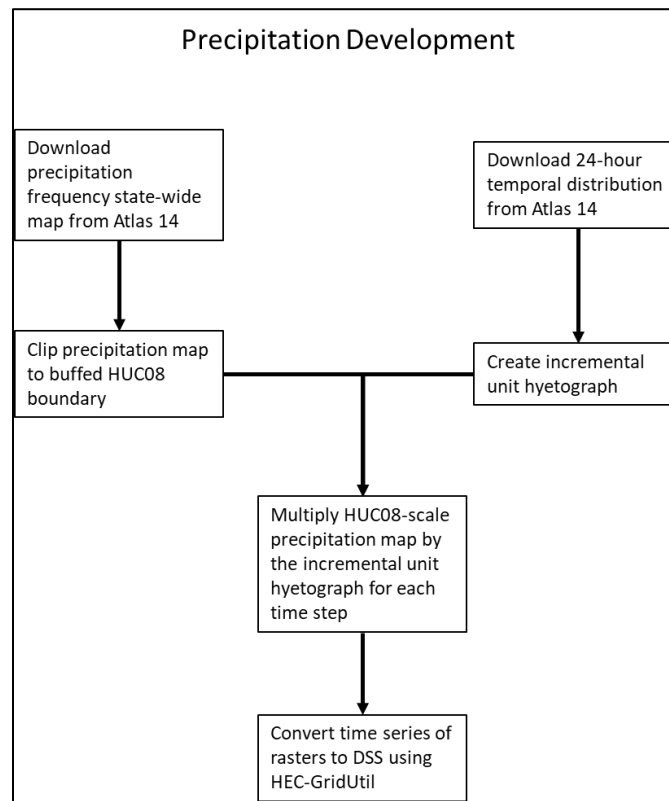


Figure B.1 – Flow chart demonstrating Stantec’s precipitation dataset derivation process.

As can be seen in Figure B.2 and B.3 below, the cumulative rainfall amount at this stadium is shown to be 11.9-inches in RASMapper (utilizing the created precipitation raster) as well as on NOAA’s website. This confirms that the gridded raster dataset used within the model is functioning correctly.

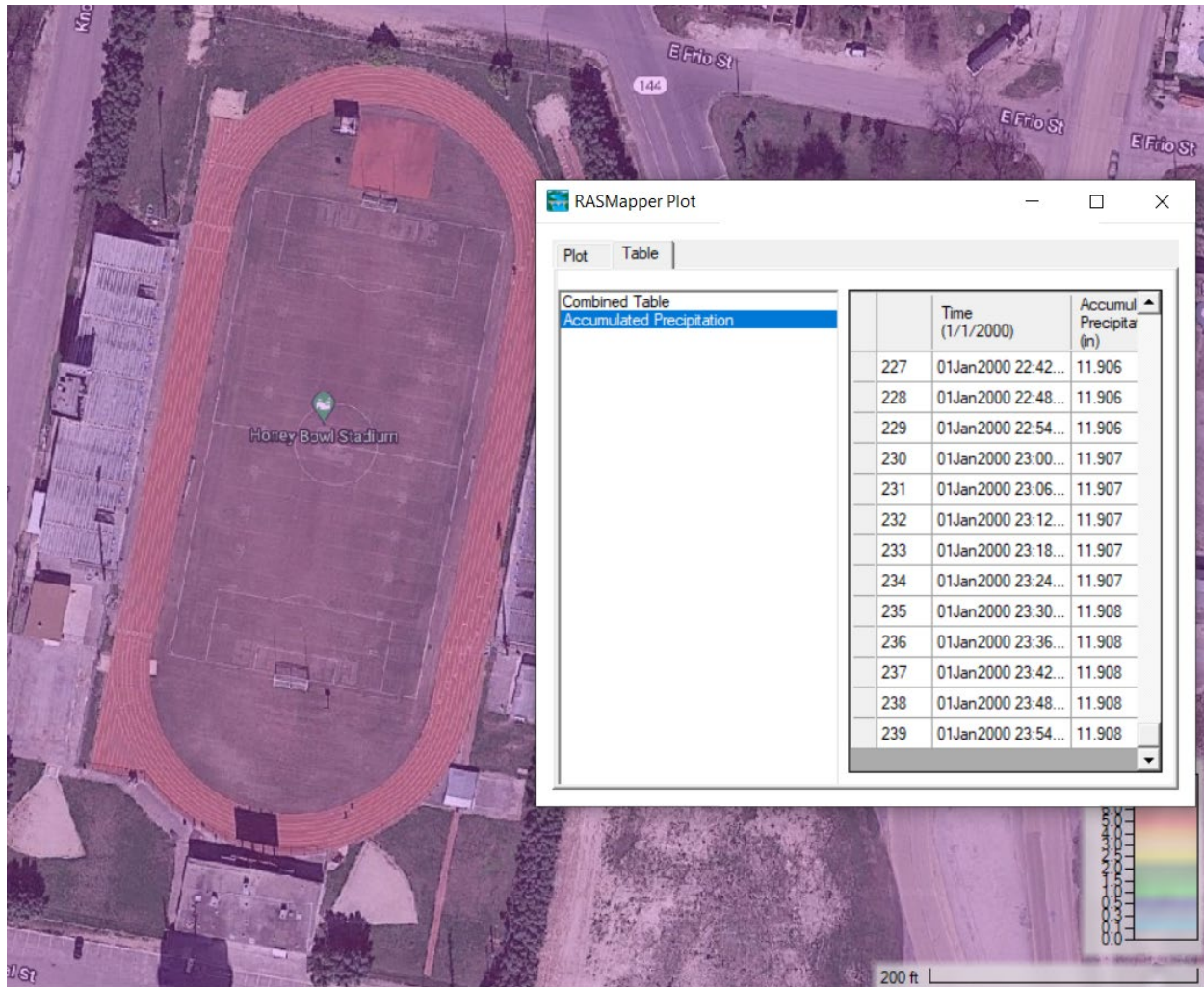


Figure B.2 – Cumulative 100-year, 24-hour precipitation at Honey Badger Stadium in Uvalde, TX



Figure B.3 –Honey Badger Stadium view from Atlas 14 browser

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches) ¹										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.437 (0.331-0.577)	0.526 (0.401-0.686)	0.671 (0.511-0.880)	0.792 (0.594-1.06)	0.961 (0.701-1.32)	1.10 (0.778-1.55)	1.23 (0.845-1.78)	1.35 (0.906-2.00)	1.51 (0.977-2.31)	1.62 (1.02-2.55)
10-min	0.695 (0.526-0.918)	0.839 (0.640-1.09)	1.07 (0.816-1.41)	1.27 (0.951-1.69)	1.54 (1.13-2.13)	1.76 (1.25-2.49)	1.97 (1.36-2.85)	2.15 (1.44-3.20)	2.38 (1.54-3.65)	2.53 (1.60-3.98)
15-min	0.884 (0.669-1.17)	1.06 (0.808-1.38)	1.34 (1.02-1.76)	1.58 (1.19-2.11)	1.91 (1.40-2.63)	2.17 (1.54-3.08)	2.43 (1.68-3.52)	2.67 (1.79-3.96)	2.97 (1.93-4.56)	3.18 (2.01-5.02)
30-min	1.25 (0.944-1.65)	1.49 (1.14-1.94)	1.88 (1.43-2.47)	2.21 (1.66-2.94)	2.66 (1.93-3.65)	3.01 (2.13-4.25)	3.36 (2.31-4.86)	3.70 (2.48-5.49)	4.14 (2.69-6.37)	4.47 (2.83-7.05)
60-min	1.60 (1.21-2.12)	1.93 (1.47-2.52)	2.46 (1.87-3.23)	2.91 (2.18-3.87)	3.53 (2.56-4.84)	4.01 (2.84-5.65)	4.50 (3.10-6.51)	5.00 (3.36-7.43)	5.68 (3.69-8.73)	6.20 (3.92-9.78)
2-hr	1.89 (1.45-2.48)	2.36 (1.80-3.02)	3.09 (2.37-4.01)	3.73 (2.82-4.92)	4.65 (3.41-6.32)	5.39 (3.84-7.53)	6.18 (4.29-8.85)	7.04 (4.75-10.3)	8.25 (5.38-12.5)	9.22 (5.86-14.4)
3-hr	2.04 (1.57-2.66)	2.61 (1.99-3.29)	3.47 (2.67-4.47)	4.25 (3.23-5.57)	5.38 (3.97-7.29)	6.32 (4.53-8.79)	7.36 (5.12-10.5)	8.50 (5.75-12.4)	10.1 (6.63-15.3)	11.5 (7.31-17.8)
6-hr	2.30 (1.78-2.97)	3.03 (2.30-3.73)	4.08 (3.16-5.19)	5.06 (3.88-6.57)	6.53 (4.85-8.76)	7.78 (5.62-10.7)	9.19 (6.44-12.9)	10.8 (7.34-15.5)	13.1 (8.62-19.6)	15.1 (9.66-23.1)
12-hr	2.56 (2.00-3.28)	3.39 (2.59-4.11)	4.56 (3.56-5.75)	5.69 (4.40-7.32)	7.40 (5.55-9.83)	8.88 (6.46-12.1)	10.6 (7.46-14.7)	12.6 (8.59-17.9)	15.5 (10.2-22.9)	18.1 (11.6-27.2)
24-hr	2.85 (2.25-3.61)	3.77 (2.90-4.51)	5.07 (3.99-6.32)	6.32 (4.93-8.06)	8.25 (6.23-10.9)	9.94 (7.29-13.4)	11.9 (8.44-16.4)	14.2 (9.75-19.9)	17.7 (11.7-25.7)	20.6 (13.3-30.6)
2-day	3.23 (2.57-4.05)	4.26 (3.30-5.05)	5.71 (4.53-7.05)	7.11 (5.59-8.98)	9.28 (7.07-12.1)	11.2 (8.26-14.9)	13.4 (9.53-18.2)	15.9 (10.9-22.0)	19.5 (13.0-28.0)	22.6 (14.6-33.2)
3-day	3.50 (2.80-4.37)	4.60 (3.59-5.44)	6.14 (4.91-7.55)	7.63 (6.03-9.58)	9.90 (7.58-12.8)	11.9 (8.81-15.8)	14.2 (10.1-19.1)	16.7 (11.6-23.0)	20.4 (13.6-29.1)	23.6 (15.3-34.3)
4-day	3.72 (2.98-4.62)	4.85 (3.82-5.75)	6.47 (5.19-7.93)	8.00 (6.35-10.0)	10.3 (7.92-13.3)	12.3 (9.14-16.2)	14.6 (10.5-19.6)	17.1 (11.9-23.5)	20.9 (14.0-29.6)	24.1 (15.6-34.8)
7-day	4.21 (3.40-5.19)	5.40 (4.32-6.42)	7.17 (5.81-8.73)	8.78 (7.01-10.9)	11.2 (8.57-14.2)	13.1 (9.75-17.1)	15.3 (11.0-20.4)	17.9 (12.5-24.3)	21.7 (14.5-30.4)	24.9 (16.2-35.6)
10-day	4.61 (3.74-5.65)	5.84 (4.73-6.96)	7.72 (6.29-9.37)	9.39 (7.53-11.6)	11.8 (9.09-14.9)	13.7 (10.2-17.8)	15.9 (11.5-21.0)	18.5 (12.9-24.9)	22.3 (15.0-31.0)	25.5 (16.6-36.2)
20-day	5.73 (4.69-6.94)	7.08 (5.84-8.45)	9.24 (7.61-11.1)	11.1 (8.96-13.5)	13.7 (10.6-17.1)	15.7 (11.8-20.1)	17.9 (13.0-23.4)	20.4 (14.3-27.2)	23.9 (16.2-32.9)	26.9 (17.6-37.6)
30-day	6.63 (5.45-7.99)	8.09 (6.73-9.64)	10.4 (8.66-12.5)	12.4 (10.1-15.1)	15.2 (11.8-18.8)	17.3 (13.1-22.0)	19.5 (14.3-25.3)	22.0 (15.5-29.1)	25.3 (17.2-34.5)	28.0 (18.4-38.9)
45-day	7.91 (6.54-9.48)	9.52 (7.98-11.3)	12.2 (10.1-14.5)	14.3 (11.7-17.3)	17.3 (13.6-21.4)	19.6 (14.8-24.7)	21.9 (16.0-28.2)	24.3 (17.2-32.0)	27.6 (18.8-37.3)	30.2 (19.8-41.6)
60-day	9.05 (7.51-10.8)	10.8 (9.10-12.8)	13.7 (11.5-16.3)	16.0 (13.2-19.3)	19.2 (15.1-23.6)	21.6 (16.4-27.1)	24.0 (17.6-30.7)	26.5 (18.8-34.6)	29.8 (20.3-40.0)	32.3 (21.3-44.2)

Figure B.4 – 100-yr 24-hr precipitation value from Atlas 14 (corresponding to location show in figure 2 and 3, Honey Badger stadium)

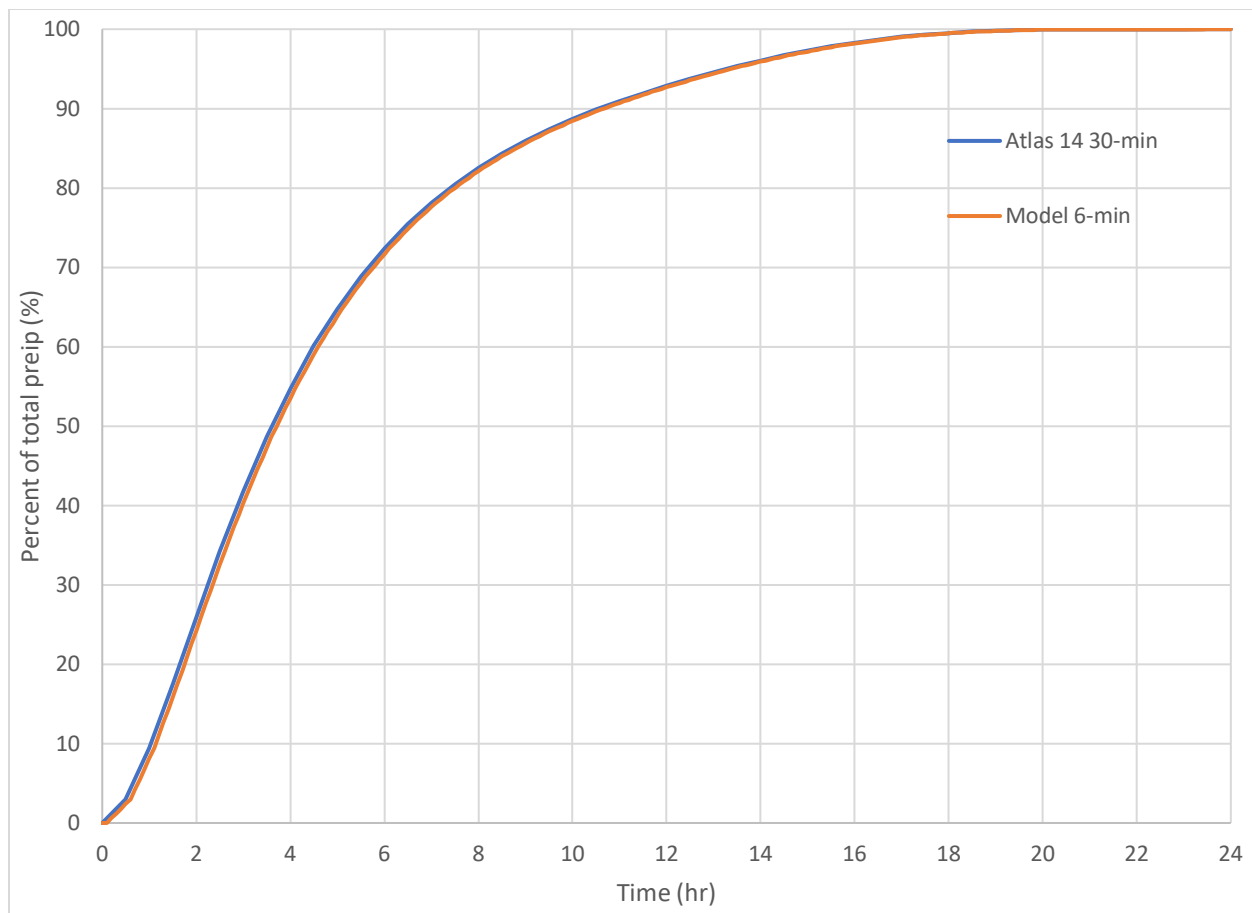


Figure B.00-1. Comparison of Atlas 14 and normalized model cumulative precipitation.

Figure B.6 below provides an overview of the development methodology for the Curve Number and Manning's n base data layers.

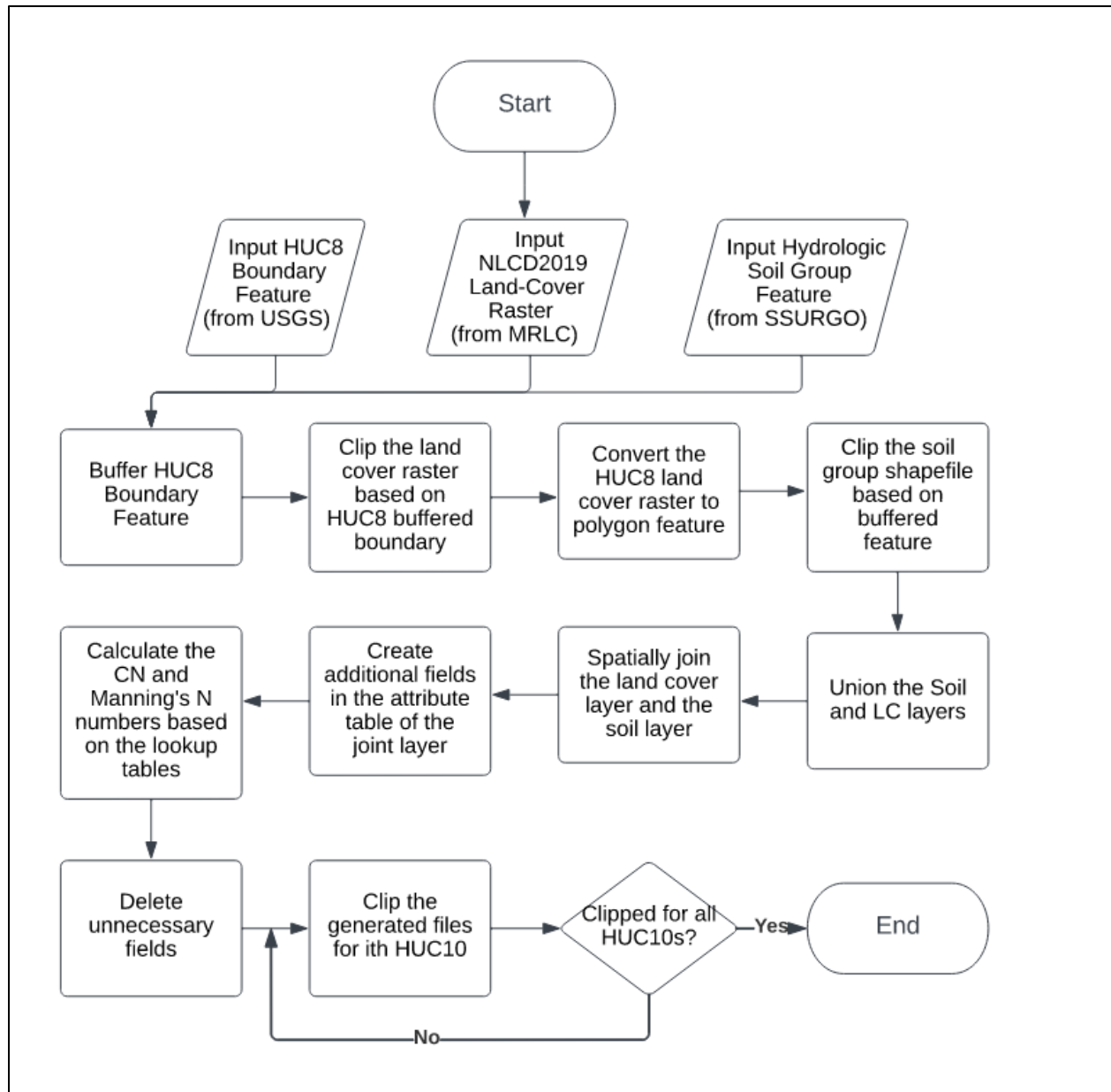


Figure B-6. Flow chart demonstrating Stantec's curve number spatial dataset derivation process.