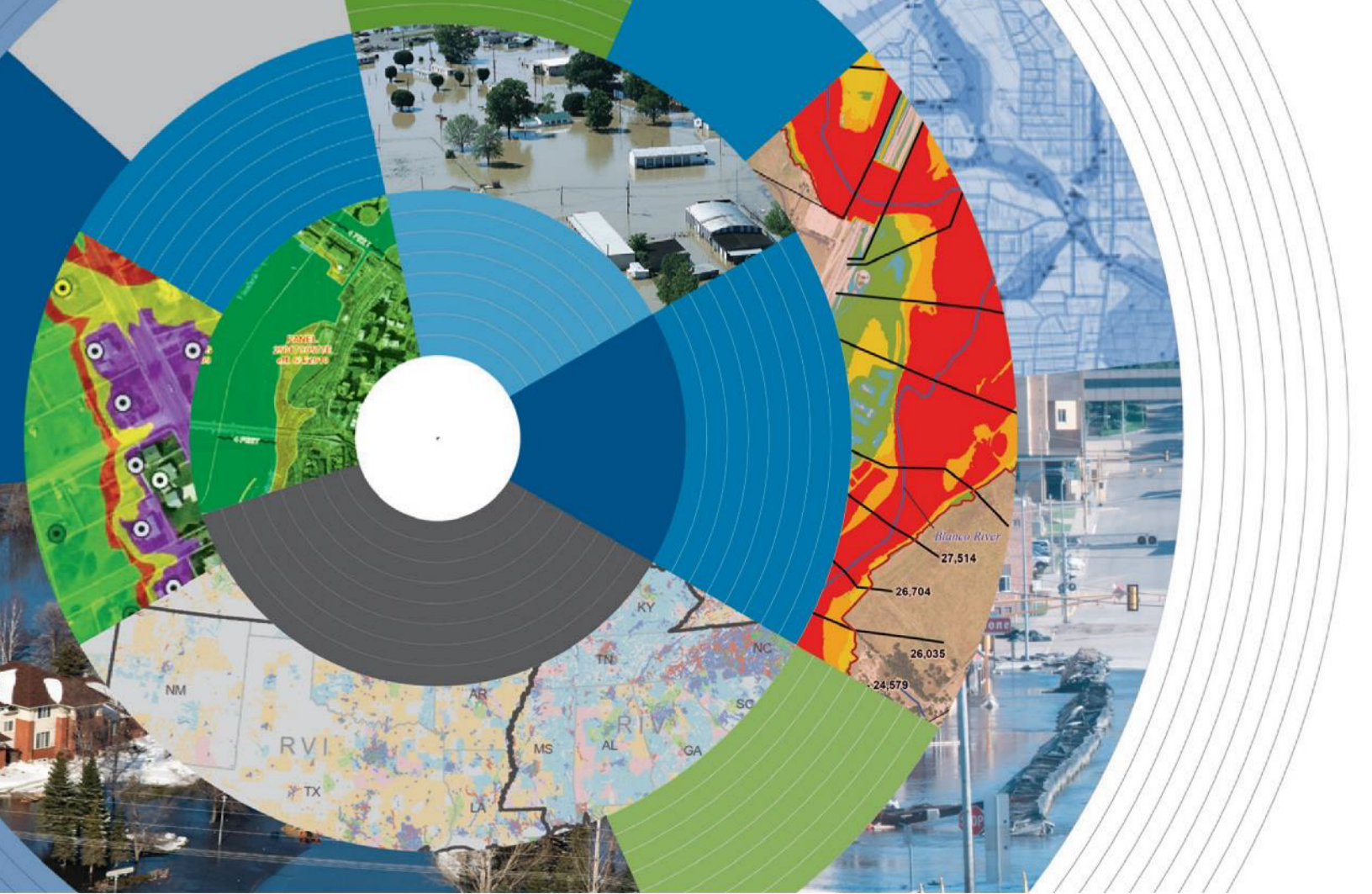




Base Level Engineering Report

Lower Salt Fork Red River Watershed (HUC 11120202)

CASE NUMBER: 22-06-0048S

Texas Water
Development Board

Stantec WaterEarth

Gauge
ENGINEERING

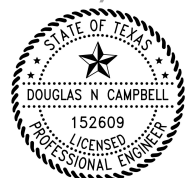
Floodace

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02	5/22/205	Final deliverable to TWDB	Stantec/ Gauge/ Watearth/Cardinal/Floodace

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Acronyms

AAL	Average Annualized Loss
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
H&H	Hydrology and Hydraulics
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
NAVD	North American Vertical Datum
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
SCS	Soil Conservation Service
SFHA	Special Flood Hazard Area
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 Lower Salt Fork Red River watershed, as part of CONTRACT 2101792546, Task Order # 2. A summary of the study parameters and results for the Lower Salt Fork Red River watershed is provided below in Table 0-1 and Table 0-2.

Table 0-1: Summary of Stream Miles

Source	Stream Miles
Current Inventory – CNMS (S_Studies_Ln)	395
New Study Streams – CNMS (S_Unmapped_Ln) Informed by NHD 1:100	1,256
Total (BLE) Stream Miles	1,651

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	395	395	395

TWDB contracted Stantec under Task Order #2 to complete a BLE analysis for the following five, HUC8-scale watersheds in the Canadian -Upper Red River basins and Texas flood planning region:

- Upper Salt Fork Red - #11120201
- Lower Salt Fork Red - #11120202
- Lower Salt Fork Red River - #11120301
- Middle North Fork Red - #11120302
- Elm Fork Red - #11120304

Results of this study span a portion of both Texas and Oklahoma and affect the Texas counties of Carson, Gray, Donley, Wheeler, and Collingsworth. 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 – Average Annualized Loss (AAL) Analysis
- Task 5 – CNMS (Section 7)

1 Introduction and Project Scope

TWDB contracted Stantec under Task Order # 2 to complete a BLE analysis for the following five, National Hydrography Dataset (NHD) Hydrologic Unit Code 8 (HUC 8) scale watersheds in the Canadian - Upper Red River basins and Texas flood planning region:

- Upper Salt Fork Red - #11120201
- Lower Salt Fork Red - #11120202
- Lower Salt Fork Red River - #11120301
- Middle North Fork Red - #11120302
- Elm Fork Red - #11120304

The five watersheds comprise a total of approximately 5,700 sq miles of drainage area, and 2,170 stream miles spanning both the Northeast portion of the Texas Panhandle and a portion of Southwest Oklahoma. Results of this study affect the Texas counties of Carson, Gray, Donley, Wheeler, and Collingsworth.

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 – Average Annualized Loss (AAL) Analysis
- 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 HUC 8 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

Task ID	Task	Task Phase ID	Task Phase
		2.3	Phase3: Multi-frequency Runs
		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 the Lower Salt Fork Red River watershed (Figure 1-1) which includes coverage of Donley, Wheeler, Collingsworth, Harmon, Greer, and Jackson counties.

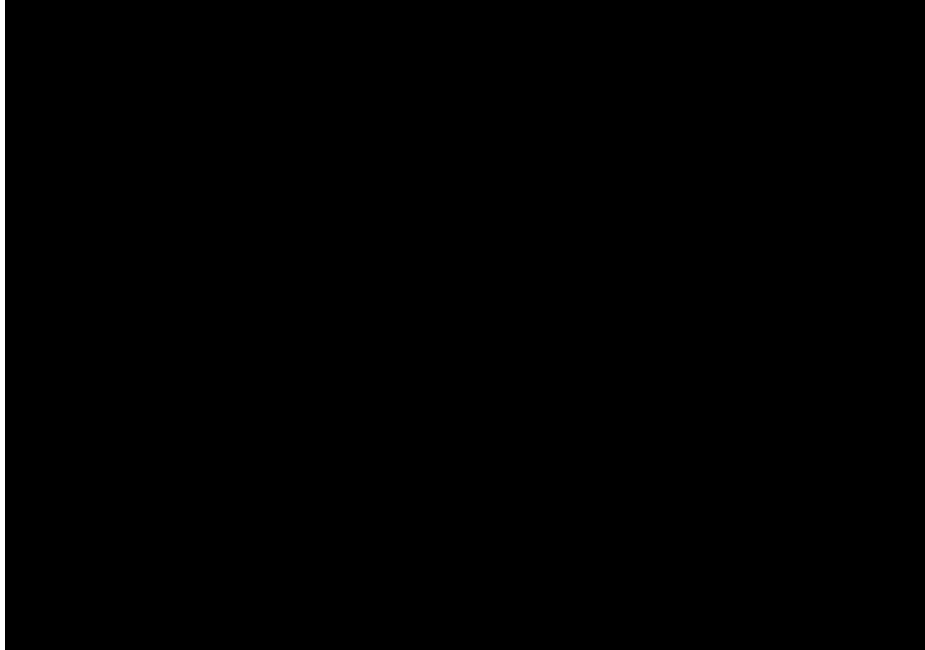


Figure 1-1. Lower Salt Fork Red River watershed (11120202) – HUC 10 Basins

The BLE assessment prepared cursory engineering analysis for approximately 494 miles of stream reaches within the Lower Salt Fork Red River watershed with a minimum drainage area tolerance of one square mile. The selection and extent of stream reaches studied was based upon the number of stream miles with minimum drainage area of one square mile and not the 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

This HUC8 watershed is entirely covered by five data sources. The data sources for this watershed include the Texas Panhandle 2018 D18 Lidar project obtained from the United States Geological Survey (USGS), the Oklahoma Woodward 2017 Lidar project obtained from the USGS, and the Oklahoma Dam Rehab Assessment 2011 project obtained from the USGS, and two datasets (B13 and TL) from the 2018 TX West Central Lidar Project obtained from the USGS. Combined, these sources cover the Texas Panhandle and Southwest area of Oklahoma within the Lower Salt Fork Red HUC-8 NHD boundary.

The individual Digital Elevation Model (DEM) tiles from each of the data sources were used to create one seamless DEM mosaic for the Lower Salt Fork Red Watershed using various methodologies and tools in ESRI's ArcGIS Pro 2.9.2 environment as described below.

The Texas Panhandle seamless DEM was developed by cataloging the tiles then mosaicking them into one DEM while maintaining the original projection and raster cell values (NAD 1983 2011 UTM Zone 14N 1-meter by 1-meter); this was done for each individual data source applicable to the project watershed.

The Oklahoma Woodward 2017 DEM was developed by cataloging the tiles then mosaicking them into one DEM while maintaining the original projection and raster cell values (NAD 1983 UTM Zone 14N 1-meter by 1-meter).

The OK Dam Rehab Assessment 2011 DEM was developed by cataloging the tiles then mosaicking them into one DEM while maintaining the original projection and raster cell values (NAD 1983 NSRS2007 UTM Zone 14N 2-meter by 2-meter). This seamless DEM was then resampled from 2-meter by 2-meter resolution to 1-meter by 1-meter as further described below.

The 2018 TX West Central DEM was developed by cataloging the tiles from B13 and TL then mosaicking them into one DEM while maintaining the original projection and raster cell values (NAD 1983 UTM Zone 14 1-meter by 1-meter).

The final seamless DEM was developed by cataloging the tiles then mosaicking them into one DEM while maintaining the original projection and raster cell values; this was done for each individual data source applicable to the project watershed. Each raster was individually converted from values in meters to values in feet. Each DEM was then re-projected into the NAD83 Texas North FIPS 4201 (US Feet) NAVD 1988 horizontal coordinate system and clipped to a one-mile buffer based on the NHD HUC8 boundary.

In instances where the watershed was covered by multiple overlapping data sources, the mosaicking process prioritized using the most recent data source within the overlapping area. Otherwise, a Blend option was used in areas where tiles may overlap with one another.

Special Considerations

There were no issues encountered when developing the final seamless DEM. There should be special consideration at the location of two overlapping data sources covering one 1-meter by 1-meter horizontal line. The pixel values in the final seamless DEM where the Texas Panhandle B9 on the far eastern side of the source dataset and Oklahoma Woodward on the far western side of the source dataset overlap by one 1-meter by 1-meter horizontal line have a visibly distinct difference in elevation values when these sources were mosaicked together. These visual differences between the pixel values are an artifact of the standardized processing methodology, as described in the section above, which prioritize representing the true values of the data sources. The observed differences between the data sources fall in a range of 0.2 feet to 0.5 feet across various ground coverage using ESRI aerial imagery. The implications of the visual difference appear to only impact the aesthetic component of the dataset and are not expected to have a significant impact on the modeling outputs. See Figures 2-1 and 2-2 for examples of the Special Considerations area.

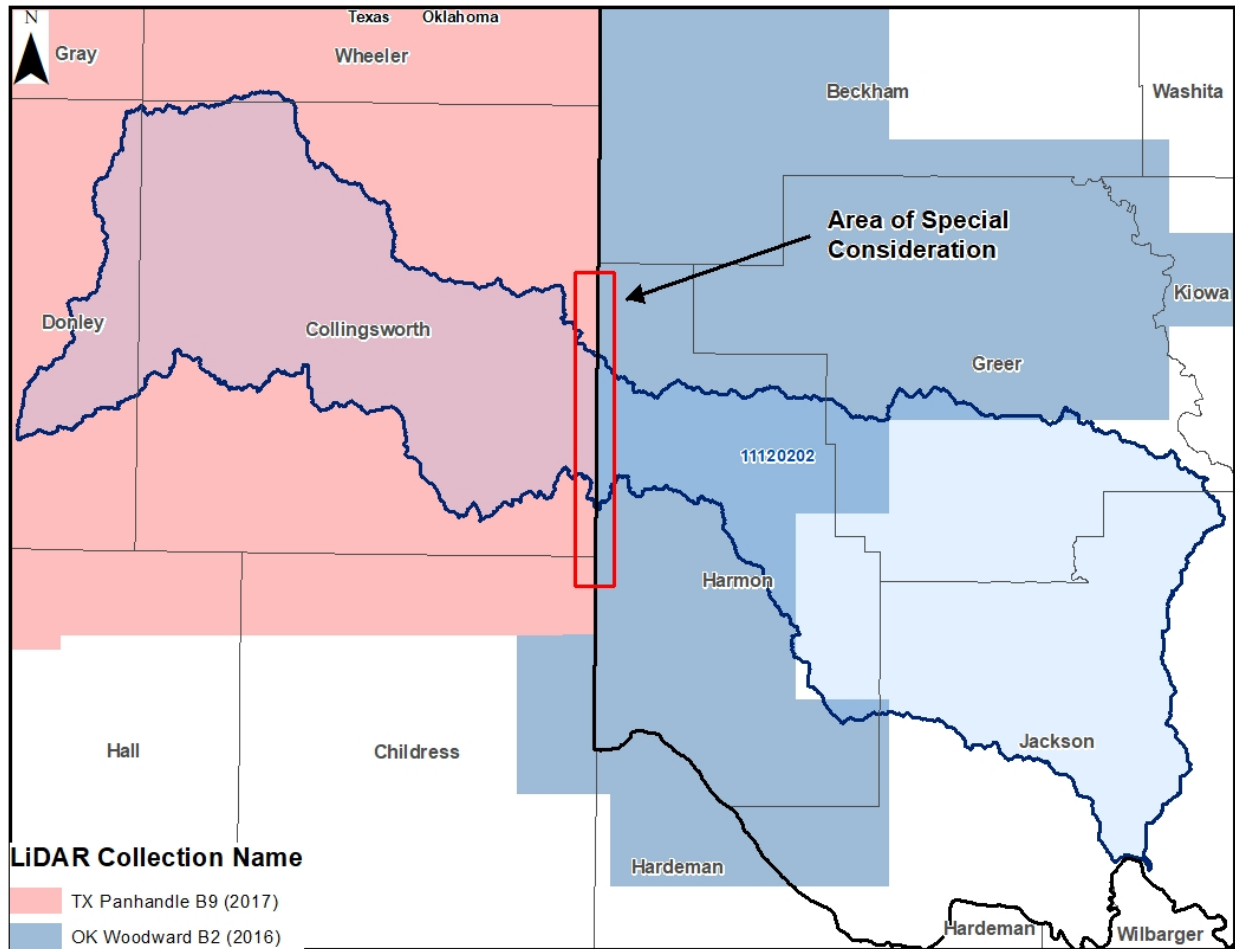


Figure 2-1: Extent and coverage of Special Consideration area as it relates to project watershed.

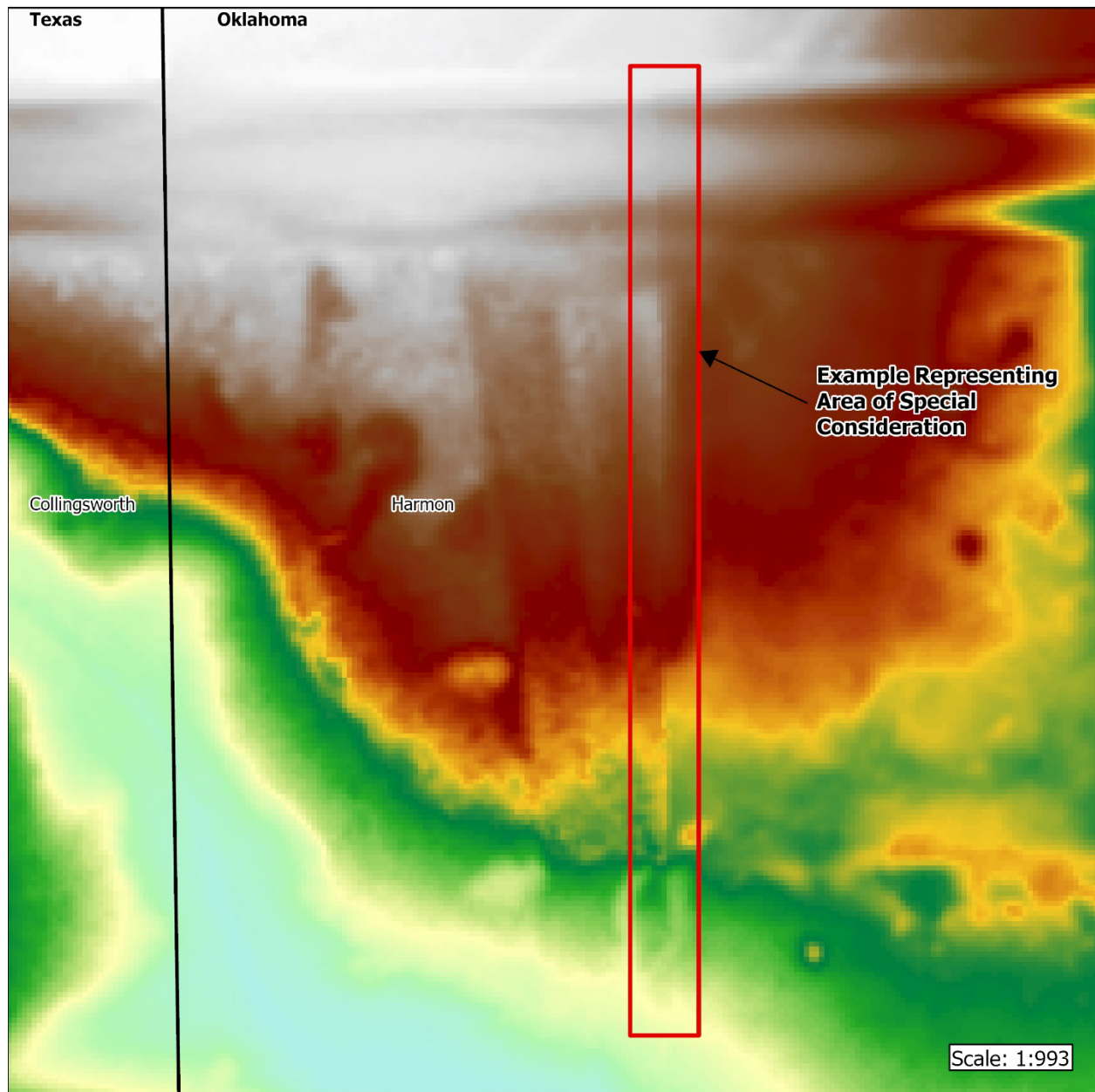


Figure 2-2: Example of a portion of the Special Consideration area.

Table 2-1. LiDAR Data Sources

County	Age/Year	Accuracy	Source & Contact	Approximate Footprint (Sq Mi)
Texas: Collingsworth, Donley, Gray, Wheeler ¹	February 9, 2018 – May 20, 2018	Horizontal ² : USGS QL2 Vertical ³ : DEM VVA RMSEz at 95 th Percentile 0.218 m DEM NVA RMSEz at 95% Confidence Level 0.072 m	United States Geological Survey (USGS)	34,005 ⁴
Oklahoma: Harmon ¹	December 13, 2016 – April 17, 2017	Horizontal ² : 3DEP QL2 Vertical ³ : DEM NVA RMSEz at 95% confidence level 0.092 m DEM NVA RMSEz at 95% confidence level 0.093 m DEM VVA 95 th percentile 0.185 m	United States Geological Survey (USGS)	14,869 ⁴
Oklahoma: Beckham, Greer, Kiowa ¹	December 8, 2011 – February 16, 2012	Horizontal ² : 3DEP QL3 Vertical ³ : NSSDA RMSEz at 95% confidence level 0.08 m	United States Geological Survey (USGS)	Unknown ⁵
Texas: Wilbarger ¹		Horizontal ² : 3DEP QL2 Vertical ³ : 0.090 meters VNA at a 95%	United States Geological Survey (USGS)	42,557 ⁴

County	Age/Year	Accuracy	Source & Contact	Approximate Footprint (Sq Mi)
		confidence level using RMSEz x 1.9600		
Texas: Wilbarger ¹ Oklahoma: Jackson ¹		Horizontal ² : 3DEP QL2 Vertical ³ : 0.090 meters VNA at a 95% confidence level using RMSEz x 1.9600	United States Geological Survey (USGS)	42,557 ⁴

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

²Explicit horizontal accuracy not specified in the report.

³Accuracy derived from original Lidar project report.

⁴Area reported reflects coverage of entire lidar project beyond the current project watershed.

⁵Metadata from project did not specify project footprint.

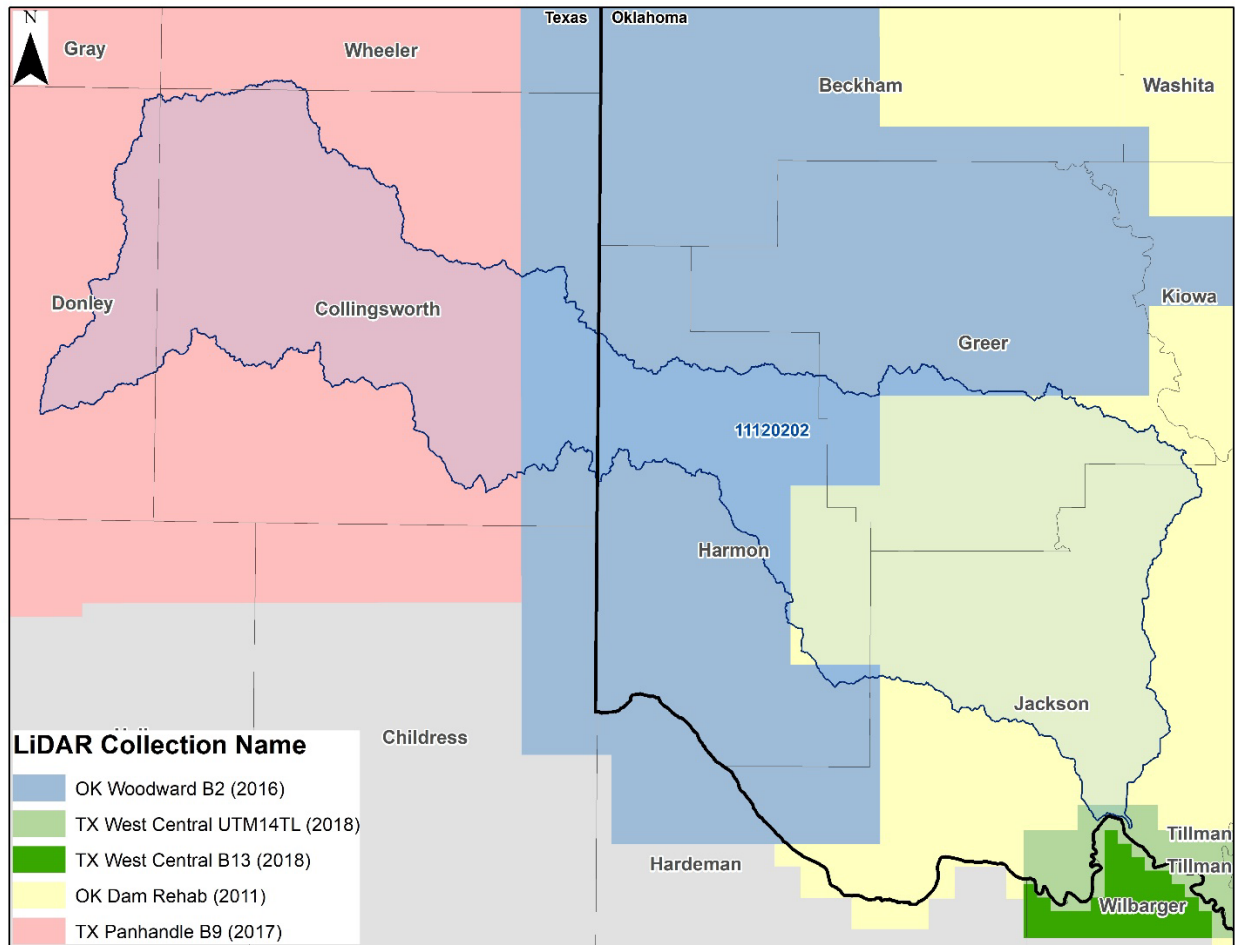


Figure 2-3. Extent and coverage of LiDAR Data as it relates to the project watershed

2.2 Final Seamless DEM

The final DEM developed covers the project watershed, has been re-projected into the local State Plane horizontal coordinate system: NAD 1983 State Plane Texas North FIPS 4201 Feet and the vertical coordinate system of NAVD88 height (ft US). The raster cells values were adjusted from meters to feet. The DEM is a 32-Bit floating point with a single band (1) and 3.28084 by 3.28084 feet cell size.

2.3 Watershed Data Development

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

1. Rasterize the Stream Centerlines
2. DEM Reconditioning
3. Fill Sinks
4. Flow Direction
5. Flow Accumulation (Spatial Analyst Tools)

6. Stream Definition (1 sq. mile threshold used)
7. Stream Segmentation
8. Catchment Grid Delineation
9. Catchment Polygon Processing
10. Drainage Line Processing
11. Adjoin Catchment Processing
12. Watershed Delineation

The final data products from this phase include a geodatabase developed using Arc Hydro tools, a collection of rasters developed using Arc Hydro tools, a geodatabase containing the drainage lines within the study watershed, and a new HUC8 watershed boundary.

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 using the various Arc Hydro and Spatial Analyst processing tools in ESRI's ArcGIS Pro 2.x environment. The hydrography data contains streams that represent drainage of at least 1 square mile, the raw watershed delineation from ArcHydro, updated HUC8 watershed boundary smoothed with a 10-foot tolerance, and a comparison between the NHD HUC8 watershed boundary and the projection watershed delineation.

All data submitted, vector and raster, is in NAD83 Texas North FIPS 4201 (US Foot) NAD 1988 horizontal coordinate system.

2.4.1 Arc Hydro Data Model (Geodatabase and Rasters)

- Geodatabase (.gdb)
 - ArcHydro (feature dataset)
 - Adjoin Catchment – An adjoin 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)
 - Agree DEM (AgreeDEM) – A modified DEM with the rasterized stream centerlines burned into the terrain. A 100-foot burn value was applied to the pixel values along the rasterized stream centerline ensuring the stream centerlines are represented in the Agree DEM. There is now a distinct flow path in the DEM produced by modifying the low values along the linear path of the stream centerlines. This raster is used explicitly for understanding the drainage basins and the flow accumulation values and not intended for purposes where elevation accuracy is important.
 - 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 (Fill) – 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.
- Streams to Burn (StreamsToBurn) – A rasterized version of the stream centerline polyline.
- 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.
- NHD WBD Watershed – The NHD HUC8 boundary downloaded from USGS National Hydrography Dataset representing the project area.
- Raw Watershed Delineation – The direct output from ArcHydro data model of the HUC8 watershed delineation.
- Raw Watershed Delineation Point – The point at which ArcHydro created the Raw Watershed Delineation boundary based on elevations within the Seamless DEM created in Task 1 Phase 1.
- Watershed – A watershed delineation developed through Arc Hydro smoothed to a 10-foot tolerance and based on the elevations within the Seamless DEM created in Task 1 Phase 1.
- Watershed Comparison – A comparison of the Watershed feature class and the NHD WBD HUC8 feature class boundary.

3 Hydrology

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) Version 6.3 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.

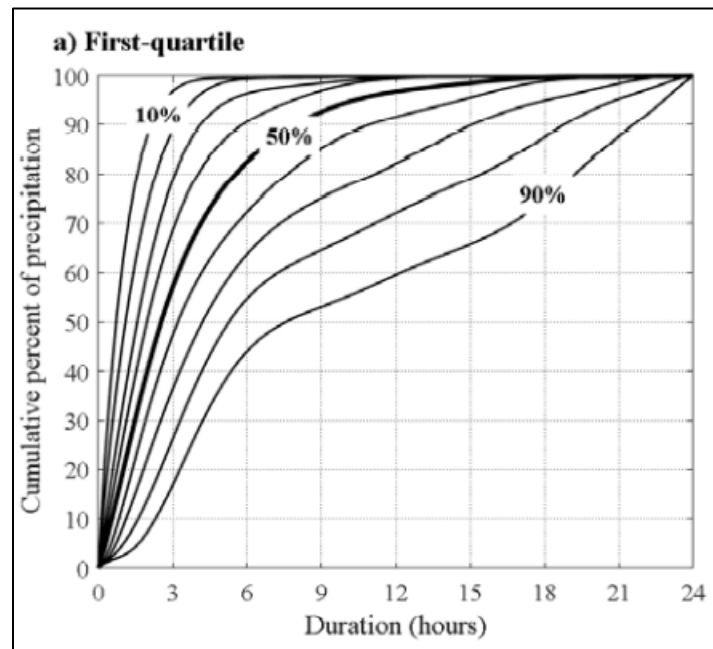


Figure 3-1: Example of temporal distribution curves for first-quartile events with 24-hour duration. Taken from NOAA Atlas 14 Volume 11. Accessed 12/13/2021.

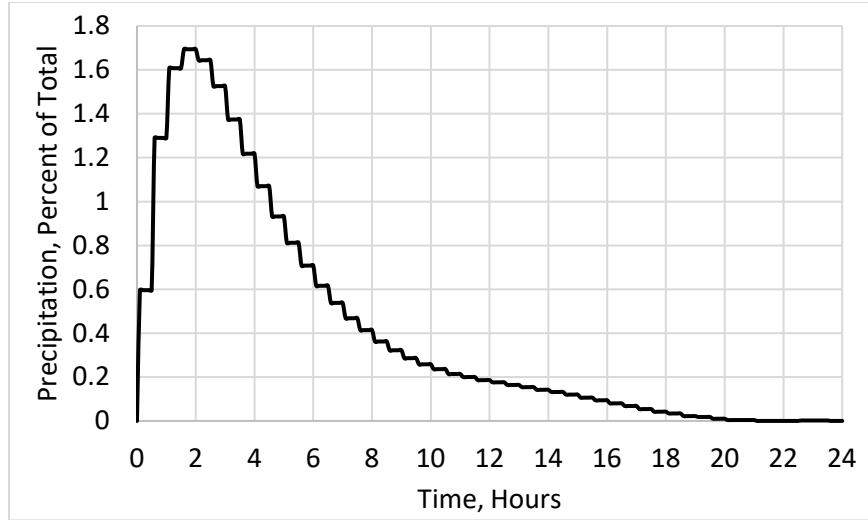


Figure 3-2: Incremental unit hyetograph used to create timeseries of precipitation rasters.

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 Lower Salt Fork Red River 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 3-4 shows a map of the baseline 1-in-100 (1%) annual-chance event rainfall totals for Lower Salt Fork Red River 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 (Figure 3-3), 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. The first quartile event shape was selected because it represents the shape of 49% of historical events for Region 2

Appendix A – Supplemental Hydrology Data (refer to Appendix B for tabular information on event quartiles).

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 (NOAA 2018). The 50% event was selected as a balanced option, not too conservative but also not erroneously overestimating the floodplain. The use of spatially varying precipitation was used to capture the heterogeneity of event magnitude across an individual HUC8 (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 Lower Salt Fork Red River 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 and historic records.

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

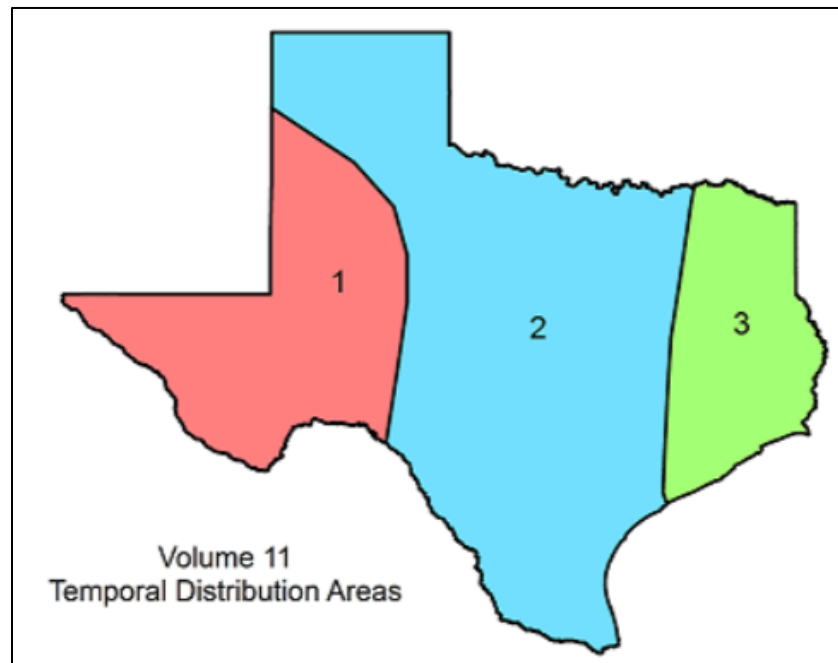


Figure 3-3. NOAA Atlas 14 Volume 11 – Texas Temporal Distribution Areas: Interior Highlands (1), Central Plains (2), and Gulf Coast (3) regions.

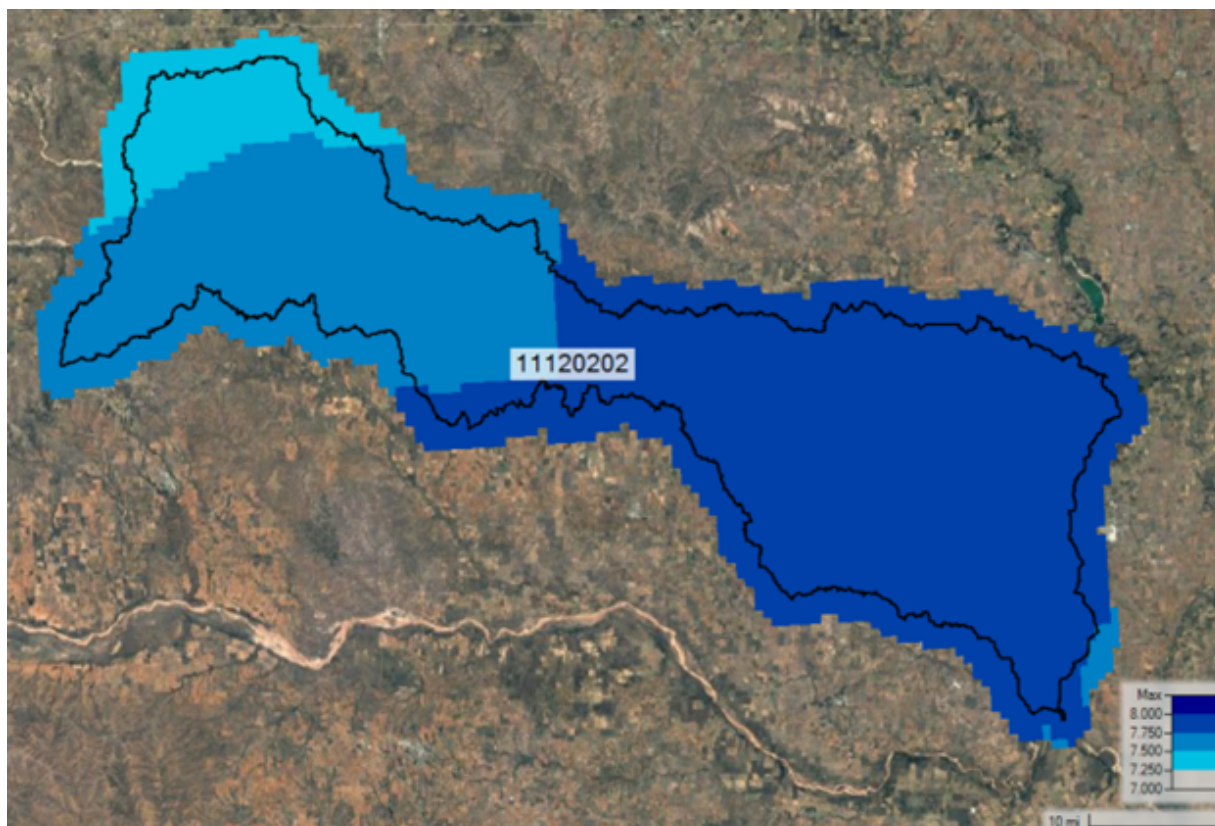


Figure 3-4.Total precipitation (inches) for baseline 1% event across Lower Salt Fork Red River watershed

3.2 Infiltration Parameters

The infiltration layer containing attributes for Soil Conservation Service (SCS; now the Natural Resources Conservation Service (NRCS)) curve numbers (CN), abstraction ratio, and minimum infiltration rate (Table 3-1) 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).

Table 3-1. SCS Hydrologic Soil Groups and Infiltration Parameters (Source: USACE 2022)

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	0.38
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	0.025

* Base minimum infiltration rate chosen based HEC-RAS 6.3 technical guidance manual

A land-use – soils – CN table (Table 3-2) was used to determine 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 3-1) 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 3-2. 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	<i>Open Space – Fair Condition (grass cover 50 – 75%)</i>
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 Deliverables

The hydrology deliverables are summarized with the hydraulics deliverables in Section 4.8 for the combined Task 2 deliverables.

4 Hydraulics

The hydraulic approach for the Lower Salt Fork Red River watershed's BLE analysis consisted of developing HUC 10-scale two-dimensional (2D) hydraulic models with the Hydrologic Engineering Center's River Analysis System (HEC-RAS) program version 6.3. 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 Lower Salt Fork Red River watershed consisted of five HUC 10 catchments resulting in the creation of five HUC10-scale models, listed below from upstream to downstream:

- Richardson Creek-Salt Fork Red River 1112020201
- Sand Creek-Salt Fork Red River 1112020202
- Cave Creek-Salt Fork Red River 1112020203
- Turkey Creek 1112020204
- Bitter Creek-Salt Fork Red River 1112020205

The models were coupled through outflow and inflow boundary conditions in order to create a unified floodplain which is described in section 4.5. Each model was developed with consistency by applying the same parameters and procedures described in this chapter. Unique variances from these procedures are noted and described in sections 4.2 to 4.5 as applicable to each model.

4.1 2D Computational Mesh and Settings

The base computational mesh for the models in the Lower Salt Fork Red River watershed was developed at a 200 ft x 200 ft grid cell size. Breaklines and refinement regions were implemented to create a higher mesh resolution for both channels with contributing drainage area of at least 1 square mile (0.5 square mile for populated areas) and in areas of terrain elevation change, which is detailed further in section 4.2. The total number of mesh elements and average cell size varies per HUC 10 model; spatial parameters of each HUC 10 model for the Lower Salt Fork Red River watershed are summarized in Table 4-1.

Table 4-1. HUC 10 Mesh Parameters

HUC 10 Model Name and Number	Size of Study Area (sq mi)	Number of Mesh Elements (grid cells)	Average cell size (sq ft)
Richardson Creek-Salt Fork Red River (1112020201)	311.86	317,381	27,393
Sand Creek-Salt Fork Red River (1112020202)	214.80	213,366	28,066
Cave Creek-Salt Fork Red River (1112020203)	190.22	203,449	26,355

Turkey Creek (1112020204)	318.46	315,430	28,146
Bitter Creek-Salt Fork Red River (1112020205)	253.44	259,926	27,182

4.1.1 Model Computational Settings

Models were run using the Diffusion Wave equation set for 2D flow using an adaptive 30-second timestep for each frequency event discussed in this report. Diffusion Wave (simplified Full Momentum) 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 6.3 2D user's manual.

An adaptive 30-second timestep was applied to iteratively control the maximum courant number below 2 for the duration of each simulation. With the advanced timestep controls in RAS, the adaptive timestep was set with a max allowance of 240 seconds, and a minimum of 3.75 seconds. The default 2D flow options were applied for the multi-frequency runs.

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 100 ft x 100 ft) on a case-by-case basis per engineering judgement. The development of these features is described in the following sections.

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 primary breaklines for the Lower Salt Fork Red River watershed is shown in Figure 4-1. Smaller breaklines, enforced for additional hydraulically significant features, are not shown in Figure 4-1 for simplicity but vary on a per-model basis.

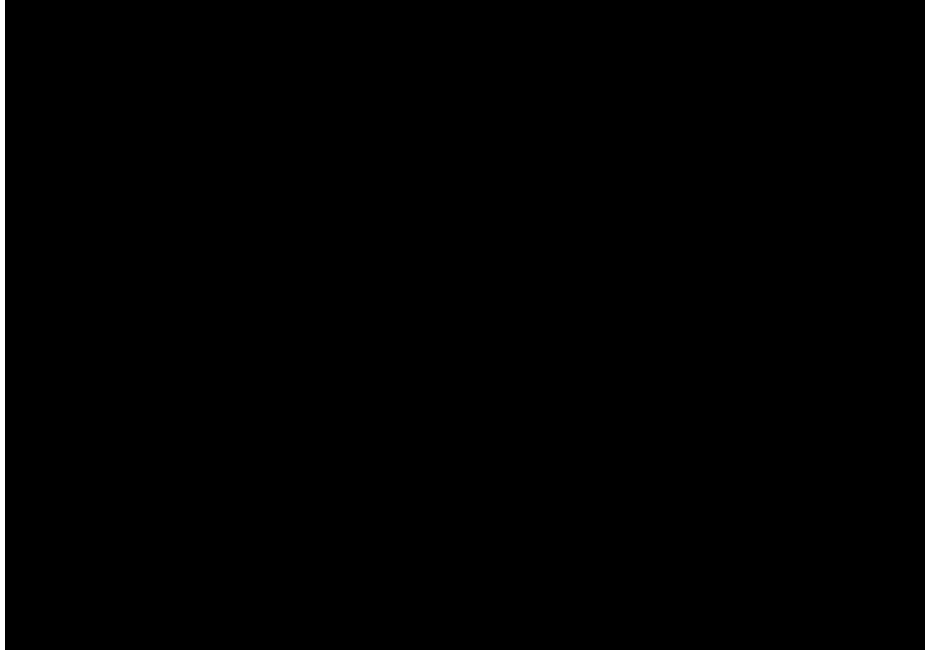


Figure 4-1. Overview of HUC 8 Scale Breaklines for Lower Salt Fork Red River watershed

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 the bank full flow (Figure 4-2).

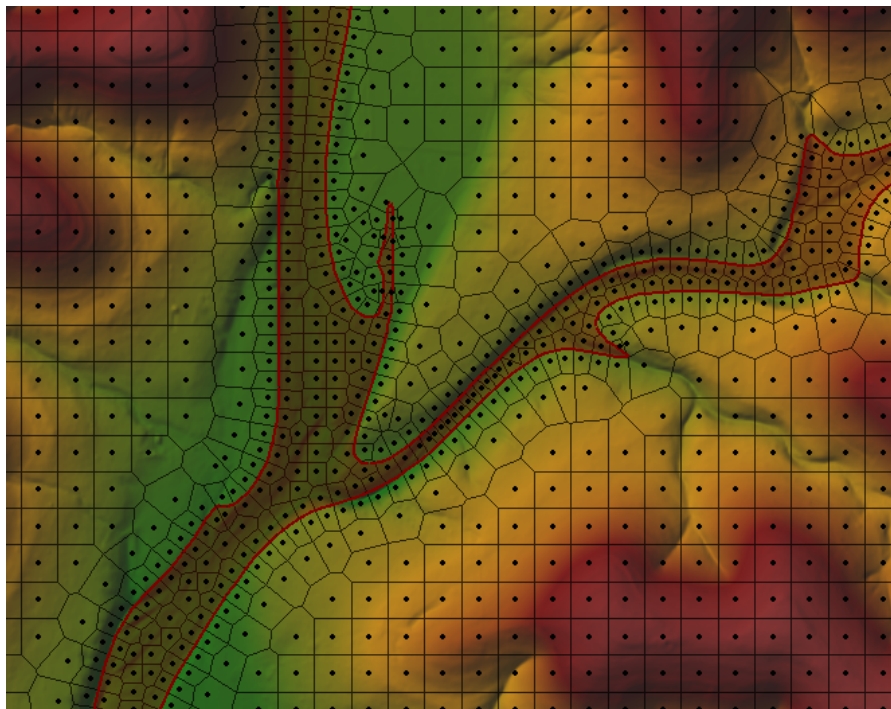


Figure 4-2. Example of Refinement Region Polygon

The refinement region polygon was created using a proprietary ArcGIS python toolbox. The process used a coarse-run (1000x1000-ft cells) 10-year inundation raster in conjunction with orthographically corrected stream centerlines. Aerial imagery and the terrain DEM were used to make any necessary adjustments to the toolbox polygon to capture bank-full extents more accurately. The processed polygon was imported into the model geometry as a refinement region in the HEC-RAS geometry. An overview of the refinement regions for the Lower Salt Fork Red River watershed is shown in Figure 4-3.

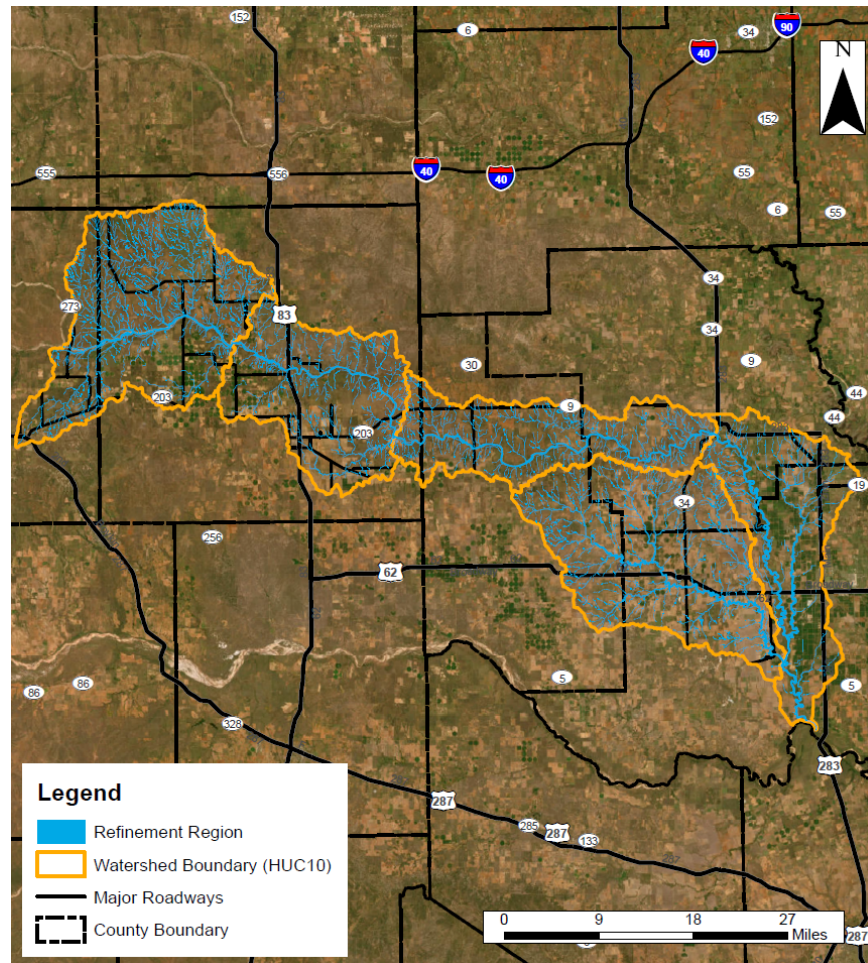


Figure 4-3. Overview of HUC 8 Scale Mesh Refinement Regions for Lower Salt Fork Red River Watershed

4.3 Manning's Roughness Coefficients and Land Use

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 values for a given land-cover were taken from a table reported by NRCS in 2016, developed based on a 2D modeling study for Kansas (Table 4-2). This table was selected provided the values are within the range of values provided by the HEC-RAS 2D manual and appear to compare well with aerial imagery.

Table 4-2: Manning's N Values Applied in Base Models

Land Use Classification	Allowable Range of n values	Lower Salt Fork Red 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	0.120
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 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.

4.4 Terrain Modification

Terrain modifications were made through the HEC-RAS layer modifications feature in RASMapper Version 6.3. Direct modifications were not made to the original terrain. A modifications layer was added to each model terrain to apply Hydrologic Connectors (HCs) which allow flow to be conveyed through structures, such as roadway culverts, that the original DEM otherwise impedes (Figure 4-4). HC width was estimated based on LiDAR features and aerial imagery and the minimum HC width applied is 7 ft. In HUC 1112020205 additional terrain modifications were made to fill in the existing irrigation canals to eliminate their conveyance capacity, as the irrigation system is intended to act independent of flood control measures in the watershed. These modifications were made by raising the terrain using levees between berms to avoid interactions between the irrigation canals and the stormwater runoff being modeled. The irrigation canals are discussed in more detail in Section 4.7.2.

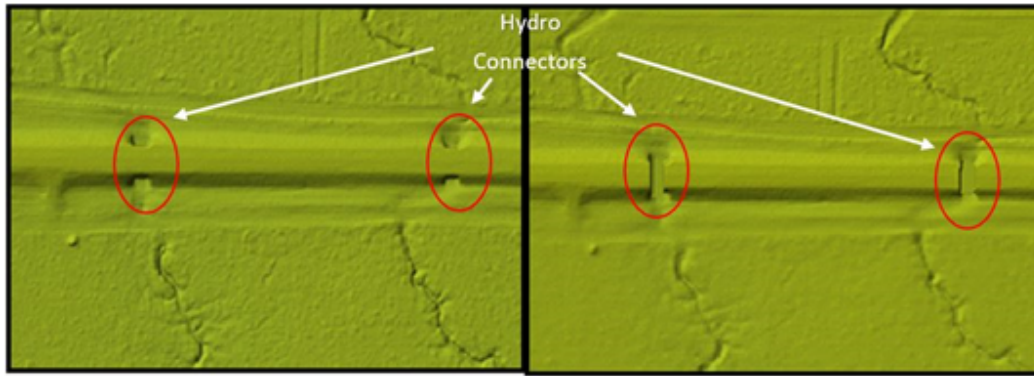


Figure 4-4. Example of localized original terrain (left) and terrain after addition of modification layer (right)

4.5 HUC 10 Model Integration

A diagram showing inter-basin connectivity and boundary condition (BC) locations for the Lower Salt Fork Red River watershed is included in Figure 4-5.

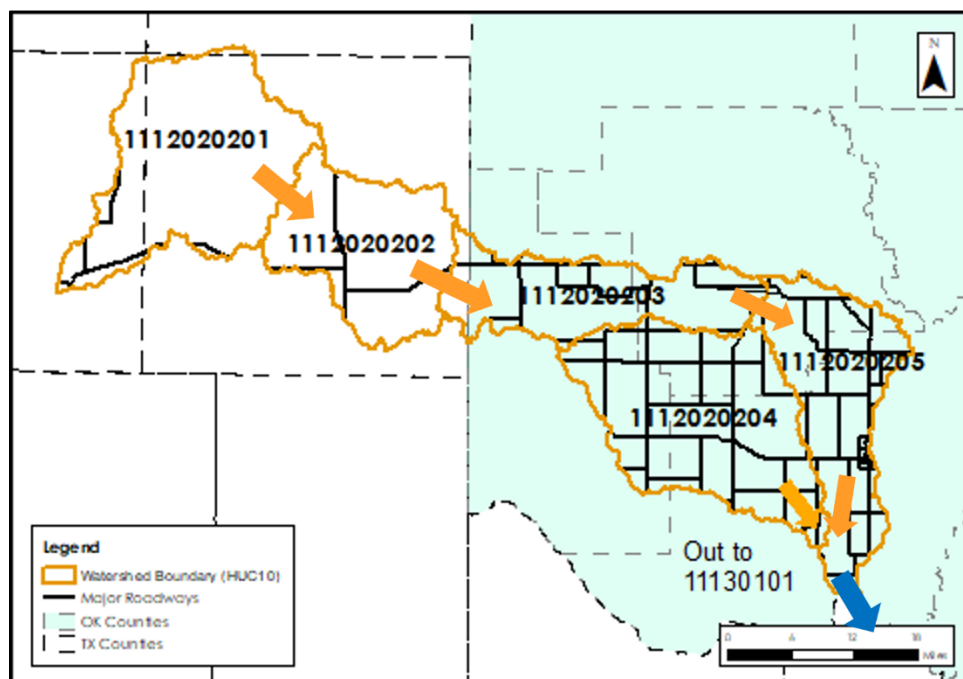


Figure 4-5. Overview of HUC 8 with HUC 10 Model Connectivity

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 BCs. The upstream SA/2D location was isolated based on a normal depth sensitivity analysis where the placement distance from the downstream BC was determined by the location of channel WSEL convergence for runs of varying normal depth BC values (Figure 4-6). This was done in order to minimize the margin of error in

floodplain delineation due to potential inaccuracies in normal depth input in the upstream model's downstream BC.

The channel characteristics within HUC8 11120201 required the SA/2D connector to be located within the upper main stem of HUC10 1112020201. The modeling coverage upstream of this SA/2D connector is provided by the HUC10 1112020102, included in this submission.

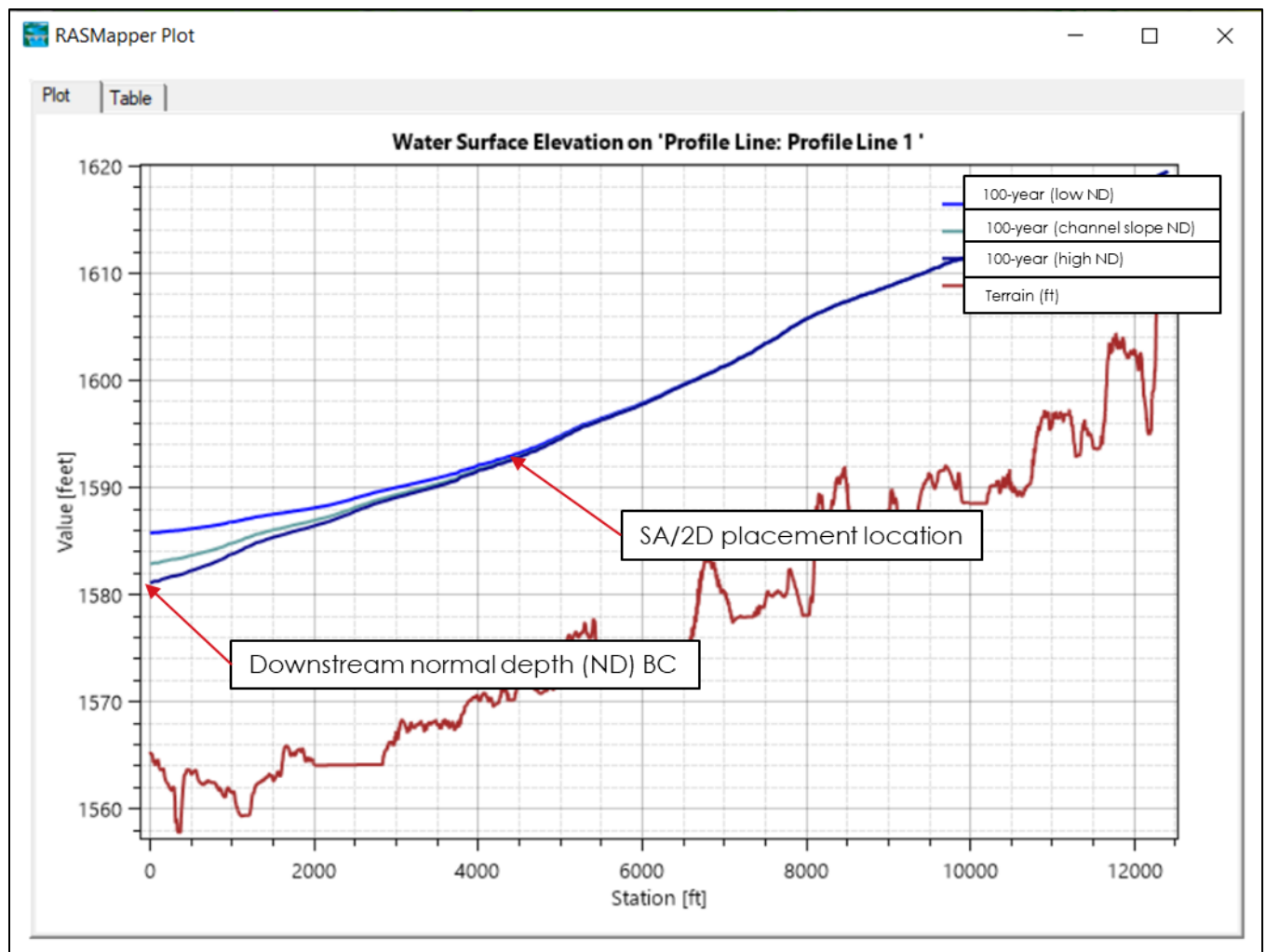


Figure 4-6. SA/2D Normal Depth sensitivity and placement example

The upstream and downstream model meshes were modified from the USGS HUC 10 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 Lower Salt Fork Red River watershed models are shown in Figure 4-7. In locations

where the models overlap the downstream model's water surface elevation and flow in the receiving model represents the overlapped area.

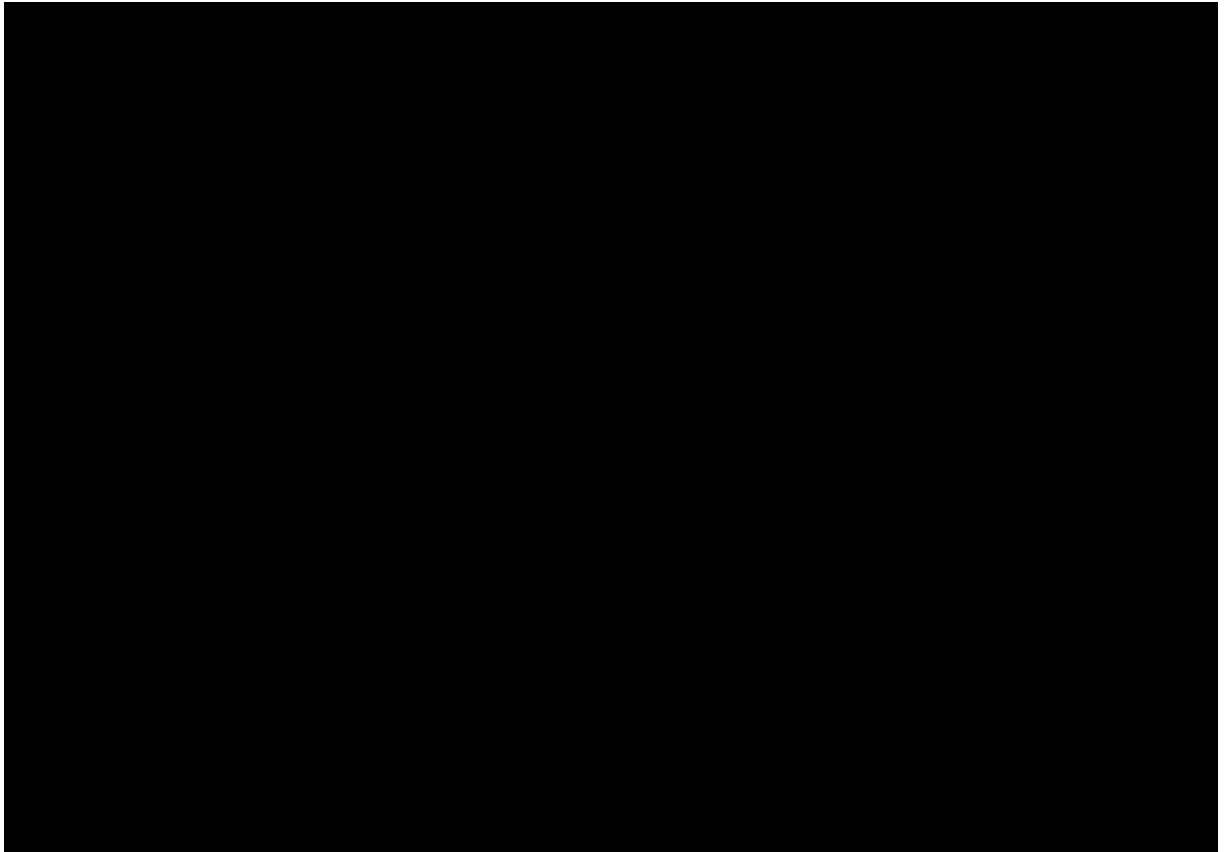


Figure 4-7. Overview of Adjusted Model Domains

The SA/2D connections were calibrated to ensure continuity of both flow and water surface elevation (+/- 0.5 ft) between upstream and downstream models. Flow hydrograph inflows were calibrated by setting the initial Energy Grade (EG) slope of the boundary condition as the channel slope derived from the terrain. The flow transfer locations were calibrated by adding a channel n-value override region in the upstream or downstream model to maintain modeled WSEL continuity between models. In locations where model integration was challenging the EG was iteratively adjusted to reflect modeled EG. The BCs for each model are described in more detail in the following sections. Final continuity metrics for the Lower Salt Fork Red River watershed are summarized in Table 4-3.

Table 4-3. HUC 10 Model Integration Summary

Upstream Model Name and Number	Downstream 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)
Upper Salt Fork Red HUC8 (11120201)	Richardson Creek –Salt Fork Red River (1112020201)	1	1,000	0.00	0.0
Richardson Creek – Salt Fork Red River (1112020201)	Sand Creek-Salt Fork Red River (1112020202)	2	4,000	0	0.0
			9,900	0	0.4
Sand Creek-Salt Fork Red River (1112020202)	Cave Creek- Salt Fork Red River (1112020203)	2	7,400	2	0.1
			3,100	0	0.3
Cave Creek – Salt Fork Red River (1112020203)	Bitter Creek – Salt Fork Red River (1112020205)	1	8,200	0	0.2
Turkey Creek (1112020204)	Bitter Creek – Salt Fork Red River (1112020205)	1	5,900	0	0.9*

*The SA/2D location was outside of the +/- 0.5 ft WSEL difference metric. The mapping for this interval was tied-in, within 0.5 ft, downstream of the SA/2D location within the overlap region between models.

4.5.1 HUC8 Upper Salt Fork Red (11120201) to HUC10 Richardson Creek – Salt Fork Red River (1112020201)

The HUC8 11120201 and HUC10 1112020201 models overlap for a distance of approximately 3,100 feet upstream of the HUC10 1112020201 USGS boundary perimeter, and approximately 1,300 ft upstream of the TX-273 bridge near Hudley, TX. The extent of the model overlap is shown in Figure 4-8. Outflow from the upstream model was captured using an SA2D connection at the tie-in location and applied using a flow hydrograph boundary condition in the downstream model at the tie-in location. The energy grade slope for distributing flow along the boundary condition line was set at 0.003557 ft/ft based on terrain measurements. The Manning’s n roughness coefficient applied to the refinement regions within the overlap area was staggered to go from 0.05 to 0.045 and back up to 0.05 to tie-in with the 0.055 Manning’s n value within HUC 10 1112020201. This was done to match peak stage within 0.5 ft between the upstream model and the downstream model at the tie-in location. Continuity between the HUC10 1112020102 and HUC10 1112020201 is summarized in Table 4-4 below.

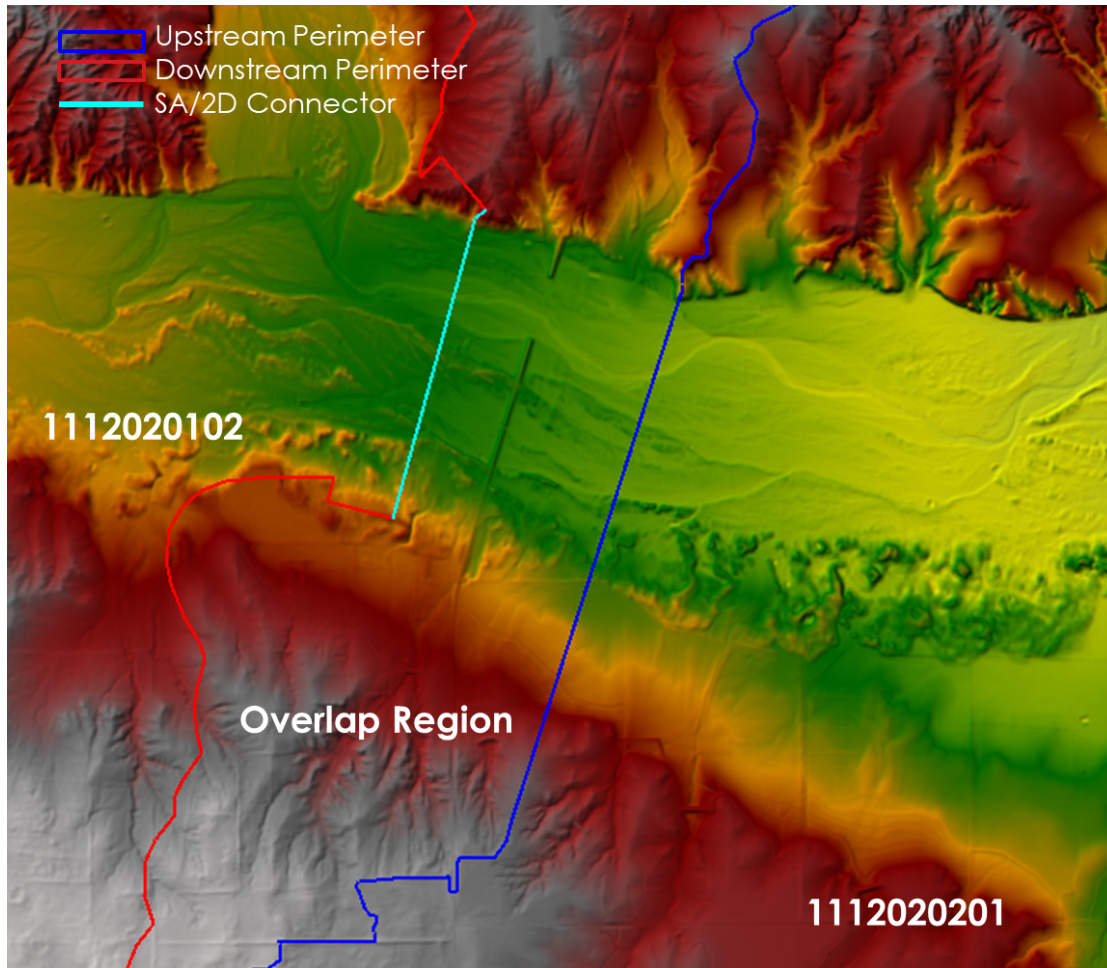


Figure 4-8. HUC10 1112020102 and HUC10 1112020201 Boundary Plan View

Table 4-4. HUC10 1112020102 and HUC10 1112020201 Continuity – all modeled events

Annual- chance Event	HUC10 1112020102 (Upstream)		HUC10 1112020201 (Dowstream)		Absolute Difference	Absolute Difference
Event	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)
10pct	2,251.5	9,285	2,251.5	9,285	0.0	0.0
4pct	2,253.1	19,694	2,253.0	19,694	0.0	0.0
2pct	2,254.1	30,433	2,254.1	30,433	0.0	0.0
1pct	2,255.1	44,275	2,255.1	44,275	0.1	0.0
0_2pct*	2,257.4	97,738	2,258.0	97,738	0.6	0.0
1PLUpct	2,256.4	71,279	2,256.8	71,279	0.4	0.0
1MINpct	2,253.6	24,427	2,253.5	24,427	0.0	0.0

*The SA/2D location was outside of the +/- 0.5 ft WSEL difference metric. The mapping for this interval was tied-in, within 0.5 ft, downstream of the SA/2D location within the overlap region between models.

4.5.2 Richardson Creek – Salt Fork Red River (1112020201) and Sand Creek – Salt Fork Red River (1112020202)

The HUC10 1112020201 to HUC10 1112020202 models overlap for a distance of approximately 3,700 ft upstream of the HUC10 1112020202 USGS boundary perimeter near Samnorwood, TX. The extent of the model overlap is shown by the yellow perimeter and the SA/2D connectors are depicted by the purple lines in Figure 4-9. Outflow from the upstream model was captured using two SA/2D connectors with one placed along the main stream, called Outflow_LowerSaltForkRed_201_1, and the other along a northern tributary, called Outflow_LowerSaltForkRed_201_2. Outflow data was then used to apply a flow hydrograph boundary condition to the downstream model at the tie-in location. The energy grade slope for distributing flow along the boundary condition line was set at 0.002051 ft/ft for Outflow_201_Main and at 0.003323 ft/ft for Outflow_201_Nort based on terrain measurements. A Manning's n roughness coefficient of 0.06 was applied to refinement regions along the main channel within the overlap area to match peak stage within 0.5 ft between the upstream model and the downstream model at the tie-in location. To tie-in the northern tributary within the overlap region, Manning's n values would change by 0.005 at a time and ranged from 0.06 to 0.07. Continuity between the HUC10 1112020201 and HUC10 1112020202 is summarized below in Table 4-5 and Table 4-7 below.

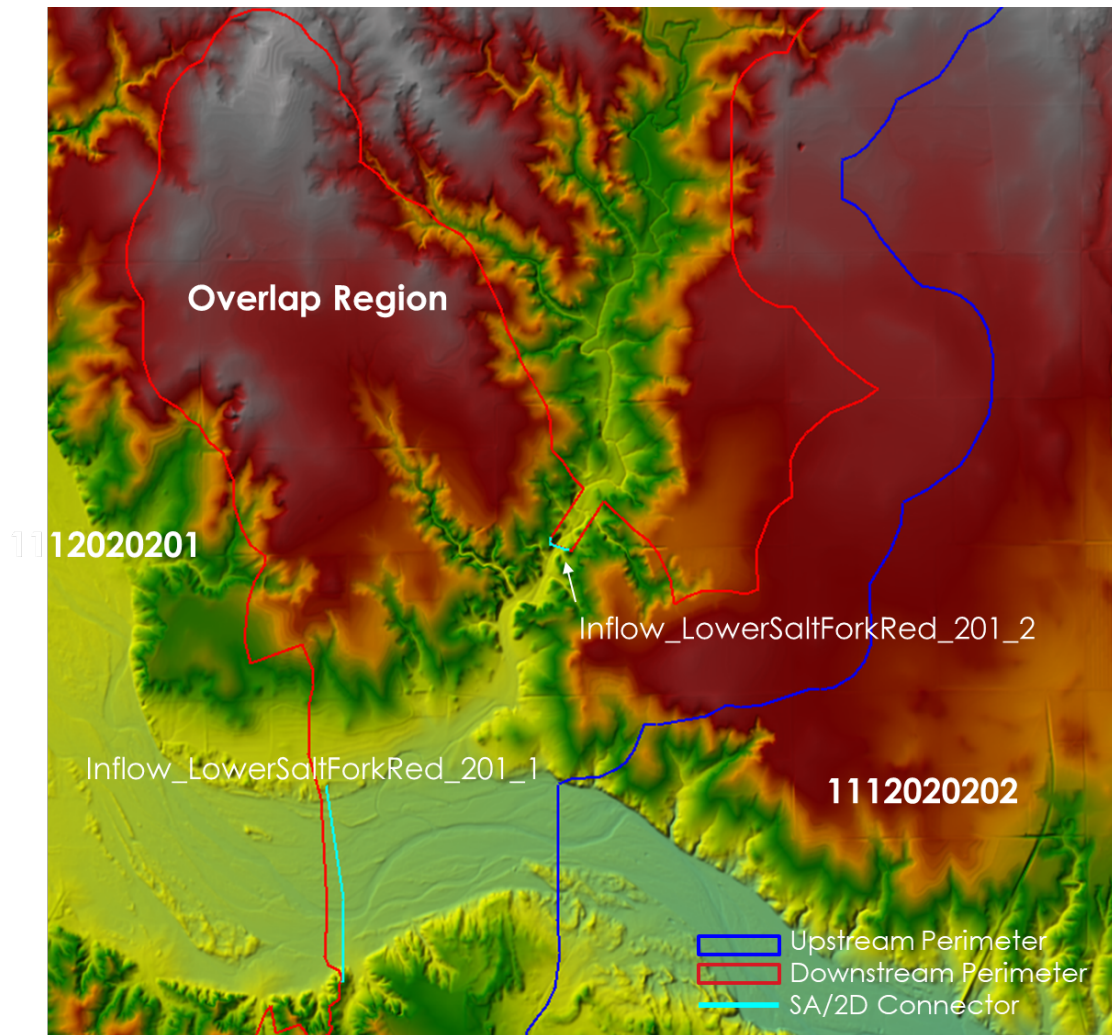


Figure 4-9. HUC 1112020201 and HUC 1112020202 Boundary Plan View

Table 4-5. Outflow_201_Main and Inflow_201_Main Continuity – all modeled events

Annual- chance Event	HUC10 201 (Upstream)		HUC10 202 (Dowstream)		Absolute Difference	Absolute Difference
	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)
10pct	2,020.4	11,653	2,020.5	11,653	0.1	0.0
4pct	2,021.8	24,735	2,021.9	24,735	0.2	0.0
2pct	2,023.0	39,086	2,023.2	39,086	0.2	0.0
1pct	2,024.4	58,370	2,024.7	58,370	0.3	0.0
0_2pct	2,028.7	131,646	2,029.1	131,646	0.4	0.0
1PLUpct	2,026.7	94,660	2,027.0	94,660	0.4	0.0
1MINpct	2,022.3	31,100	2,022.5	31,100	0.2	0.0

Table 4-6. Outflow_201_Nort and Inflow_201_North Continuity – all modeled events

Annual-chance Event	HUC10 201 (Upstream)		HUC10 202 (Dowstream)		Absolute Difference	Absolute Difference
Event	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)
10pct*	2,045.2	1,695	2,044.5	1,695	0.7	0.0
4pct*	2,046.3	2,737	2,045.7	2,737	0.6	0.0
2pct	2,047.2	3,679	2,046.6	3,679	0.5	0.0
1pct	2,048.0	4,790	2,047.5	4,790	0.5	0.0
0_2pct	2,049.9	8,270	2,049.7	8,270	0.3	0.0
1PLUpct	2,049.1	6,615	2,048.8	6,615	0.3	0.0
1MINpct*	2,046.7	3,197	2,046.2	3,197	0.6	0.0

*The SA/2D location was outside of the +/- 0.5 ft WSEL difference metric. The mapping for this interval was tied-in, within 0.5 ft, downstream of the SA/2D location within the overlap region between models.

4.5.3 Sand Creek-Salt Fork Red River (1112020202) and Cave Creek- Salt Fork Red River (1112020203) Boundary

The HUC10 1112020202 to HUC10 1112020203 models overlap for a distance of approximately of 7,320 ft of the HUC10 1112020203 USGS boundary perimeter near downstream of State Highway 203 TX. The extent of the model overlap is shown by the yellow perimeter in Figure 4-9. Outflow from the upstream model was captured using two SA2D connections at the tie-in location (i.e., the north of the overlap area and far southwest overlap area). Outflow data was then used to apply a flow hydrograph boundary condition to the downstream model at the tie-in location. The Energy Grade slope for distributing flow along the boundary condition line was set at 0.00142 ft/ft based on terrain measurements. A Manning's n roughness coefficient of 0.060 was applied to refinement regions within the overlap area to match peak stage within 0.5 feet between the upstream model and the downstream model at the tie-in location. Continuity between the HUC 1112020202 and HUC 1112020203 models is summarized in Table 4-7 and Table 4-8 below.

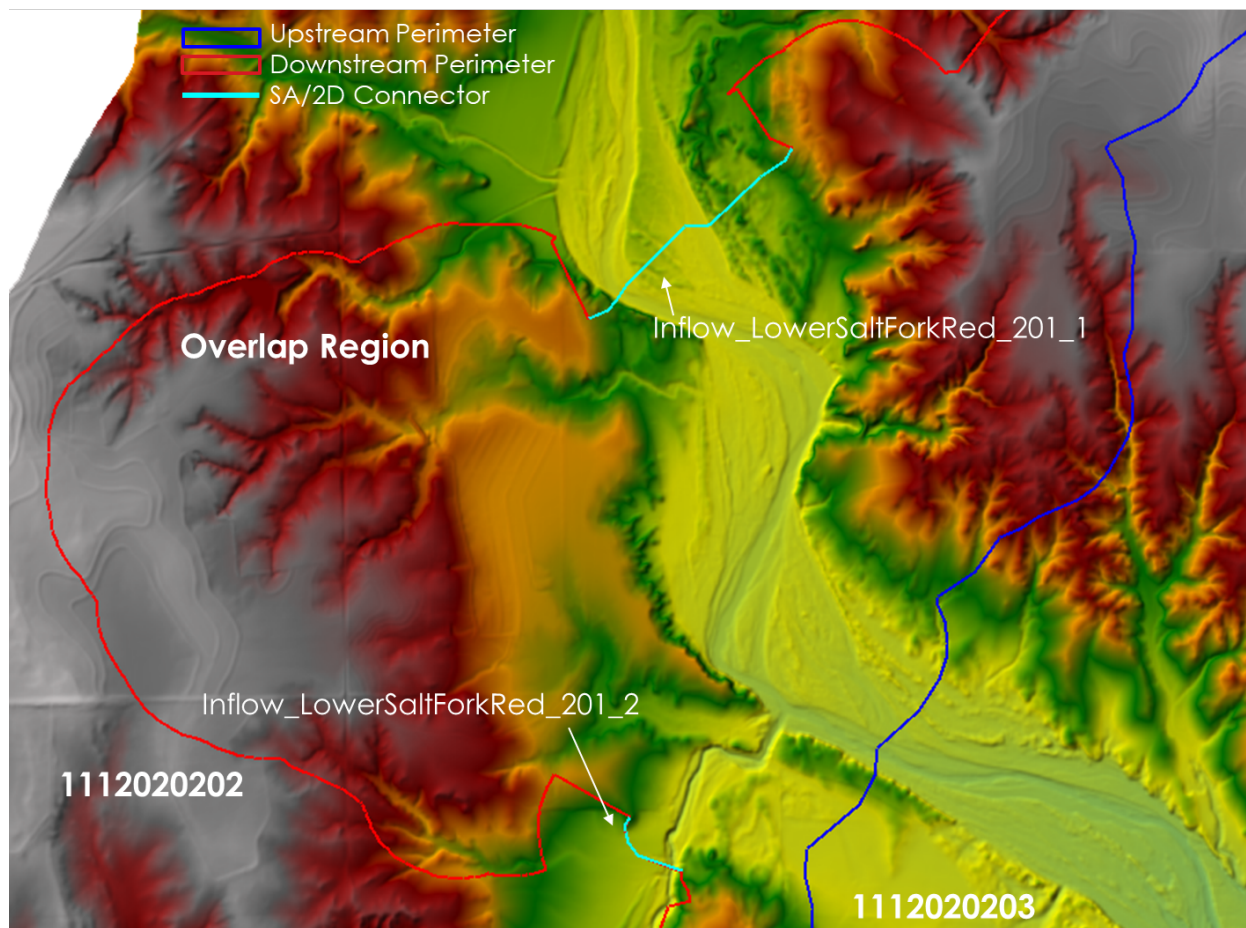


Figure 4-10. 111202022 and HUC 111202023 Boundary Plan View

Table 4-7. HUC10 111202022 and HUC10 111202023 -1 Continuity– all modeled events

Annual - chance Event	HUC202 (Upstream)		HUC203(Downstream)		Absolute Difference	Absolute Difference
	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)
10pct	1,811.7	12,071	1,811.2	12,071	0.5	0.0
4pct	1,814.0	25,133	1,813.8	25,133	0.2	0.0
2pct	1,815.9	39,443	1,815.8	39,443	0.1	0.0
1pct	1,818.1	58,925	1,818.0	58,925	0.0	0.0
0_2pct	1,824.0	131,901	1,824.0	131,901	0.0	0.0
1PLUpct	1,821.4	95,545	1,821.3	95,545	0.1	0.0
1MINpct	1,814.9	31,629	1,814.8	31,629	0.1	0.0

Table 4-8. HUC10 11120202 and HUC10 11120203 -2 Continuity– all modeled events

Annual- chance Event	HUC202 (Upstream)		HUC203(Downstream)		Absolute Difference	Absolute Difference
Event	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)
10pct*	1,806.1	3,577	1,807.1	3,577	1.0	0.0
4pct*	1,808.2	6,465	1,809.3	6,465	1.1	0.0
2pct*	1,809.5	9,224	1,810.8	9,224	1.3	0.0
1pct*	1,810.7	12,525	1,812.3	12,525	1.6	0.0
0_2pct*	1,814.5	22,406	1,815.3	22,406	0.8	0.0
1PLUpct*	1,812.3	17,759	1,814.1	17,759	1.8	0.0
1MINpct*	1,808.8	7,765	1,810.0	7,765	1.2	0.0

*The SA/2D location was outside of the +/- 0.5 ft WSEL difference metric. The mapping for this interval was tied-in, within 0.5 ft, downstream of the SA/2D location within the overlap region between models.

4.5.4 Cave Creek – Salt Fork Red River (1112020203) and Bitter Creek – Salt Fork Red River (1112020205) Boundary

The HUC 112020203 and 112020205 models overlap for a distance of approximately 8,200 feet upstream of the State Highway 34 bridge near Mangum, OK. The extent of the model overlap is shown by the yellow perimeter in Figure 4-9. Outflow from the upstream model was captured using an SA2D connection at the tie-in location (i.e. the upstream limit of the overlap area). Outflow data was then used to apply a flow hydrograph boundary condition to the downstream model at the tie-in location. The Energy Grade slope for distributing flow along the boundary condition line was set at 0.001 ft/ft based on terrain measurements. A Manning's n roughness coefficient of 0.060 was applied to refinement regions within the overlap area to match peak stage within 0.5 feet between the upstream model and the downstream model at the tie-in location. Continuity between the HUC 1112020203 and HUC 1112020205 models is summarized in Table 4-9 below.

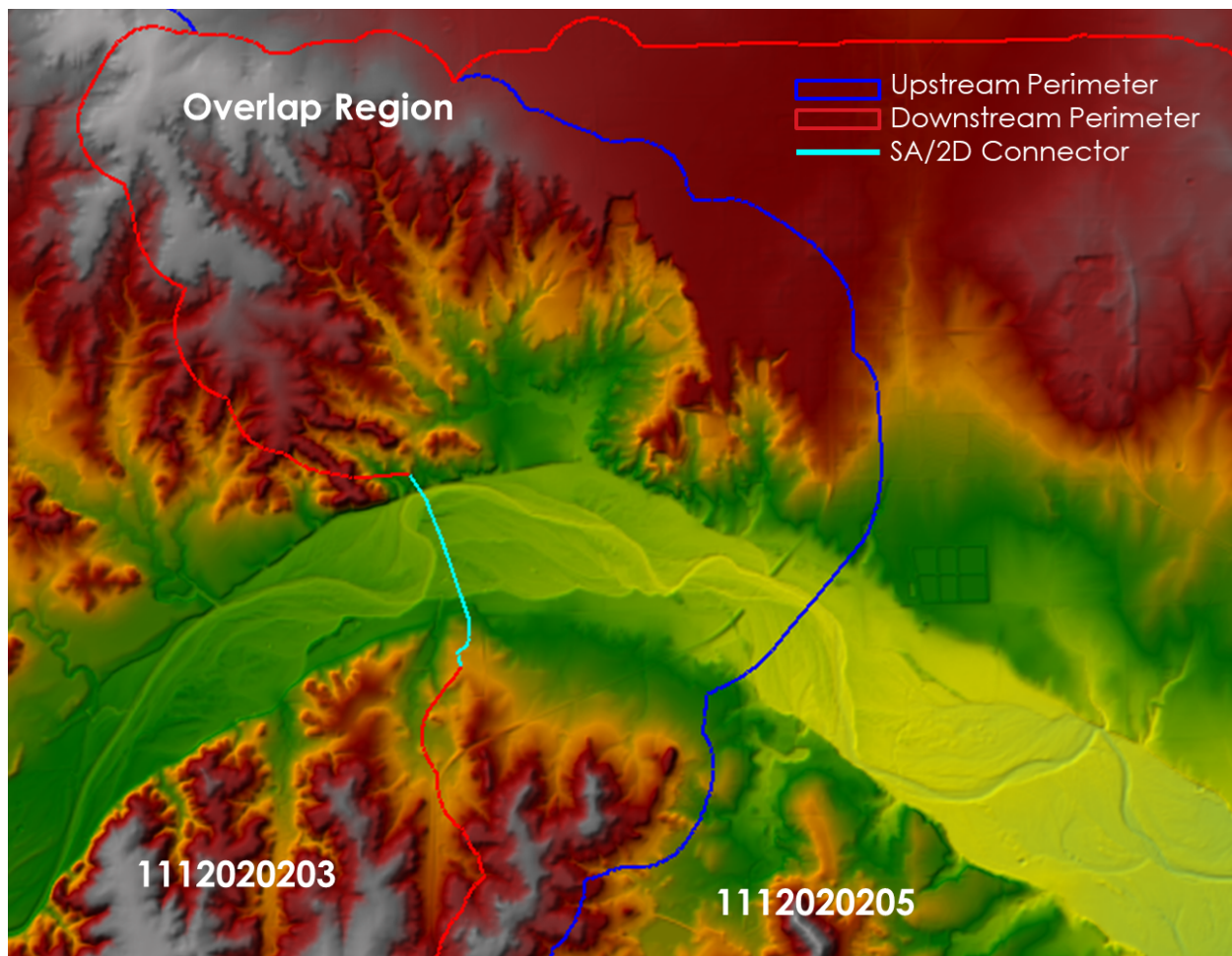


Figure 4-11. HUC 1112020203 and HUC 1112020205 Boundary Plan View

Table 4-9. HUC 1112020203 Outflow and HUC 1112020205 Inflow Continuity – all modeled events

Annual-chance Event	HUC10 203 (Upstream)		HUC10 205 (Downstream)		Absolute Difference	Absolute Difference
	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)
10pct	1,521.9	11,920	1,521.9	11,920	0.0	0.0
4pct	1,516.2	24,358	1,516.0	24,355	0.2	3.4
2pct	1,521.3	38,105	1,521.3	38,105	0.0	0.0
1pct	1,519.5	56,827	1,519.5	56,827	0.0	0.0
0_2pct	1,524.8	125,457	1,524.8	125,457	0.0	0.0
1PLUpct	1,522.4	91,458	1,522.4	91,458	0.0	0.0
1MINpct	1,521.6	30,572	1,521.6	30,571	0.0	0.7

4.5.5 Turkey Creek (1112020204) and Bitter Creek – Salt Fork Red River (1112020205) Boundary

The HUC 112020204 and 112020205 models overlap for a distance of approximately 5,900 feet upstream of the confluence of Turkey Creek and the Salt Fork Red River near Olustee, OK. The extent of the model overlap is shown by the yellow perimeter in Figure 4-10. Outflow from the upstream model was captured using an SA2D connection at the tie-in location (i.e. the upstream limit of the overlap area). Outflow data was then used to apply a flow hydrograph boundary condition to the downstream model at the tie-in location. The Energy Grade slope for distributing flow along the boundary condition line was set at 0.001 ft/ft based on terrain measurements. A Manning's n roughness coefficient of 0.060 was applied to refinement regions within the overlap area to match peak stage within 0.5 feet between the upstream model and the downstream model at the tie-in location. Continuity between the HUC 1112020204 and HUC 1112020205 models is summarized in Table 4-10 below.

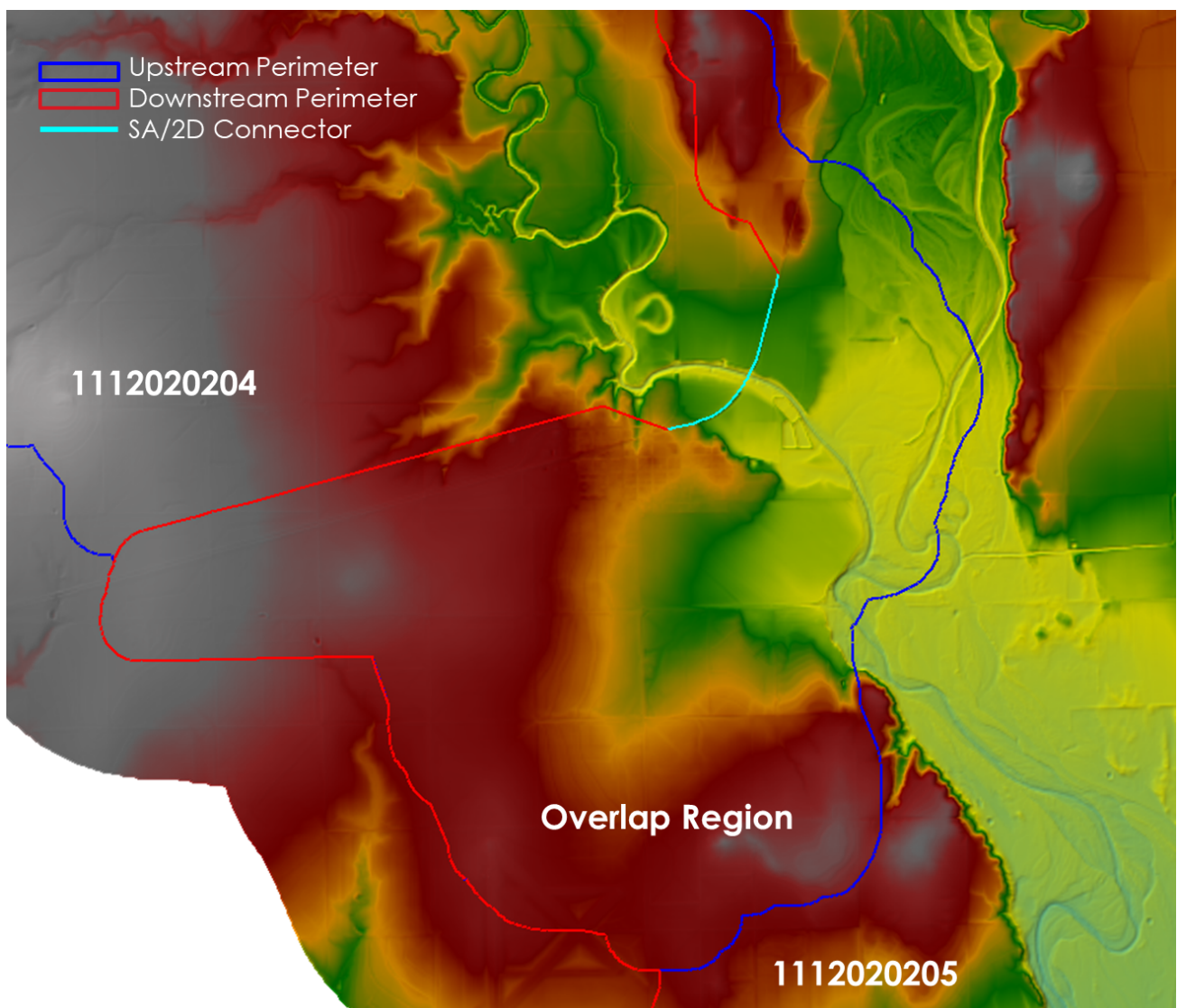


Figure 4-12. HUC 1112020204 and HUC 1112020205 Boundary Plan View

Table 4-10. HUC 1112020204 Outflow and HUC 1112020205 Inflow Continuity – all modeled events

Annual-chance Event	HUC10 204 (Upstream)		HUC10 205 (Downstream)		Absolute Difference	Absolute Difference
Event	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)	Max WSEL (ft)	PeakFlow (Cfs)
10pct	1,312.0	15,728	1,312.0	15,728	0.0	0.0
4pct	1,313.8	25,537	1,313.7	25,537	0.1	0.0
2pct	1,315.0	35,216	1,314.9	35,216	0.1	0.0
1pct	1,316.2	46,709	1,316.0	46,709	0.2	0.0
0_2pct	1,318.6	81,478	1,318.2	81,478	0.4	0.0
1PLUpct	1,317.5	63,242	1,317.2	63,242	0.3	0.0
1MINpct	1,314.6	31,842	1,314.5	31,842	0.1	0.0

4.6 Calibration and Validation

Model parameter adjustments and calibration in the Task Order #2 BLE study were performed for models encompassing USGS gages with a minimum of 10 years of record. Model adjustments were based on estimates of a 1% annual chance peak flow values but did not consider hydrograph timing or flow volume. Table 4-11 summarizes modeled peak flows and the Bulletin 17C flood frequency analysis at each USGS gage. Peak flows at each gage are within the confidence limits of the Bulletin 17C analysis and did not require model parameter adjustments. No model adjustments were made based on USGS regional regression estimates.

The Lower Salt Fork Red River watershed models are shown below in Figure 4-13. The three USGS gages containing 10 or more years of record considered for calibration are shown below. Gage extension was not considered as part of this study. Calibration was based on the 1% annual chance peak flow values estimates from a Bulletin 17C statistical flood frequency analysis using the USGS program PeakFQ. A 2021 Texas regional skew factor was also applied (England et. al 2018; Cleveland and Fang 2021). A technical memo describing the Bulletin 17C analyses for gages in the Task Order 2 study area, as well as raw PeakFQ output for gages in Lower Salt Fork Red River watershed, is included in **Appendix A – Bulletin 17C Statistical Analysis Technical Memo and Peak FQ Output**.

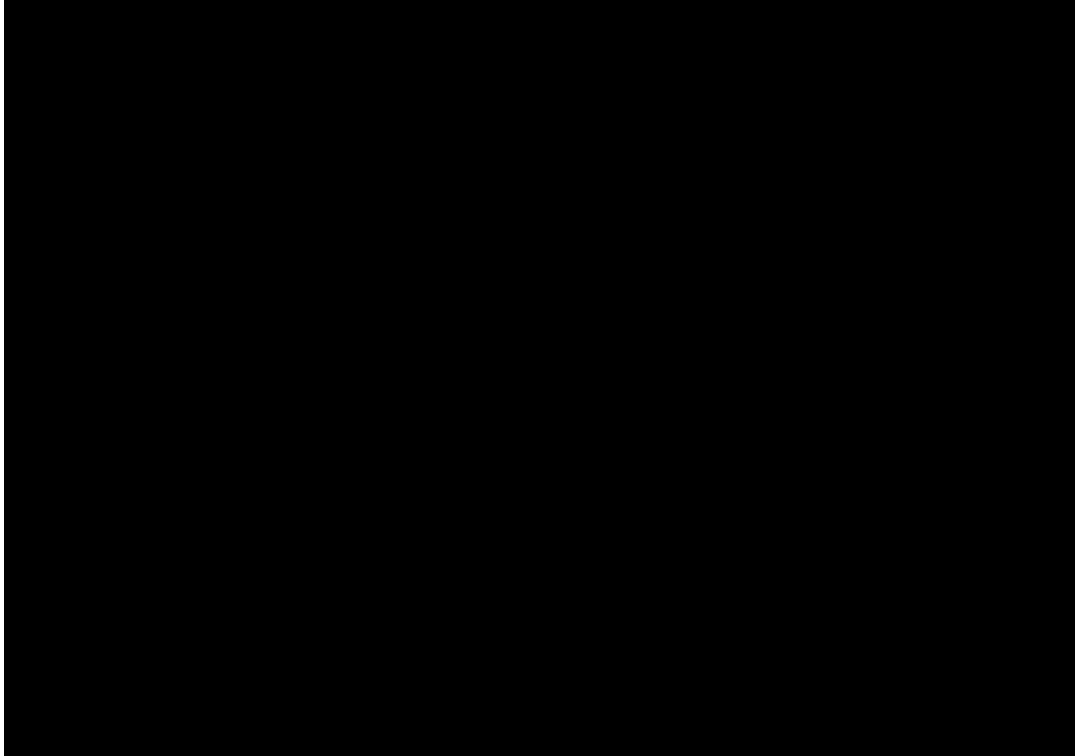


Figure 4-13. USGS Gages in Lower Salt Fork Red River watershed

Table 4-11. 1% Annual Storm Calibration Results Summary for Lower Salt Fork Red River watershed

USGS Gage	Drainage Area (Sq. Mi)	Historic Record Bulletin 17C Flood Frequency Analysis – 1% Annual chance Flow (CFS)			Modeled Peak Flow (1%)	Percent Difference (Modeled v. Historic median)
		Median	Lower 5% Confidence Limit	Upper 95% Confidence Limit		
07300000	1,222	99,210	53,220	275,100	59,396	50.2%
07300500	1,319	80,860	56,530	133,300	56,446	35.6%
07301110	1,848	45,480	29,220	112,200	69,961	42.4%

4.6.1 Comparison to USGS Regression Estimates for Unregulated Streams and Watersheds

The model results were compared to calculated flow estimates derived from USGS regional regression equations corresponding to the USGS gage locations in the HUC8 watershed. The regression estimates were derived from a 2020 USGS report for unregulated stream in Oklahoma, which covered the Task Order 2 study area, and did not include parameters for calculating uncertainty bounds for the estimates (USGS 2020). The comparison, summarized in Table 4-12, shows an over-estimation of the modeled flows at two gages within the HUC8 202 watershed and an under-estimation at the most downstream gage. However, modeled flows do fall within the confidence intervals for the Bulletin 17C analysis of all three gages, as shown in Table 4-11.

Table 4-12. 1% Annual-chance Flood Event – Modeled Peak Flow Comparison to USGS Regional Regression Estimates (equations and parameters via USGS 2020)

USGS Gage	Modeled Peak Flow	Regression Estimate	% difference
07300000	67,652	45,491	26.5%
07300500	56,446	51,495	9.2%
07301110	69,961	68,059	2.8%

4.7 Results

4.7.1 Comparison to Existing Study Data

The modeled WSEL and floodplain extents were compared to effective FEMA data, where existing. Currently, National Flood Hazard Layer (NFHL) regulatory data is only available for Harmon, Greer, and Jackson County, Oklahoma (HUCs 1112020203, 1112020204, and 1112020205). 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 inundation extent was compared from the modeled max depth 1% annual chance flood event. The modeled results on the mainstem of the watershed are highly correlated with the NFHL Zone A estimates, specifically in the deeper extents of the of the floodplain. Generally, the modeled results are somewhat narrower than the NFHL flood extents. This may be due to the resolution of the terrain used in the analysis, the application of spatially varied precipitation in this BLE study.

4.7.2 Challenges and Recommendations

Within the HUC 10 1112020201 and 1112020202 watersheds, there was only one active gage at the upper end of 1112020202. The Bulletin 17C analysis for the USGS gage was the main point of comparison for modeling results for both HUC 10s as the regression analysis values differed significantly from the modeled flows. There were no gages in HUC1112020204, so only regression flows were used as for comparison of the model results. USGS gage 07300500 near Mangum, OK is at the border between HUC 1112020203 and HUC 1112020205 and was used to compare model results for both HUCs. Model results comparisons for HUC 1112020205 are supplemented by a second USGS gage (07301110) in the downstream reach of the watershed near Elmer, OK.

Specific to the Texas Panhandle, there are many “terraced” farms along boundary of Upper and Lower Elm Fork Red River HUC10 models. When using ArchHydro watershed delineation these features lead to convoluted model boundaries which required manual correction using topographic contour mapping to simplify. The corrected boundaries have resulted in locations with ponding along these terraces, drained using normal depth boundary conditions in the model. As described in Section 4.4, polygon terrain modifications were made in HUC 1112020205 along irrigation ditches with raised berms on both sides to avoid interactions between the irrigation ditches and stormwater drainage. This process required a manual review of the terrain and engineering judgment due to a lack of spatial data for the irrigation ditches.

4.7.3 Crossing Profile Errors

To verify the results, profile lines were generated at the downstream end of each model and multi-frequency data was plotted along these lines to identify any potential crossing profile errors. On performing a detailed review of these profile lines no such errors were found. Figure 4-14 through Figure 4-17 are examples of profile checks using max WSE results for the models in this watershed with upstream inflow.

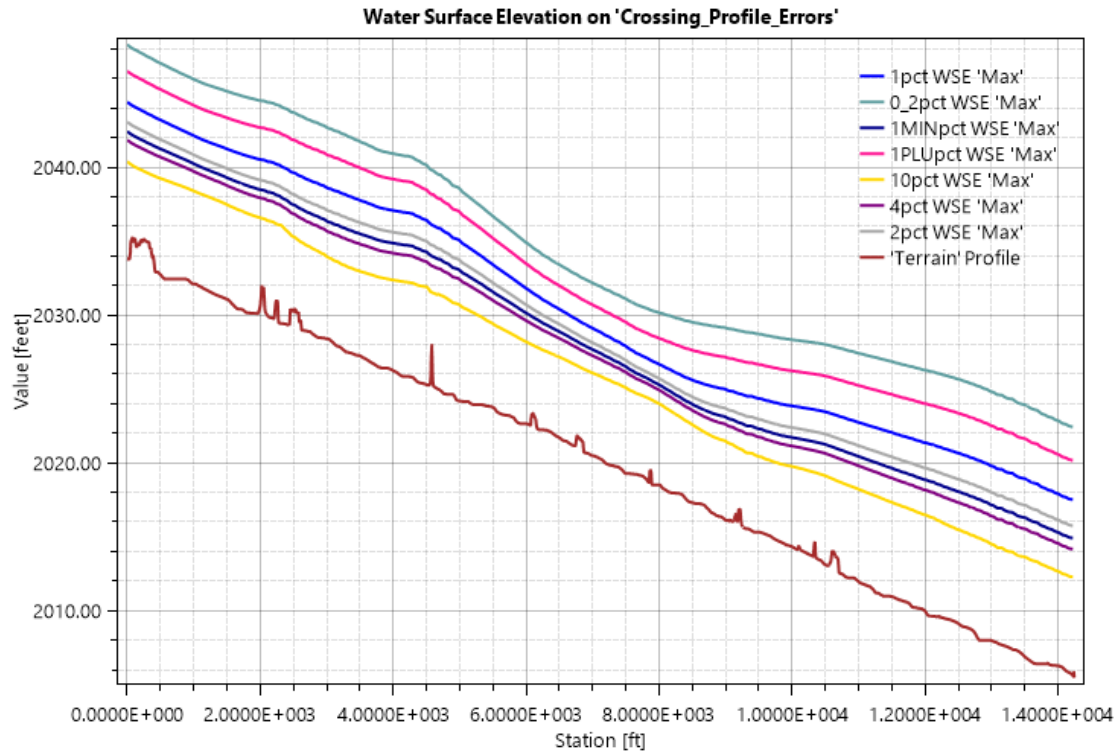


Figure 4-14. HUC 1112020201 WSE Profile Plot – all modeled events

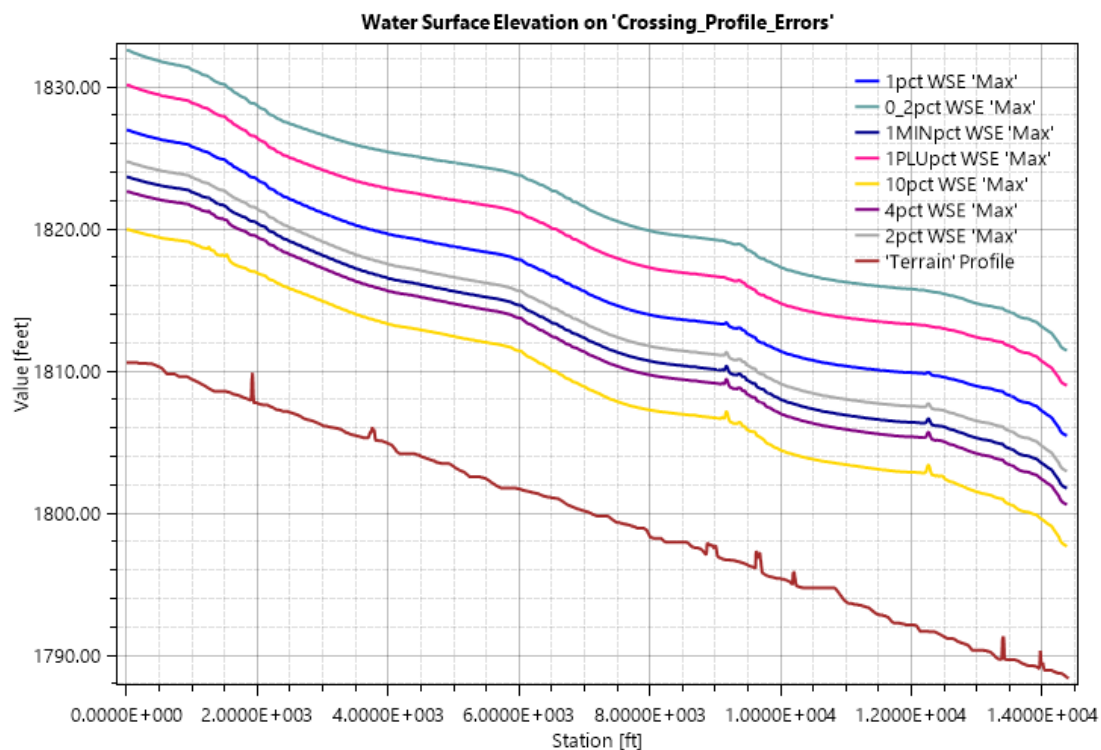


Figure 4-15. HUC 1112020202 WSE Profile Plot – all modeled events

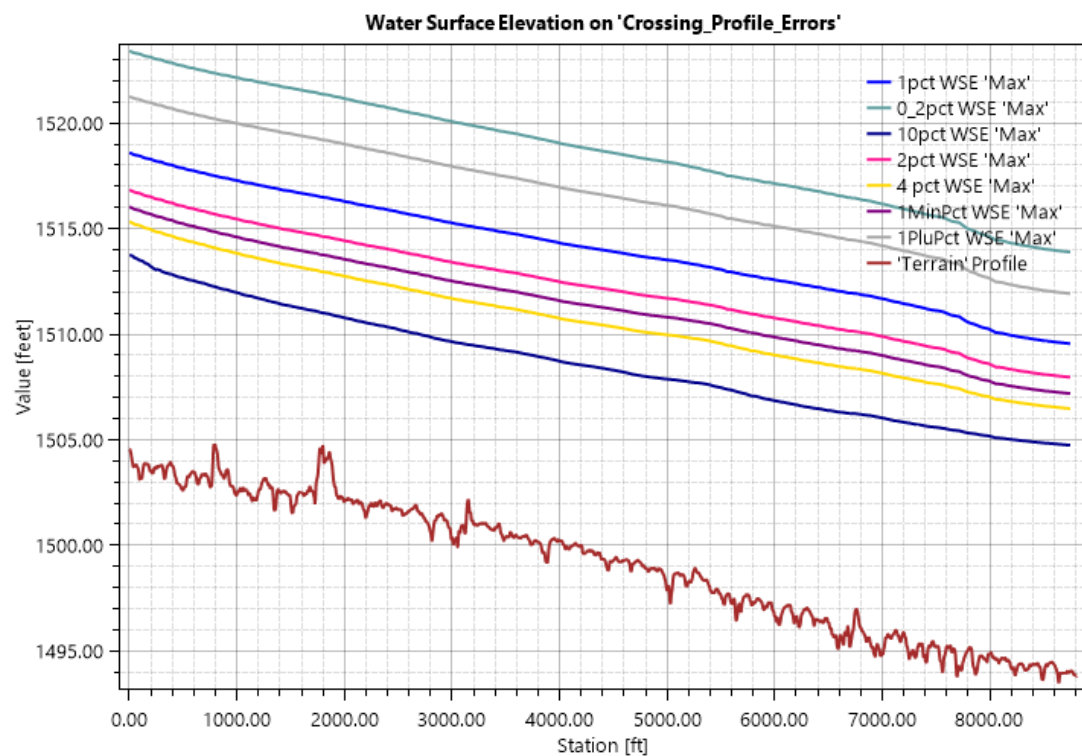


Figure 4-16. HUC 1112020203 WSE Profile Plot – all modeled events

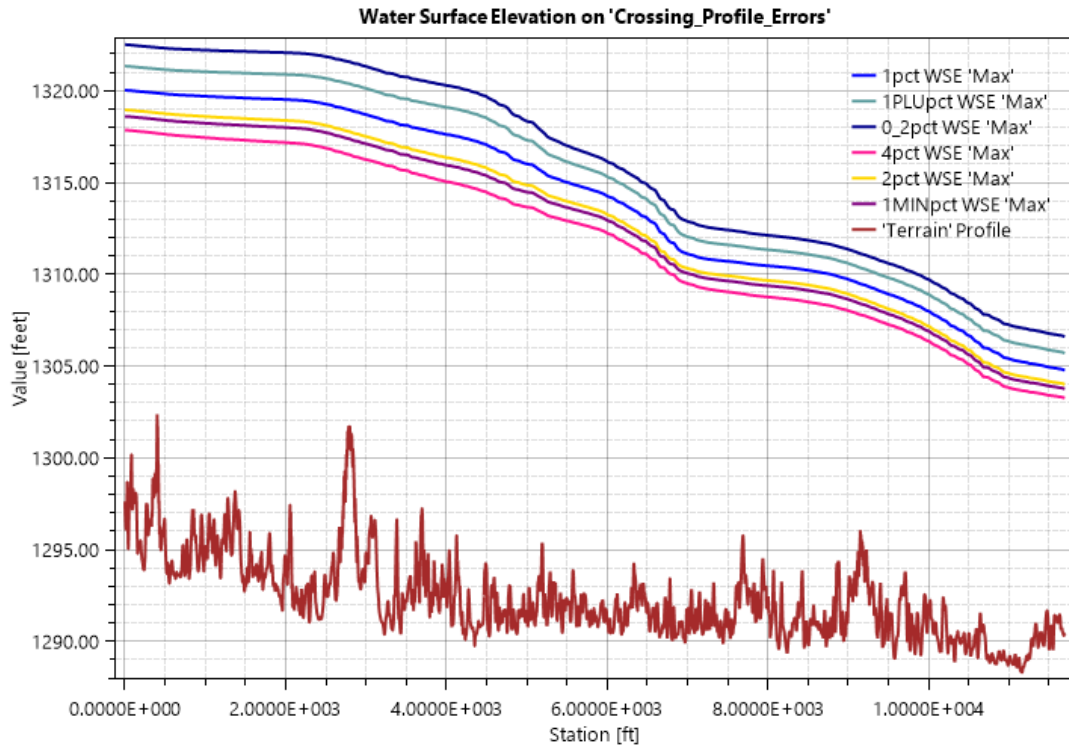


Figure 4-17. HUC 1112020204 WSE Profile Plot – all modeled events

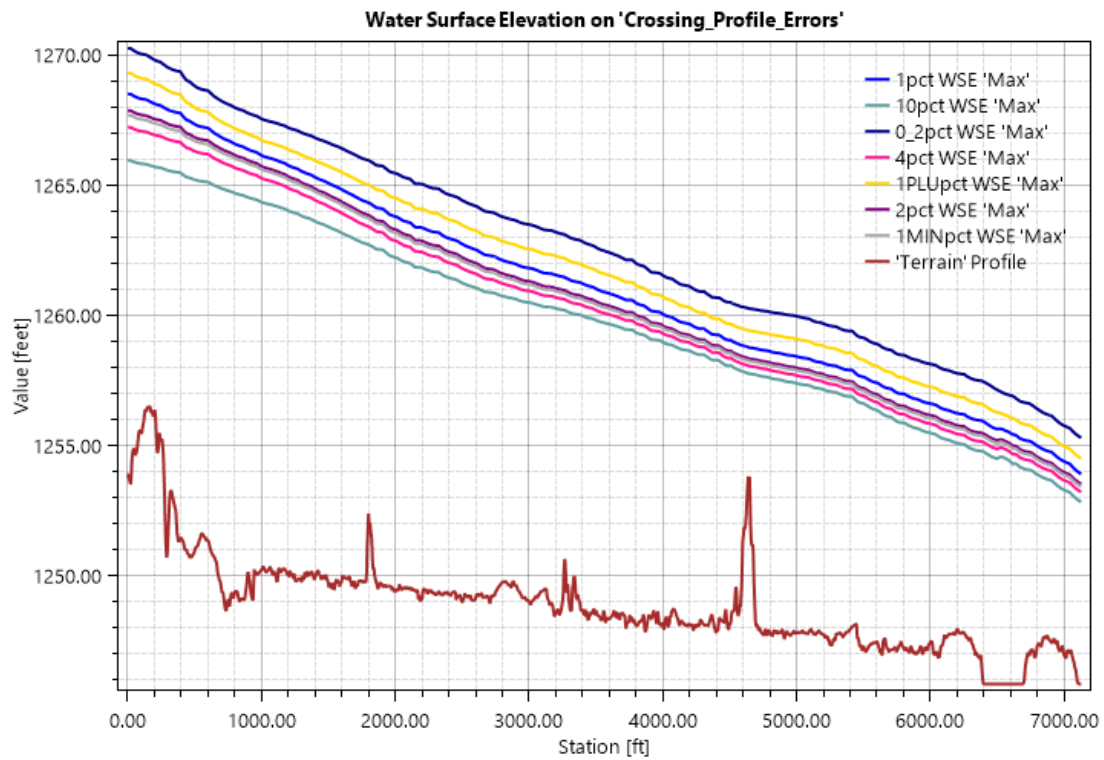


Figure 4-18. HUC 1112020205 WSE Profile Plot – all modeled events

4.7.4 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 4-7 to Table 4-9 for USGS gages in the watershed (shown on Figure 4-13). Floodplain delineation for these events is described in the following section (Chapter 6 Floodplain Delineation (10%, 1% and 0.2% events)) and exhibits corresponding to modeled results are included in (Chapter 7 CNMS Validation of Effective Zone A Special Flood Hazard Area (SFHA)).

Table 4-13. 10% Storm Results Summary for Lower Salt Fork Red River watershed

HUC 10 Model Name and Number	Gage Description	Peak Flow (CFS)	WSEL * (ft)
HUC 1112020202 Sand Creek-Salt Fork Red River	07300000	11,885	1,954.6
HUC 1112020205 Bitter Creek-Salt Fork Red River	07300500	11,886	1505.6
HUC 1112020205 Bitter Creek-Salt Fork Red River	07301110	24,133	1276.7

**Note: vertical datum of modeled WSEL is NAVD88*

Table 4-14. 1% Storm Results Summary for Lower Salt Fork Red River watershed

HUC 10 Model Name and Number	Gage Description	Peak Flow (CFS)	WSEL * (ft)
HUC 1112020202 Sand Creek-Salt Fork Red River	07300000	59,396	1,962.5
HUC 1112020205 Bitter Creek-Salt Fork Red River	07300500	56,446	1514.3
HUC 1112020205 Bitter Creek-Salt Fork Red River	07301110	69,961	1279.4

**Note: vertical datum of modeled WSEL is NAVD88*

Table 4-15. 0.2% Storm Results Summary for Lower Salt Fork Red River watershed

HUC 10 Model Name and Number	Gage Description	Peak Flow (CFS)	WSEL * (ft)
HUC 1112020202 Sand Creek-Salt Fork Red River	07300000	133,752	1,969.4
HUC 1112020205 Bitter Creek-Salt Fork Red River	07300500	123,904	1519.6
HUC 1112020205 Bitter Creek-Salt Fork Red River	07301110	127,855	1281.2

**Note: vertical datum of modeled WSEL is NAVD88*

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 Lower Salt Fork Red River 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 the following parameter: areas of floodplain that are less than 0.33 acres with an average depth less than 0.33 feet were removed. Lake, reservoir, and/or ponding areas of approximately 20 acres or greater were incorporated into the final mapping.

After the Matrix Tool is run, post-processing was performed to fill any additional islands of 2 acres or less for 0.2% and 1% floodplains while 10% floodplain received an 0.5 acre fill. In order for the flooding product extents to match, a 0.1ft was applied to the Depth Grid resulting in a 0.1ft depth low value. 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 original 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 Lower Salt Fork Red River watershed mapping products demonstrate a 0.5ft tie-ins at all overlap locations.

6.2 Hazus

As a part of the Base Level Engineering assessment effort, Hazus was run using version 6.1 and resampled 10ft cell size 1% Depth Grid. Hazus 6.1 uses parcel data to map the results but, attribute data by census block number. S_FRAC_Ar was populated with the 1% Hazus results. Data that intersects the HUC8 boundary is left as is, no clipping was performed. All census/parcel data completely outside of the HUC8 boundary was removed.

6.3 Special Consideration

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 potential future studies in the watershed:

- Significant artificial depth increases at floodplain fringes occur in some areas of the mapping products because 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, resulting in significant areas of inundation where there should really be no inundation. This erroneous mapping result is referred to herein as “cupping”.

- In Lower Salt Fork Red River 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.
 - There is a shapefile provided within the Supplemental Folder that categorizes whether the stream segment outside the 1% floodplain was fixed (Y) to be within the boundary or a ROAD/Embankment was present and no containment was possible.
- Portions of Lower Salt Fork Red watershed are playa-driven due to the caprock geology resulting in very limited 1% floodplain stream centerline containment. As a result, the stream centerlines within areas of caprock have been removed from the WTR_LN feature class within the Flood Risk Database and placed within the Supplemental Folder for reference.
- The Elevation Void Fill routine is used to fill holes in the rasters. For the 1% and 0.2% ACEs, holes less than 2 acres were filled, while for the 10% ACE, holes less than 0.5 acres were filled. Occasionally, this routine produces WSELs that are below ground elevation. In such cases, the WSELs were not revised, but the depths at these locations were set to 0.1 feet. The routine fills the holes via an interpolation process that uses the WSELs around the edge of the hole to estimate the WSELs within the hole. Minor discontinuities may appear around the hole’s perimeter, especially near the maximum fill area of 2 acres. These discontinuities typically occur where cupping is present in the raster near the edge of the hole or when the WSELs near the hole are changing rapidly. This issue is not present in all holes and is usually limited to those approaching the maximum fill area.

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

All the Zone A studies (395 miles) in the Lower Salt Fork Red watershed were classified in CNMS with a validation status of “UNVERIFIED” and status type of “BEING STUDIED”. The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A5 were evaluated for the CNMS inventory of Zone A studies.

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 Upper Salt Fork Red watershed study area, the effective Zone A topographic data leveraged a variety of sources.

The effective topo used for the effective Zone A in HUC8 11120202 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 11120202 fail A1.

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.

128 effective Zone A reaches used regression equations in HUC8 11120202. All of these reaches used WRIR 97-4202, which has been replaced by SIR 2009-5087, but sensitivity analysis does not show significant change between the two equations. Therefore, these reaches pass A2. The 1 other Zone A reach in HUC8 11120202 did not use regression equations for hydrology, so it automatically passes A2.

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 11120202 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	Change from old to new report not significant
A3 - Development	Pass	Urbanization increase is not significant

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.

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

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

All effective Zone A studies in HUC8 11120202 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.

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

Validation Status	Status Type	Total Mileage
Valid	NVUE Compliant	0
Unverified	Being Studied	395 mi

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison	Priority Score
Watershed Name	HUC12 ID						

						Pass? (>85%)	
Salt Fork Red River	111202020504	982	578	404	41%	>90%	FAIL
Lower Bitter Creek	111202020502	974	385	589	60%	>90%	FAIL
Spring Branch-Turkey Creek	111202020405	1084	561	523	48%	>85%	FAIL
Upper Bitter Creek	111202020501	1297	491	806	62%	>90%	FAIL
Bear Creek-Salt Fork Red River	111202020301	811	622	189	23%	>95%	FAIL
Horse Creek-Salt Fork Red River	111202020302	1522	1170	352	23%	>95%	FAIL
Cave Creek	111202020303	745	575	170	23%	>95%	FAIL
Mulberry Creek-Salt Fork Red River	111202020305	748	459	289	39%	>85%	FAIL
Claude Seymour Reservoir-Salt Fork Red River	111202020304	987	802	185	19%	>95%	FAIL
Club Lake-Turkey Creek	111202020401	1933	1105	828	43%	>95%	FAIL
Town of McQueen-Turkey Creek	111202020402	1622	983	639	39%	>95%	FAIL
Town of Prairie Hill-Turkey Creek	111202020407	963	468	495	51%	>85%	FAIL
Allred-Sessions Lake	111202020204	58	22	36	62%	>90%	FAIL
Town of Russell	111202020403	320	167	153	48%	>95%	FAIL
Cottonwood Creek	111202020404	1342	724	618	46%	>95%	FAIL
Town of Olustee-Turkey Creek	111202020408	884	484	400	45%	>85%	FAIL
Borders Lake-Salt Fork Red River	111202020503	1644	969	675	41%	>90%	FAIL

Horse Branch	111202020406	1061	553	508	48%	>85%	FAIL
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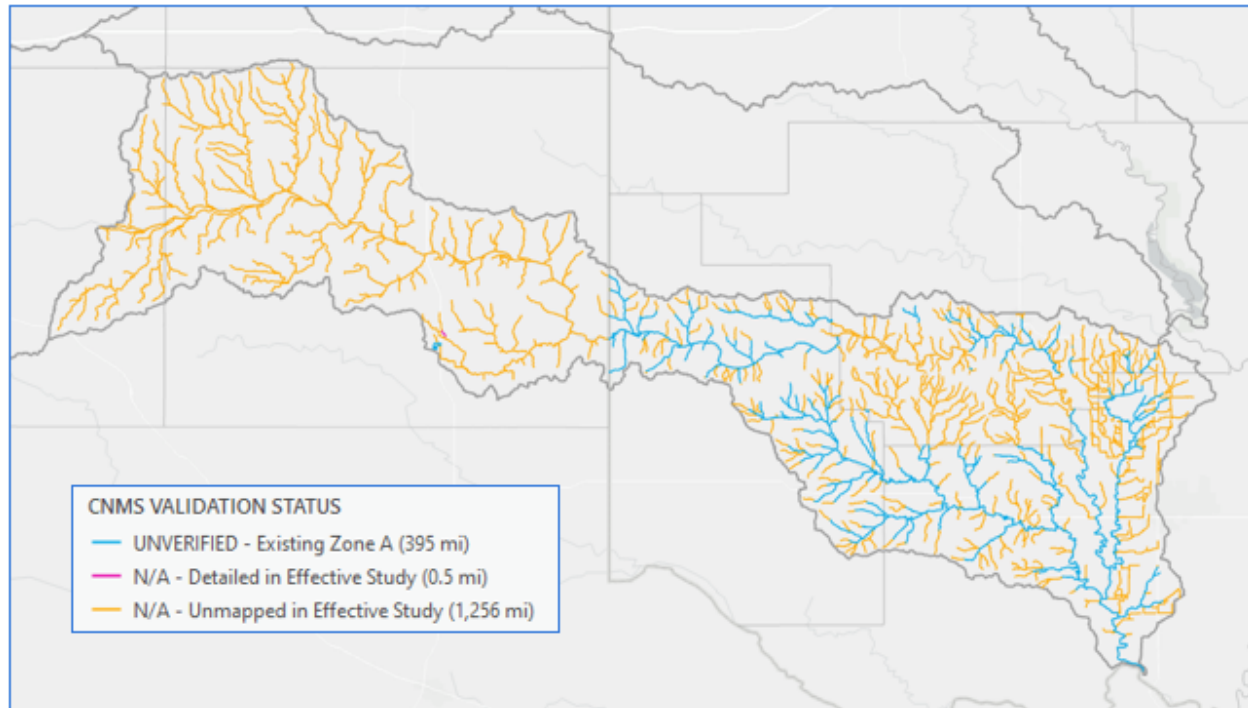


Figure 7-1. CNMS Validation Results

7.1 Deliverables

- **Coordinated Needs Management Strategy (CNMS) Geodatabase**
 - Contains all CNMS relationship and feature classes for reaches in HUC8 11120202.
- **Results generated by A5 analysis using the Basic method**
 - FBS points and A5 Pass/Fail results aggregated by HUC12 feature classes.

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Appendix A – 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.

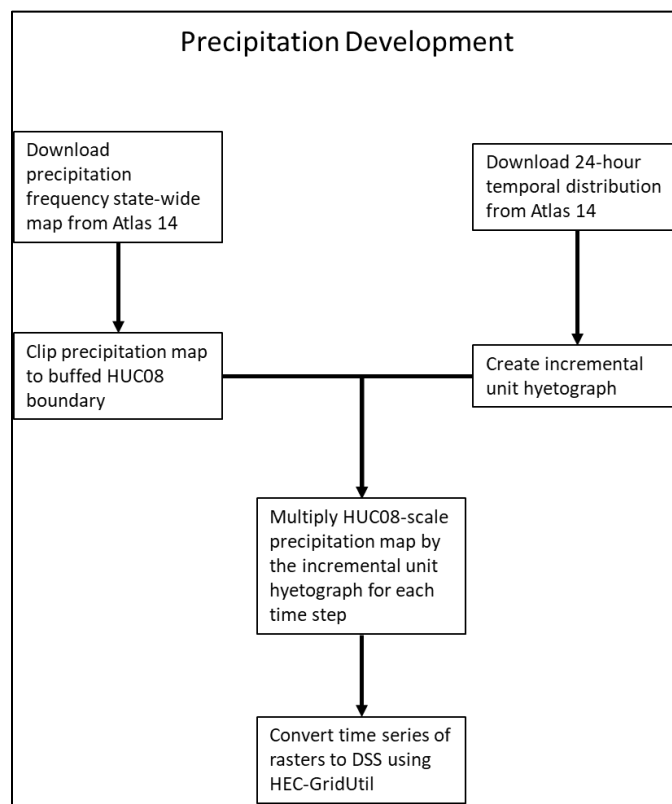


Figure B.1 - Flow chart demonstrating Stantec's precipitation dataset derivation process

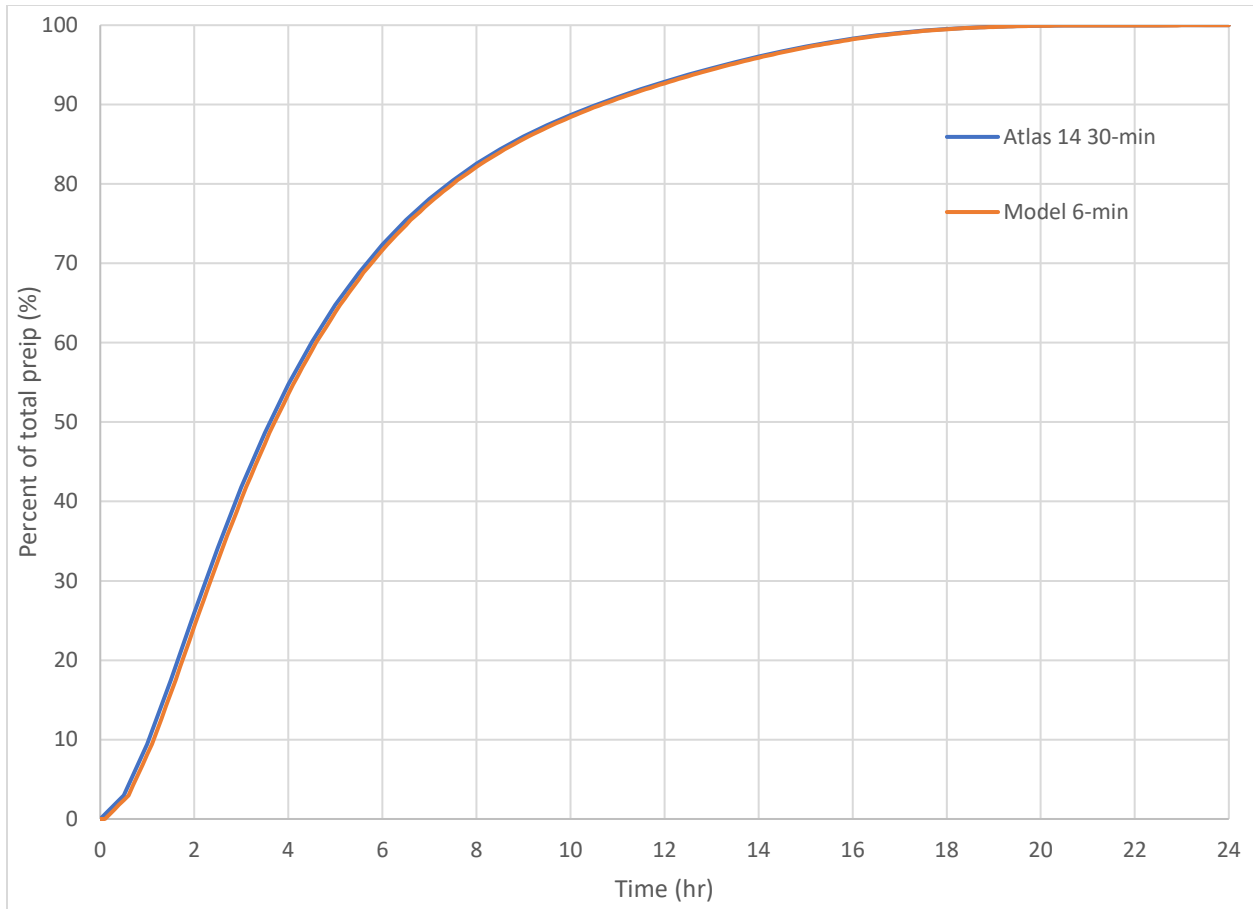


Figure B.2 Comparison of Atlas 14 and normalized model cumulative precipitation.

Table B.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 B.3 below provides an overview of the development methodology for the Curve Number and Manning's n base data layers.

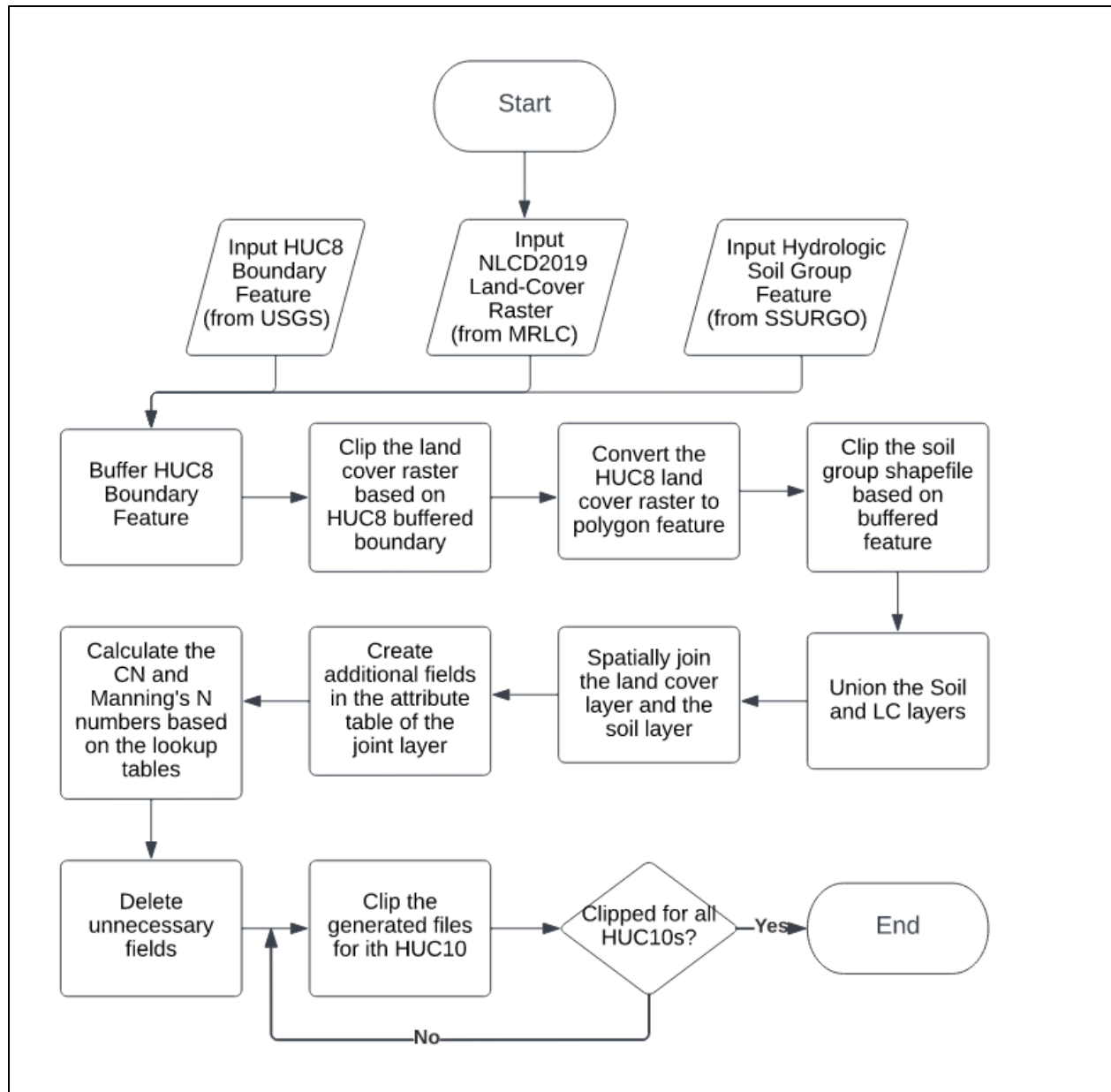


Figure B.3 Flow chart demonstrating Stantec's curve number spatial dataset derivation process

Appendix B – Bulletin 17C Statistical Analysis Technical Memo and Peak FQ Output

Bulletin 17C Annual Peak Flood Flow Frequency Analysis using PeakFQ

To support Texas Water Development Board Task Order-2, eleven (11) stream gage stations in the project area (see Figure 2) were analyzed using USGS software PeakFQ¹ (Version 7.3) to determine 100-year flood frequency estimates. The PeakFQ software uses Bulletin 17C methods to estimate flood frequency estimates, specifically the Expected Moments Algorithm (EMA; Cohn et al. 1997; Cohn et al. 2001). EMA was adopted as the approved method for performing a Bulletin 17C analysis (England et al. 2019) and is currently implemented in the PeakFQ software as well as HEC-SSP. EMA integrates systematic observations (i.e., the stream gage flow record), as well as historical (e.g., high water marks), paleoflood reconstructions, and perception thresholds for periods of missing data. This memo summarizes the details of the analysis and its results.

Stream Gage Station Locations

Figure 2 shows the map of gage stations indicating location of each gage station within corresponding HUC 8. Table 0-1 lists 9 gage stations included in this study, corresponding HUC8, name of the station, and the name of the river/tributary it is located at.

¹ <https://water.usgs.gov/software/PeakFQ/>

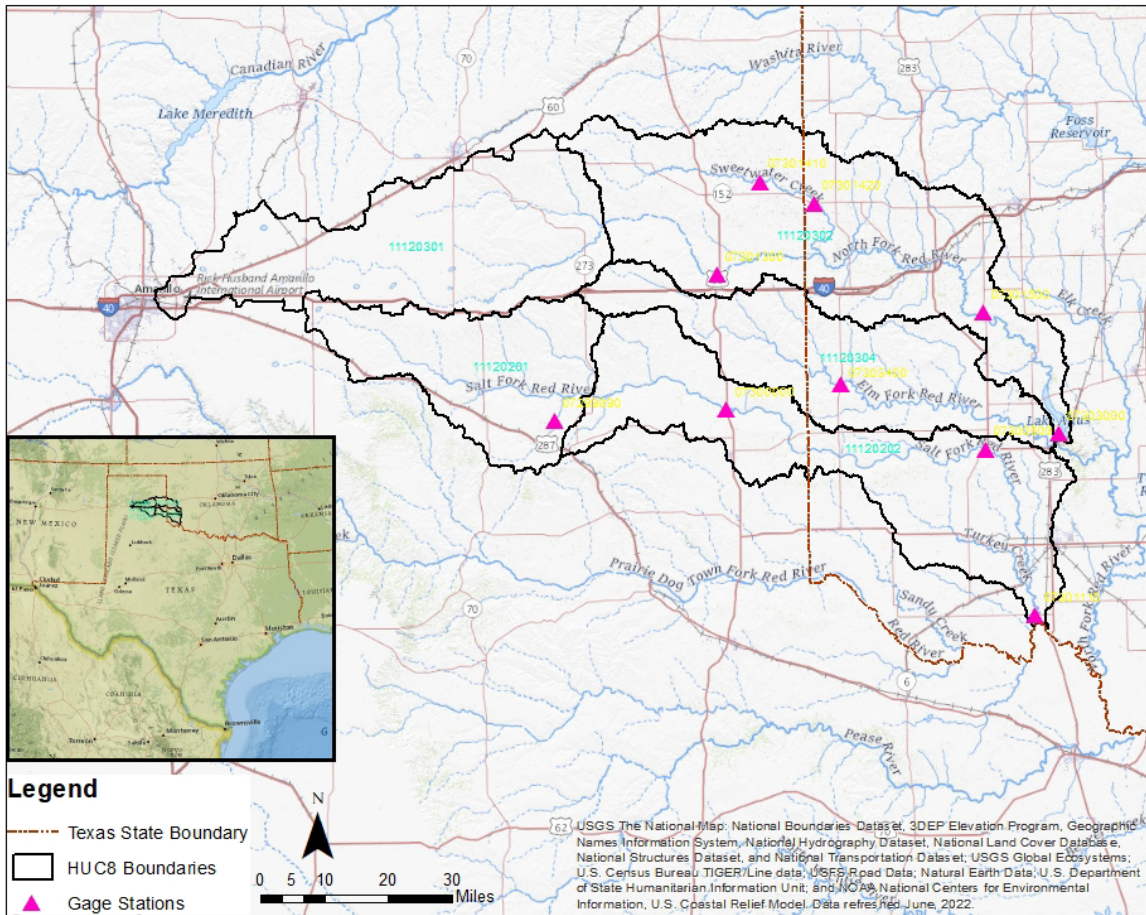


Figure 0-1: Map of the stream gaging stations

Table 0-1: List of the gaging stations

HUC8	Station ID	Longitude	Latitude	Station Name	River
11120201	07299890	-100.6961	34.93556	Lelia Lk Ck bl Bell Ck nr Hedley, TX	Lelia Lake Creek
11120202	07300000	-100.2206	34.9575	Salt Fork Red River near Wellington, TX	Salt Fork Red River
11120202	07300500	-99.50833	34.85833	Salt Fork Red River at Mangum, OK	Salt Fork Red River
11120202	07301110	-99.38194	34.47889	Salt Fork Red River near Elmer, OK	Salt Fork Red River
11120302	07301300	-100.2414	35.26417	N Fk Red Rv nr Shamrock, TX	North Fork Red River
11120302	07301410	-100.1206	35.47306	Sweetwater Ck nr Kelton, TX	Sweetwater Creek
11120302	07301420	-99.96889	35.42222	Sweetwater Creek near Sweetwater, OK	Sweetwater Creek
11120302	07301500	-99.50694	35.16806	North Fork Red River near Carter, OK	North Fork Red River
11120304	07303400	-99.90334	35.01167	Elm Fork of North Fork Red River nr Carl, OK	Elm Fork Red River

Peak Flow Data

The historical records of peak flow at each gage station were collected from USGS Surface Water for Texas: Peak Streamflow² website. Table 0-2 summarizes the period of record available at each gage, number of observations, drainage area, and contributing drainage area. The drainage area is the total delineation of the basin to the gage station. In some cases, basins may have non-contributing sub-basins where the runoff stays within the sub-basin and does not contribute to the larger basin. The contributing drainage area only includes runoff that contributes to flow at the gage, excluding non-contributing areas of the basin. Figure 3 through Figure 11 show the systematic annual peak flow data for the entire period of record at each gage station.

² USGS Surface Water for Texas: Peak Streamflow: <https://nwis.waterdata.usgs.gov/tx/nwis/peak>

Table 0-2: Data information at each gaging station

Station ID	Drainage Area (mi ²)	Contributing Drainage Area (mi ²)	Period of data	Number of observations
7299890	74	74	1998-2021	24
7300000	1222	1222	1953-2021	69
7300500	1454	1319	1938-2021	84
7301110	1983	1848	1980-2021	42
7301300	1368.6	816.7	1964-2021	58
7301410	297	281	1962-2021	60
7301420	437	410	1986-2021	36
7301500	2652	2073	1904-1907; 1928; 1930-1932; 1935; 1938-1944, 1945-2021	93
7303400	438	438	1960-1979, 1995-2021	27

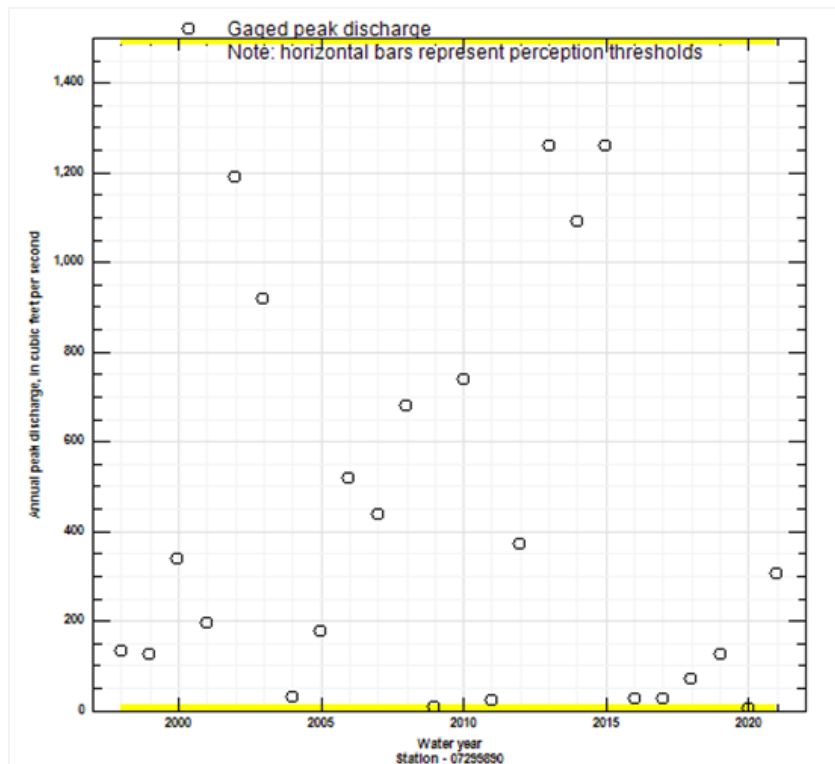


Figure 0-2: Gaged peak discharge at station 07299890

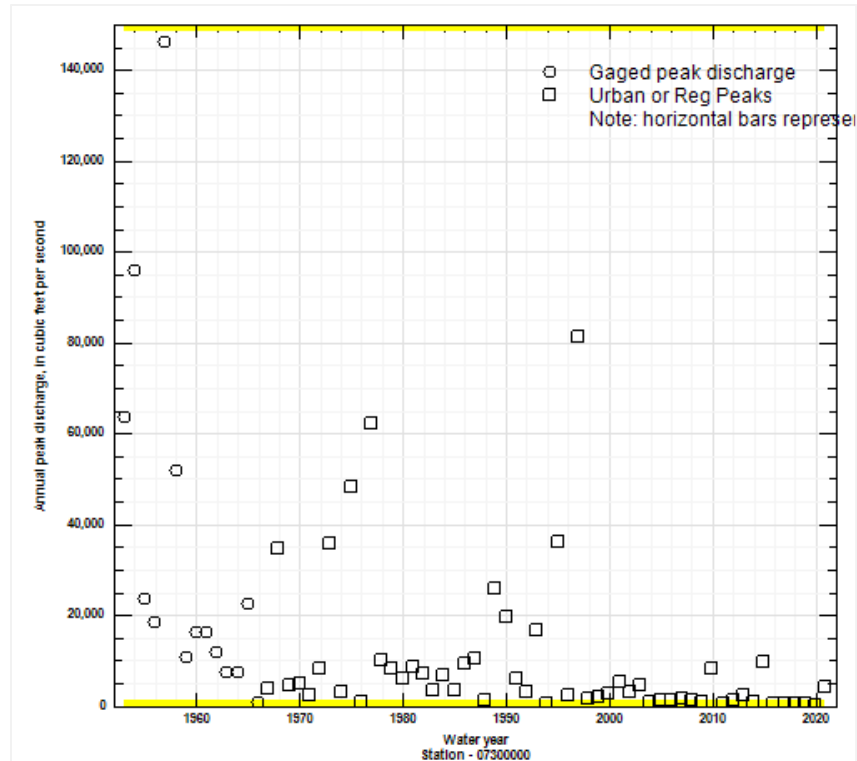


Figure 0-3: Gaged peak discharge at station 07300000 (Most of the data are affected by regulation or diversion)

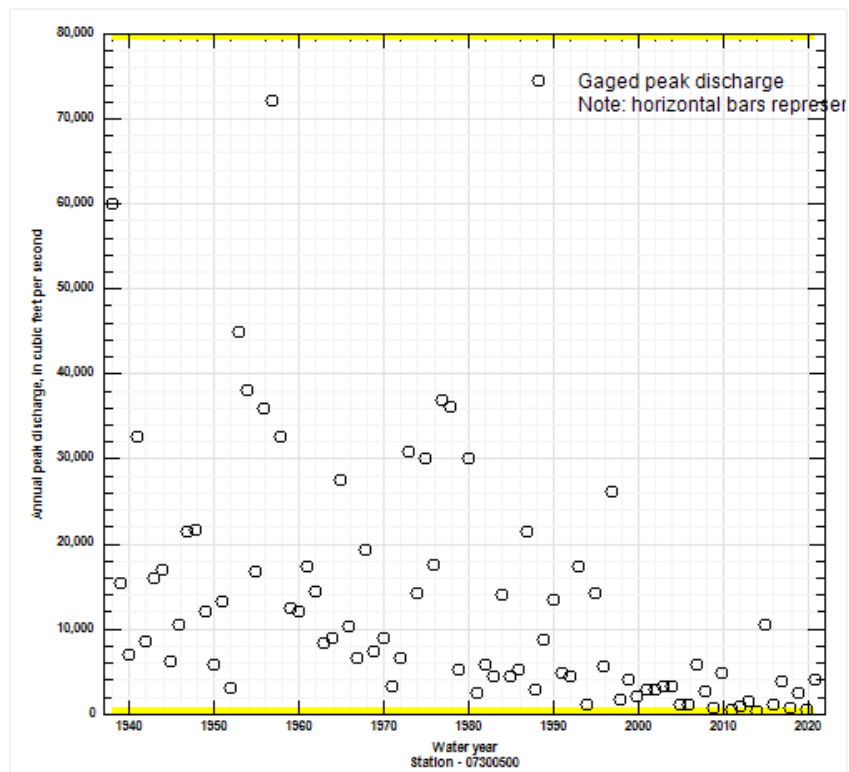


Figure 0-4: Gaged peak discharge at station 07300500

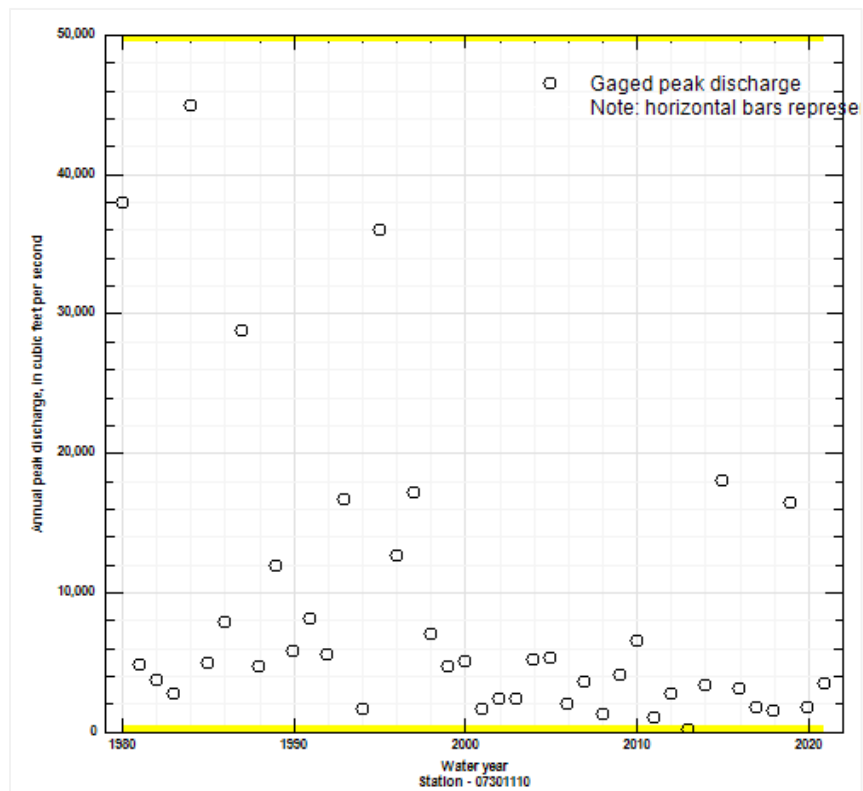


Figure 0-5: Gaged peak discharge at station 07301110

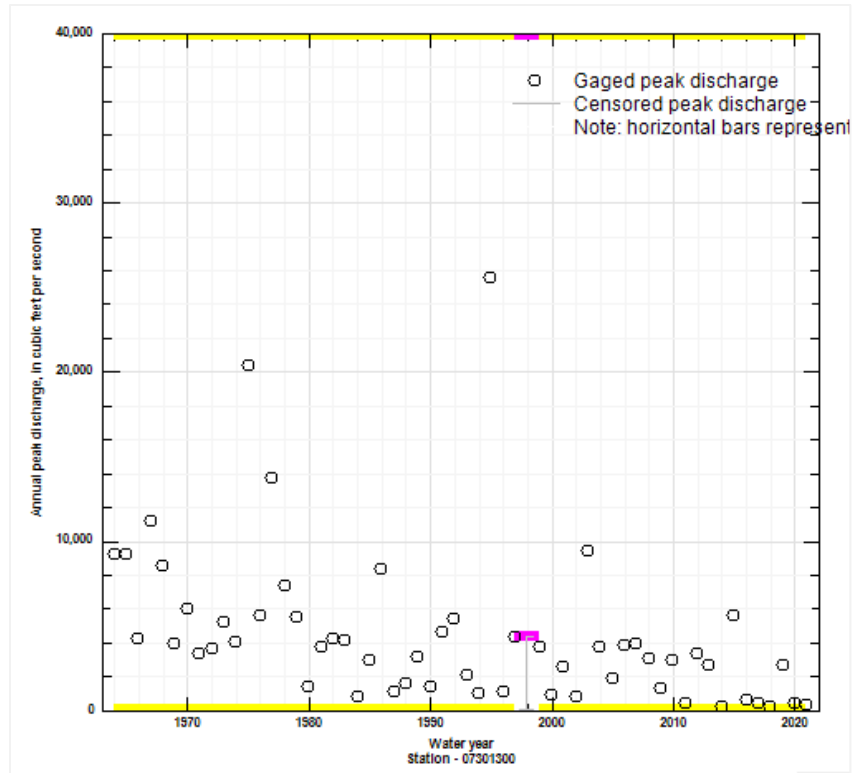


Figure 0-6: Gaged peak discharge at station 07301300

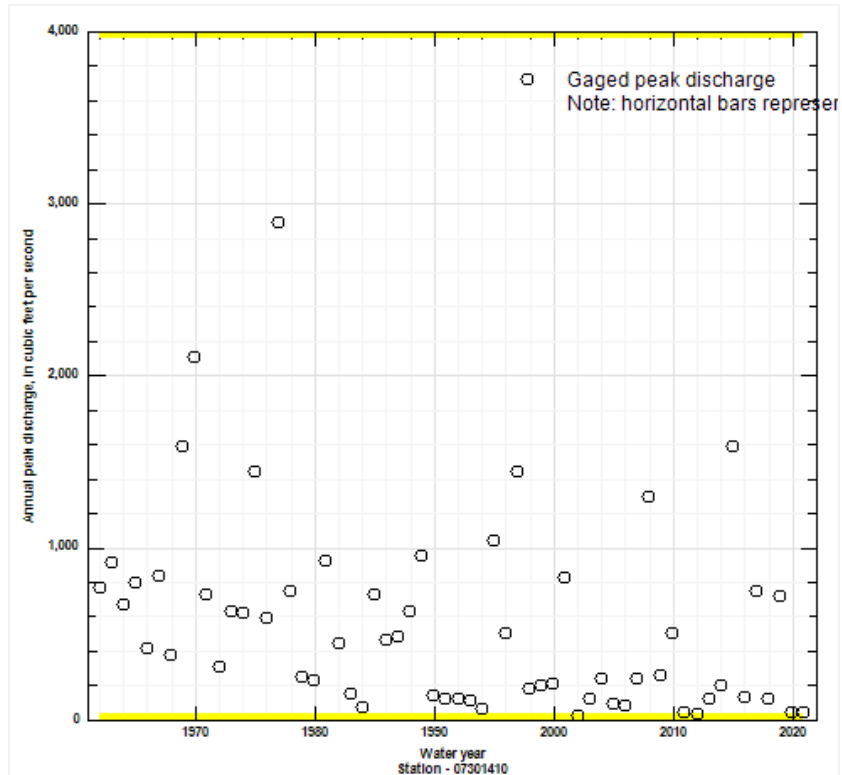


Figure 0-7: Gaged peak discharge at station 07301410

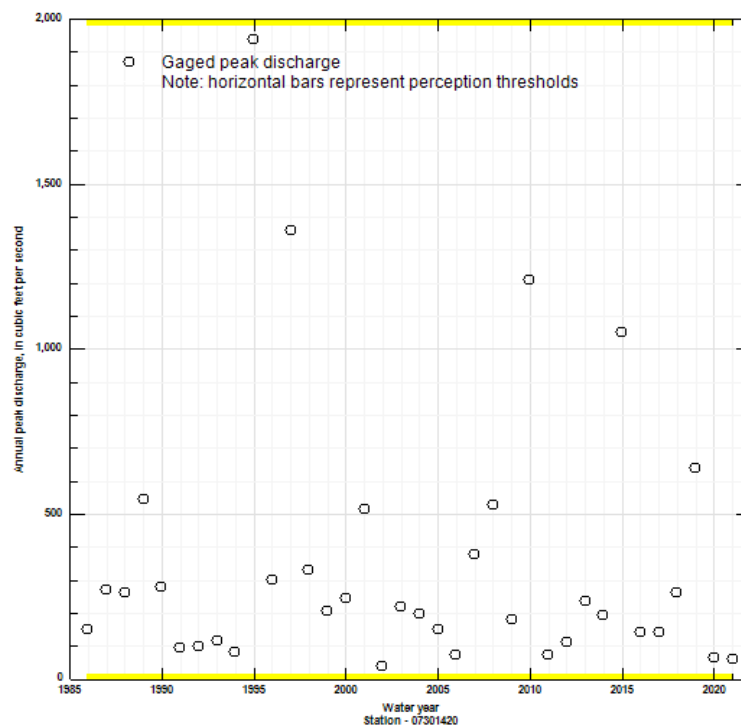


Figure 0-8: Gaged peak discharge at station 07301420

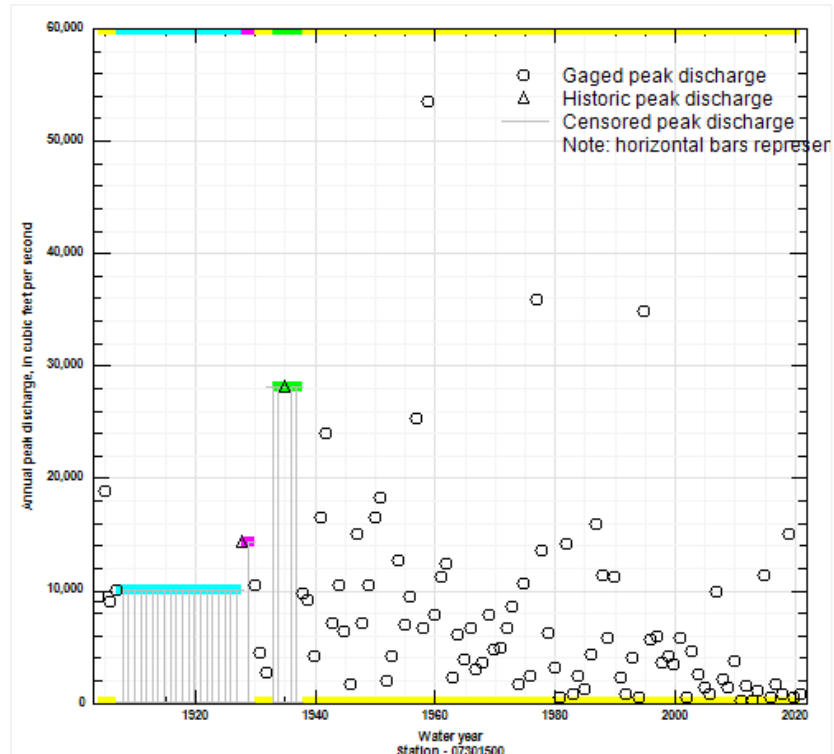


Figure 0-9: Gaged peak discharge at station 07301500

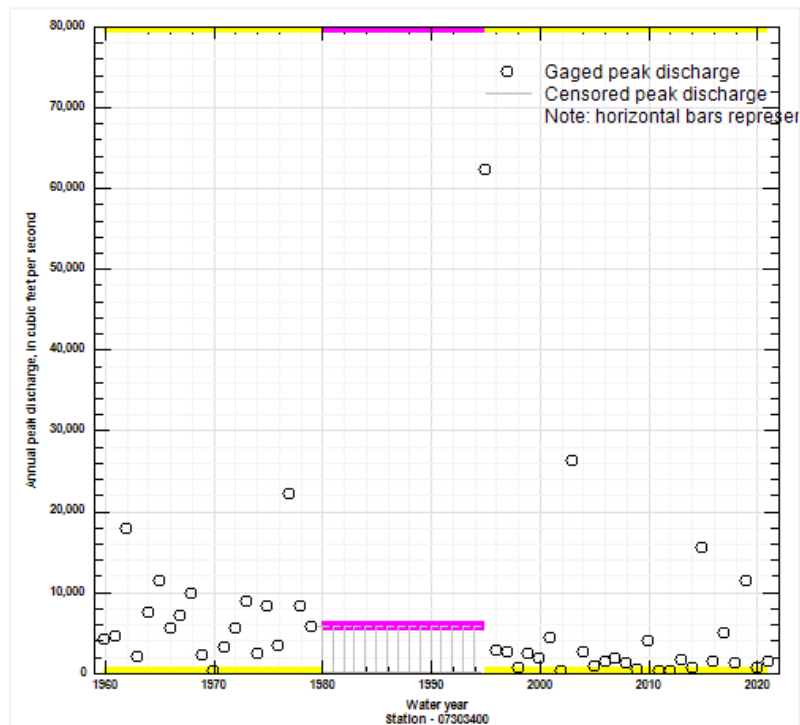


Figure 0-10: Gaged peak discharge at station 07303400

Texas Skew values

The regional skew information (Regional Skew and Regional Skew Std Error) is extracted using a tool available at Texas Data Repository³ (Cleveland and Fang, 2021a) for respective stream gages using the location coordinates of the gage stations. The skew values used in this analysis were taken from centroid location generalized additive modeling map (Figure 4.2, Cleveland and Fang 2021b) as recommended by Cleveland and Fang (2021b). This skew information is used in the Expected Moments Algorithm (EMA) analysis as an important moment for defining the annual peak flood flow frequency curve. The mean standard error applied in EMA method for each station is 0.465 and is same for all sites in this region. Table 0-3 lists the regional skew and station skew values required for PeakFQ analysis for each stream gaging station. Table A.1 (see Appendix A) lists the skew values used for the analysis without excluding records.

Table 0-3: Skew values extracted at each gaging station

Station ID	Weighted Skew	Regional Skew	Station Skew
07299890	-0.493	-0.392	-1.043
07300000	-0.062	-0.355	0.641
07300500	-0.505	-0.273	-0.765
07301110	0.149	-0.222	0.452
07301300	-0.505	-0.369	-0.683
07301410	-0.405	-0.365	-0.577
07301420	0.09	-0.353	0.452
07301500	-0.402	-0.296	-0.525
07303400	-0.15	-0.328	-0.049

Results

The results of PeakFQ analysis for 100-year flood using EMA method (Bulletin 17C) with the weighted skew, station skew, and regional skew options are summarized in the following Section **PeakFQ Output for Lower Salt Fork Red River Watershed**.

It is usually recommended to use 100-year frequency estimates using the weighted skew method unless there are excessively negative or positive station skew values. For stations 07301110 and 07301420, it was recommended to use 100-year frequency estimates obtained using the regional skew method because of excessively positive station skews being used in the weighted skew method.

summarizes the 100-year flow estimates using all three PeakFQ analysis skew options.

PeakFQ excludes from the analysis data that is flagged as being impacted by regulation or diversion. However, PeakFQ provides an option to ignore flags and include these data in the analysis. All the gaging stations were analyzed for all three skew methods without excluding flagged data records to investigate any significant impact of excluded records on the 100-year frequency estimates. Station 7300000 is the only station in this analysis that has data flagged for being impacted by regulation or diversion. Regarding

³ <https://dataverse.tdl.org/file.xhtml?fileId=123271&version=6.1>

station 7300000, when all records from 1953 to 2021 are used in the analysis, the skew values are observed to be excessively positive. It was recommended to include only data from water years 1953 through 1997, based upon visual inspection of the peak discharge plots (e.g., see Figure 25). The results obtained using Regional Skew Method are recommended to use at this station.

Table 0-4: 100-year frequency estimates at gage stations

Station ID	Using Weighted Skew Method	Using Station Skew Method	Using Regional Skew Method
7299890	3886	2563	4172
*7300000	173300	187100	151400
7300500	80860	66570	95690
7301110	59280	72990	45480
7301300	22350	19920	24370
7301410	2870	2718	2905
7301420	2061	2625	1521
7301500	39660	37270	41750
7303400	40940	44660	35090

* Included peak streamflow for water years 1953 through 1997.

‡ Bold numbers are recommended results to use for that station

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PeakFQ Output for Lower Salt Fork Red River Watershed

The output will be added as PDF for final submittal. For external review, please see PeakFQ output in hydrology submittal folder.