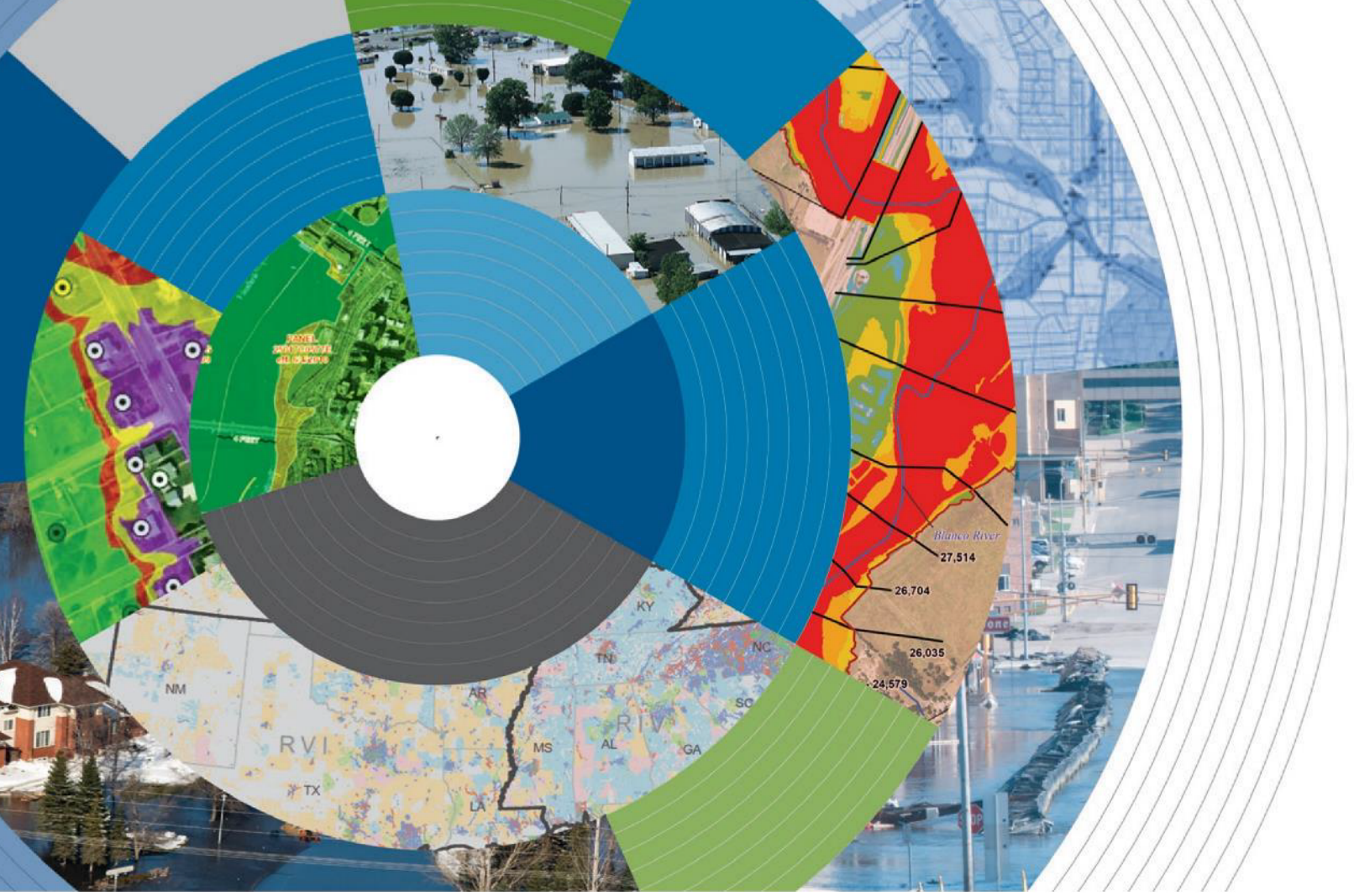


Base Level Engineering Report

Upper Salt Fork Red Watershed (11120201)

CASE NUMBER: 22-06-0048S

Texas Water Development Board

Stantec MAESTAS

May 22, 2025

Engineered by Stantec Consulting Services Inc. - Texas Registered Engineering Firm F-6324

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02	07/18/2023	Detail added regarding CN, Greenbelt Reservoir, and validation	Maestas
03	03/29/2024	Updated Floodplain Mapping	Stantec/Maestas
04	05/22/2025	Final deliverable to TWDB	Stantec/Maestas

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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 Upper Salt Fork Red watershed, as part of CONTRACT 2101792546, Task Order # 2. A summary of the study parameters and results for the Upper Salt Fork Red 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)	**22**
New Study Streams – CNMS (S_Unmapped_Ln) Informed by NHD 1:100	**722**
Total (BLE) Stream Miles	**744**

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	BEING STUDIED	17	17	17

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
- Upper North Fork Red - #11120301
- Middles 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
- Upper North Fork Red - #11120301
- Middles 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 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 Upper Salt Fork Red watershed Figure (1-1) which includes coverage of Armstrong, Carson, Dunley, and Gray counties.

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)

Task ID	Task	Task Phase ID	Task Phase
2	Hydrology and Hydraulic Analyses	2.1	Phase1: Draft HEC-RAS Model
		2.2	Phase2: Model Adjustments/Calibration
		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

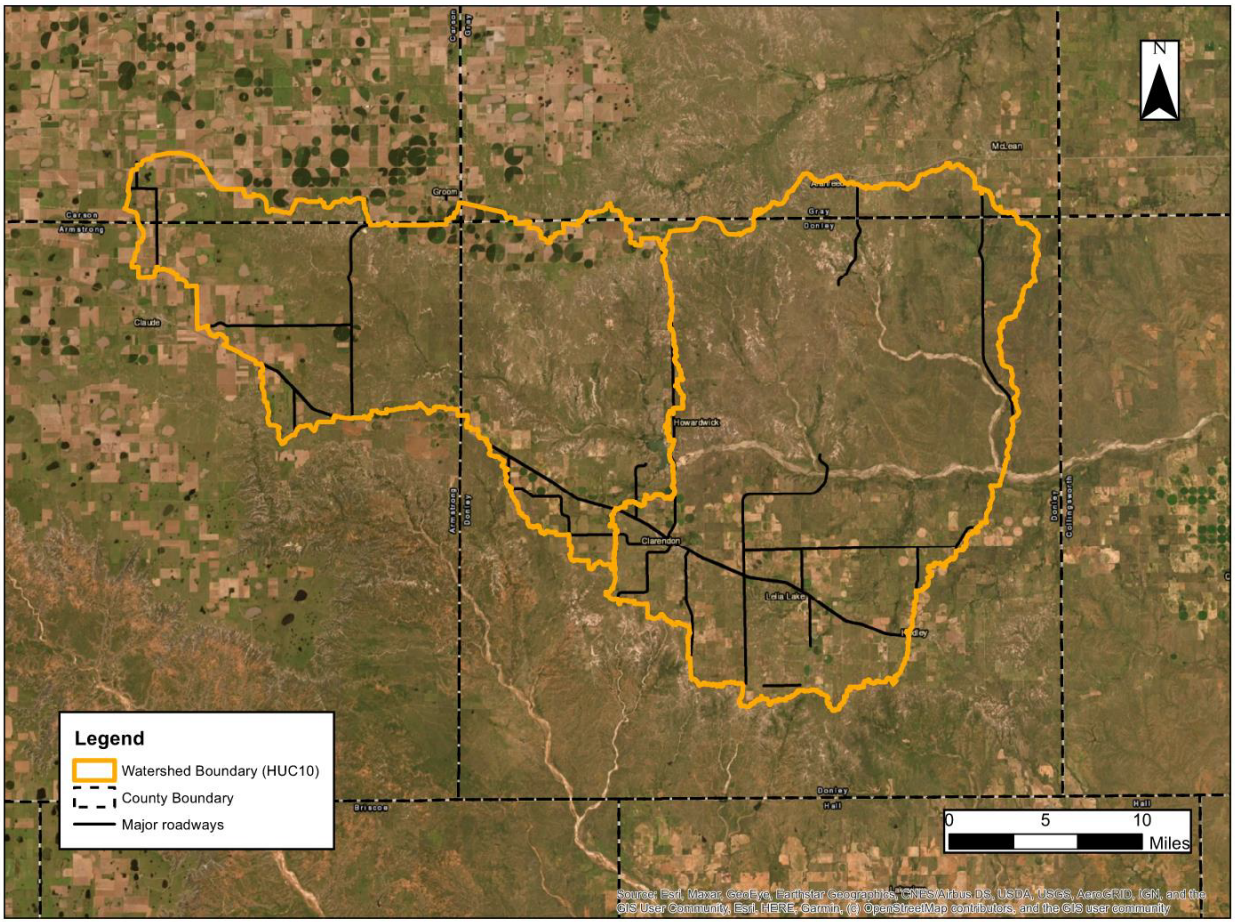


Figure 1-1. Upper Salt Fork Red Watershed (11120201) – HUC 10 Basins

The BLE assessment prepared cursory engineering analysis for approximately 1,699 miles of stream reaches within the Upper Salt Fork Red 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

The primary data source for this watershed was the TX Panhandle 2018 D18 Lidar project obtained from the United States Geological Survey (USGS) for the Texas Panhandle and Red River Regions as shown in Figure 1. The individual Digital Elevation Model (DEM) tiles from the data source were used to create one seamless DEM mosaic for the Upper Salt Fork Watershed using various methodologies and tools in ESRI's ArcGIS Pro 2.x environment as described below. This HUC8 watershed is entirely covered by one data source.

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 (UTM Zone 14 NAVD88 1 meter by 1 meter); this was done for each individual data source applicable to the project watershed. The full DEM was then re-projected into the NAD83 Texas North FIPS 4201 (US Foot) NAD 1988 horizontal coordinate system and clipped to a one-mile buffer based on the NHD HUC8 boundary. The raster values from the clipped output were converted from meters to feet.

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.

There were no issues encountered when developing the final seamless DEM.

Table 2-1: LiDAR Data Sources

County[1]	Age	Accuracy	Source & Contact	Approximate Footprint (Sq Mi)[3]
Carson, Donley, Armstrong, and Gray [1]	February 9, 2018 – May 20, 2018	Horizontal[2]: USGS QL2 Vertical[3]: DEM VVA RMSEz at 95th Percentile 0.218 m DEM NVA RMSEz at 95% Confidence Level 0.072 m	United States Geological Survey (USGS)	34,005[4]

[1]Counties listed are only those applicable to current project watershed.
[2]Explicit horizontal accuracy not specified in the report.
[3]Accuracy derived from original Lidar project report.
[4]Area reported reflects coverage of entire lidar project beyond the current project watershed.

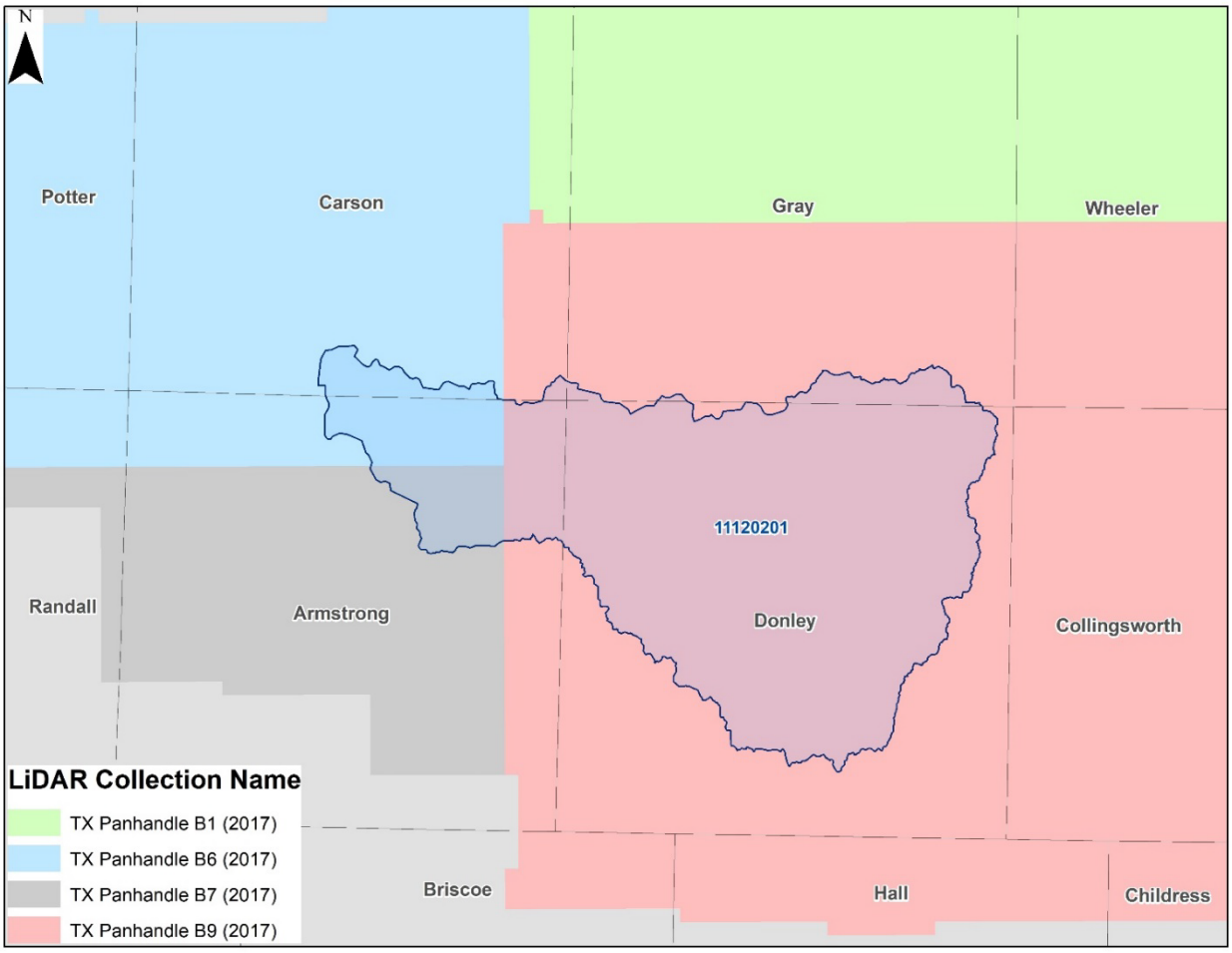


Figure 2-1. Extent and coverage of LiDAR Data as it relates to the project watershed

2.2 Final Seamless DEM

The final DEM 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)
        - 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)
    - 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.

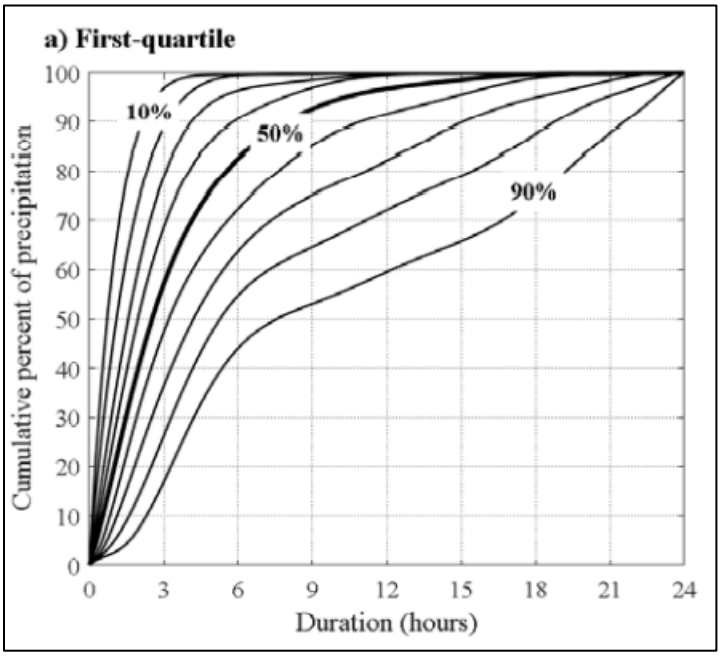


Figure 3-1: Example of temporal distribution curves for first-quartile events with 24-hour duration. Taken from NOAA Atlas 14 Volume 11. Accessed 12/13/2021.

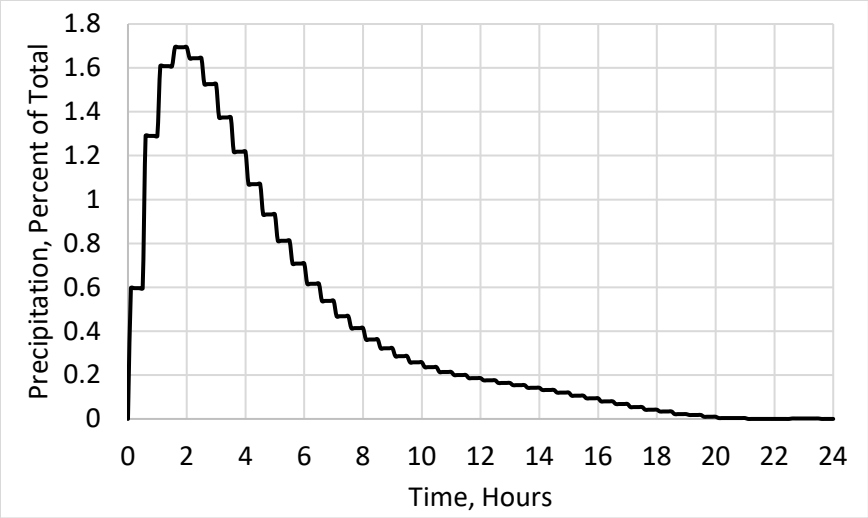


Figure 3-2: Incremental unit hyetograph used to create timeseries of precipitation rasters.

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 Upper Salt Fork RedUpper Salt Fork Red 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 Upper Salt Fork RedUpper Salt Fork Red 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 B – 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 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 Upper Salt Fork Red 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. The final basin (HUC 10) average precipitation values modeled for each frequency event can be found in Table 3-1.

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

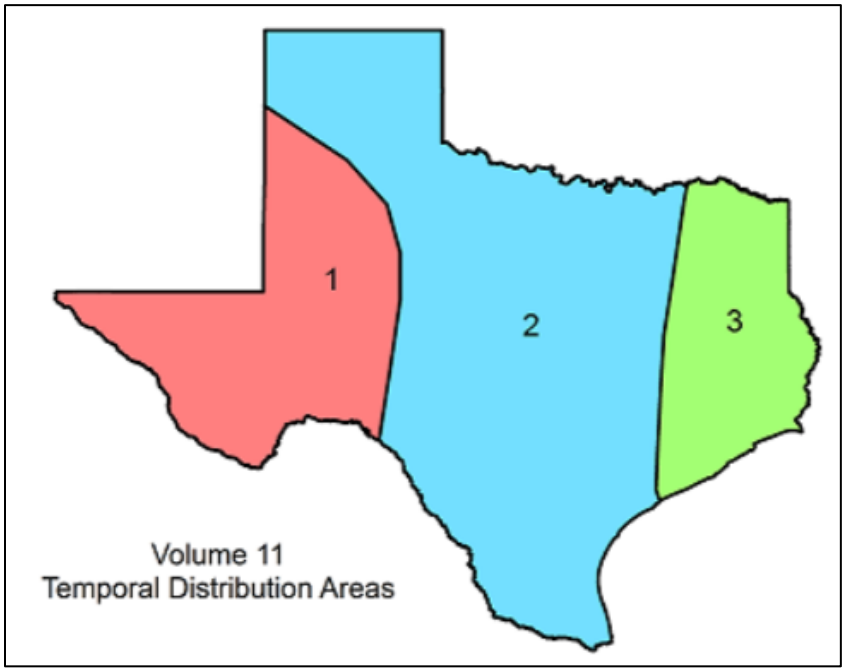


Figure 3-3. NOAA Atlas 14 Volume 11 – Texas Temporal Distribution Areas: Interior Highlands (1), Central Plains (2), and Gulf Coast (3) regions.

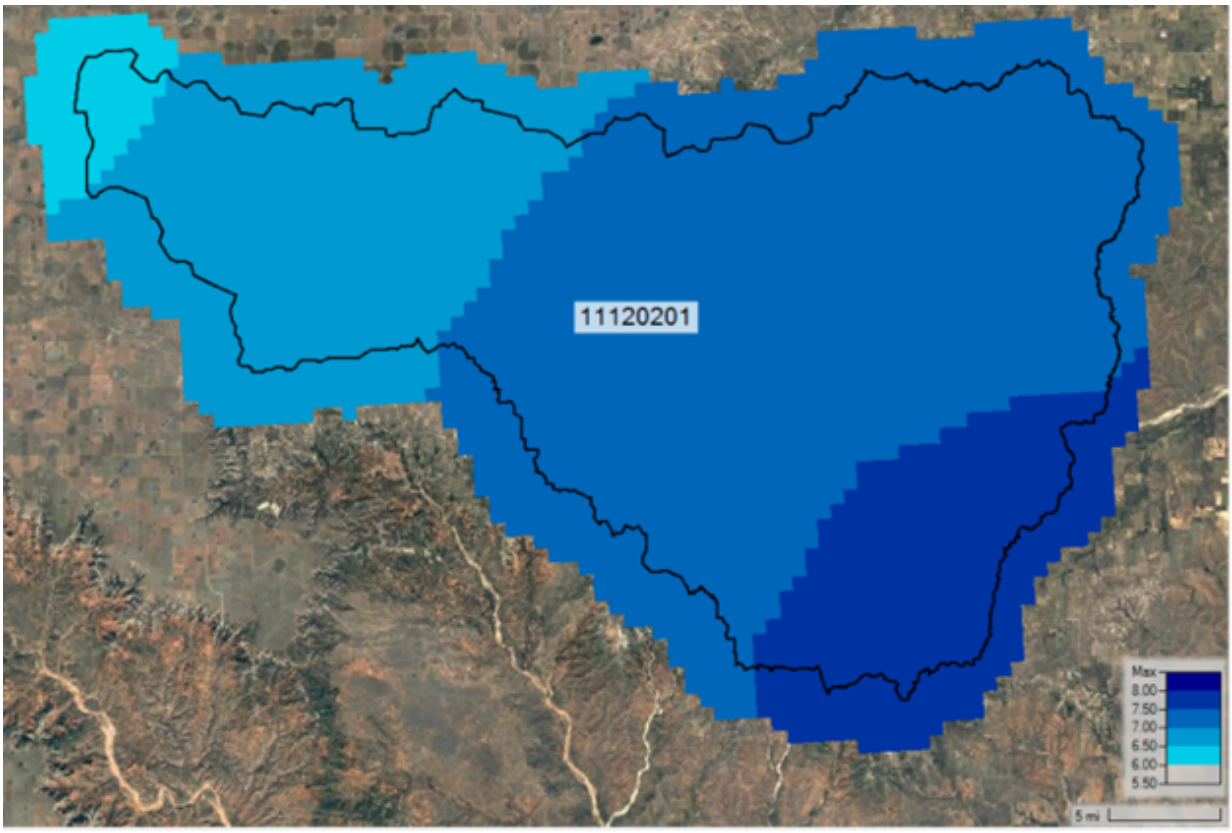


Figure 3-4.Total precipitation (inches) for baseline 1% event across Upper Salt Fork Red Watershed

Table 3-1. NOAA Atlas 14 Precipitation Means for HEC-RAS 2D Computational Mesh (inches)

USGS HUC 10 Name and Number	10%	4%	2%	1%	0.2%	1% Minus	1% Plus
Greenbelt Reservoir- Salt Fork Red River 1112020101	4.32	5.31	6.10	6.92	9.16	5.64	8.20
Whitefish Creek-Salt Fork Red River 1112020102	4.59	5.65	6.50	7.43	9.93	6.05	8.80

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).

Table 3-2. 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 3-3) 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%)*
22	Developed Low Intensity	77	86	91	94	*Newly graded areas*
23	Developed Medium Intensity	89	92	94	95	*Urban Districts – commercial and business*
24	Developed High Intensity	98	98	98	98	*Impervious areas: paved*
31	Barren Land	77	86	91	94	*Fallow – bare soil*
41	Deciduous Forest	32*	48	57	63	*Oak- aspen – fair hydrologic condition *Woods – grass combination, good hydrologic condition*

LU_GridCode	NLCD LU Description	Hydrologic Soil Group				TR-55 Land Use Cover Type
		A	B	C	D	
42	Evergreen Forest	39*	58	73	80	*Pinyon – juniper – fair hydrologic condition* **Pasture – good hydrologic condition*
43	Mixed Forest	46	60	68	74	*Woods/ Woods – grass combination – hydrologic condition ranging poor - good*
52	Shrub Scrub	49	69	79	84	*Pasture, grassland, or range – fair hydrologic condition*
71	Herbaceous	64	71	81	89	*Herbaceous – fair hydrologic condition*
81	Hay Pasture	49	69	79	84	*Pasture, grassland, or range – fair hydrologic condition*
82	Cultivated Crops	71	80	87	90	*Row Crops – poor hydrologic condition*
90	Woody Wetlands	88	89	90	91	*Within range of impervious cover (wetlands), herbaceous and woods.*
95	Emergent Herbaceous Wetlands	89	90	91	92	*Within range of impervious cover (wetlands), herbaceous and woods.*

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.

4 Hydraulics

The hydraulic approach for the Upper Salt Fork Red 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 Upper Salt Fork Red watershed consisted of 2 HUC 10 catchments:

- Greenbelt Reservoir- Salt Fork Red River 1112020101
- Whitefish Creek-Salt Fork Red River 1112020102

A separate model was created for each HUC 10. The models were coupled through outflow and inflow boundary conditions 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 as applicable to each model.

4.1 2D Computational Mesh and Settings

The base computational mesh for the models in the Upper Salt Fork Red 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 Upper Salt Fork Red watershed are summarized in Table 4-1.

Table 4-1. HUC 10 Mesh Parameters

HUC 10 Name	Size of Study Area (sq mi)	Number of Mesh Elements (grid cells)	Average cell size (sq ft)
Greenbelt Reservoir -Salt Fork Red River	322.43	312,863	28,731
Whitefish Creek - Salt Fork Red River	427.87	448,860	26,575

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. Courant values of less than or equal to 2 are considered ideal, with 5 considered the maximum acceptable for simulations applying Diffusion Wave computational methods (USACE 2021). 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 50 ft x 50 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, railroads 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 Upper Salt Fork Red watershed is shown in Figure 4-1.

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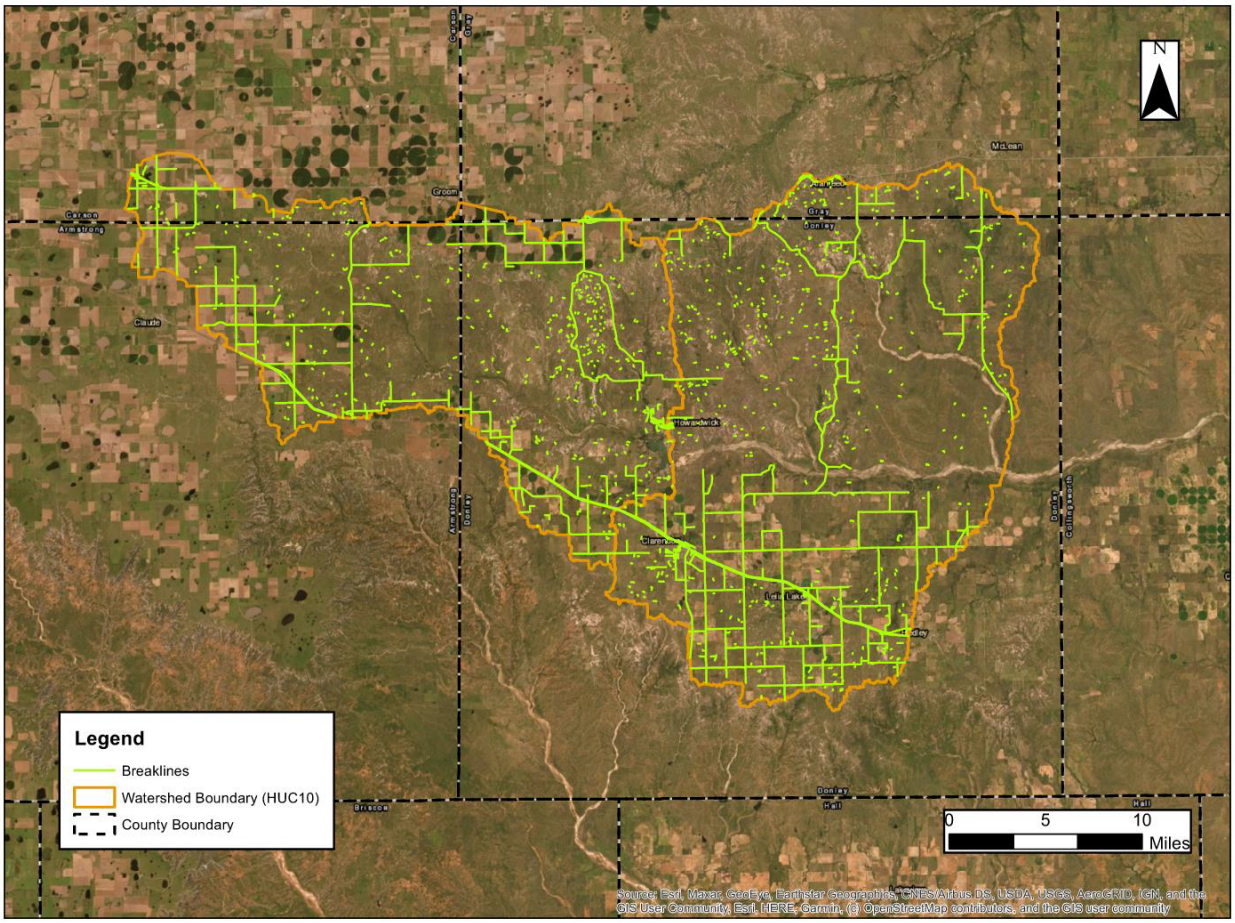


Figure 4-1. Overview of HUC 8 Scale Breaklines for Upper Salt Fork Red Watershed

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 4-1).

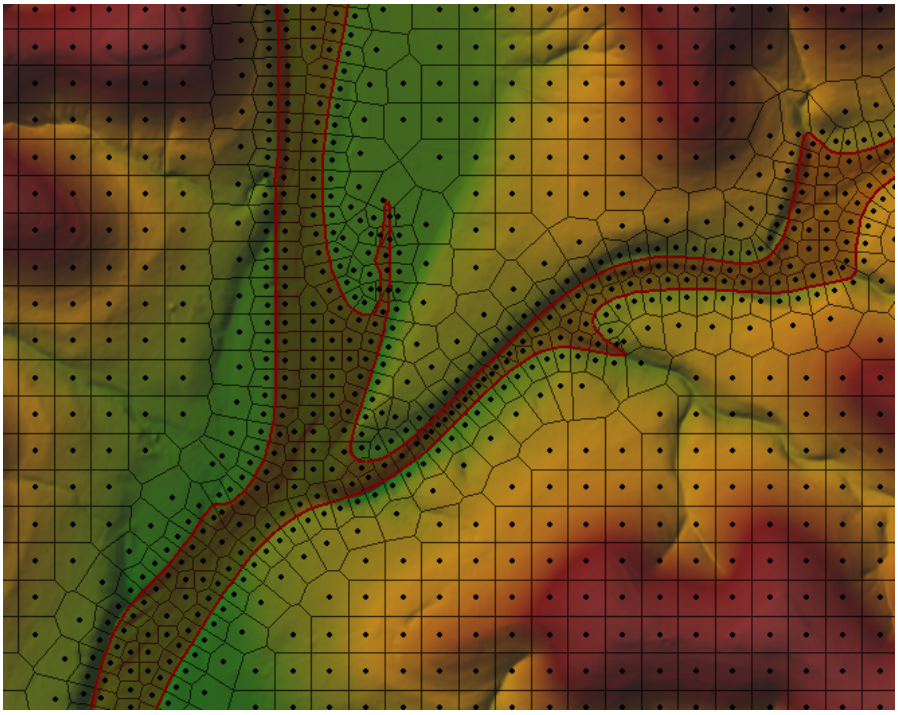


Figure 4-1. Example of Refinement Region Polygon

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 more accurately capture bank-full extents. 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 Upper Salt Fork Red watershed is shown in Figure 4-3.

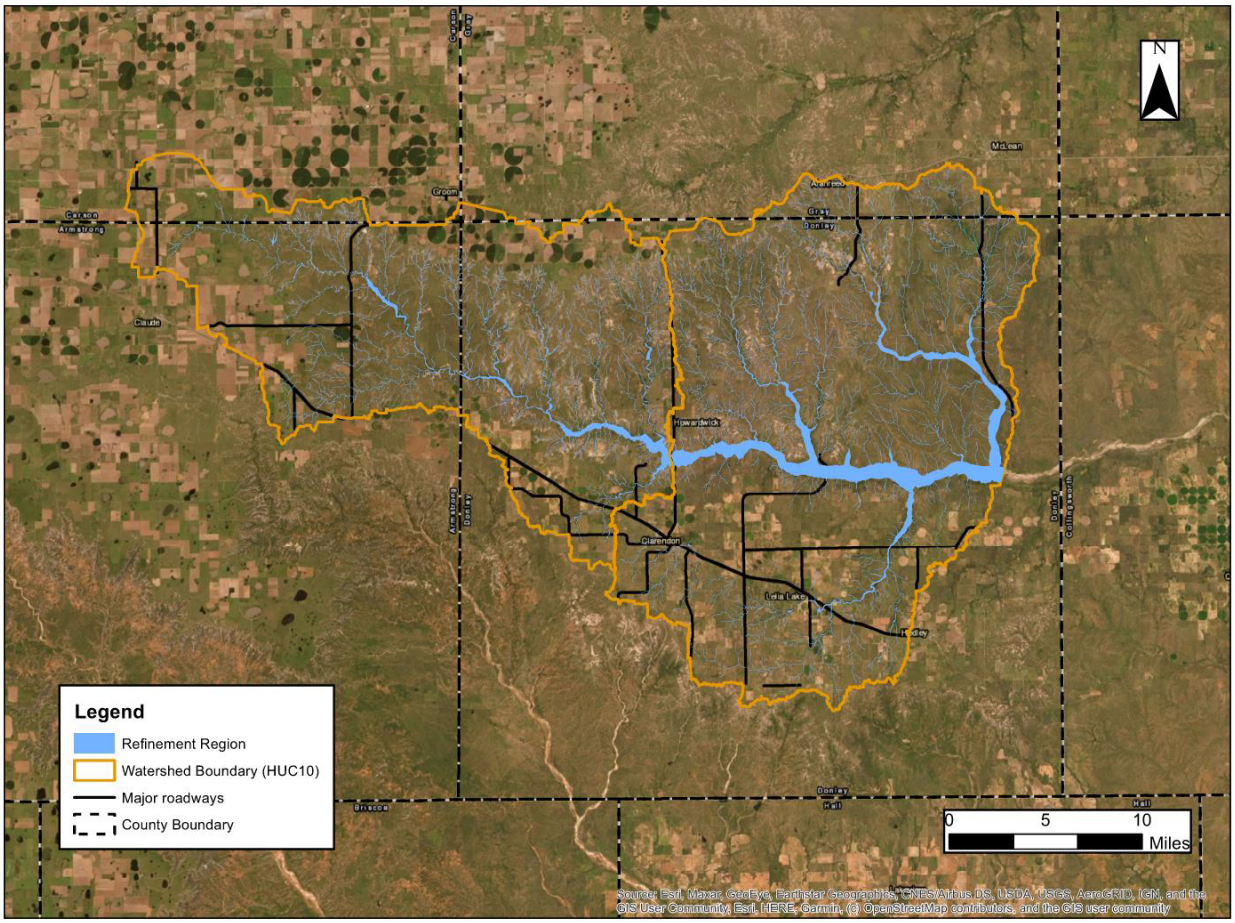


Figure 4-3. Overview of HUC 8 Scale Mesh Refinement Regions for Upper Salt Fork Red Watershed

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 selected for the Upper Salt Fork Red watershed are presented in Table 4-2 below. The values selected are within the range of values provided by the Texas Water Development Board's Base Level Engineering Guidelines (May 2022) and the HEC-RAS 2D manual (USACE 2021).

Table 4-2: Manning's N Values

Land Use Classification	Allowable Range of n values	Upper 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 Crop	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 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 Hydraulic Connectors (HCs) which allow flow to be conveyed through structures, such as roadway culverts, that the original DEM otherwise impedes (Figure 4-2). HCs were added with a criterion of a minimum of 6 feet width, or a reasonable width based on structure size as shown in LiDAR features and aerial imagery.

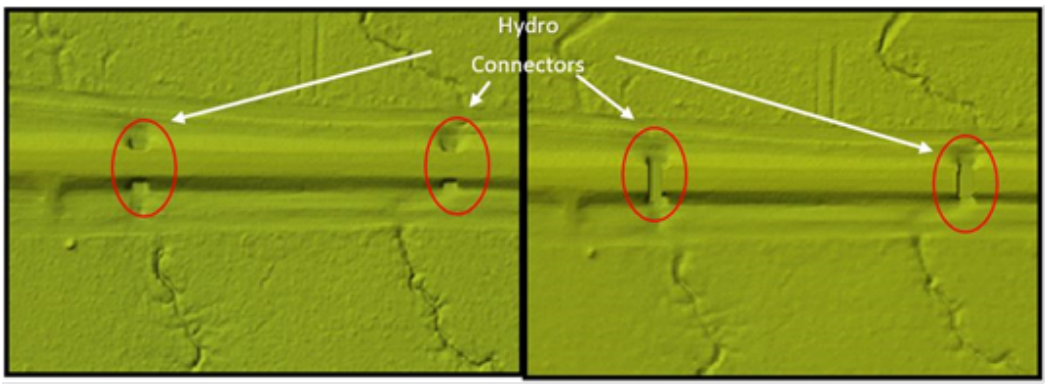


Figure 4-2. Example of localized original terrain (left) and terrain after resampling and addition of modification layer (right)

4.5 HUC 10 Model Integration

A diagram showing inter-basin connectivity and boundary condition (BC) locations for the Upper Salt Fork Red watershed is included in Figure 4-3.

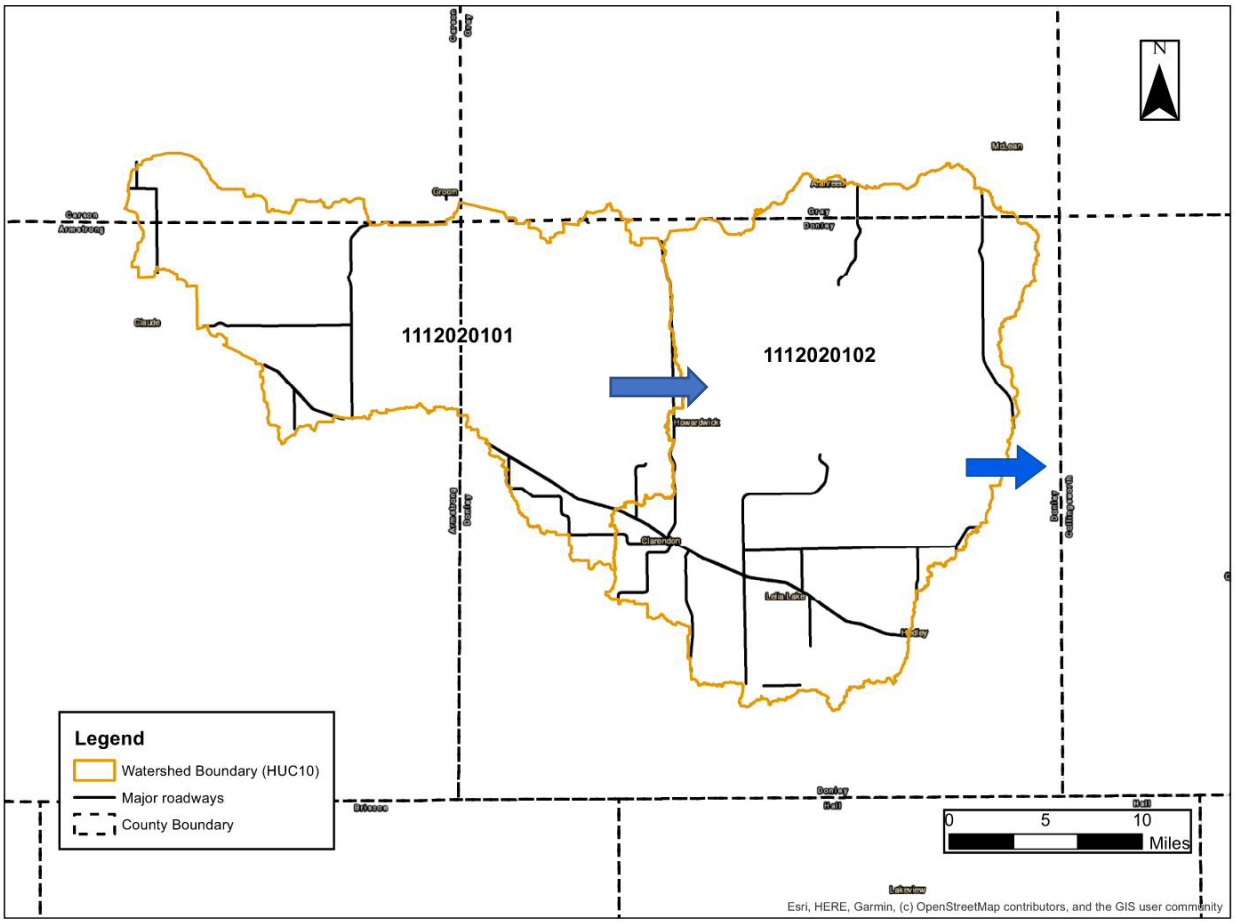


Figure 4-3. Overview of HUC 8 with HUC 10 Model Connectivity

For this BLE study, 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 typical 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 4-4). 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. An atypical connection exists between the 1112020101 and 1112020102 basins and is further discussed in section 4.5.1.

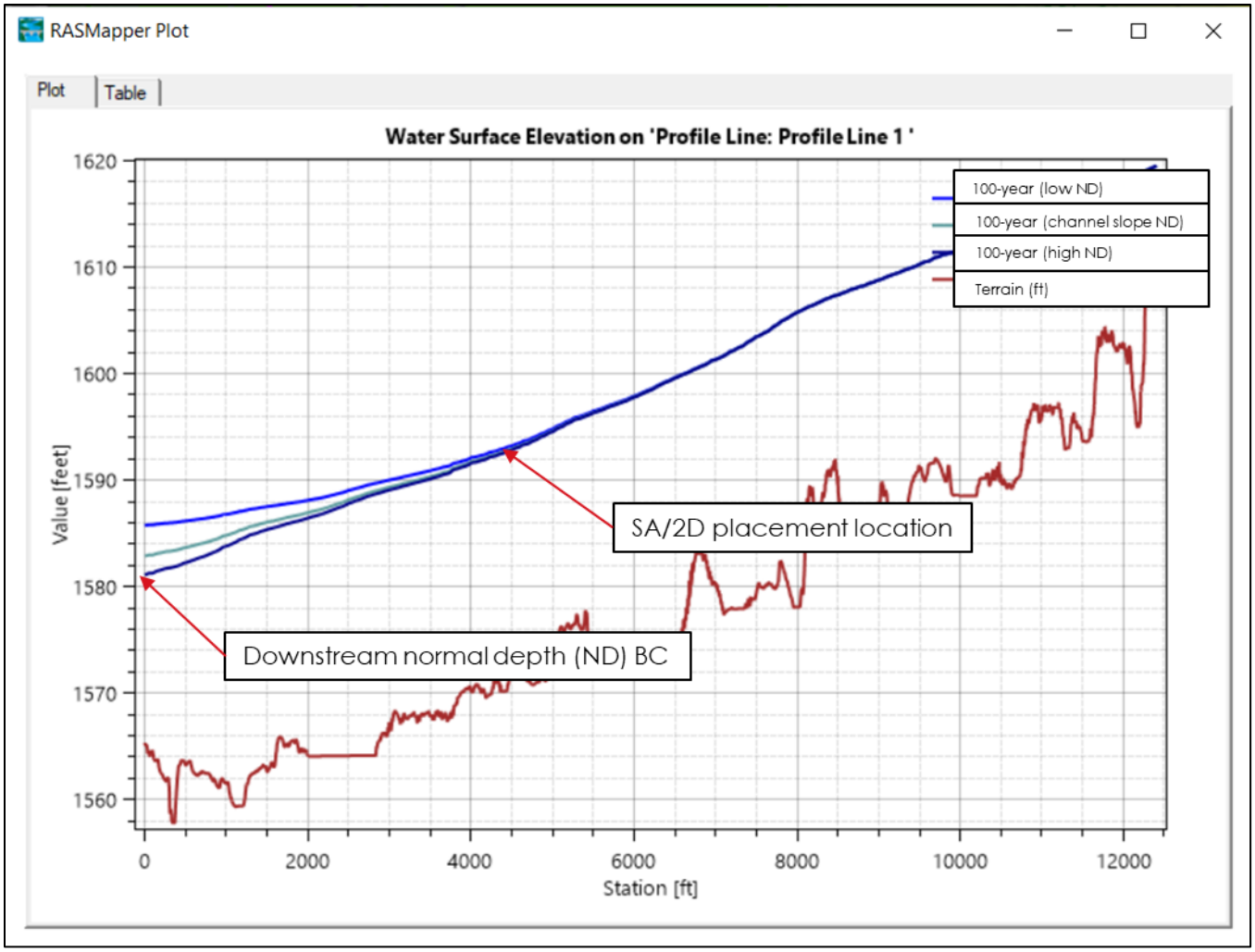


Figure 4-4. SA/2D Normal Depth sensitivity and placement example

For the connection of this HUC8 to the downstream HUC8, 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. As stated above, the internal connection for models within this HUC 8 (e.g. between HUC 10 1112020101 and 1112020102) was “atypical” in that it the connection did not require an overlap area. This is described further in section 4.5.1.

Final model meshes for the Upper Salt Fork Red 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.

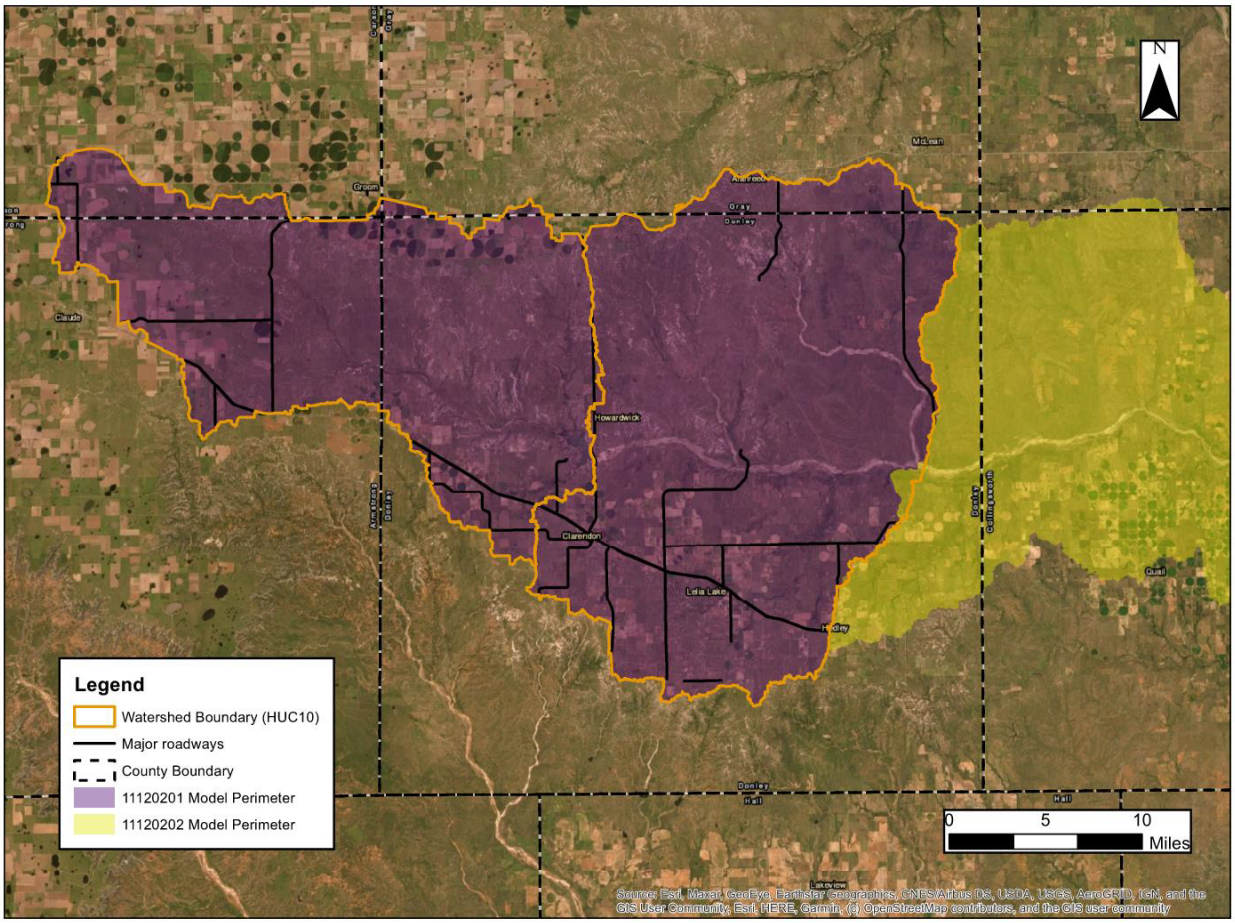


Figure 4-7. Overview of Adjusted Model Domains

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 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 BCs for each model are described in more detail in the following sections. Final continuity metrics for the Upper Salt Fork Red watershed are summarized in Table 4-3.

Table 4-3. HUC 10 Model Integration Summary

Upstream Watershed Name and Number	Downstream Watershed 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)
Greenbelt Reservoir -Salt Fork Red River 1112020101	Whitefish Creek -Salt* Fork Red River 1112020102	1	N/A	N/A	N/A

Upstream Watershed Name and Number	Downstream Watershed 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)
Whitefish Creek - Salt Fork Red River 1112020102	Lower Salt Fork Red 11120202**	1	12,000	0	0.0

*No downstream connection from Greenbelt Reservoir as seen in section 4.5.1
**More information on the connection to the downstream HUC 8 can be found in the BLE report for Lower Salt Fork Red (11120202)

4.5.1 Greenbelt Reservoir – Salt Fork Red River (1112020101) and Whitefish Creek – Salt Fork Red River (1112020102) Boundary

The downstream boundary of the Greenbelt Reservoir – Salt Fork Red River HUC 10 model is the Greenbelt Reservoir. This reservoir is large, with a maximum capacity of 81,357 acre-feet and a conservation capacity of 59,968. In 1975 the reservoir reached its maximum historical capacity of 44,198 acre-feet. Since 1997, the reservoir has experienced a general downward trend from 30,000 acre-ft in 1997 to 7,888 acre-ft in present day.

There are two main hydraulic outflow structures in the Greenbelt Reservoir. The main outflow structure is an emergency overflow weir. The bottom of the weir has an elevation of 2,674 feet and the top of dam is at 2,686 feet. The width of this weir is approximately 2,000 feet wide. This outlet has not been utilized in the historical period since the dam was built. The secondary outflow structure is a circular morning glory type structure with a spillway crest of 2,664 feet, an outer diameter of 27 feet, and inner diameter of 7 feet. Both outlets theoretically transfer flow from upstream HUC 10 basin, Greenbelt Reservoir – Salt Fork Red River (1112020101), to the downstream HUC 10, Whitefish Creek – Salt Fork Red River (1112020102). The reservoir is modeled with present day conditions.

Because the connection between the two HUC 10s is atypical, an SA/2D connection overlap area to transfer flows as described in section 4.5 was not used. Instead, a BC line representing the emergency spillway overflow was inserted to transfer flow directly. Additionally, in order to model the morning glory outlet, an SA/2D connection line with a rating curve outlet was used to transfer flow out of the model. The rating curve selected was calculated with spillway and orifice equations. A subsequent boundary condition line was inserted to the downstream model for both the spillway and morning glory scenarios.

In the 500-year modeled event the maximum water surface elevation in Greenbelt Reservoir reaches an elevation of 2,666.02. Modeled events do not reach the emergency spillway crest in any scenario. For the 500-year scenario only, the water surface elevation reaches the morning glory spillway and transferred to the downstream basin via DSS file. This model can be found in the supplemental model files. The maximum transfer flow is approximately 370 cfs. The connection was deleted from the model

due to excessive runtimes and insignificant flows however, the 500-year spill data was added to the downstream basin for the 500 year storm events in order to account for flow transfer.

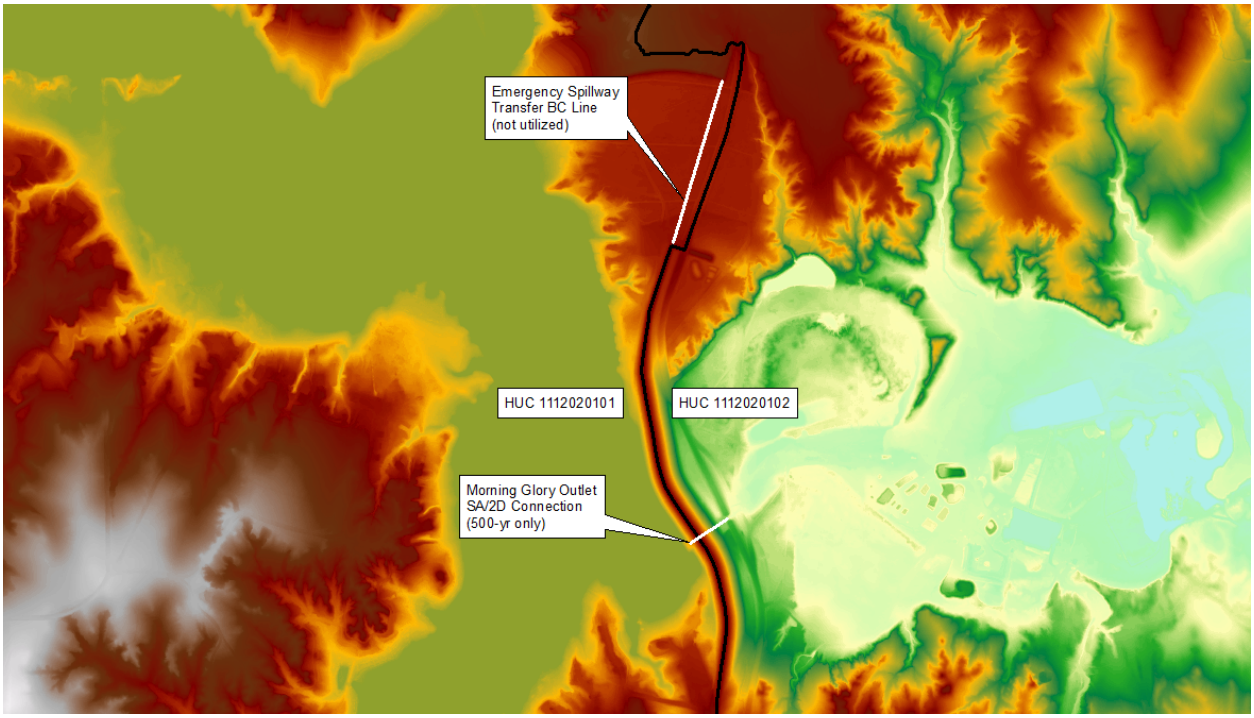


Figure 4-5. Greenbelt Reservoir – Salt Fork Red River 1112020101 and Whitefish Creek – Salt Fork Red River 1112020102 Boundary Plan View

Table 4-4 Greenbelt Reservoir – Salt Fork Red River (1112020101) and Whitefish Creek – Salt Fork Red River (1112020101) Continuity – all modeled events

Annual-chance Event	HUC101 (Upstream)		HUC102 (Downstream)		Absolute Difference	Absolute Difference
Event	Max WSEL (ft)	Peak Flow (Cfs)	Max WSEL (ft)	Peak Flow (Cfs)	Max WSEL (ft)	Peak Flow (Cfs)
10	N/A	0	N/A	0	0	0
25	N/A	0	N/A	0	0	0
50	N/A	0	N/A	0	0	0
100	N/A	0	N/A	0	0	0
100-	N/A	0	N/A	0	0	0
100+	N/A	0	N/A	0	0	0
500*	N/A	300	N/A	300	0	0

*Flow transfer via rating curve

4.5.2 Whitefish Creek – Salt Fork Red River (1112020102) and Lower Salt Fork Red (11120202) Boundary

The Whitefish Creek – Salt Fork Red River HUC10 is part of the Upper Salt Fork Red watershed and is approximately 430 square miles in size. A minor community, Clarendon, existing in the southwest part of the basin. This basin has similar characteristics to the upstream HUC10. This area contains upper flat plains area which flow into steep canyon areas. In addition, large natural playa ponds exist throughout the area. The runoff from this HUC10 flows generally west to east and outflows to the HUC8 Lower Salt Fork Red, or more specifically HUC10 Sand Creek – Salt Fork Red River 1112020202. A single SA/2D connector outflow to an inflow flow hydrograph was the preferred method to transfer flow from Whitefish Creek – Salt Fork Red River to the downstream Sand Creek – Salt Fork Red River basin. This method was chosen due to the relatively short distances between the inflow boundary, confluence, and outflow boundary. The location of model connection is shown in plain view in Figure 4-6. The continuity metrics at the model connection are discussed in more detail for each storm event in the BLE report for HUC 8 11120202 Lower Salt Fork Red.

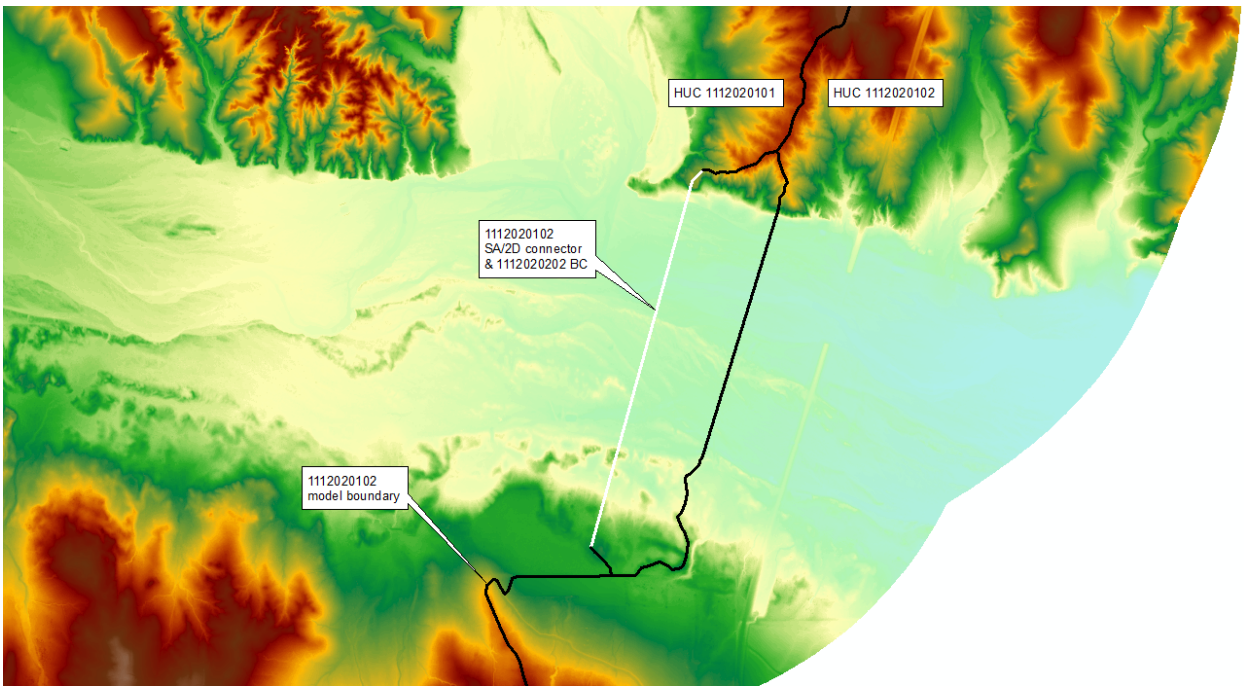


Figure 4-6. Greenbelt Reservoir – Whitefish Creek – Salt Fork Red River 1112020102 and HUC 8 Lower Salt Fork Red - Boundary Plan View

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. No model adjustments were made based on USGS regional regression estimates. 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 Upper Salt Fork Red watershed, is included in **Appendix A – Bulletin 17C**

Statistical Analysis Technical Memo and Peak FQ Output. This appendix encompasses all flow gages in the Task Order, including the one referenced above.

The Upper Salt Fork Red watershed models are shown below in Figure 4-7. The USGS gages containing 10 or more years of record that were initially considered for calibration are shown below. There are two USGS gages in the Upper Salt Fork Red HUC-8. Gage 07299840 contains only water surface elevation data for the Greenbelt Reservoir. This data was not used for calibration as it is not flow data. Additionally, historical reservoir storage according to the gage data has a downwards trend since the pond's inception in the 1970's, making direct comparisons between modeled and historical results difficult. A discrepancy exists between the modeled spillway elevation of 2,676 feet and the recorded dam spillway elevation of 2,674 feet. This may be due to two factors. State Highway 70 runs through this dam spillway and since the dam's impoundment date of January 01, 1968, roadway improvements to this State Highway 70 may have occurred. Historical TxDOT records of SH 70 improvements were searched to no conclusion. In addition, the original USGS Geological Survey records the dam as of October 8, 1967 at 2,674 using the vertical transformation at the time, NGVD29. This modeling scenario uses the current vertical transformation NAVD 88. The difference between NGVD29 and NAVD88 at this point according to the NOAA Online Vertical Datum Transformation web tool, is +0.40 meters or +1.32 feet. A combination of these factors may explain the spillway elevation difference.

1% annual chance peak flow value estimates from a Bulletin 17C statistical flood frequency analysis using the USGS program PeakFQ were used to analyze the second gage, 07299890. However, gage 07299890 is located on an isolated tributary in the downstream portion of the basin (Figure 4-7), and therefore global parameter calibration was not informed by model comparison at this gage. Modeled results at this gage are reported in Table 4-5 as compared to the Bulletin 17C analysis for the 100-year event and results fall within the 95% confidence interval of the flood frequency analysis. See section 4.7.2 for further discussion on the usage of this gage.

Due to lack of mainstem historic flow data in the Upper Salt Fork Red watershed, model performance was primarily validated by the 17C analysis for gage 07300000 which is located on mainstem Salt Fork in the downstream HUC8 watershed (Figure 4-7). This gage is approximately 24 miles downstream of the 1112020102 Greenbelt Reservoir – Whitefish Creek model outlet. While this gage is modeled within a separate, downstream watershed model, the drainage area in HUC 8 11120201 (downstream of the Greenbelt Reservoir) contributes approximately 40% of the drainage area for the gage. The runoff rate for the Upper Salt Fork outlet, 1% event (about 100 CFS/sq mi) is slightly lower than the runoff rate suggested by the 17C analysis at the gage (120 CFS/sq mi). Corresponding to this runoff rate, curve numbers in the 1112020102 model were set to the higher end of the published "acceptable range" for primarily rural watersheds and were therefore, not adjusted further for calibration (USGS 2015; TWDB 2022). The modeled peak flow at gage 07300000 is within the 95% confidence intervals for the gage while remaining lower than the 1% median (Table 4-5). This is thought to be an accurate representation of the watershed response incorporating the effects of the Greenbelt Reservoir operations.

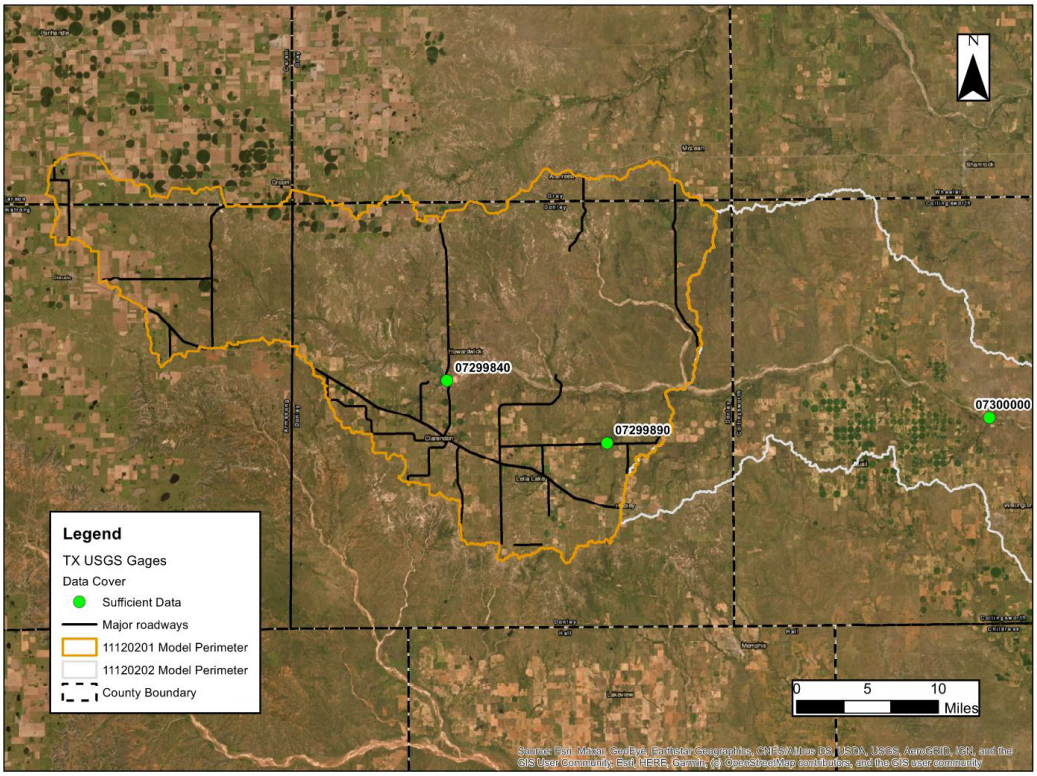


Figure 4-7. USGS Gages in Upper Salt Fork Red Watershed

Table 4-5. 1% Annual Storm Calibration Results Summary for Upper Salt Fork Red 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		
USGS Gage 07299890	74	3,886	1,872	18,860	11,900	102%
USGS Gage 07300000	1,222	99,210	53,220	275,100	65,300	34%

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 modeled outflow of the downstream boundary for the HUC-8. 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).

A large reservoir with historically low water surface elevations, the Greenbelt Reservoir, bisects this HUC 8 and retains all 100-year flows from the HUC 10 named Greenbelt Reservoir – Salt Fork Red River

(1112020101). Due to this reservoir, regression analysis to the downstream-most point in the HUC 8 includes only the area from the Whitefish Creek – Salt Fork Red River (1112020102) basin. A regression comparison was not included for the portion of the watershed upstream of the Greenbelt Reservoir (Greenbelt Reservoir – Salt Fork Red River 1112010201). Referring to Table 4-6, the modeled results are higher than regression estimates, yet lower than the Bulletin 17C analysis (as discussed in the previous section). Therefore, in combination with the bisecting reservoir, there is low confidence in the applicability of the regression results for this HUC 8.

Table 4-6. 1% Annual-chance Flood Event – Modeled Peak Flow Comparison to USGS Regional Regression Estimates (equations and parameters via USGS 2020)

HUC10 Watershed	Modeled Peak Flow (CFS)	Regression Estimate (CFS)	% difference
Whitefish Creek – Salt Fork Red River 1112020102	44,287	23,774	60.3%

4.7 Results

4.7.1 Comparison to Existing Study Data

Research was performed in the area to find any available Existing Conditions Study Data. FEMA Flood maps were found for the towns of Clarendon and Howardwick. In general, the flood extents of the effective maps were similar to modeled results. However, these maps are outdated (pre- NOAA Atlas 14 rainfall data) and not based on a detailed study. Comparison of modeled results to existing NFHL data were not considered in model calibration.

There were no existing detailed studies for the Greenbelt Reservoir Dam.

4.7.2 Challenges and Recommendations

The first modeling challenge for this HUC 8 was the Greenbelt Reservoir. Initial conditions of the dam and connections to the downstream model were considered. Upon discussions with the analysis team, it was determined that existing conditions of the dam should be used for modeling purposes. As described in section 4.5.1, this dam has historically declining storage. An atypical SA/2D connection was used to determine outflow from the morning glory outlet using and outflow curve calculated from weir and orifice equations.

The second modeling challenge was calibration to the USGS gage 07299890 at Leila Lake Creek. This gage is off the main stem for this HUC. The available data for the gage created skewed results. There are five analyzed storm events in between the annual exceedance probability intervals of 20% to 5%. All five of the discharges at the gage from these storms are approximately 1000 cfs. It also appears that the 4% storm and the 16% storm have the same flow rate. The 1% modeled peak flow at this gage falls withing the Upper and Lower 95% confidence interval based on the Historic Record Bulletin 17C Flood Frequency Analysis.

4.7.3 Crossing Profile Errors

To verify the modeled 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 4-8 and Figure 4-9 are examples of profile checks using max WSE results for the models in this watershed.

In the model for HUC 1112020101, the profile line was placed upstream of the Greenbelt Reservoir. The reservoir WSEL can be seen in the 0.2% and 1% Plus events in Figure 4-8.

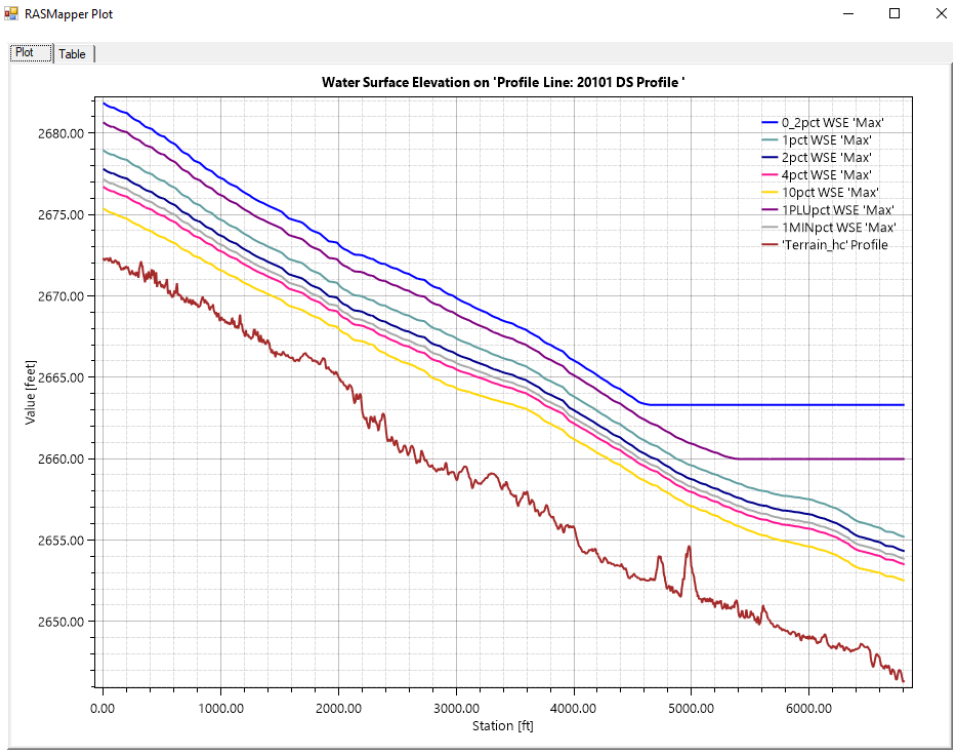


Figure 4-8. HUC 1112020101 WSE Profile Plot – all modeled events

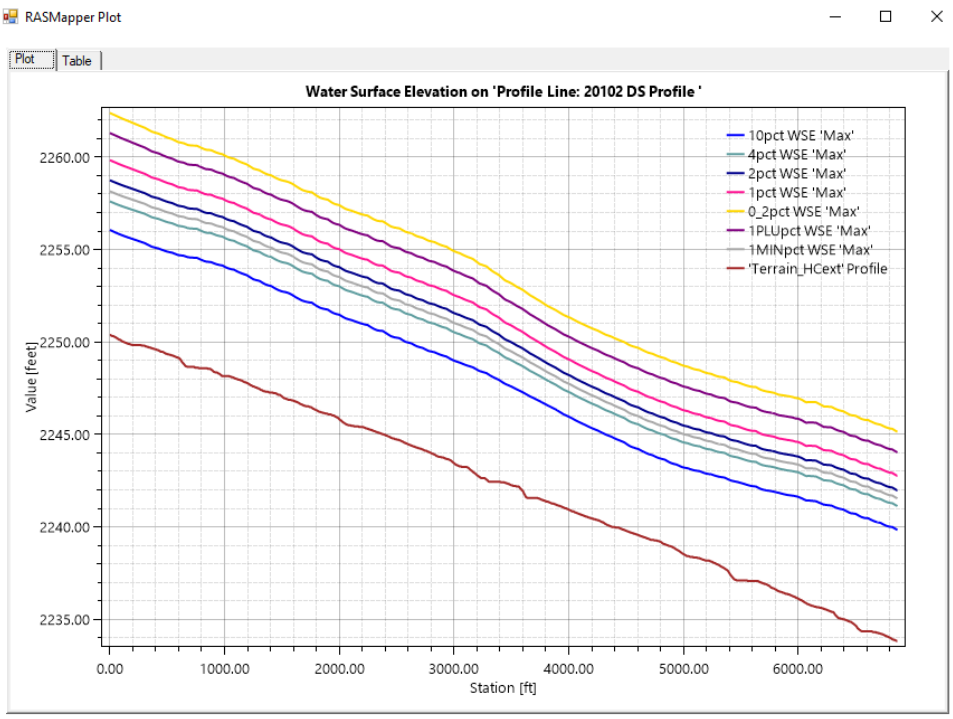


Figure 4-9. HUC 1112020102 WSE Profile Plot – all modeled events

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 and NWS gages in the watershed. The reported results correspond to the gages shown in Figure 4-10. 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)). The hydraulic study results will be shared with the Upper Salt Fork Red watershed communities during the Discovery Process.

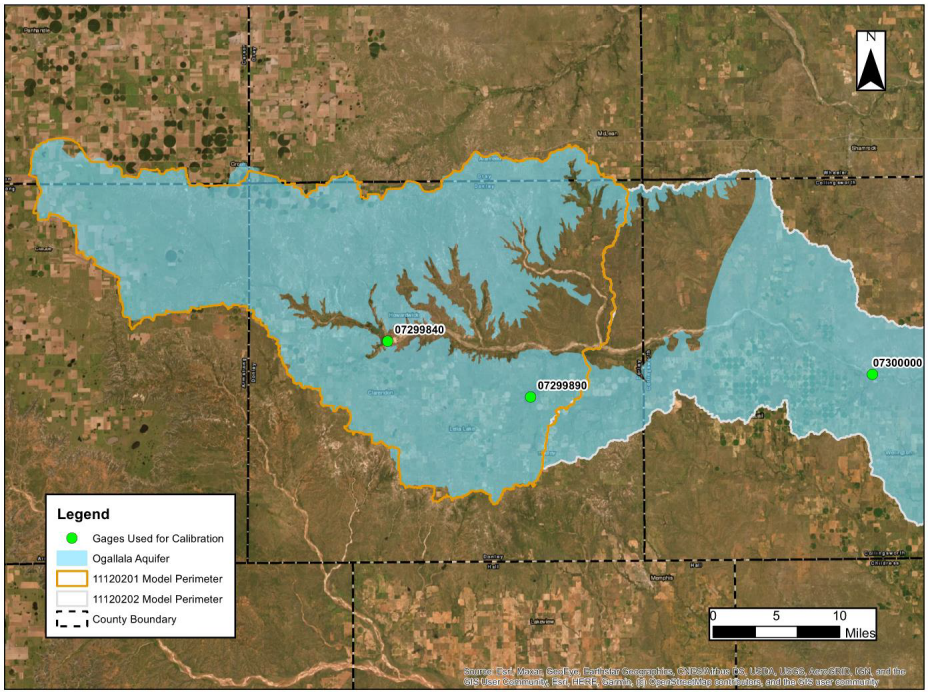


Figure 4-10. Gage Locations corresponding to reported modeled results

Table 4-7. 10% Storm Results Summary for Upper Salt Fork Red watershed

HUC 10 Model Name and Number	Gage Description	Peak Flow (CFS)	WSEL* (ft)
Greenbelt Reservoir – Salt Fork Red River 1112020101	Greenbelt Lake near Clarendon, TX ID07299840	N/A**	2,645.1
Whitefish Creek – Salt Fork Red River 1112020102	Leila Lake Creek Bell Creek near Hedley, TX ID 7299890	2,765	2,420.5

Note: vertical datum of modeled WSEL is NAVD88

*** No outflow from reservoir for 10% event*

Table 4-8. 1% Storm Results Summary for Upper Salt Fork Red watershed

HUC 10 Model Name and Number	Gage Description	Peak Flow (CFS)	WSEL* (ft)
Greenbelt Reservoir – Salt Fork Red River 1112020101	Greenbelt Lake near Clarendon, TX ID07299840	N/A**	2,654.0

HUC 10 Model Name and Number	Gage Description	Peak Flow (CFS)	WSEL* (ft)
Whitefish Creek – Salt Fork Red River 1112020102	Leila Lake Creek Bell Creek near Hedley, TX ID 7299890	11,877	2,424.0

Note: vertical datum of modeled WSEL is NAVD88

*** No outflow from reservoir for 1% event*

Table 4-9. 0.2% Storm Results Summary for Upper Salt Fork Red watershed

HUC 10 Model Name and Number	Gage Description	Peak Flow (CFS)	WSEL* (ft)
Greenbelt Reservoir – Salt Fork Red River 1112020101	Greenbelt Lake near Clarendon, TX ID07299840	N/A**	2,665.4
Whitefish Creek – Salt Fork Red River 1112020102	Leila Lake Creek Bell Creek near Hedley, TX ID 7299890	22,882	2,426.7

Note: vertical datum of modeled WSEL is NAVD88

**No outflow from reservoir for 0.2% event

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 Upper Salt Fork Red 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 aces 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 Upper Salt Fork Red 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:

- There are no detailed study areas/lines (DTL_STUD_AR & DTL_STUD_LN) within Upper Salt Fork Red Watershed, only approximate zones as provided from the National Flood Hazard Layer (NFHL) and TWDB Floodplain Quilt.
- 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 Upper Salt Fork Red 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 Upper Salt Fork 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 vector and rasters features are fully contained within the boundaries of the HUC8 polygon extents using the appropriate clipping and extracting tools. The feature datasets within the Flood Risk Database follow FEMA's resolution and tolerance specifications for the GCS projection (FEMA 2023). If features were still outside the HUC8 polygon, those were identified and corrected, when outside FEMA tolerances. Visual differences may appear where features are alongside of the HUC8 boundary.

6.4 Results and Recommendations

The BLE results for the Upper Salt Fork Red watershed 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 as part of 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 (17.4 miles) in the Upper 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 11120201 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 11120201 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.

Only six effective Zone A reaches used regression equations in HUC8 11120201. These six reaches used 0–4405–2 which has been replaced by SIR 2008-5084, and sensitivity analysis shows significant change between the two equations. Therefore, these six reaches fail A2. The rest of the effective Zone A reaches in HUC8 11120201 did not use regression equations for hydrology, so they automatically pass 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 11120201 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	Fail	Significant change from old to new report for 6/16 reaches

A3 - Development	Pass	Urbanization increase is not significant

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.

The six effective Zone A studies in HUC8 11120201 studied using regression equations have known hydraulic models and therefore pass A4. All other Zone A reaches in HUC8 11120201 have no information available on their hydraulic model and are therefore not considered to be model backed. These reaches fail A4.

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 11120201 either failed the BLE comparison check or did not have enough FBS points for the check to be valid. 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.

CNMS Validation Results

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in Upper Salt Fork Red Headwaters 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.

Table 7-2: Zone A Validation Results

Validation Status	Status Type	Total Mileage
Valid	NVUE Compliant	0
Unverified	Being Studied	17

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						
Record Creek	111202010104	8	3	5	62%	>85%	Insufficient points for comparison
Carrol Creek	111202010107	154	143	11	7%	>85%	FAIL
Kelly Creek-Salt Fork Red River	111202010108	18	17	1	6%	>85%	Insufficient points for comparison
West Lelia Lake Creek	111202010204	46	37	9	20%	>90%	FAIL
Upper Whitefish Creek	111202010208	878	678	200	23%	>85%	FAIL
Skillet Creek	111202010209	334	178	156	47%	>85%	FAIL

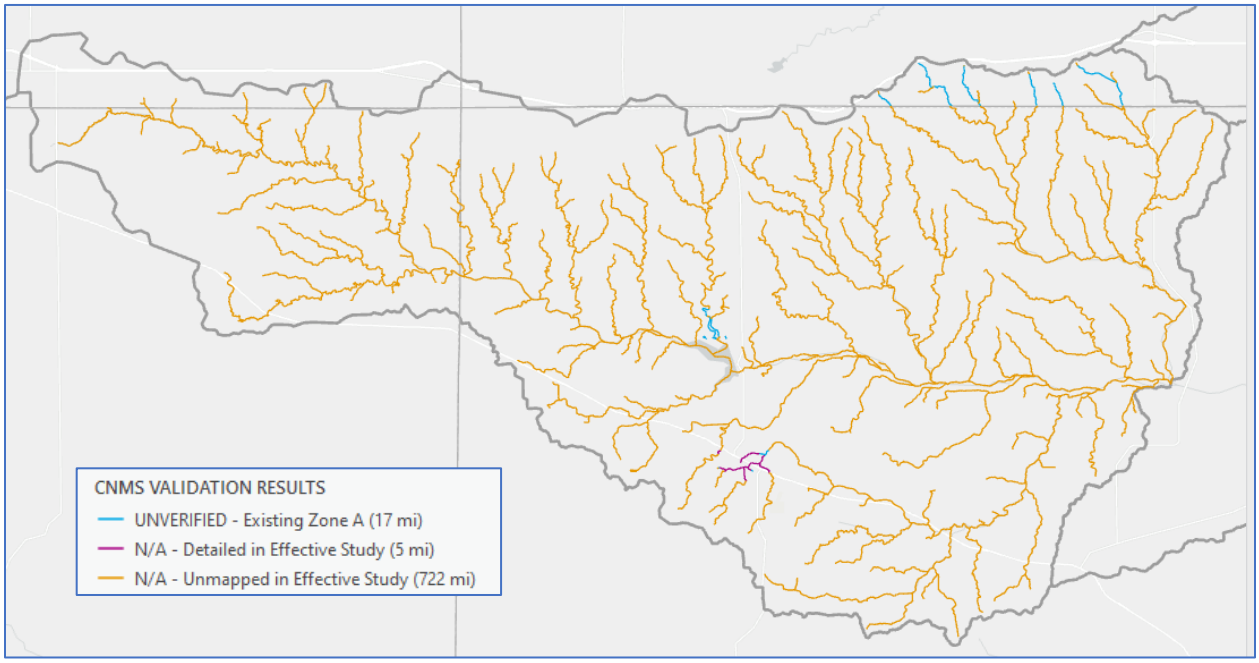


Figure 7-1. CNMS Validation Results

7.1 Deliverables

- **Coordinated Needs Management Strategy (CNMS) Geodatabase**
  - Contains all CNMS relationship and feature classes for reaches in HUC8 11120201.
- **Results generated by A5 analysis using the Basic method**
  - FBS points and A5 Pass/Fail results aggregated by HUC12 feature classes.

References

Bibliography list of references used and referred to throughout document.

1. Multi-Resolution Land Characteristics Consortium (MRCL). National Land Cover Database (NLCD) 2019 Land Cover (CONUS). Online at: https://www.mrlc.gov/data/nlcd-2019-land-cover-conus

2. Ajmal, M., Waseem, M., Kim, D., and Kim, T.W. 2020. A Pragmatic Slope-Adjusted Curve Number Model to Reduce Uncertainty in Predicting Flood Runoff from Steep Watersheds. *Water*. 2020, 12, 1469.

3. Chow, Ven T. "Development of Uniform Flow and Its Formulas." Open Channel Hydraulics. Caldwell, NJ: Blackburn, 1959. 109-113. Print.

4. Cleveland, Theodore G; Fang, Nick, 2021, "texas-skew-update-2021", https://doi.org/10.18738/T8/SVLCOQ, Texas Data Repository, V6

5. England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O., Jr., Veilleux, A.G., Kiang, J.E., and Mason, R.R., Jr., 2018, Guidelines for determining flood flow frequency--Bulletin 17C: U.S. Geological Survey Techniques and Methods, book 4, chap. B5, 148 p., https://doi.org/10.3133/tm4B5.

6. URS Corporation. (2016). FINAL Upper Brushy Creek Watershed Flood Protection Plan. June 2016.

7. United States Army Corps of Engineers (USACE). (2021). River Analysis System, HEC-RAS, v. 6.0.0

8. United States Geological Study (USGS). (2020). Methods for Estimating the Magnitude and Frequency of Peak Streamflows for Unregulated Streams in Oklahoma Developed by Using Streamflow Data Through 2017. USGS Report 2019-5143, version 1.1. Online at: Methods for Estimating the Magnitude and Frequency of Peak Streamflows for Unregulated Streams in Oklahoma Developed by Using Streamflow Data Through 2017 (usgs.gov)

9. Hydrologic Engineering Center (USACE HEC). HEC-RAS 2D User's Manual. 2022. https://www.hec.usace.army.mil/confluence/rasdocs/r2dum/latest

10. FEMA, "Guidance for Flood Risk Analysis and Mapping – First Order Approximation", November 2014. (http://www.fema.gov/media-library-data/1420849667914-c1656173985d814d0e62f80818505969/FOA_Guidance_Nov_2014.pdf).

11. FEMA Region 6, "Base Level Engineering Submittal Guidance", June 2017. (https://rmd.msc.fema.gov/Regions/VI/Ph0_Investment/1/Base%20Level%20Engineering/Submittal%20Guidance/20170615_BLE%20Submittal%20Guidance_R6.pdf).

12. ESRI ArcMap (2018). ArcGIS v. 10.6.1

13. NOAA. (2017). “NOAA Atlas 14 Precipitation Frequency Estimates in GIS Compatible Format”. Webpage last modified April 21, 2017. Downloadable online at: PF in GIS Format - PFDS/HDSC/OWP (noaa.gov)

14. NOAA. (2018). NOAA Atlas 14 Precipitation-Frequency Atlas of the United States. Volume 11 Version 2.0: Texas. Online at: NOAA Atlas 14 (weather.gov)

15. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Available online at https://sdmdataaccess.sc.egov.usda.gov. Accessed [July/07/2021]

16. USGS. (2015). Documentation of Input Datasets for the Soil-Water Balance Groundwater Recharge Model for the Upper Colorado River Basin. Fred D. Tillman. Online at: cover v 3.5.1 (usgs.gov)

17. Texas Water Development Board (TWDB). (2022). Texas Two-Dimensional Base Level Engineering Guidelines. Version 1.

18. FEMA, "Coordinated Needs Management Strategy (CNMS) Technical Reference", November 2021. (https://www.fema.gov/sites/default/files/documents/fema_CNMS-technical-reference_112021.pdf).

Appendix A – 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 0-1) were analyzed using USGS software PeakFQ[1] (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 0-1 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.

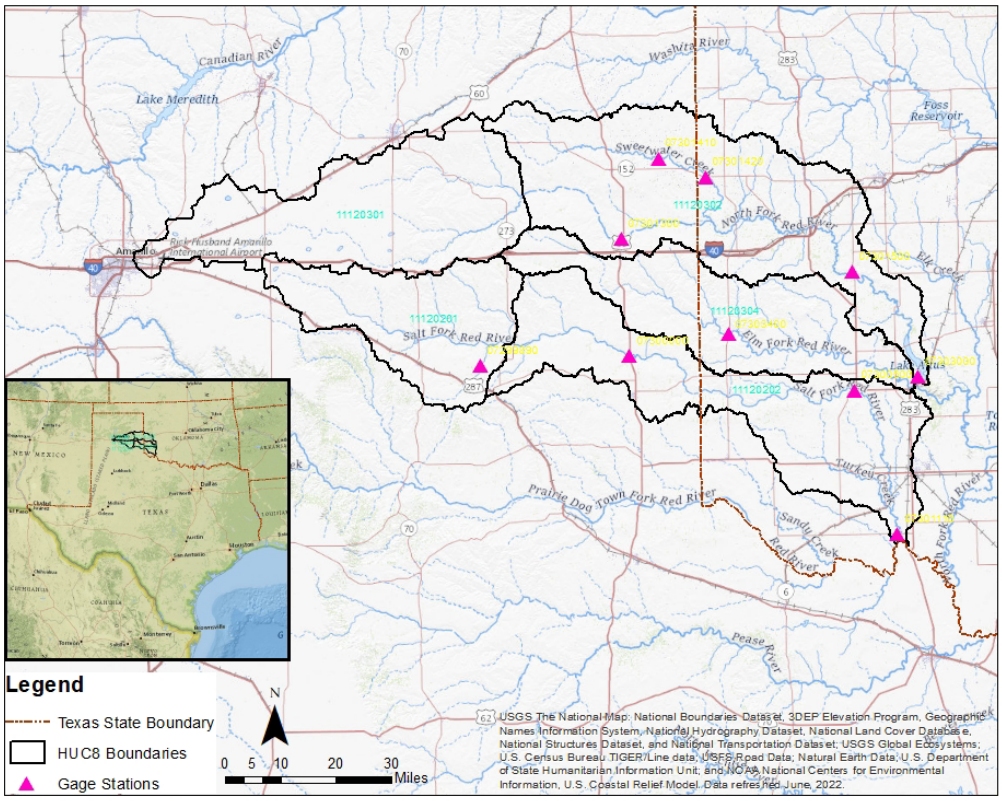


Figure 0-1: Map of the stream gaging stations

[1] https://water.usgs.gov/software/PeakFQ/

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 Streamflow[2] 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 0-2 through Figure 0-10 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

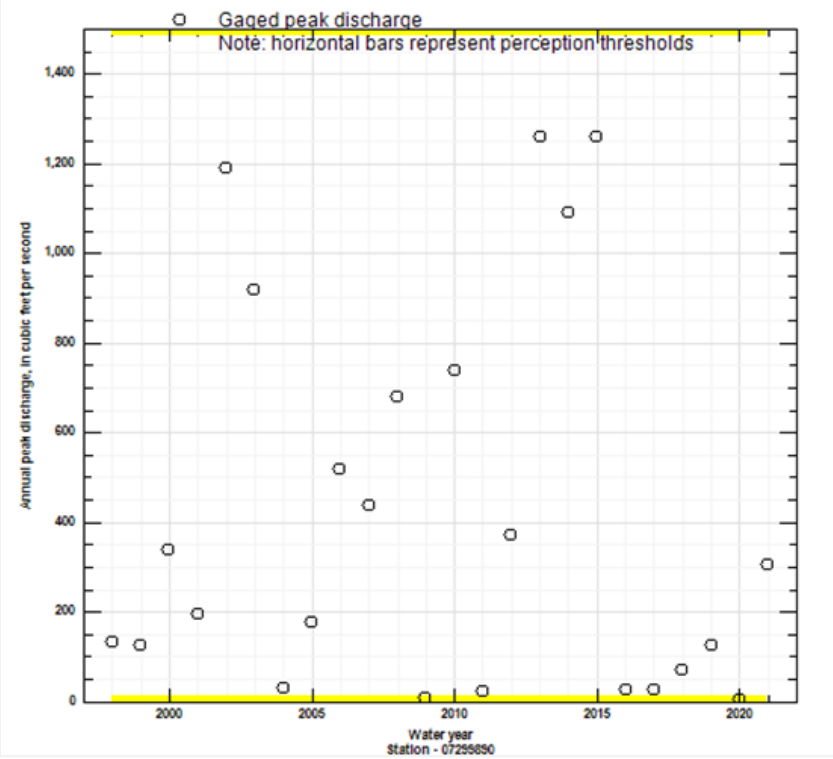


Figure 0-2: Gaged peak discharge at station 07299890

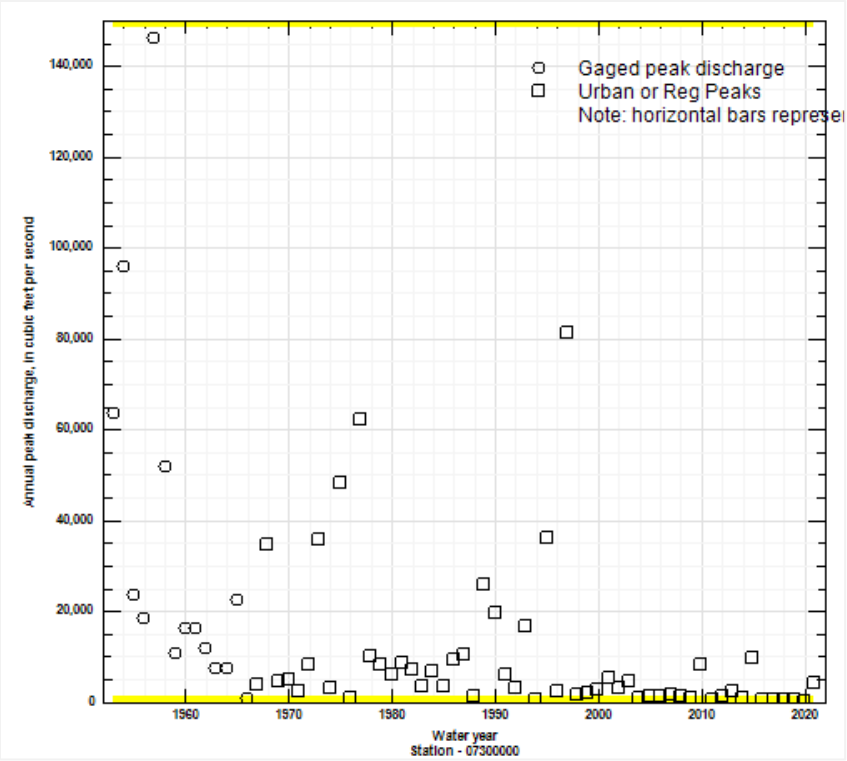


Figure 0-3: Gaged peak discharge at station 07300000 (Most of the data are affected by regulation or diversion)

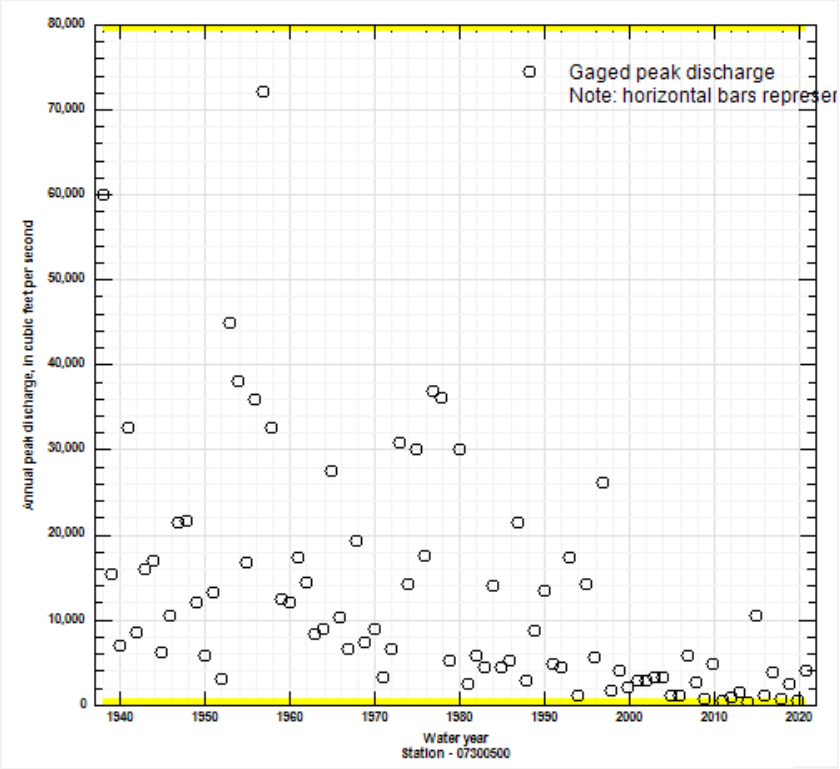


Figure 0-4: Gaged peak discharge at station 07300500

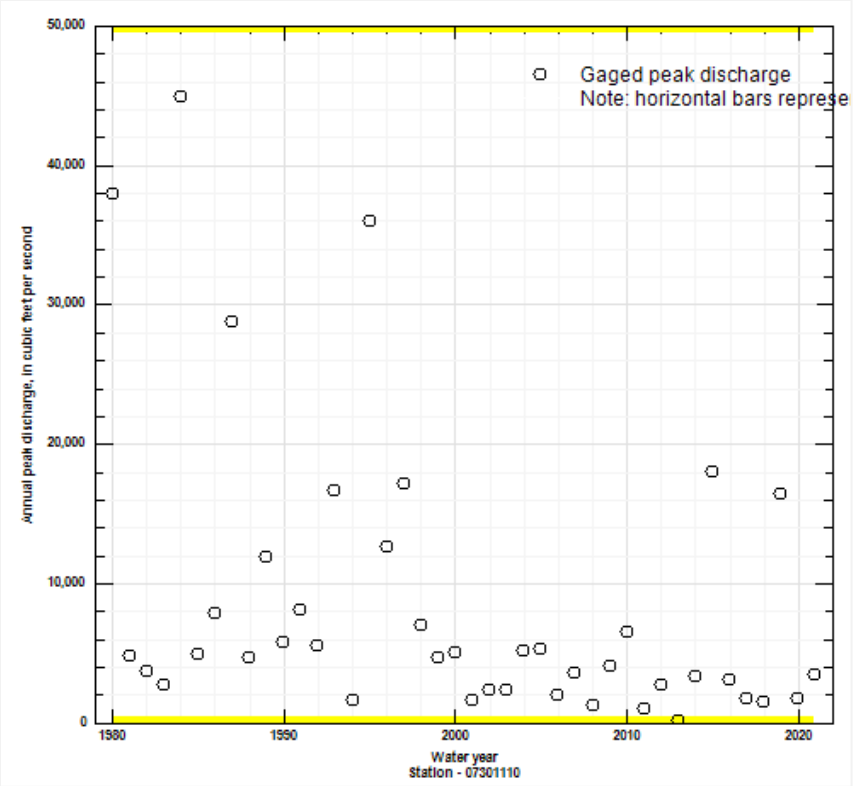


Figure 0-5: Gaged peak discharge at station 07301110

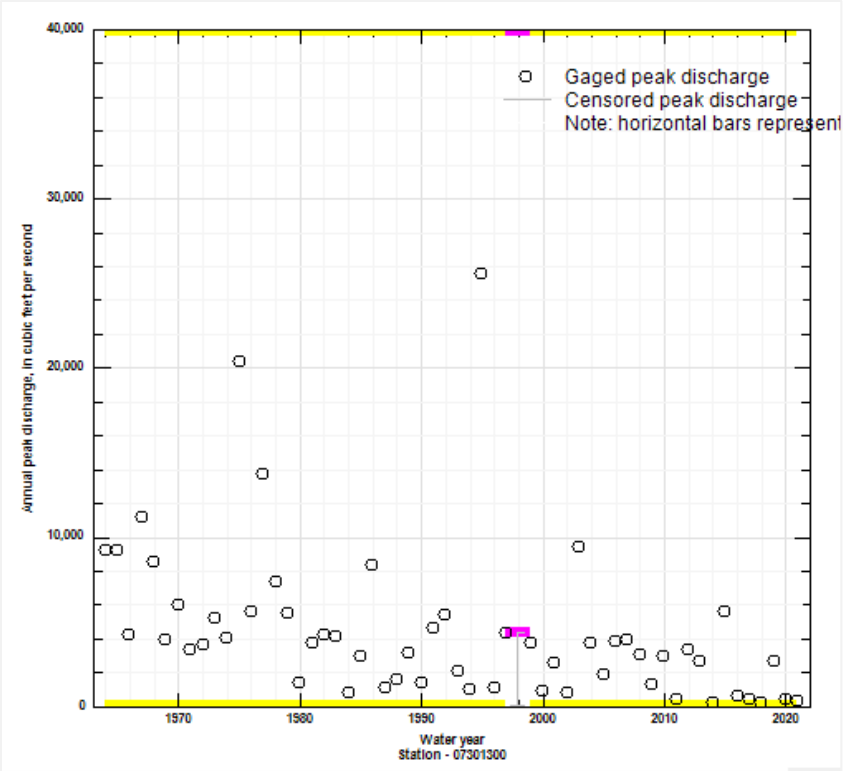


Figure 0-6: Gaged peak discharge at station 07301300

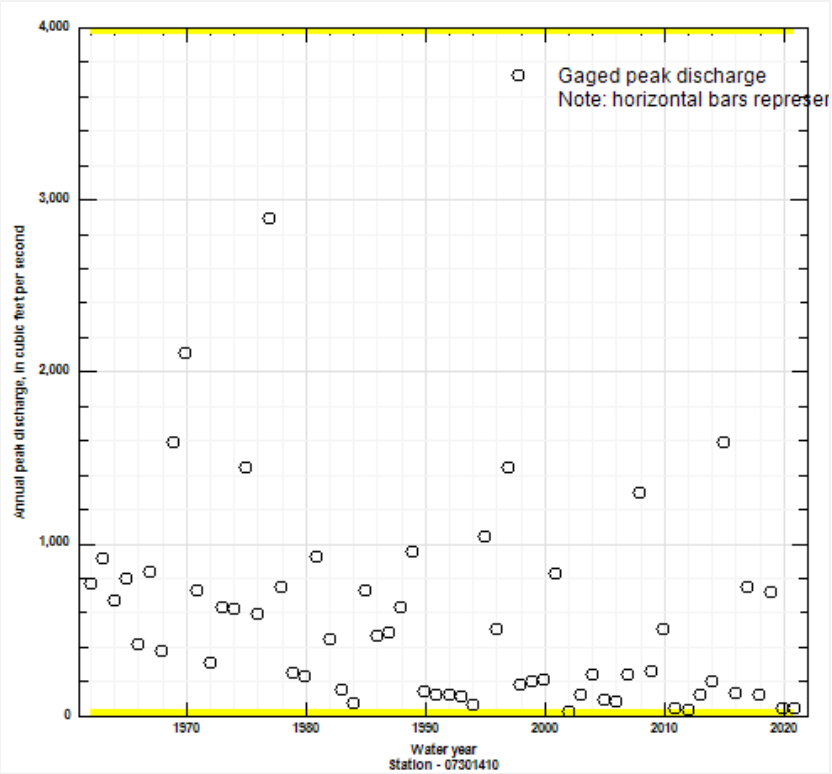


Figure 0-7: Gaged peak discharge at station 07301410

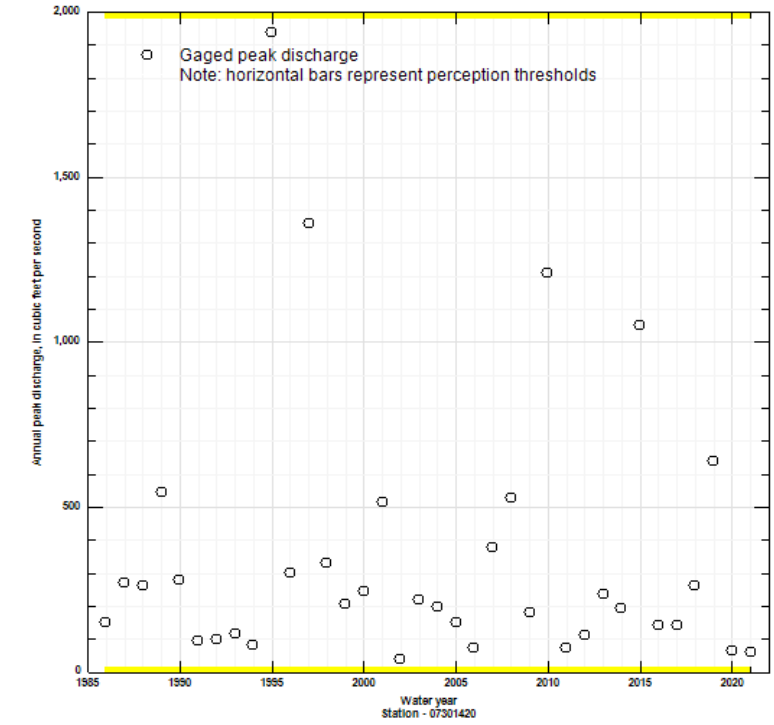


Figure 0-8: Gaged peak discharge at station 07301420

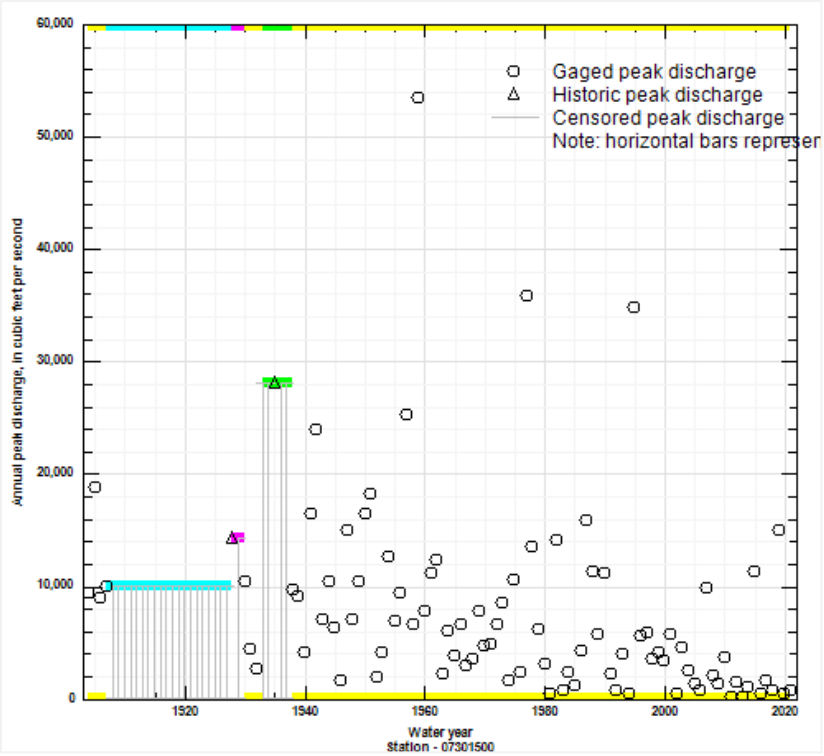


Figure 0-9: Gaged peak discharge at station 07301500

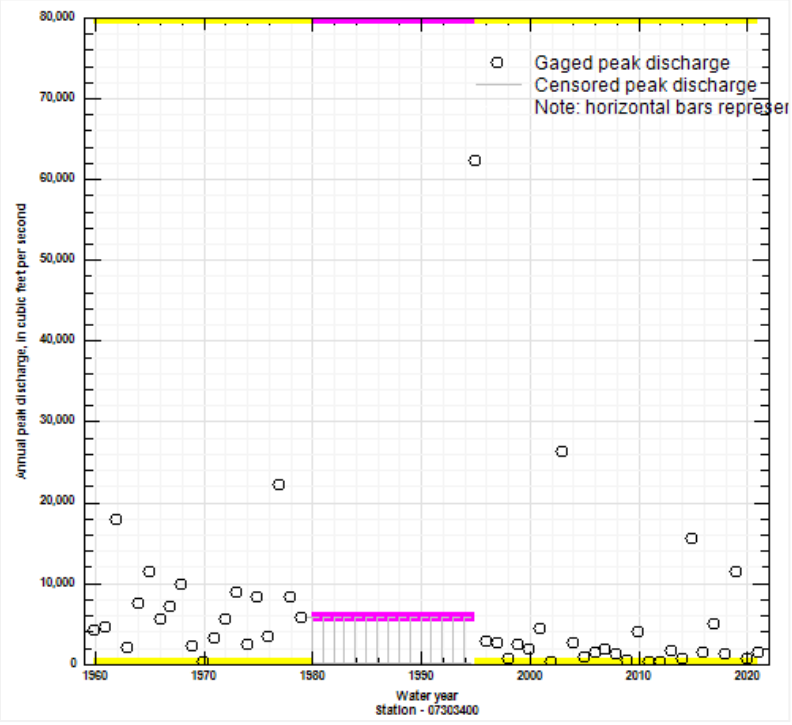


Figure 0-10: Gaged peak discharge at station 07303400

Texas Skew values

The regional skew information (Regional Skew and Regional Skew Std Error) is extracted using a tool available at Texas Data Repository[3] (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 PeakFQ Output For Upper Salt Fork Red (HUC 8 11120201). 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.. PeakFQ Output For Upper Salt Fork Red (HUC 8 11120201) 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 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,

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

based upon visual inspection of the peak discharge plots (e.g., see Figure 0-3). 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	119200	136600	**99210**
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.
ǂ Bold numbers are recommended results to use for that station

References

Cleveland, Theodore G.; Fang, Nick, 2021a, "texas-skew-update 2021", https://doi.org/10.18738/T8/SVLCOQ, Texas Data Repository, V6; texas-skew-training.mp4

Cleveland, Theodore G.; Fang, Nick, 2021b, "texas-skew-update-2021", https://doi.org/10.18738/T8/SVLCOQ, Texas Data Repository, V8; 0-6977-1.pdf

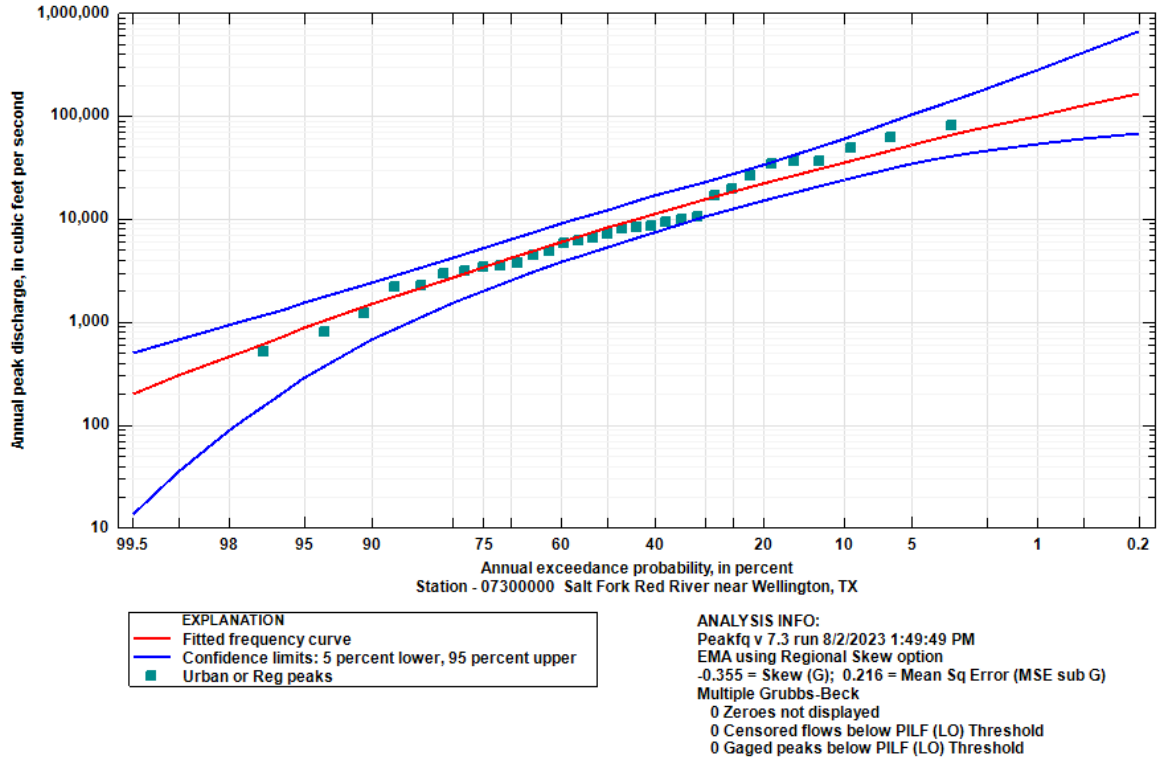
Cohn, T.A., Lane, W.L., and Baier, W.G., 1997, An algorithm for computing moments-based flood quantile estimates when historical flood information is available: Water Resources Research, v. 33, no. 9, p. 2089–2096

Cohn, T.A., Lane, W.L., and Stedinger, J.R., 2001, Confidence intervals for Expected Moments Algorithm flood quantile estimates: Water Resources Research, v. 37, no. 6, p. 1695–1706

England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O., Jr., Veilleux, A.G., Kiang, J.E., and Mason, R.R., Jr., 2019, Guidelines for determining flood flow frequency — Bulletin 17C (ver. 1.1, May 2019): U.S. Geological Survey Techniques and Methods, book 4, chap. B5, 148 p., https://doi.org/10.3133/tm4B5.

PeakFQ Output For Upper Salt Fork Red (HUC 8 11120201)

USGS Gage 07300000 near Wellington, Texas




```
1
  Program PeakFq           U. S. GEOLOGICAL SURVEY              Seq.002.000
  Version 7.3         Annual peak flow frequency analysis       Run Date /
Time
  10/25/2019                                                     08/02/2023
13:47

                        --- 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\averdin\Projects\Active\TWDB\Task02\backcheck\07300000-PEAK-1967-
1997.TXT
```

specifications -
C:\Users\averdin\Projects\Active\TWDB\Task02\backcheck\PKFQWPSF.TMP
Output file(s):
main -
C:\Users\averdin\Projects\Active\TWDB\Task02\backcheck\07300000-PEAK-1967-1997.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 08/02/2023 13:47

Station - 07300000 Salt Fork Red River near Wellington, TX

TABLE 1 - INPUT DATA SUMMARY

Number of peaks in record	=	31
Peaks not used in analysis	=	0
Gaged peaks in analysis	=	31
Historic peaks in analysis	=	0
Beginning Year	=	1967
Ending Year	=	1997
Historical Period Length	=	31
Skew option	=	REGIONAL
Regional skew	=	-0.355
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
1967	1997	0.0	INF DEFAULT

Interval Data = None Specified

TABLE 2 - DIAGNOSTIC MESSAGE AND PILF RESULTS

*WCF151I-17B WEIGHTED SKEW REPLACED BY USER OPTION. -0.158 -0.355
1
WCF002J-CALCS COMPLETED. RETURN CODE = 2
EMA002W-CONFIDENCE INTERVALS ARE NOT EXACT IF HISTORIC PERIOD > 0

MULTIPLE GRUBBS-BECK TEST RESULTS
MULTIPLE GRUBBS-BECK PILF THRESHOLD N/A
NUMBER OF PILFS IDENTIFIED 0

Kendall's Tau Parameters

	TAU	P-VALUE	MEDIAN SLOPE	No. of PEAKS
GAGED PEAKS	0.037	0.786	53.333	31

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.002
Version 7.3 Annual peak flow frequency analysis Run Date / Time
10/25/2019 08/02/2023 13:47

Station - 07300000 Salt Fork Red River near Wellington, TX

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

	LOGARITHMIC		
	MEAN	STANDARD DEVIATION	SKEW
EMA WITHOUT REG SKEW	3.8769	0.5428	-0.010
EMA WITH REG SKEW	3.8769	0.5428	-0.355

EMA ESTIMATE OF MSE OF SKEW WITHOUT REG SKEW 0.1623
EMA ESTIMATE OF MSE OF SKEW W/GAGED PEAKS ONLY (AT-SITE) 0.1623

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	199.0	297.6	0.1195	13.5	489.5

0.9900	298.3	407.5	0.0867	34.5	657.3
0.9500	856.7	960.6	0.0353	281.8	1507.0
0.9000	1459.	1516.	0.0229	662.1	2382.0
0.8000	2704.	2633.	0.0154	1530.0	4195.0
0.6667	4683.	4404.	0.0124	2933.0	7134.0
0.5000	8109.	7548.	0.0110	5349.0	12210.0
0.4292	10100.	9432.	0.0107	6739.0	15120.0
0.2000	21900.	21580.	0.0104	14810.0	33350.0
0.1000	35370.	37310.	0.0125	23850.0	60240.0
0.0400	57230.	66860.	0.0197	36760.0	118200.0
0.0200	76880.	97400.	0.0286	45600.0	183400.0
0.0100	99210.	136600.	0.0405	53220.0	275100.0
0.0050	124200.	186100.	0.0556	59720.0	404400.0
0.0020	161400.	270600.	0.0800	66850.0	659500.0

*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

Station - 07300000 Salt Fork Red River near Wellington, TX

TABLE 5 - INPUT DATA LISTING

WATER YEAR	PEAK VALUE	PEAKFQ CODES	FLOW INTERVALS (WHERE LOWER BOUND NOT = UPPER BOUND) LOWER BOUND	UPPER BOUND	REMARKS
1967	3650.0	K			
1968	34500.0	K			
1969	4360.0	K			
1970	4800.0	K			
1971	2210.0	K			
1972	8050.0	K			
1973	35600.0	K			
1974	3080.0	K			
1975	48300.0	K			
1976	798.0	K			
1977	62100.0	K			
1978	9920.0	K			
1979	8330.0	K			
1980	6050.0	K			
1981	8500.0	K			
1982	7010.0	K			
1983	3480.0	K			
1984	6560.0	K			

1985	3430.0	K
1986	9300.0	K
1987	10400.0	K
1988	1200.0	K
1989	25700.0	K
1990	19400.0	K
1991	5850.0	K
1992	2920.0	K
1993	16600.0	K
1994	504.0	K
1995	36200.0	K
1996	2190.0	K
1997	81100.0	K

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
O	O	Opportunistic peak
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

Station - 07300000 Salt Fork Red River near Wellington, TX

TABLE 6 - EMPIRICAL FREQUENCY CURVES -- HIRSCH-STEDINGER PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	EMA ESTIMATE	FLOW INTERVALS (WHERE LOWER BOUND NOT = UPPER BOUND) LOWER BOUND	UPPER BOUND
1997	81100.0	0.0312		
1977	62100.0	0.0624		

1975	48300.0	0.0937
1995	36200.0	0.1249
1973	35600.0	0.1562
1968	34500.0	0.1874
1989	25700.0	0.2187
1990	19400.0	0.2500
1993	16600.0	0.2812
1987	10400.0	0.3125
1978	9920.0	0.3437
1986	9300.0	0.3750
1981	8500.0	0.4062
1979	8330.0	0.4375
1972	8050.0	0.4687
1982	7010.0	0.5000
1984	6560.0	0.5313
1980	6050.0	0.5625
1991	5850.0	0.5938
1970	4800.0	0.6250
1969	4360.0	0.6563
1967	3650.0	0.6875
1983	3480.0	0.7188
1985	3430.0	0.7500
1974	3080.0	0.7813
1992	2920.0	0.8126
1971	2210.0	0.8438
1996	2190.0	0.8751
1988	1200.0	0.9063
1976	798.0	0.9376
1994	504.0	0.9688

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.005
Version 7.3 Annual peak flow frequency analysis Run Date / Time
10/25/2019 08/02/2023 13:47

Station - 07300000 Salt Fork Red River near Wellington, TX

TABLE 7 - EMA REPRESENTATION OF DATA

	<---- USER-ENTERED ----><-------- FINAL ------->								
	WATER <----- OBSERVED ---->		<-------- EMA ------->		<- PERCEPTIBLE RANGES ->		<- PERCEPTIBLE RANGES ->		
	YEAR	Q_LOWER	Q_UPPER	Q_LOWER	Q_UPPER	LOWER	UPPER	LOWER	UPPER
	1967	3650.0	3650.0	3650.0	3650.0	0.0	INF	0.0	INF
	1968	34500.0	34500.0	34500.0	34500.0	0.0	INF	0.0	INF

1969	4360.0	4360.0	4360.0	4360.0	0.0	INF
0.0	INF					
1970	4800.0	4800.0	4800.0	4800.0	0.0	INF
0.0	INF					
1971	2210.0	2210.0	2210.0	2210.0	0.0	INF
0.0	INF					
1972	8050.0	8050.0	8050.0	8050.0	0.0	INF
0.0	INF					
1973	35600.0	35600.0	35600.0	35600.0	0.0	INF
0.0	INF					
1974	3080.0	3080.0	3080.0	3080.0	0.0	INF
0.0	INF					
1975	48300.0	48300.0	48300.0	48300.0	0.0	INF
0.0	INF					
1976	798.0	798.0	798.0	798.0	0.0	INF
0.0	INF					
1977	62100.0	62100.0	62100.0	62100.0	0.0	INF
0.0	INF					
1978	9920.0	9920.0	9920.0	9920.0	0.0	INF
0.0	INF					
1979	8330.0	8330.0	8330.0	8330.0	0.0	INF
0.0	INF					
1980	6050.0	6050.0	6050.0	6050.0	0.0	INF
0.0	INF					
1981	8500.0	8500.0	8500.0	8500.0	0.0	INF
0.0	INF					
1982	7010.0	7010.0	7010.0	7010.0	0.0	INF
0.0	INF					
1983	3480.0	3480.0	3480.0	3480.0	0.0	INF
0.0	INF					
1984	6560.0	6560.0	6560.0	6560.0	0.0	INF
0.0	INF					
1985	3430.0	3430.0	3430.0	3430.0	0.0	INF
0.0	INF					
1986	9300.0	9300.0	9300.0	9300.0	0.0	INF
0.0	INF					
1987	10400.0	10400.0	10400.0	10400.0	0.0	INF
0.0	INF					
1988	1200.0	1200.0	1200.0	1200.0	0.0	INF
0.0	INF					
1989	25700.0	25700.0	25700.0	25700.0	0.0	INF
0.0	INF					
1990	19400.0	19400.0	19400.0	19400.0	0.0	INF
0.0	INF					
1991	5850.0	5850.0	5850.0	5850.0	0.0	INF
0.0	INF					
1992	2920.0	2920.0	2920.0	2920.0	0.0	INF
0.0	INF					
1993	16600.0	16600.0	16600.0	16600.0	0.0	INF
0.0	INF					
1994	504.0	504.0	504.0	504.0	0.0	INF
0.0	INF					
1995	36200.0	36200.0	36200.0	36200.0	0.0	INF
0.0	INF					

```
   1996     2190.0     2190.0     2190.0     2190.0          0.0         INF
0.0         INF
   1997    81100.0    81100.0    81100.0    81100.0          0.0         INF
0.0         INF
1


 End PeakFQ analysis.
   Stations processed :        1
   Number of errors   :        0
   Stations skipped   :        0
   Station years      :       31


Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4,  or *.)
(2, 4, and * records are ignored.)

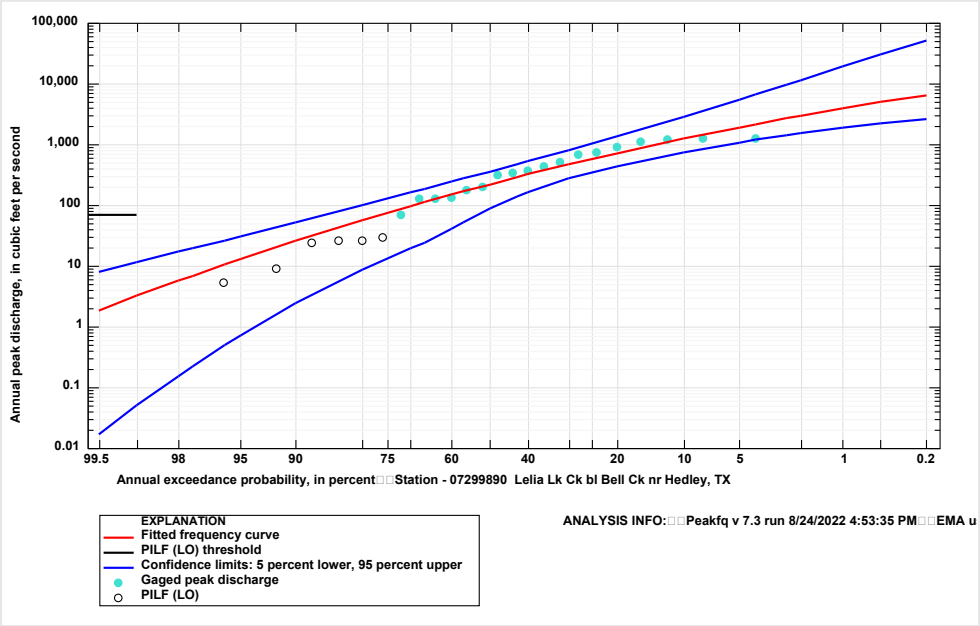
 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:  07300000       USGS Salt Fork Red River
near Well


 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:
```

USGS Gage 07299890 near Hedley, Texas



Program PeakFq U. S. GEOLOGICAL SURVEY Seq.002.000
Version 7.3 Annual peak flow frequency analysis Run Date / Time
10/25/2019 08/24/2022 16:53

--- 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\TO-2\Weighted Skew\7299890\07299890_PEAK.TXT
specifications - C:\Users\snarkhede\Documents\PROJECTS\TWDB\TO-2\Weighted Skew\7299890\PKFQWPSF.TMP
Output file(s):
main - C:\Users\snarkhede\Documents\PROJECTS\TWDB\TO-2\Weighted Skew\7299890\07299890_PEAK.PRT

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

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.001
Version 7.3 Annual peak flow frequency analysis Run Date / Time
10/25/2019 08/24/2022 16:53

Station - 07299890 Lelia Lk Ck bl Bell Ck nr Hedley, TX

TABLE 1 - INPUT DATA SUMMARY

Number of peaks in record	=	24
Peaks not used in analysis	=	0
Gaged peaks in analysis	=	24
Historic peaks in analysis	=	0
Beginning Year	=	1998
Ending Year	=	2021
Historical Period Length	=	24
Skew option	=	WEIGHTED

```
                Regional skew                          =   -0.392
                     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
                          1998      2021          0.0          INF
DEFAULT
                Interval Data                      =   None Specified


    TABLE 2 - DIAGNOSTIC MESSAGE AND PILF RESULTS
6868686868686868686868686868686868686868686868686868686868686868686868686868686868
6868686868686868686868686868686868686868686868686868686868686868686868686868686868
686868686868

    WCF002J-CALCS COMPLETED.  RETURN CODE =  2
    EMA002W-CONFIDENCE INTERVALS ARE NOT EXACT IF HISTORIC PERIOD > 0



    MULTIPLE GRUBBS-BECK TEST RESULTS

    MULTIPLE GRUBBS-BECK PILF THRESHOLD    69.7
    NUMBER OF PILFS IDENTIFIED                6
        CLASSIFICATION OF PILFS:
            NUMBER OF ZERO FLOWS              0
            NUMBER OF CENSORED FLOWS          0
            NUMBER OF GAGED PEAKS             6
                GAGED PEAKS AND CORRESPONDING P-VALUES
                         5.3    (0.2899)
                         9.0    (0.1155)
                        24.0    (0.3627)
                        25.5    (0.1313)
                        26.0    (0.0202)
                        29.0    (0.0018)



                        Kendall's Tau Parameters

                                          MEDIAN   No. of
                        TAU    P-VALUE    SLOPE   PEAKS
                  ----------------------------------------
    GAGED PEAKS     -0.083      0.585     -3.089    24


1
```

Station - 07299890 Lelia Lk Ck bl Bell Ck nr Hedley, TX

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

	LOGARITHMIC		
	MEAN	STANDARD DEVIATION	SKEW
EMA WITHOUT REG SKEW	2.2499	0.7438	-1.043
EMA WITH REG SKEW	2.2870	0.6647	-0.493

EMA ESTIMATE OF MSE OF SKEW WITHOUT REG SKEW	0.3456
EMA ESTIMATE OF MSE OF SKEW W/GAGED PEAKS ONLY (AT-SITE)	0.3456

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	1.9	0.4	0.3847	0.0	8.0
0.9900	3.2	1.0	0.2997	0.1	11.5
0.9500	12.8	7.1	0.1433	0.7	30.8
0.9000	25.6	17.9	0.0936	2.4	52.3
0.8000	56.2	49.0	0.0548	8.6	99.8
0.6667	111.8	112.0	0.0335	23.9	184.9
0.5000	219.5	238.2	0.0218	88.0	359.3
0.4292	286.4	315.1	0.0193	138.0	474.1
0.2000	718.3	762.6	0.0187	434.0	1335.0
0.1000	1248.	1208.	0.0247	737.5	2797.0
0.0400	2141.	1789.	0.0368	1180.0	6540.0
0.0200	2956.	2195.	0.0483	1528.0	11450.0
0.0100	3886.	2563.	0.0617	1872.0	18860.0
0.0050	4924.	2889.	0.0767	2205.0	29600.0
0.0020	6450.	3258.	0.0989	2618.0	50790.0

*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.

Station - 07299890 Lelia Lk Ck bl Bell Ck nr Hedley, TX

TABLE 5 - INPUT DATA LISTING

WATER YEAR	PEAK VALUE	PEAKFQ CODES	FLOW INTERVALS (WHERE LOWER BOUND NOT = UPPER BOUND) LOWER BOUND	UPPER BOUND	REMARKS
1998	134.0				
1999	126.0				
2000	338.0				
2001	197.0				
2002	1190.0				
2003	917.0				
2004	29.0				
2005	178.0				
2006	517.0				
2007	437.0				
2008	680.0				
2009	9.0				
2010	737.0				
2011	24.0				
2012	370.0				
2013	1260.0				
2014	1090.0				
2015	1260.0				
2016	26.0				
2017	25.5				
2018	69.7				
2019	125.0				
2020	5.3				
2021	306.0				

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
O	O	Opportunistic peak
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.004
Version 7.3 Annual peak flow frequency analysis Run Date / Time
10/25/2019 08/24/2022 16:53

Station - 07299890 Lelia Lk Ck bl Bell Ck nr Hedley, TX

TABLE 6 - EMPIRICAL FREQUENCY CURVES -- HIRSCH-STEDINGER PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	EMA ESTIMATE	FLOW INTERVALS (WHERE LOWER BOUND NOT = UPPER BOUND) LOWER BOUND	UPPER BOUND
2013	1260.0	0.0799		
2015	1260.0	0.0399		
2002	1190.0	0.1199		
2014	1090.0	0.1599		
2003	917.0	0.1999		
2010	737.0	0.2399		
2008	680.0	0.2800		
2006	517.0	0.3200		
2007	437.0	0.3600		
2012	370.0	0.4000		
2000	338.0	0.4400		
2021	306.0	0.4800		
2001	197.0	0.5200		
2005	178.0	0.5600		
1998	134.0	0.6000		
1999	126.0	0.6400		
2019	125.0	0.6800		
2018	69.7	0.7200		
* 2004	29.0	0.7601		
* 2016	26.0	0.8001		
* 2017	25.5	0.8401		
* 2011	24.0	0.8801		
* 2009	9.0	0.9201		
* 2020	5.3	0.9601		

* DENOTES PILF (LO)

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Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.005
Version 7.3 Annual peak flow frequency analysis Run Date / Time
10/25/2019 08/24/2022 16:53

Station - 07299890 Lelia Lk Ck bl Bell Ck nr Hedley, TX

TABLE 7 - EMA REPRESENTATION OF DATA

WATER YEAR	<---- OBSERVED ---- Q_LOWER	Q_UPPER	<-------- EMA -------- Q_LOWER	Q_UPPER	<- PERCEPTIBLE RANGES -> LOWER	UPPER	<- USER-ENTERED PERCEPTIBLE RANGES -> LOWER	UPPER
1998	134.0	134.0	134.0	134.0	0.0	INF	69.7	INF
1999	126.0	126.0	126.0	126.0	0.0	INF	69.7	INF
2000	338.0	338.0	338.0	338.0	0.0	INF	69.7	INF
2001	197.0	197.0	197.0	197.0	0.0	INF	69.7	INF
2002	1190.0	1190.0	1190.0	1190.0	0.0	INF	69.7	INF
2003	917.0	917.0	917.0	917.0	0.0	INF	69.7	INF
2004	29.0	29.0	0.0	69.7	0.0	INF	69.7	INF
2005	178.0	178.0	178.0	178.0	0.0	INF	69.7	INF
2006	517.0	517.0	517.0	517.0	0.0	INF	69.7	INF
2007	437.0	437.0	437.0	437.0	0.0	INF	69.7	INF
2008	680.0	680.0	680.0	680.0	0.0	INF	69.7	INF
2009	9.0	9.0	0.0	69.7	0.0	INF	69.7	INF
2010	737.0	737.0	737.0	737.0	0.0	INF	69.7	INF
2011	24.0	24.0	0.0	69.7	0.0	INF	69.7	INF
2012	370.0	370.0	370.0	370.0	0.0	INF	69.7	INF
2013	1260.0	1260.0	1260.0	1260.0	0.0	INF	69.7	INF
2014	1090.0	1090.0	1090.0	1090.0	0.0	INF	69.7	INF
2015	1260.0	1260.0	1260.0	1260.0	0.0	INF	69.7	INF

```
   2016       26.0       26.0        0.0       69.7         0.0         INF
69.7        INF
   2017       25.5       25.5        0.0       69.7         0.0         INF
69.7        INF
   2018       69.7       69.7       69.7       69.7         0.0         INF
69.7        INF
   2019      125.0      125.0      125.0      125.0         0.0         INF
69.7        INF
   2020        5.3        5.3        0.0       69.7         0.0         INF
69.7        INF
   2021      306.0      306.0      306.0      306.0         0.0         INF
69.7        INF
1


 End PeakFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      24


Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4,  or *.)
(2, 4, and * records are ignored.)

 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:  07299890       USGS Lelia Lk Ck bl Bell Ck
nr Hed


 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:
```

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.

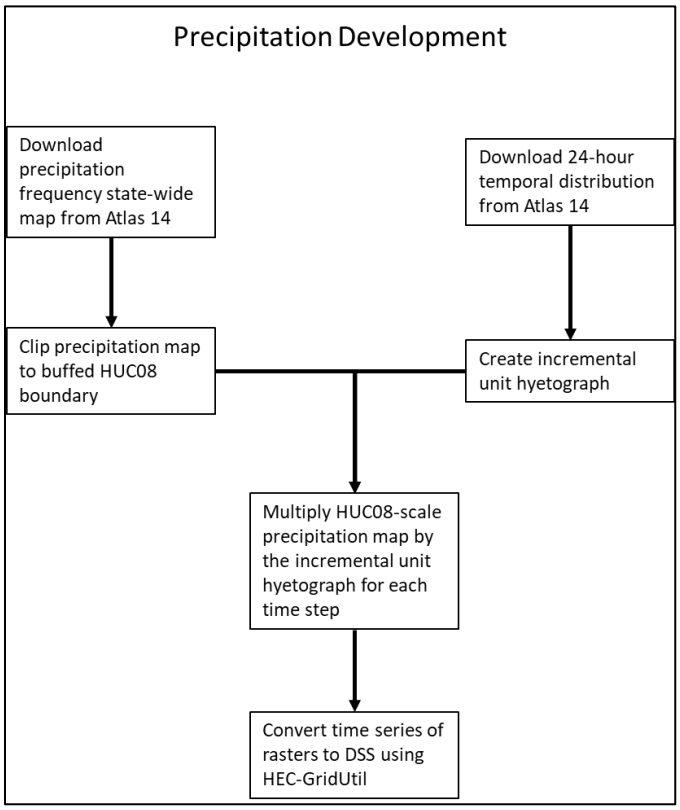


Figure B.1 - Flow chart demonstrating Stantec's precipitation dataset derivation process

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	1st Quartile Cases	2nd Quartile Cases	3rd Quartile Cases	4th 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%)

Duration	Region	All Cases	1st Quartile Cases	2nd Quartile Cases	3rd Quartile Cases	4th Quartile Cases
	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.6 below provides an overview of the development methodology for the Curve Number and Manning's n base data layers.

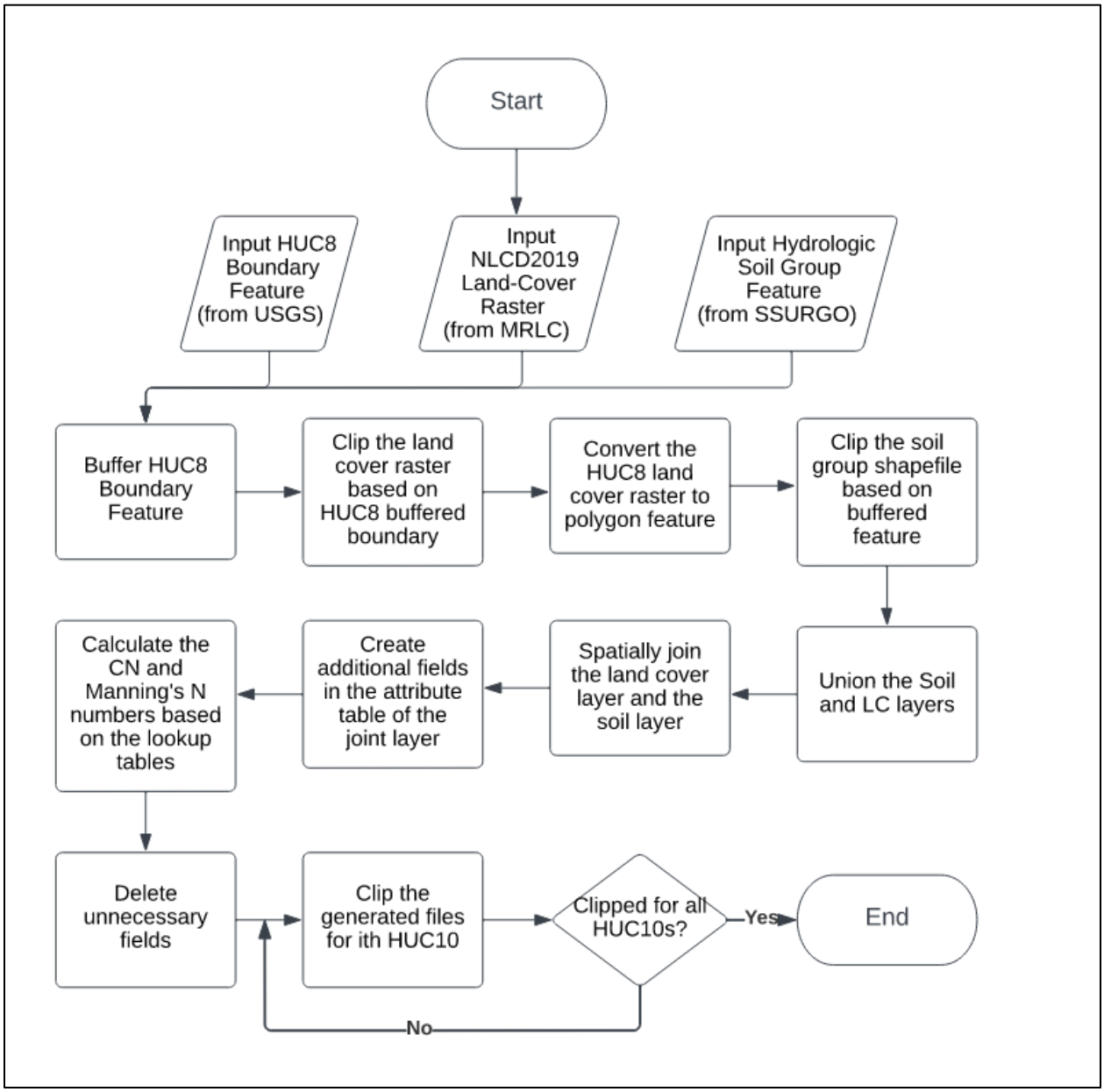


Figure B.1 Flow chart demonstrating Stantec's curve number spatial dataset derivation process