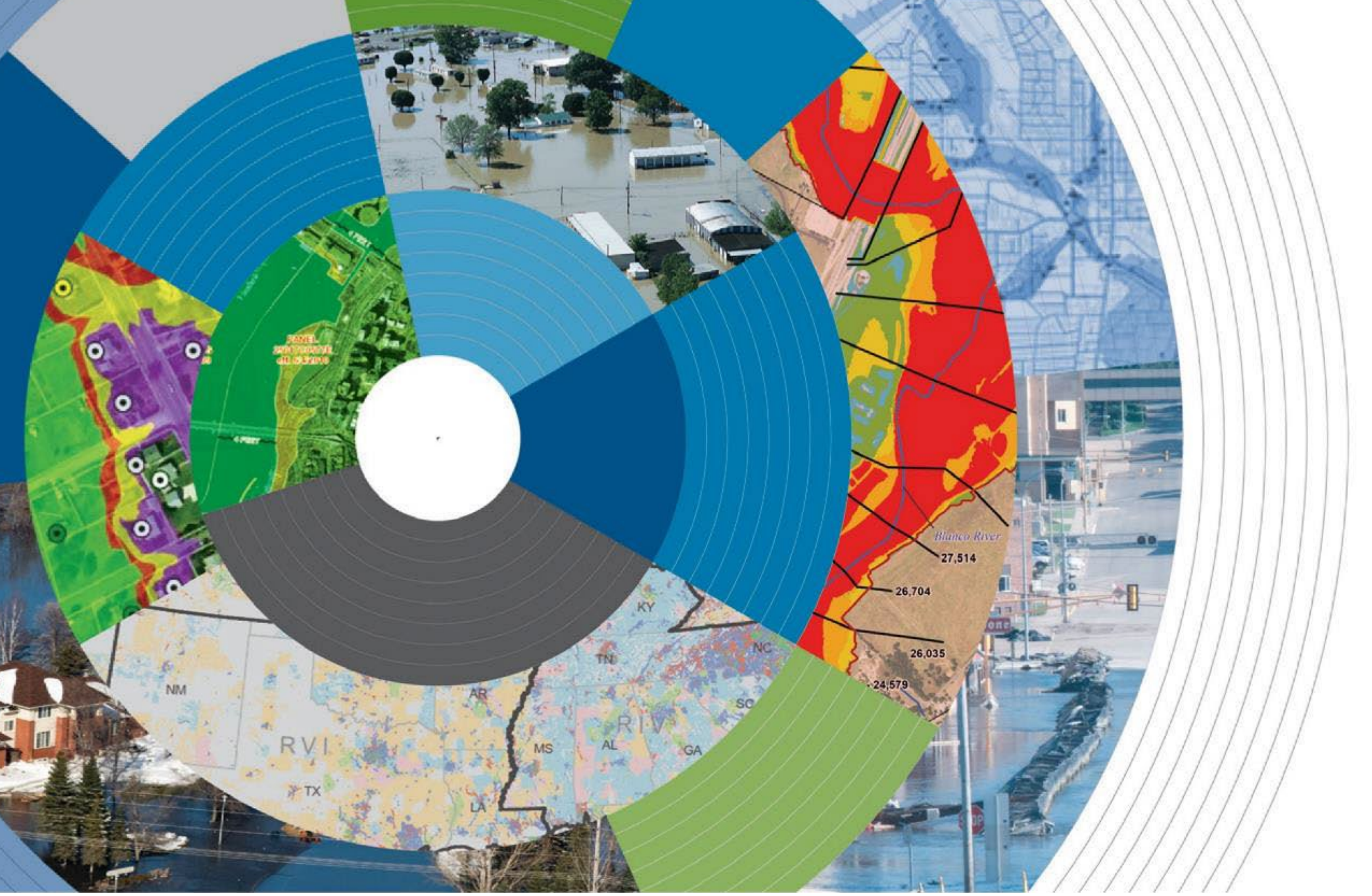


Base Level Engineering Report

Hondo Watershed (12110107)

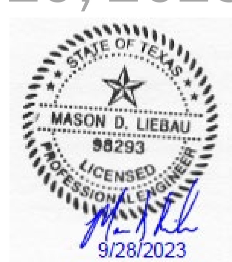
CASE NUMBER: 22-06-0047S

Texas Water Development Board

Stantec

September 29, 2023

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



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Revision History

Version Number	Version Date	Summary of Changes	Author
1.0	April 2023	Draft Deliverable to TWDB	Stantec
1.1	June 2023	Final Deliverable to TWDB (CNMS removed pending completion)	Stantec
1.2	September 2023	Final Deliverable to TWDB	Stantec

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Acronyms

AAL	Average Annualized Loss
AOMI	Area of Mitigation Interest
BFE	Base Flood Elevation
BLE	Base Level Engineering
CN	Curve Number
CNMS	Coordinated Needs Management Strategy
DEM	Digital Elevation Map
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HAZUS	Hazards United States
HC	Hydraulic Connector
H&H	Hydrology and Hydraulics
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
NAVD	North American Vertical Datum
NFHL	National Flood Hazard Layer
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
PILF	Potentially influential low flow
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 Hondo watershed, as part of CONTRACT 2101792546, Task Order # 1. A summary of the study parameters and results for the Hondo 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)	**764 mi**
New Study Streams – CNMS (S_Unmapped_Ln) Informed by NHD 1:100	**523 mi**
Total (BLE) Stream Miles	**1287 mi**

Table 0-2: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment	Total Miles
VALID	NVUE COMPLIANT	0	0	0
UNKNOWN	DEFERRED, TO BE ASSESSED AND TO BE STUDIED	0	0	0
UNVERIFIED	BEING STUDIED	690	690	690

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

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

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

- Task 1 – Terrain Development (Section 2)

- Task 2 – Hydrologic and Hydraulic Analysis (Section 3 and 4)
- Task 3 – Floodplain Mapping (Section 6)
- Task 4 – Average Annualized Loss (AAL) Analysis
- Task 5 – CNMS (Section 7)

1 Introduction and Project Scope

TWDB contracted Stantec under Task Order # 1 to complete a BLE analysis for six, National Hydrography Dataset (NHD) Hydrologic Unit Code 8 (HUC 8) scale watersheds in the Nueces and Frio River Basins, west of San Antonio within the Edward's Aquifer region:

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

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

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

- Task 1 – Terrain Development (Section 2)
- Task 2 – Hydrologic and Hydraulic Analysis (Section 3 and 4)
- Task 3 – Floodplain Mapping (Section 6)
- Task 4 – Average Annualized Loss (AAL) Analysis
- Task 5 – CNMS (Section 7)
- Task 6 – Project Management (includes community outreach)

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

Table 1-1. BLE Task Configuration

Task ID	Task	Task Phase ID	Task Phase
1	Terrain Data Development	1.1	Phase1: Seamless HUC 8 DEM
		1.2	Phase2: Streams and sub-watersheds
		1.3	Phase3: Incremental deliverables, report, internal QA/QC
		1.4	Phase4: Independent QA/QC (Respond/Resolve comments only)
2	Hydrology and Hydraulic Analyses	2.1	Phase1: Draft HEC-RAS Model
		2.2	Phase2: Model Adjustments/Calibration
		2.3	Phase3: Multi-frequency Runs
		2.4	Phase4: Incremental deliverables, report, internal QA/QC

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

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

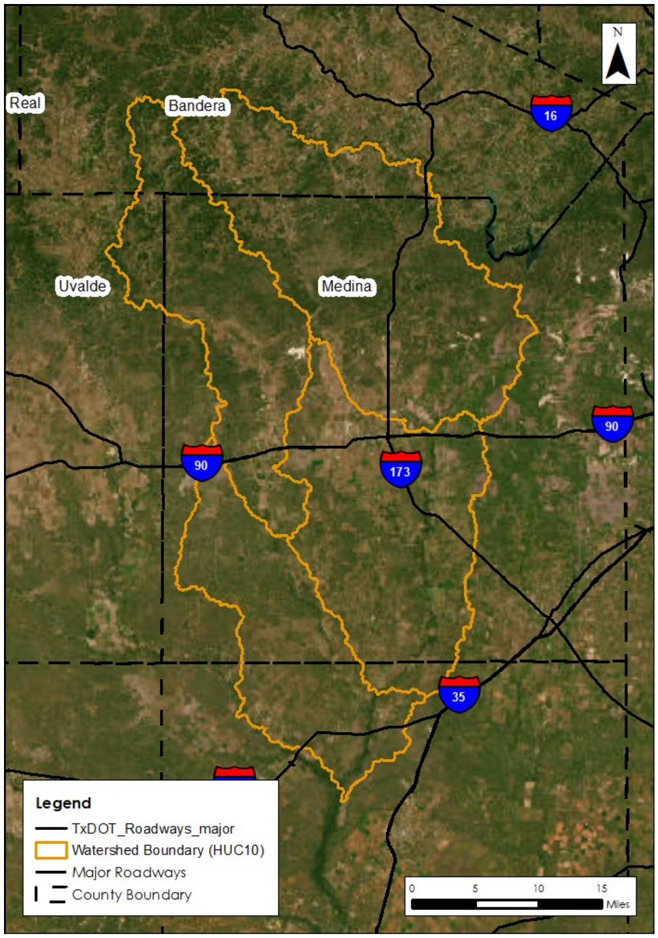


Figure 1-1.Hondo watershed (12110107) – HUC 10 Basins

The BLE assessment prepared cursory engineering analysis for approximately 1,107 miles of stream reaches within the Hondo 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 the Hondo Watershed was the Lower Colorado San Bernard Lidar project (2018) obtained from the Texas Natural Resource Information System (TNRIS). The individual Digital Elevation Model (DEM) tiles from the data source(s) were used to create one seamless DEM mosaic for the Hondo watershed.

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

Table 2-1: LiDAR Data Sources

LiDAR Collection Name	County[1]	Age	Accuracy[2]	Source & Contact	Approximate Footprint (Sq Mi)[3]
Lower Colorado San Bernard 2018	Bandera, Uvalde, Medina	02/2018-04/2018	Horizontal: +/-42.8cm at 95% confidence level Vertical: NVA: 4.5cm $RMSE_Z$ NVA (DEM): 4.9cm $RMSE_Z$ VVA (DEM): 17cm 95^{th} Percentile	Texas Natural Resources Information System (TNRIS)	17,942
South Central Texas 2018	Medina, Frio	01/2018	Horizontal: no horizontal accuracy thresholds were provided for this project. However, LiDAR datasets are calibrated to the accuracy of 100cm or less at the 95% confidence level. Vertical: NVA: 5.9cm $RMSE_Z$ VVA: +/- 12.3cm at 95^{th} percentile	Texas Natural Resources Information System (TNRIS)	5,847
Hurricane 2019	Medina	01/2019-02/2019	Horizontal: +/- 53.5cm at a 95% confidence level Vertical: NVA: 3.8cm $RMSE_Z$ NVA: 7.5cm at 95% confidence interval	Texas Natural Resources Information System (TNRIS) Texas Natural Resources	14,512

LiDAR Collection Name	County[1]	Age	Accuracy[2]	Source & Contact	Approximate Footprint (Sq Mi)[3]
			VVA: 19.8cm at 95th percentiles	Information System (TNRIS)	

[1]Counties listed are only those applicable to current project watershed.
[2]Accuracy derived from original Lidar project report.
[3]Area reported reflects coverage of entire lidar project beyond the current project watershed.

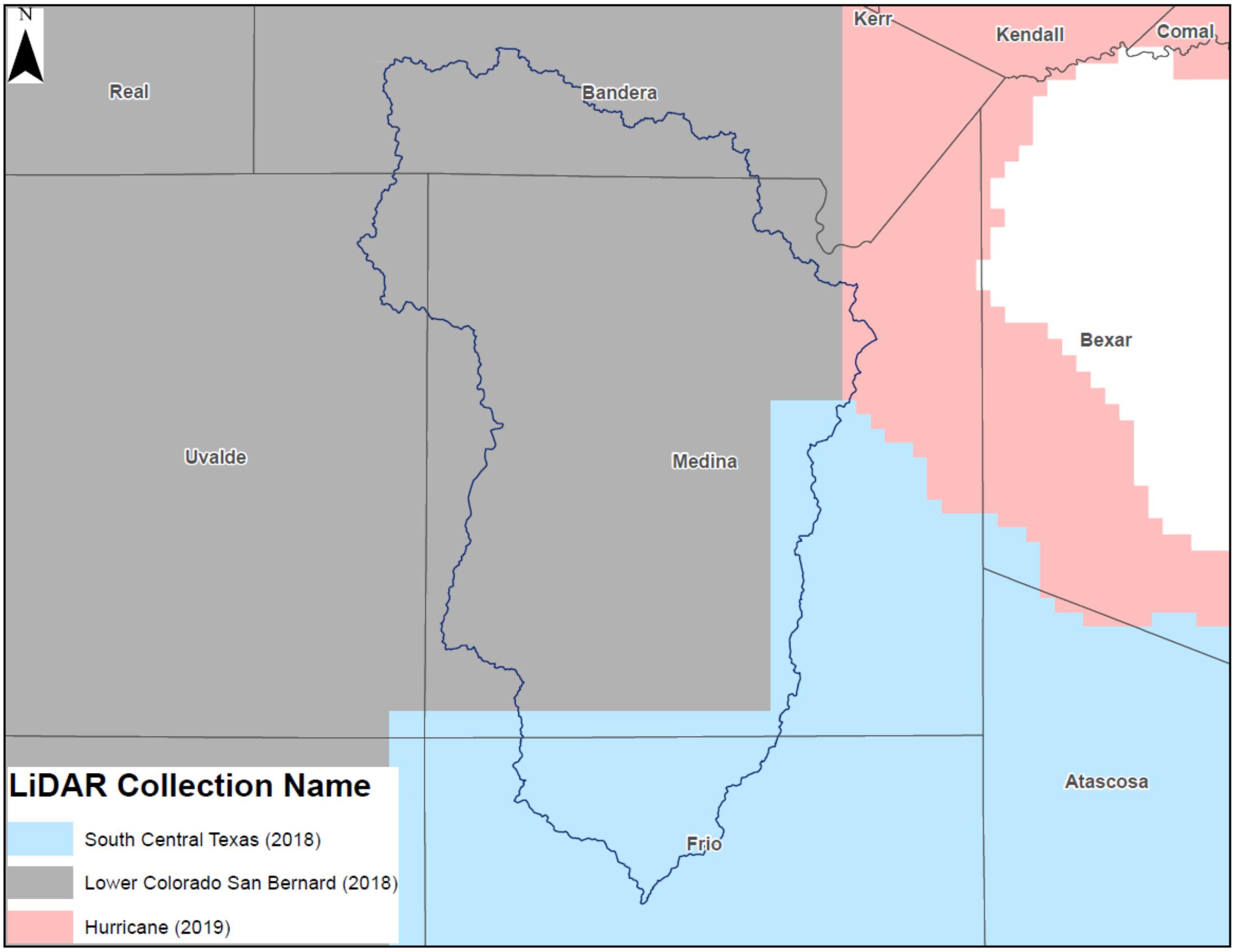


Figure 2-1. Extent and coverage of LiDAR Data as it relates to the project watershed.

2.2 Final Seamless DEM

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

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

Linear: US Feet

Horizontal Datum: NAD83

Vertical Datum: NAVD88

Vertical Units: US Survey Feet

Raster Information:

Pixel Depth: 32 bit

Number of Bands: 1

Cell Size: 3.28083333, 3.2808333 (feet)

Format: TIFF

2.3 Watershed Data Development

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

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

2.4 Final Arc Hydro Data Model

The final watershed data is composed of an Arc Hydro data model and hydrography data. The Arc Hydro data model contains vector, raster, and tabular data outputs from Arc Hydro processing tools. The hydrography data contains streams that represent a drainage area of at least 1 square mile, updated HUC 8 watershed boundary, and a comparison between the NHD HUC 8 watershed boundary and the projection watershed delineation.

2.4.1 Arc Hydro Data Model (Geodatabase and Raster's)

- 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.
    - Drainage Line – 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.
- Raster's (.tif)
  - Catchment Grid (Cat) – Drainage areas for segments in the stream link grid or sinks in the sink link grid.
  - Flow Accumulation Grid (Fac) – Created from the flow direction grid; each cell value represents the total quantity of upstream cells draining to that cell.

- Flow Direction Grid (Fdr) – Represents the direction of flow from a given cell; 8 different directional values are possible based on the eight-direction (D8) flow model.
- Fill Sinks Grid (Fil) – Gridded DEM with sinks or depressions removed.
- Stream Grid (Str) – A stream grid with cells from a flow accumulation grid that exceed a user defined cell count and/or area threshold.
- Stream Link Grid (StrLnk) – A stream grid with unique values for every link between two stream junctions.

2.4.2 Hydrography Data (Geodatabase)

- Drainage Lines – Drainage lines from the Arc Hydro data modeling within the study HUC 8.
- Watershed – A watershed delineation developed through Arc Hydro and based on the elevations within the Seamless DEM created in Task 1 Phase 1.
- Watershed Comparison – A comparison of the watershed feature and the NHD WBD HUC 8 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). Raster's of these hyetographs were generated on a HUC-8 level and converted to DSS files for import into HEC-RAS.

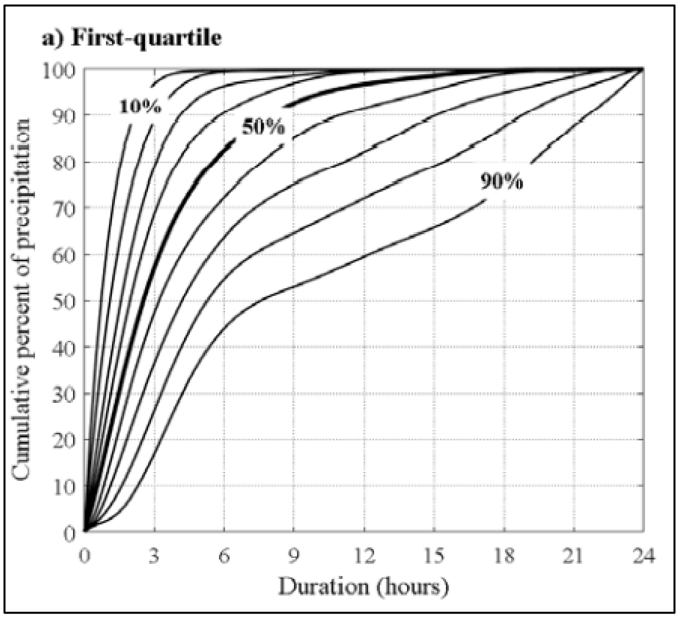


Figure 3-1: Example of temporal distribution curves for first-quartile events with 24-hour duration. Taken from NOAA Atlas 14 Volume 11. Accessed 12/13/2021.

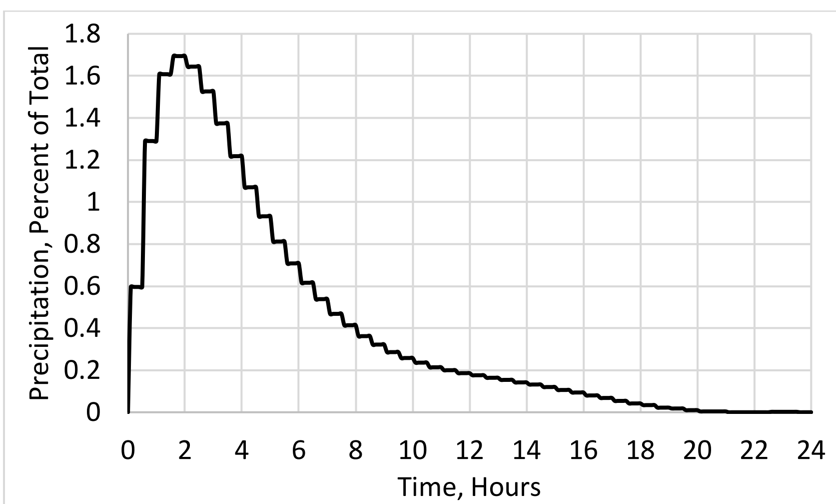


Figure 3-2: Incremental unit hyetograph used to create timeseries of precipitation rasters

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 applied 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 Hondo 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:

$$\hat{\sigma} = \frac{X_{95} - X_{05}}{Z_{95} - Z_{05}} \tag{1}$$

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

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

The NOAA Atlas 14 precipitation-frequency grids only provide total depth. To utilize the grids within HEC-RAS, they must be temporally disaggregated across the provided events duration. To accomplish this, the NOAA Atlas 14 Volume 11, Region 2, 1st quartile 50% event distribution was applied at each grid cell for the duration of the event to create a 6-minute event time series (Figure 3-4). The first quartile event shape was selected because it represents the shape of 49% of historical events for Region 2 (Table 3-1,Figure 3-4). 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 3-3). Accurately representing this spatial variability will ultimately provide a more accurate product.

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

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

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

Duration	Region	All Cases	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%)
	3	2,243	866 (39%)	507 (23%)	472 (21%)	398 (18%)
96-hour	1	1,409	656 (47%)	290 (21%)	262 (19%)	201 (14%)
	2	5,886	2,753 (47%)	1,283 (22 %)	1,001 (17%)	849 (14%)
	3	2,093	894 (43%)	443 (21%)	399 (19%)	357 (17%)

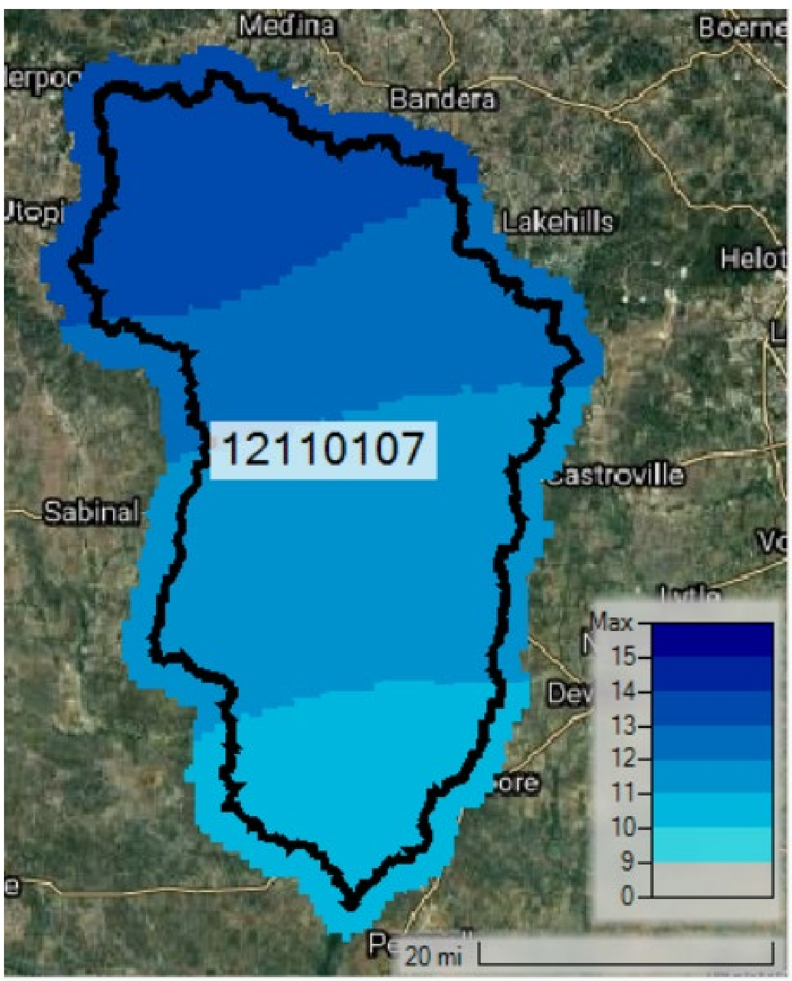


Figure 3-3.Total precipitation (inches) for baseline 1% event across Hondo watershed

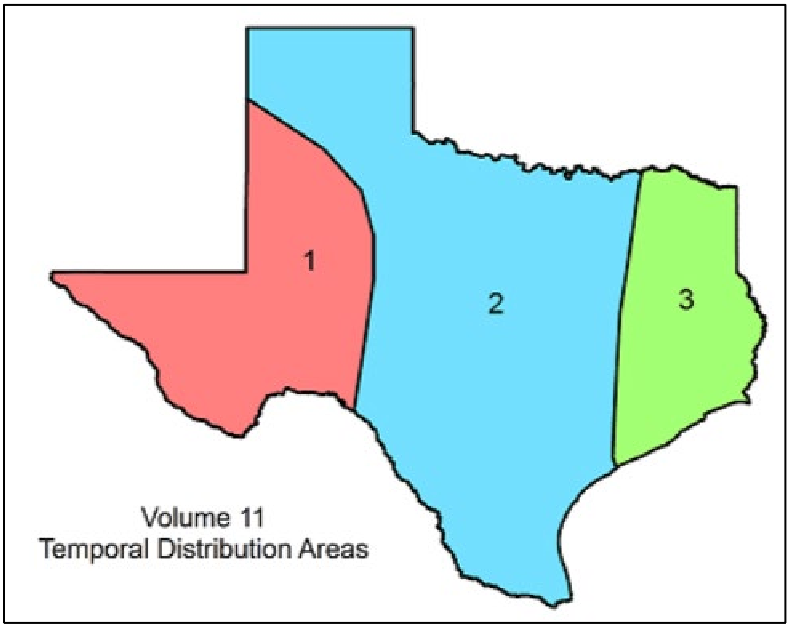


Figure 3-4: NOAA Atlas 14 Volume 11 – Texas Temporal Distribution Areas: Interior Highlands (1), Central Plains (2), and Gulf Coast (3) regions.

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 2021)

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

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

A land-use – soils – CN table (Table 3-3) was applied 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*
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.

3.3 Hydrologic Calibration

Hydrologic parameters were revised on a case-to-case basis as a result of hydraulic model comparison of the 1% annual chance comparison to historic USGS gage data on an individual model (HUC 10) scale. See hydraulic section 4.6 for more details.

4 Hydraulics

The hydraulic approach for the Hondo 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 0). 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 Hondo watershed consisted of 4 HUC 10 catchments. To simplify tying-in flow between sequential models along the mainstem, two large models were developed to comprise the HUC8 (further discussed in 4.5). The division of the models is as follows:

- Model 1 – HUC 10 Upper Hondo Creek 1211010701
- Model 2 – combined HUC10's:
    - Middle Hondo Creek 1211010702
    - Parker Creek- Seco Creek 1211010703
    - Lower Hondo Creek 1211010704

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 and described in sections 4.2 to 4.5 as applicable to each model.

4.1 2D Computational Mesh and Settings

The base computational mesh for the models in the Hondo 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 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 are summarized in Table 4-1.

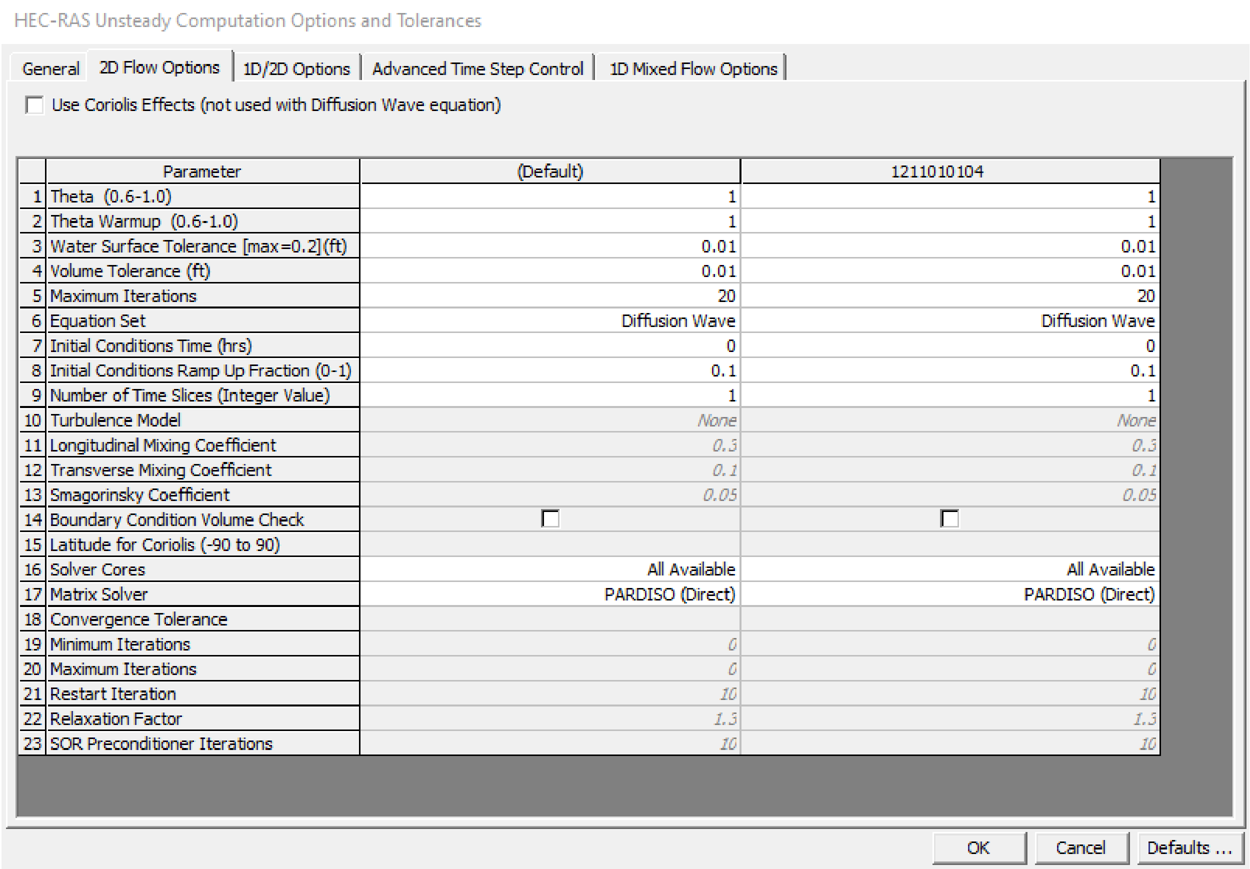
Table 4-1. HUC 10 Mesh Parameters

HUC 10 Model Name and Number	Size of Study Area (sq mi)	Number of Mesh Elements (grid cells)	Average cell size (sq ft)
Upper Hondo Creek (1211010701)	396	339,485	32,551
HUC 702, 703, and 704 Combined	682	611,159	31,089

4.1.1 Model Computational Settings

Models were run using the Diffusion Wave equation set for 2D flow at a 20-second computation interval for each frequency event discussed in this report. Diffusion Wave computational method was selected rather than the Shallow Water equations due to hydraulic structures, such as bridges, culverts, and dams, not being modeled in detail as part of this BLE study. The Full Momentum equation is typically selected to better account for energy losses in and around structures (USACE 2021). More information on the application of Diffusion Wave Equations versus the Shallow Water equations can be found in the HEC-RAS version 6.3 2D user's manual.

A 20-second computational timestep was determined from a sensitivity analysis for Courant conditions and model computational time. A time step of 20 seconds was deemed appropriate as it limited Courant numbers to less than 5 in the models tested while maintaining a reasonable run-time for base models. 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 as shown in Figure 4-1.


HEC-RAS Unsteady Computation Options and Tolerances

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

Use Coriolis Effects (not used with Diffusion Wave equation)

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

OK | Cancel | Defaults ...

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

4.2 Breaklines and Refinement Regions

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

Table 4-2. Summary of Mesh Refinement Features for Hondo watershed

HUC 10 Model Name and Number	Breaklines (linear ft)	Total area of Refinement Regions (sq mi)
Upper Hondo Creek (1211010701)	695,978	17.3
HUC 702, 703, and 704 Combined	1,521,000	46.5

4.2.1 Breaklines

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

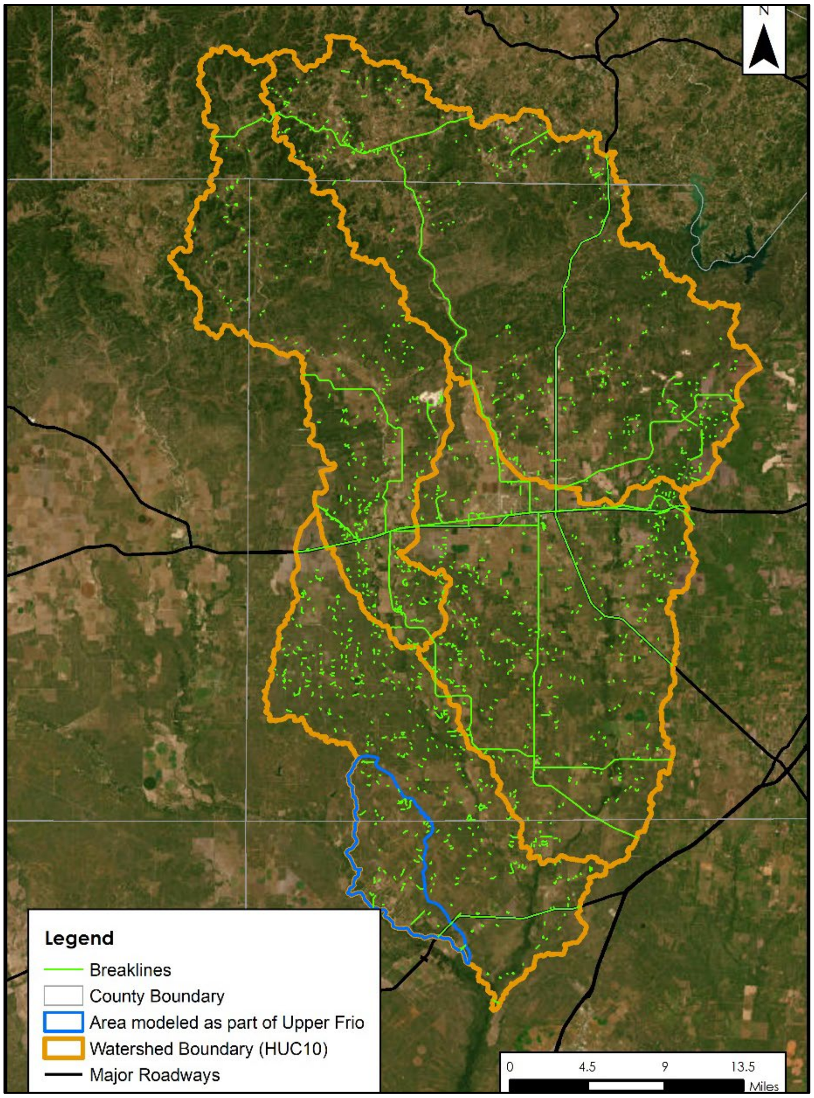


Figure 4-2. Overview of HUC 8 Scale Breaklines for Hondo watershed

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 4-3).

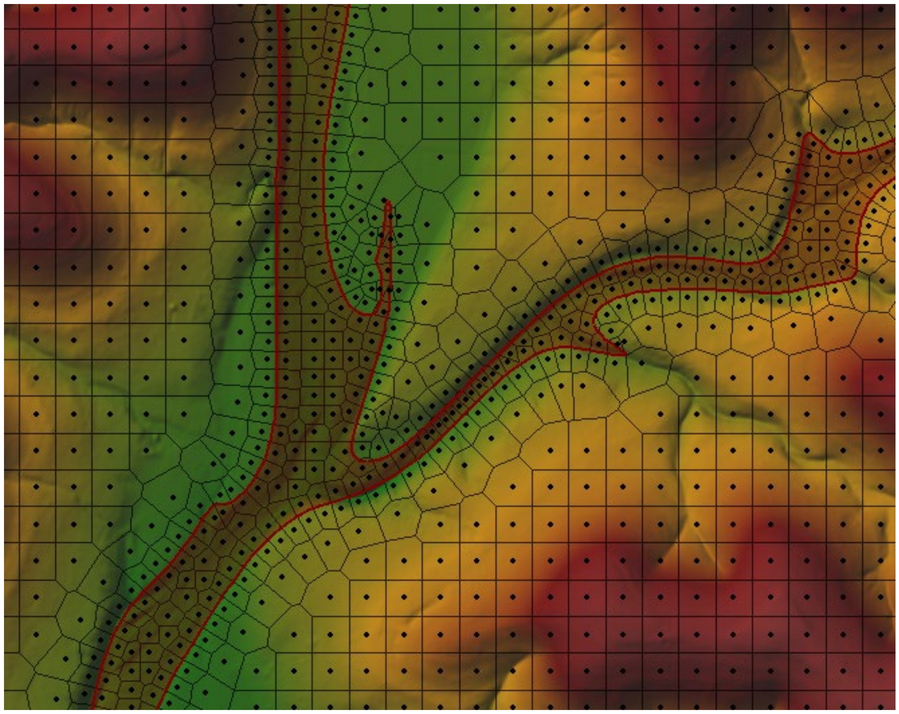


Figure 4-3. Example of Refinement Region Polygon

The polygon was developed by simulating a 2-year NOAA Atlas 14 rainfall event in each model using the base 200 ft resolution mesh. The 2-year simulation was run without breaklines, infiltration, or Manning's roughness layers enforced. The inundation boundary from the 2-year event was exported from RASMapper for post-processing and smoothing in ArcGIS. As part of the post-processing, the inundation was intersected with the streams developed in Arc Hydro representing a 1-sq mi. drainage area. A review of the final processed polygon was then performed by comparing against aerial imagery and the terrain DEM to trim or extend the refinement limits to depict the stream's bank full extents more accurately. The processed polygon was then imported into the model geometry as a refinement region in the HEC-RAS geometry. An overview of the refinement regions for the Hondo watershed is shown in Figure 4-4.

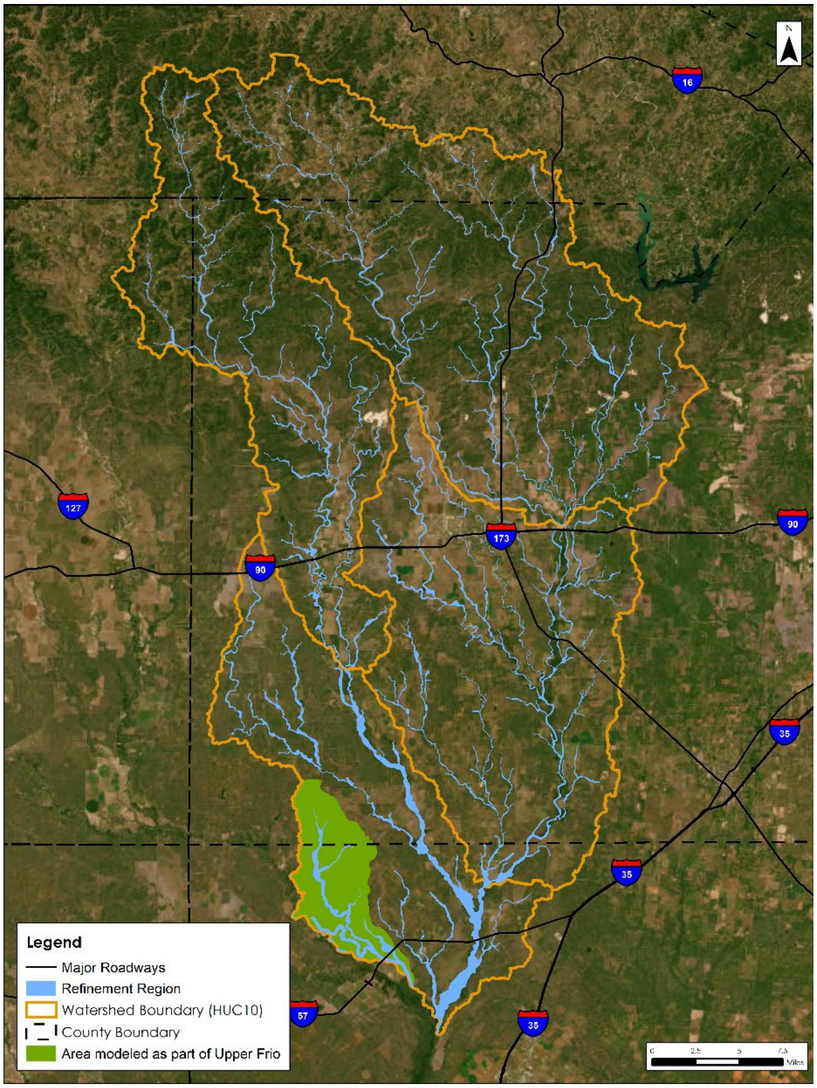


Figure 4-4. Overview of HUC 8 Scale Mesh Refinement Regions for Hondo Watershed

4.3 Manning's Roughness Coefficients and Land Use

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

Table 4-3: Manning's N Values

Land Use Classification	TWDB BLE Guidelines (May 2022)	Hondo Manning's Values
Open Water	0.025 – 0.050	0.040
Developed, Open Space	0.030 – 0.050	0.040

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

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

4.4 Terrain 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. After adding a modifications layer with all final HCs, the terrain was resampled in RASMapper to include the HC drainage pathways (Figure 4-5).

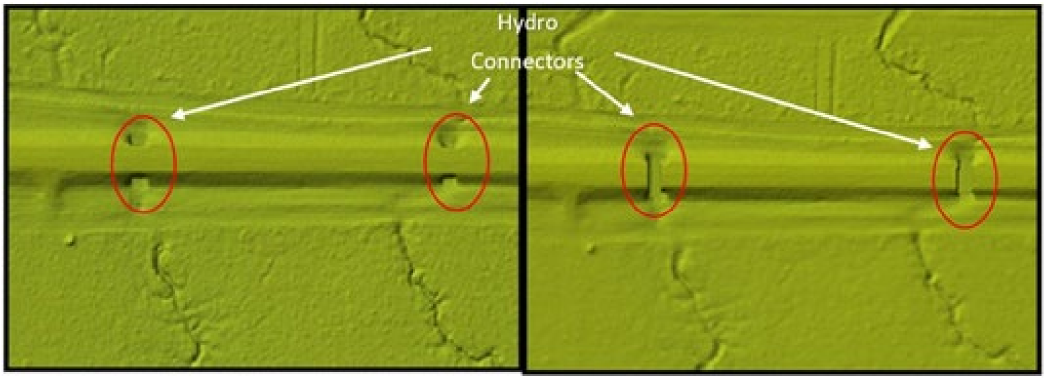


Figure 4-5. Example of localized original terrain (left) and terrain after resampling and addition of modification layer (right)

In the Parker-Seco Creek HUC 10 (1211010703), there exists a hydraulically significant sinkhole called the Seco Sinkhole (also known as Valdina Farms Sinkhole). It is a substantial water recharge feature within the Edwards Aquifer, measuring approximately 40 ft in diameter and capable of recharging the aquifer at a rate of over 1,000 cfs. On the main channel of Seco Creek, a dam was built to direct water to a diversion channel towards the sinkhole. Along the diversion channel exists a roadway crossing that freely conveyed water through large box culverts; however, in 2021 a sluice gate was installed at the roadway crossing culverts. It will prevent water from discharging into the sinkhole from the diversion channel until the point at which the roadway crossing is completely overtopped. To simulate the effect of the sluice gate, a hydraulic connector line was not burned into the terrain at this location.

4.5 HUC 10 Model Integration

A diagram showing inter-basin connectivity and boundary condition (BC) locations for the Hondo watershed is included in Figure 4-6. As previously mentioned, HUC 10s numbers 12110107-02, -03, and -04 were merged due to issues with tying HUCs 12110107-02 and -03 into HUC 1211010704 within a 0.5 ft tolerance. There is one main location between HUC 1211010701 and HUC 12110107 02 03 04 models where flow is transferred from the upstream to the downstream model via the main channel. The models were coupled along the main channel using Storage Area (SA)/2D connectors in the upstream model to transfer flow into the receiving downstream model in the form of an inflow hydrograph BC line.

Additional locations where inter-basin transfer occurs via overland sheet flow were coupled using normal depth BC lines. For example, flow spills out of a channel in HUC 1211010701 during the low frequency events. To represent this, multiple downstream, normal depth BC lines were added along these locations within the upstream model (HUC 1211010701) to allow for flow continuity into the downstream model. An inflow hydrograph was added in the downstream model to represent each of the downstream BC lines created within the upstream model.

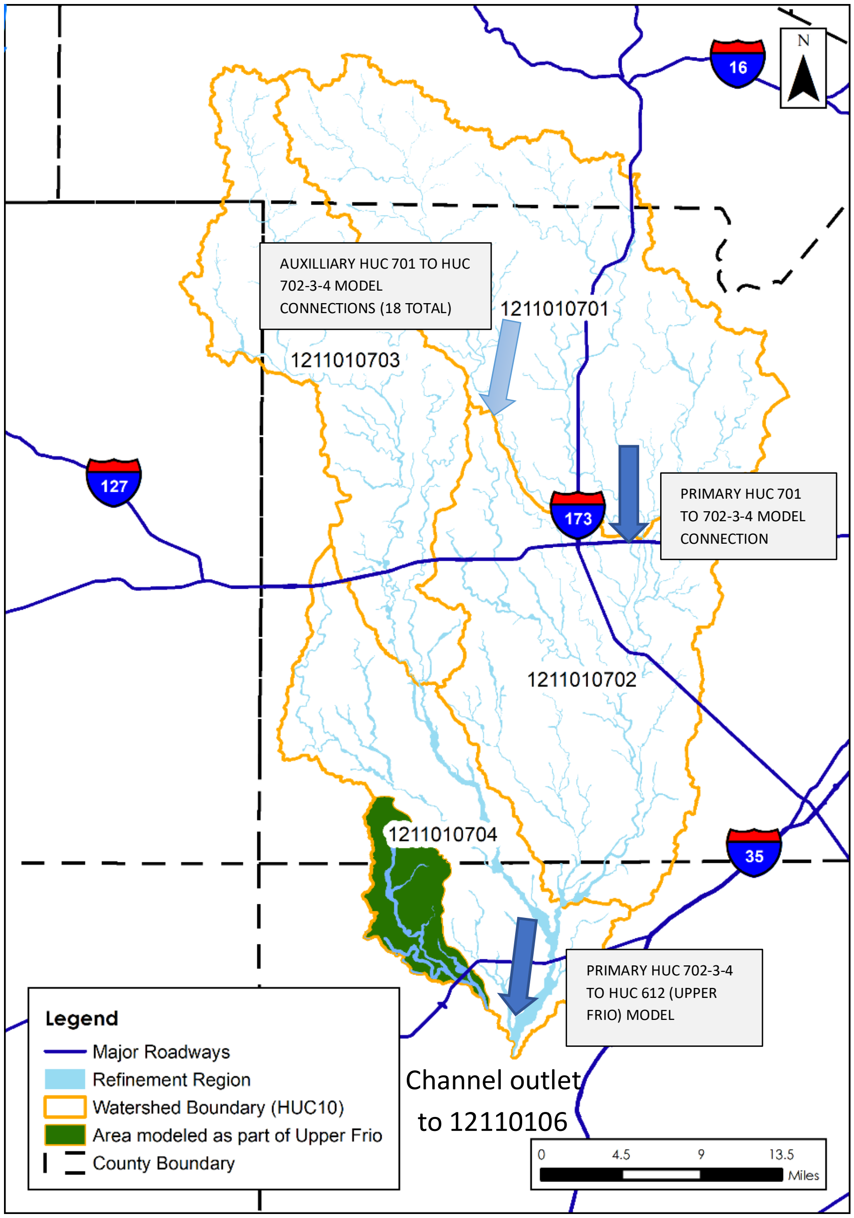


Figure 4-6. Overview of HUC 8 with HUC 10 Model Connectivity

The SA/2D connectors in the upstream model were placed perpendicular to channel flow a distance upstream of the channel outlet to avoid influence of the downstream normal depth BCs. The upstream SA/2D location was isolated based on a normal depth sensitivity analysis where the placement distance from the downstream BC was determined by the location of channel WSEL convergence for runs of varying normal depth BC values (Figure 4-7). This was done to minimize the margin of error in floodplain delineation due to potential inaccuracies in normal depth input in the upstream model's downstream BC.

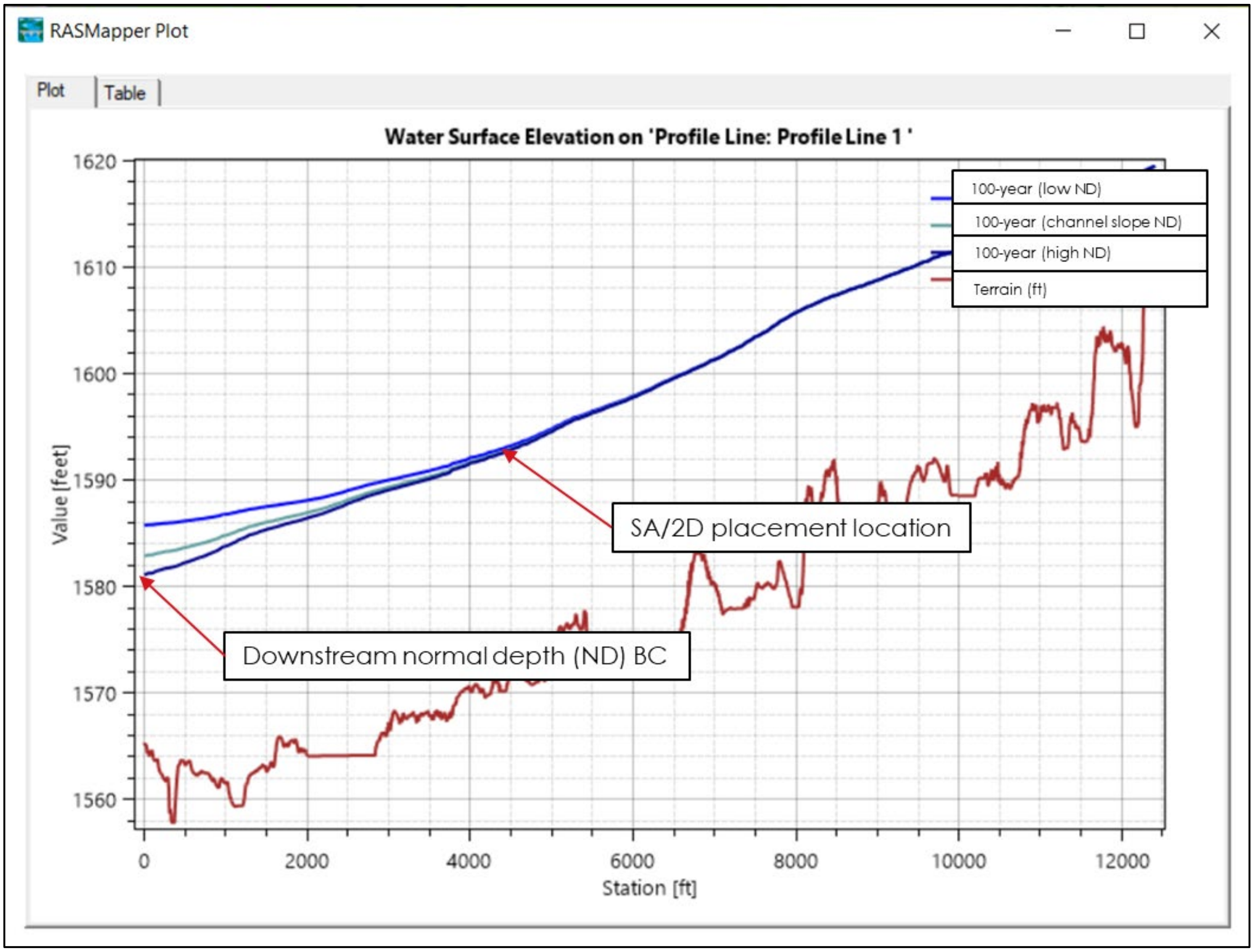


Figure 4-7. SA/2D Normal Depth sensitivity and placement example

The upstream and downstream model meshes were modified from the USGS HUC 10 delineation to overlap at the location of the SA/2D connection. To optimize the hydraulic performance of the connection, the SA/2D placement varied per model based on unique features such as terrain slope, channel dimensions, instream flow obstructions (dams, railroad crossings, low water crossings etc.) and normal depth sensitivity. Therefore, model overlap size varied per model and connection location. Final model meshes for the Hondo watershed models are shown in Figure 4-8. In locations where the models overlap, the downstream model's water surface elevation and flow take precedent and are applied in the mapping products. The downstream model should be referenced for model results downstream of the SA/2D line in the upstream model (which acts as the tie-in between the downstream model) which are consistent with the mapping product. As shown in Figure 4-8, a portion of the original HUC 10 1211010704 was modeled as part of the Upper Frio 2D BLE study due to the nature of the terrain in this area causing what would have otherwise been many hydraulic connections between the two models.

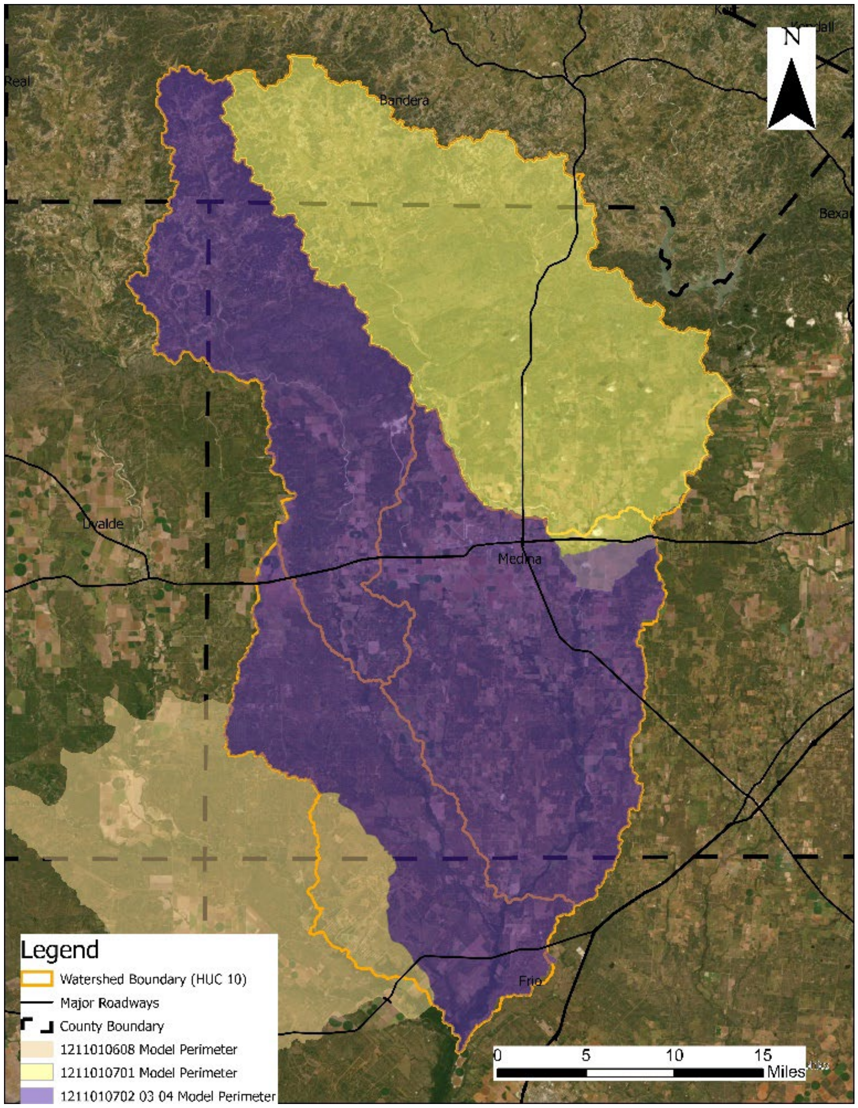


Figure 4-8. Overview of Adjusted Model Domains

The SA/2D connections were evaluated to ensure continuity of both water surface elevation and flow between upstream and downstream models, within 0.5 ft and 5%, respectively. The continuity metrics are summarized in Table 4-4 for the Hondo watershed models. Application of a stage hydrograph versus a flow hydrograph BC was also evaluated independently for each connection. Flow hydrographs were found to transfer flow with greater accuracy than stage hydrographs in reaches with flat overbank terrain, low channel slopes which promoted pooling, reaches with "braided" stream formations coupled with variable terrain elevations across the floodplain cross-section, and reaches with a proximal instream flow obstructions such as an upstream dam. Flow hydrographs were applied to connect the two models for the Hondo watershed. 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.

Table 4-4. HUC 10 Model Integration Summary

Upstream HUC 10 Model Name and Number	Downstream HUC 10 Model Name and Number	Name of SA/2D Connector	Distance from SA/2D Connector to DS BC (ft)	100-Year Flow Difference (%)	100-Year Stage Difference (ft)
Upper Hondo Creek (1211010701)	HUC 702, 703, and 704 Combined	Line 1	12,465	0	0.45
Upper Hondo Creek (1211010701)	HUC 702, 703, and 704 Combined	Line 2	12,465	0	0.06
Upper Hondo Creek (1211010701)	HUC 702, 703, and 704 Combined	Line 3	12,465	0	0.34
HUC 702, 703, and 704 Combined	**External**[1] Upper Frio (12110106)	1	23,357	0	0.3
HUC 702, 703, and 704 Combined	**External**[1] Upper Frio (12110106)	2	24,686	0	0.2
HUC 702, 703, and 704 Combined	**External**[1] Upper Frio (12110106)	3	21,093	0	0.1
HUC 702, 703, and 704 Combined	**External**[1] Upper Frio (12110106)	4	17,800	0	-0.2
HUC 702, 703, and 704 Combined	**External**[1] Upper Frio (12110106)	5	24,744	0	-0.1
HUC 702, 703, and 704 Combined	**External**[1] Upper Frio (12110106)	6	23,850	0	0.2
HUC 702, 703, and 704 Combined	**External**[1] Upper Frio (12110106)	7	25,155	0	0.0

[1]*for detailed information on model connection see BLE report for Upper Frio Watershed (HUC 8 12110106)*

4.5.1 Upper Hondo Creek (1211010701) and Middle Hondo Creek (1211010102) Boundary

The downstream boundary of the Upper Hondo Creek HUC 10 model is near the confluence of four major tributaries. The initial normal depth sensitivity test concluded that the influence of the model's normal depth BC extended upstream approximately three miles. Extending the downstream model's overlap area this far upstream would have required six SA/2D connections due to the many tributaries and braided flow. To prevent the need for numerous connections, the upstream model mesh was extended a significant distance downstream from the confluence, such that a singular SA/2D connector could be used to connect the models. In essence, the upstream overlap extent of the downstream model lies approximately where the original HUC 10 boundaries exist, which coincides with the previously mentioned tributaries converge. Outflow from the upstream model was captured by three SA/2D connector in the main channel. These flow hydrographs were then represented by three inflow hydrograph BCs in the downstream model. The resulting model meshes and hydraulic continuity results are summarized in Table 4-4, Figure 4-9, and Table 4-5.

During low frequency events, Hondo Creek spills over into the overbank and overtops a ridgeline near the boundary between the upstream and downstream model. To accurately depict flow transfer between models, eighteen normal depth BC lines were included along the ridge. These were then represented by inflow hydrograph BC lines within the downstream model (see Figure 4-9). Peak flowrates were relatively low, yet the sum-total of all the flow overtopping the ridgeline warranted continuity into the headwaters of the downstream model. To ensure mapping continuity all connections were adjusted where peak 100yr WSE were less than 0.5ft difference.

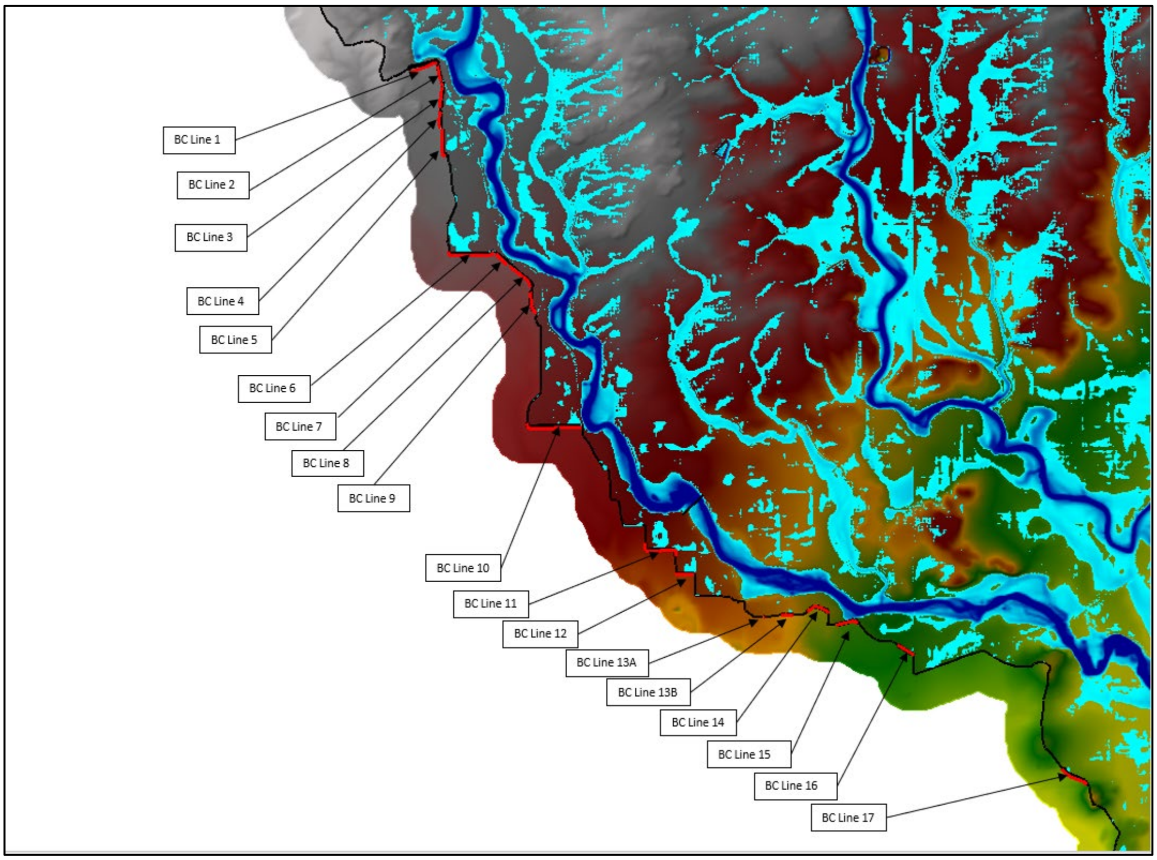


Figure 4-9. Spillover BC lines between Model 1211010701 and 1211010702,3,4 Boundary

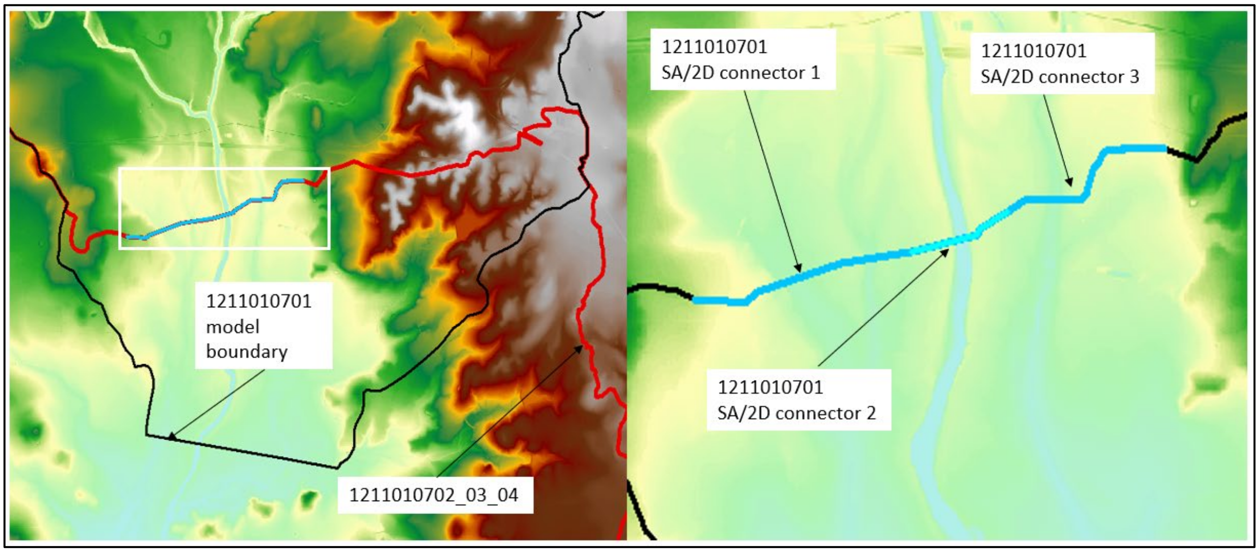


Figure 4-10. 1211010701 and 1211010702,3,4 Boundary Plan View

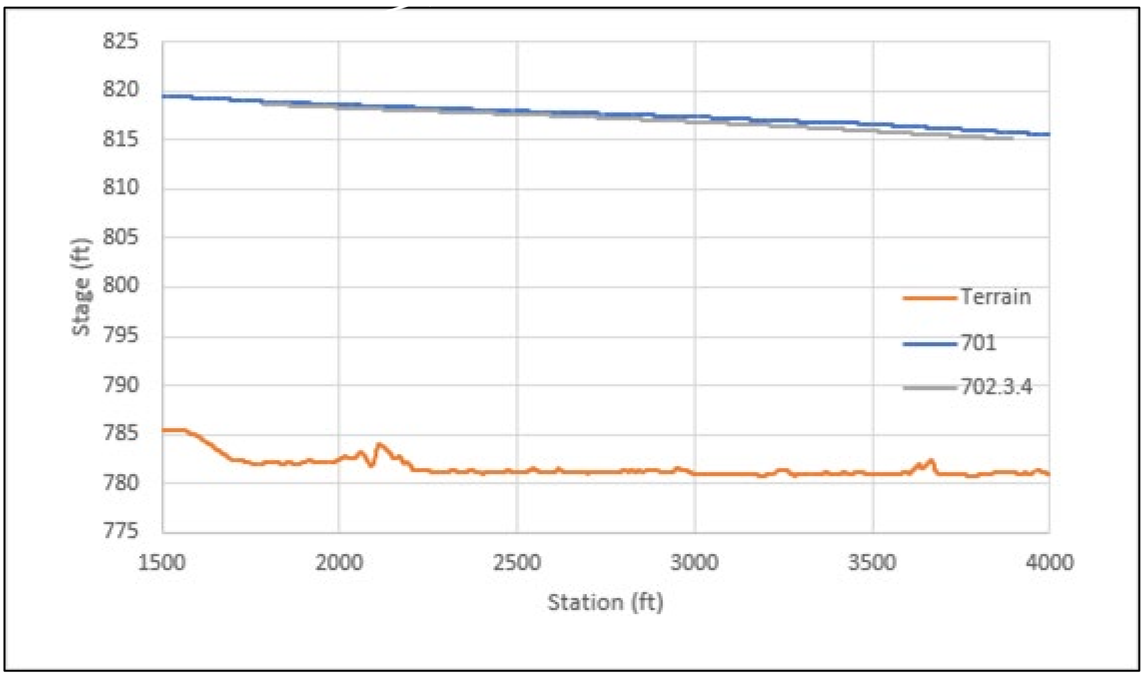


Figure 4-11. 1211010701 and 1211010702_3_4 mainstem WSEL Continuity

Three model connections were required to represent the main channel within the Hondo watershed HUC 8 since the Middle Hondo Creek, Parker-Seco Creek, and Lower Hondo Creek HUC 10 models were combined into a single model. Both the Middle Hondo Creek and Parker-Seco Creek watershed flow into the Lower Hondo Creek watershed. Originally, each of these HUC 10s were represented by a separate model, which were connected to the Lower Hondo Creek HUC 10 model using SA/2D connections. Repeated attempts were made at various locations within both upstream HUC 10 models to tie-in water surface elevations within 0.5 ft between models. Due to the braided channel structure and flat terrain, each attempt failed to meet the 0.5 ft tie-in requirement. For this reason, the three models were combined to eliminate the need for the SA/2D connections between the two upstream HUC 10 models and the downstream HUC 10 model.

Table 4-5 1211010701 and 121101070234 Continuity – all modeled events

Annual-chance Event	HUC701 (Upstream)		HUC70234 (Downstream)		Absolute Difference	Absolute Difference
Event	Max WSEL (ft)	Peak Flow (Cfs)	Max WSEL (ft)	Peak Flow (Cfs)	Max WSEL (ft)	Peak Flow (Cfs)
10YR	814.4	63,410	815.0	63,410	0.6	0
25YR	817.2	83,120	817.0	83,120	0.2	0
50YR	817.7	91,768	817.5	91,768	0.2	0
100YR-	817.6	88,819	817.3	88,819	0.3	0
100YR	818.2	101,931	818.3	101,931	0.1	0
100YR+	819.4	118,944	819.6	118,944	0.2	0
500YR	820.6	140,320	820.9	140,320	0.3	0

4.6 Calibration and Validation

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

HUC8 watersheds in this Task Order, in particular the Hondo watershed, coincide with the Edward's Aquifer recharge and contributing zone and the Carrizo-Wilcox Aquifer underlies majority of the Frio, Upper and Middle Nueces HUC8 watersheds (Figure 4-12). Coinciding with the aquifer creates a unique hydrologic rainfall-runoff response and groundwater-surface water interaction that is not reflected in the base CN derivation described in Section 3.2. Adjustment of CN's to reflect additional or enhanced infiltration in the recharge zone of the Edward's Aquifer region is a practice consistent with recent studies in Central Texas near the aquifer (URS 2016). Hydrologic losses due to the Carrizo-Wilcox influence and Karst geography in the Upper and Middle Nueces River HUC8 watersheds are well documented and being quantified by a concurrent InFRM study by USACE.

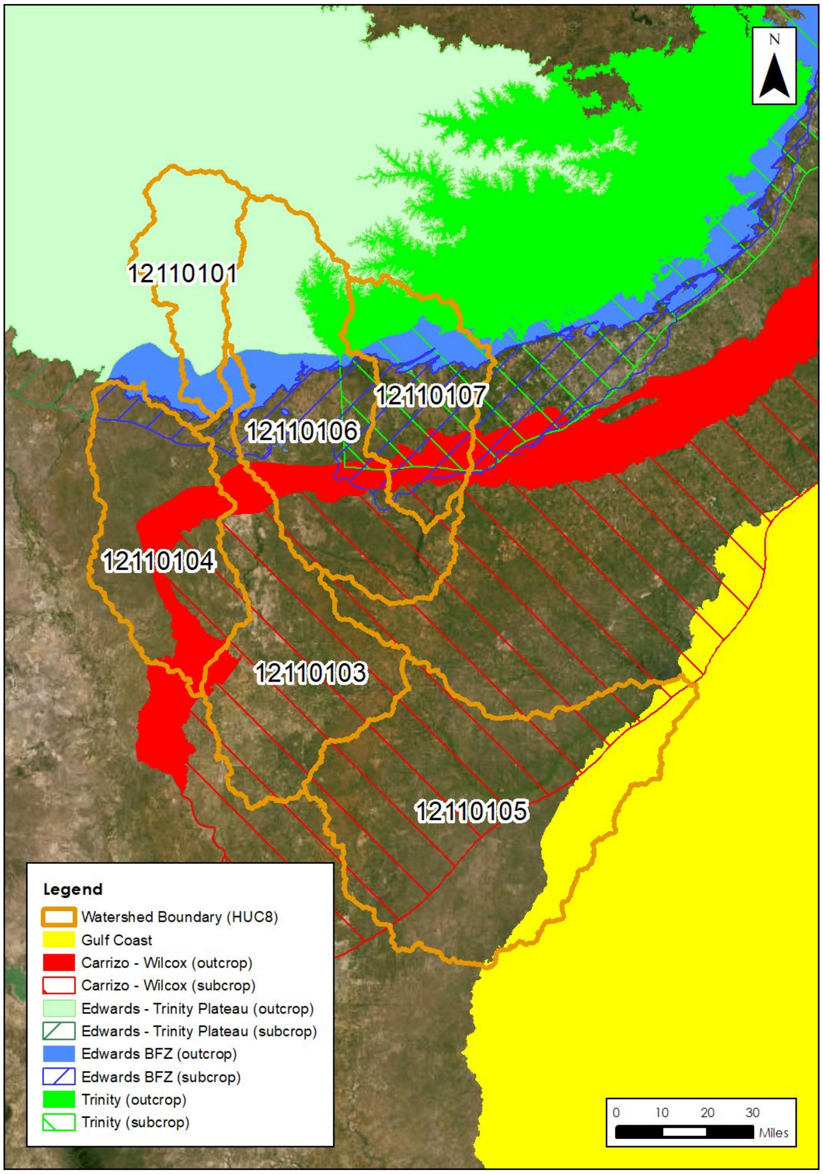


Figure 4-12. Task Order 1 HUC 8 watershed overview with major aquifer zones

The Hondo watershed models are shown in Figure 4-13. The USGS gages containing 10 or more years of record were initially considered for calibration are shown in Figure 4-14; however, only those utilized for calibration are shown as green. The gages used for calibration had a robust record history, the minimum being 44 years of record. The gages discarded from statistical analyses, while having over 10 years of record, had many recorded zero flow and very low flow observations that are screened as potentially influential low flow (PILF) outliers. Screening of these PILF outliers makes the effective record length at these gages less than 10 years, thus not recommended for Bulletin 17C analyses. Additionally, the Bulletin 17C peak 100-year estimates for these short record gages were inconsistent with the Bulletin 17C estimates for the proximal gages in watershed with longer record. Thus, only the four long record gages were considered and utilized for model calibration. Gage extension was not considered as part of this study. Calibration of the watershed models was based on the 1% annual chance peak flow values estimates from a Bulletin 17C statistical flood frequency analysis using the USGS program PeakFQ. A 2021 Texas regional skew factor was also applied (England et. al 2018; Cleveland and Fang 2021).

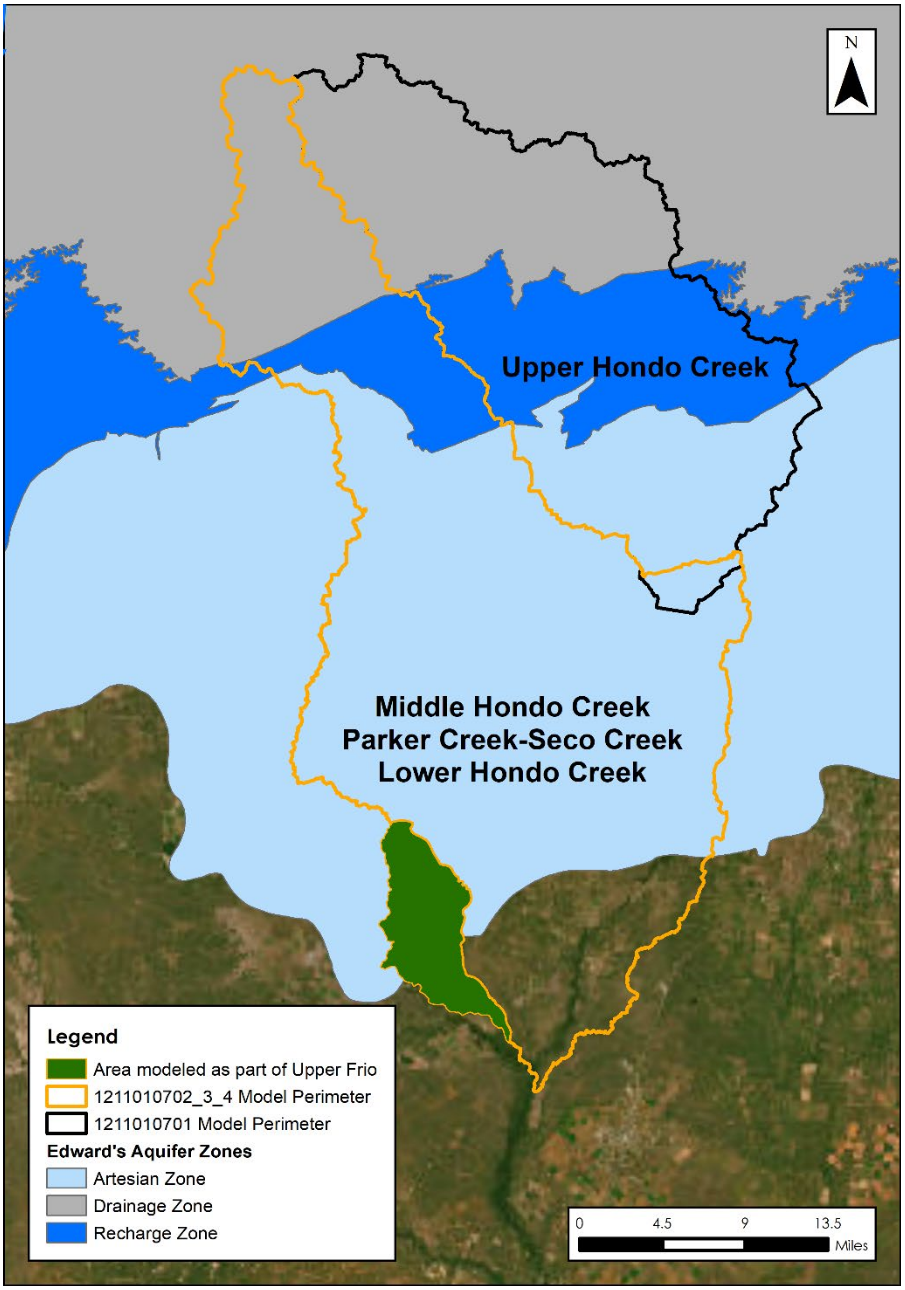


Figure 4-13. Hondo watershed HUC 10 models and Edward's Aquifer zones

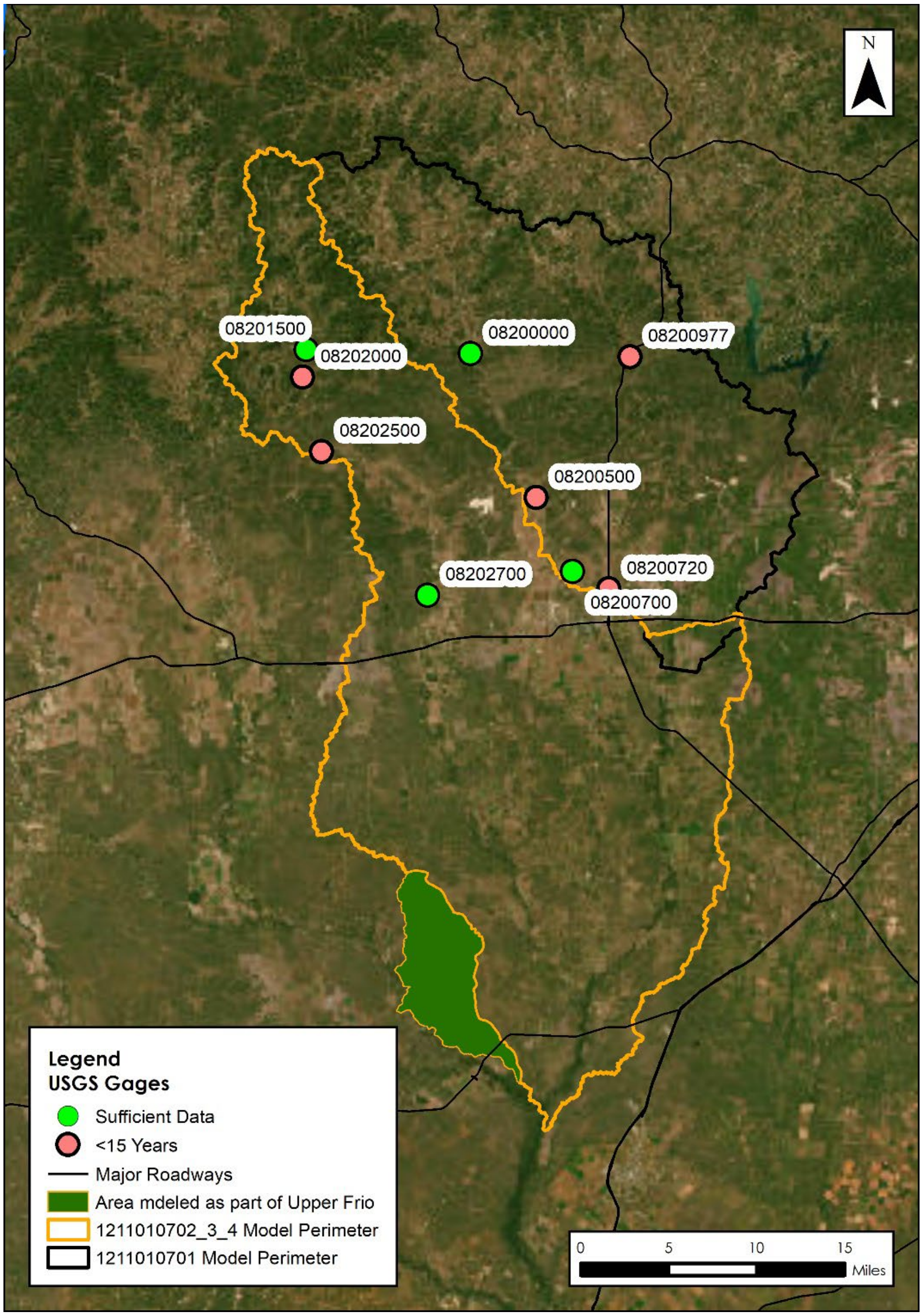


Figure 4-14. USGS Gages in Hondo watershed

The two HUC 10's that were calibrated using the Bulletin 17C analysis was HUC 1211010701 (HUC 701) and 1211010702.3.4 (HUC 702.3.4). The HUC 701 model was calibrated first with the intention to apply the same watershed adjustment per Edward's Aquifer zone to the HUC 702.3.4 model. The HUC 701 model was chosen to be the standard because a calibration gage existed both upstream and downstream of the recharge zone along the same stream. This was deemed instrumental to understand the effects of the recharge zone on watershed runoff.

The base HUC 701 model results showed 1% annual chance flows less than Bulletin 17C 1% annual chance estimate at the gage upstream of the recharge zone (8200000) by approximately 22% and flows less than the gage downstream of the recharge zone (8200700) by approximately 8%. The decrease in model results deficiencies is in line with the expectation that CN's within the recharge zone did not adequately represent the true amount of loss due to karst features. Furthermore, the base CN values in the drainage zone (upstream of the recharge zone) may be lower than what is needed to describe the higher average gradient in the headwaters (Ajmal et al., 2020).

The strategy of calibration was to adjust CN values and abstraction ratio within the model's watershed based on Edward's Aquifer zones. When CN values were increase by a percentage, a maximum CN value of 100 was maintained. Additionally, the 'Open Water' land classification was held at their base CN value and not subject to CN adjustments. The final calibrated CN layer has prefixes in the description that correspond to the aquifer zone that region lies within. The drainage zone, recharge zone, and artesian zone are designated by prefixes 'DZ', 'RZ', and 'AZ', respectively.

The CN values in the drainage zone were kept at the base values, the CN values in the recharge zone were decreased by 40%, and the CN values in the artesian zone were decreased by 20%. Additionally, the Manning's n value for the channel above the 8200000 gage was set to 0.045. The resulting model flow were brought to approximately 25% lower than that of the upstream gage's (8200000) Bulletin 17C, 1% annual chance estimate. The model flow was brought to approximately 14% lower than that of the downstream gage's (8200700) Bulletin 17C, 1% annual chance estimate.

The adjustments made to the HUC 702.3.4 model included increasing CN values in the drainage zone by 10%. The base model showed model flows 8% lower than that of gage 8202700's Bulletin 17C, 1% annual chance estimate. The calibration adjustments brought the model flow to approximately 1% lower than that of the gage estimate. No other adjustments were made from the base numbers in the model for calibration to gage 8202700. The gage 8201500 resulted in model flow of approximately 50% lower than the Bulletin 17c, 1% chance estimate, but well within the upper and lower bounds required.

Table 4-6. 1% Annual Storm Calibration Results Summary for Hondo 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		
08200000	95.6	117,700	71,920	230,000	88,416	-25%
08200700	150	127,000	68,630	457,200	109,193	-14%
08202700	168	127,300	60,890	805,200	129,464	-2%
08201500	45	97,270	49,150	351,900	55,033	-43%

The model results were compared to effective floodplains and cross section elevations where they exist within the Hondo watershed. Effective cross sections were imported into RASMapper with the WSEL attribute turned on. The maximum WSEL output raster for the 1% annual chance flood event was then compared to the effective elevations. In general, model WSELs range from 0-4 feet higher than the effective floodplain, with exceptions. Areas around structures and low gradients tended to have a higher degree of difference in WSEL between the model and effective data. This difference is likely due to a difference in precipitation application, not modeling detailed structures, as well as the increased ability of the 2D model to simulate runoff patterns in the overbanks and low gradient areas terrains.

The model results were also compared to calculated flow estimates derived from USGS regional regression equations corresponding to the USGS gage locations in the HUC8 watershed (Table 4-7). Table 4-7 shows that the model produced higher flows than the regression equation's 95% confidence limit for one of the four gage locations, which were calculated with regional equations using Texas parameters derived from the 2009 USGS report by Asquith and Roussel (USGS 2009).

Table 4-7. 1% Annual-chance Flood Event – Modeled Peak Flow Comparison to USGS Regional Regression Estimates (equations and parameters via USGS 2009)

USGS Gage	1% AEP Peak Flows (CFS)			
	Modeled Peak Flow	Regression Estimate	Regression Estimate – 5% Lower CL	Regression Estimate – 95% Upper CL
08200000	88,416	29,147	9,651	88,022
08200700	109,193	40,431	13,388	122,101
08202700	129,463	62,320	20,636	188,204
08201500	55,033	23,587	7,811	71,233

4.7 Modeled Results

A summary of modeled peak flows and WSEL results for the 10%, 1% and 0.2%-annual-chance events are summarized in Table 4-8 to Table 4-10 with locations shown in Figure 4-15 for USGS and NWS gages in the watershed. Floodplain delineation for these events is described in Chapter 6. The hydraulic study results will be shared with the Hondo watershed communities during the Discovery Process.

Table 4-8. 10% Storm Results Summary for Hondo watershed

HUC 10 Name and Number	Gage Description	Modeled Peak Flow (CFS)	WSEL* (ft)
Upper Hondo Creek (1211010701)	USGS 08200000	30,475	1199.1
Upper Hondo Creek (1211010701)	USGS 08200700	35,706	921.1
Upper Hondo Creek (1211010703)	USGS 08202700	57,575	931.3
Upper Hondo Creek (1211010703)	USGS 08201500	23580	1294.8

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

Table 4-9. 1% Storm Results Summary for Hondo watershed

HUC 10 Name and Number	Gage Description	Modeled Peak Flow (CFS)	WSEL*(ft)
Upper Hondo Creek (1211010701)	USGS 08200000	88,416	1206.4
Upper Hondo Creek (1211010701)	USGS 08200700	109,193	932.0
Upper Hondo Creek (1211010703)	USGS 08202700	129,463	933.8
Upper Hondo Creek (1211010703)	USGS 08201500	55,033	1300.9

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

Table 4-10. 0.2% Storm Results Summary for Hondo watershed

HUC 10 Name and Number	Gage Description	Modeled Peak Flow (CFS)	WSEL*(ft)
Upper Hondo Creek (1211010701)	USGS 08200000	128,844	1209.9
Upper Hondo Creek (1211010701)	USGS 08200700	165,954	937.9
Upper Hondo Creek (1211010703)	USGS 08202700	159,883	934.6
Upper Hondo Creek (1211010703)	USGS 08201500	86,475	1305.0

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

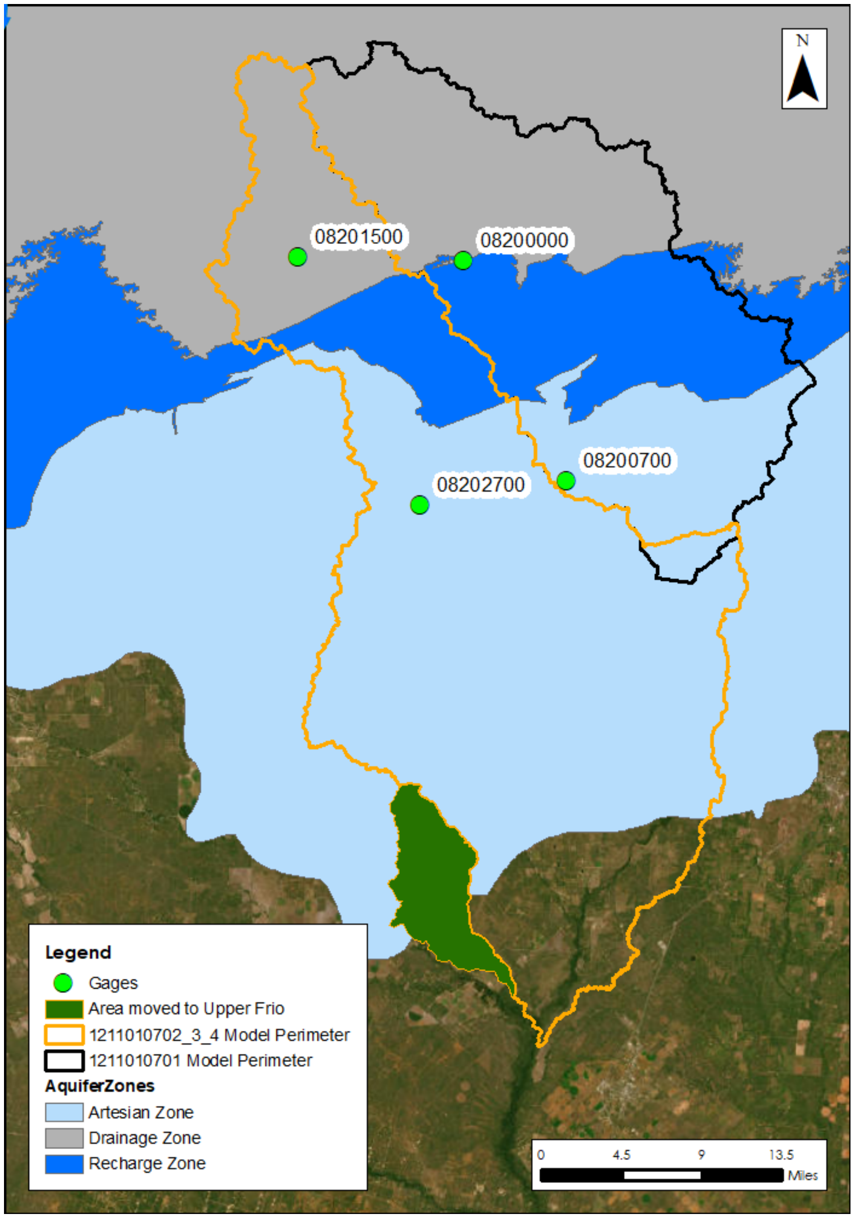


Figure 4-15. Overview of Peak Flow Locations for Hondo watershed

4.8 Challenges and Recommendations

The first challenge encountered stemmed from the fact that the existing HUC 8 boundaries were not accurately depicting the basin divide according to the latest terrain data and as such, a small area was decided to be move into the upper Frio model (HUC 8 #12110106) as it was found to be contributing to that watershed.

An additional challenge was the braided channel structure and flat terrain. This type of watershed characteristic made it very challenging to tie models in together within the required 0.5-ft tolerance.

This ultimately resulted in the combining of 3 HUC 10 models and needing multiple BC lines to accurately capture the hydrograph at the tie-in location.

Furthermore, due to the challenging terrain, there is overland flow that is being transferred between the two models along a ridge line in the southwest boundary of the upstream model. Utilizing the ridge line was the best option to separate the two models because combining them would have made the model too large to be ran within the TWDB suggested 12-hour runtime limit. This boundary location was challenging in that many BC lines were needed in order to capture all the various locations where flow legitimately left the upstream model. The combination of water/ ground interaction because of the Edwards Aquifer and the limited gages available made it challenging to validate the modeling results.

It is recommended that future model upgrades should consider leveraging or otherwise incorporating data and results for effective models within the basin.

Furthermore, future model upgrades should incorporate structures by utilizing as-builts, surveyed data, or effective models within the study area.

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

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

Additional post processing steps were applied using ArcGIS Simplifying and Smoothing tools to the 0.2% and 1% floodplain polygons. A 5-foot threshold for simplifying and 25-foot tolerance for smoothing were applied in this process. Per TWDB 2D BLE Guidance, the 10% floodplains did not go through this post processing step (TWDB 2022). This was to maintain the 10% flood extents as close to the 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 Hondo watershed mapping products demonstrate a 0.5ft tie-ins at all mainstem model overlap locations. However, along the model perimeters where there are auxiliary flooding or spill locations, often model overlaps do not exist. In some of these instances, AOMI areas are used to identify tie-in issues that were unable to be resolved due to a lack of model overlap.

Within the downstream portion of Hondo, floodplain mapping from an Upper Frio (112110106) watershed model was used to tie-in the Hondo mapping products. This overlap portion is demonstrated in Figure 6-1.

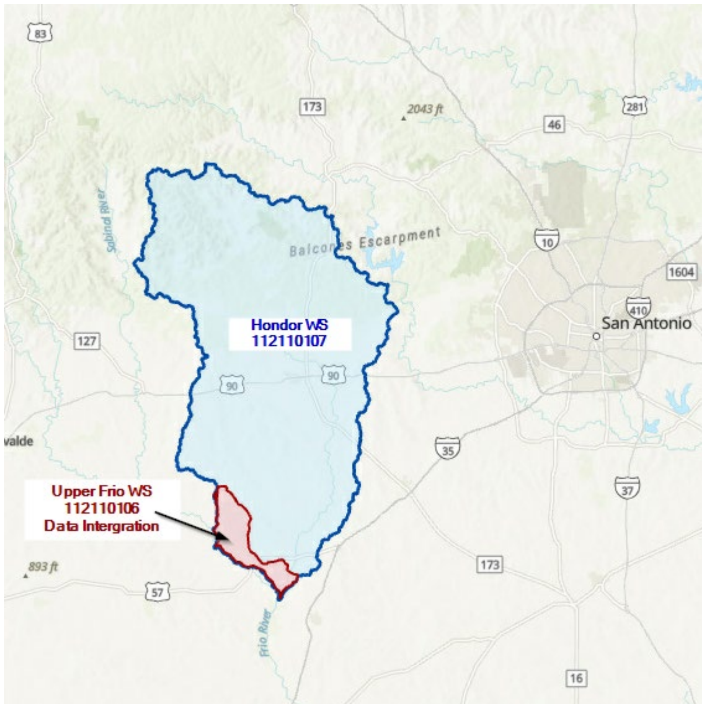


Figure 6-1. Hondo WS mapping data integration – overlap with Upper Frio WS

6.2 HAZUS

As a part of the Base Level Engineering assessment effort, Hazus was run using version 6.0 and resampled 10ft cell size 1% Depth Grid. Hazus 6.0 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 Considerations

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

- In the Hondo watershed products, stream centerlines are contained within the 1% floodplain. however, in areas where there are road crossings and embankments there is no streamline containment because the floodplain is not overtopping. In the areas with no floodplain containment, the length of stream centerline is less than 500 feet.
- Significant artificial depth increases at floodplain fringes occur in some areas of the Hondo mapping products because of an artifact of RASMapper raster generation. In the sloping rendering mode, RASMapper attempts to interpolate between adjacent cells to “slope” the water surface, but in doing so, steep canyon walls or bluffs on the floodplain fringe can artificially cause the water surface to be interpolated upstream in the rendering, resulting in significant areas of inundation where inundation was not actually modeled as existing. This

erroneous mapping result is referred to as “cupping”. Cupping may be resolved in future studies with assumed improvement of the RASMapper 2D rendering engine.

6.4 Results and Recommendations

The BLE results for the Hondo 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. These products should be shared with stakeholder communities during the discovery process and should be verified through community work map meetings before being applied to a regulatory product.

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

A large portion of the Zone A studies (689.6 miles) in the Hondo watershed were classified in CNMS with a validation status of "UNVERIFIED" and maintained a status type of "BEING STUDIED." Zero miles of Zone A studies were classified in CNMS with a validation status of "VALID" and status type of "NVUE COMPLIANT." The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A5 were evaluated for the CNMS inventory of Zone A studies.

7.1 Initial Assessment A1 – Significant Topography Update Check

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

The effective topo used for the effective Zone A in HUC8 12110107 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 12110107 fail A1.

7.2 Initial Assessment A2 – Check for Significant Hydrology Changes

This check involves first determining whether regression equations were used in the effective study. If they were then it was determined if new regression equations have become available from the USGS since the date of the effective Zone A study. If newer regression equations exist for the area of interest, then an engineer must determine whether these regression equations would significantly affect the 1-percent-annual-chance flow.

Hydrology methods are unknown or HEC-1 for the effective Zone A studies in HUC8 12110107. Therefore, all effective Zone A studies in HUC8 12110107 pass A2.

7.3 Initial Assessment A3 – Check for Significant Development

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

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

Table 7-1: Zone A Initial Assessment Results

Assessment Check	Pass/Fail	Comments/Notes
A1 - Topography	Fail	Old topo does not meet SID 43, new topo does
A2 - Hydrology	Pass	Hydrology methods unknown or HEC-1
A3 - Development	Pass	Urbanization increase is insignificant

7.4 Initial Assessment A4 – Check of Studies Backed by Technical Data

Zone A studies that pass all initial assessment checks described above may be categorized as "Valid" in the CNMS Inventory only if the effective Zone A study is supported by modeling or sound engineering judgment and all regulatory products are in agreement. If the effective Zone A study passes all initial assessment checks, but is not supported by modeling, or if the original engineering method used is unsupported or undocumented, a comparison of the BLE results and effective Zone A's is performed.

Effective Zone A studies in HUC8 12110107 and in Medina County are mode backed, according to the effective FIS. These reaches pass A4. All other Zone A reaches in HUC8 12110107 have no information available on their hydraulic model and are therefore not considered to be model backed. These reaches fail A4.

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

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

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

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

All effective Zone A reaches in HUC8 12110107 failed the BLE comparison check. The National Risk Index risk deciles were grouped to represent risk classes and used to evaluate the threshold of points that pass the A5 comparison for each HUC12. Results are listed in Table 7-3.

7.6 CNMS Validation Results

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Hondo watershed study area has been updated, total miles in each of these categories are summarized in Table 7-2 and Table 7-3 and illustrated in Figure 7-1.

Table 7-2: Zone A Validation Results

Validation Status	Status Type	Total Mileage
Valid	NVUE Compliant	0
Unverified	Being Studied	689.6

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						
Wards Creek-Hondo Creek	121101070102	2147	1430	717	33%	>95%	FAIL
Eschenburg Lake-Seco Creek	121101070403	1410	937	473	34%	>95%	FAIL
Gross Tank	121101060801	70	45	25	36%	>95%	FAIL
Quihi Creek	121101070108	1748	1025	723	41%	>95%	FAIL
Verde Creek-Hondo Creek	121101070109	1278	785	493	39%	>95%	FAIL
West Squirrel Creek	121101070401	1583	907	676	43%	>95%	FAIL
Squirrel Creek	121101070402	2372	1541	831	35%	>95%	FAIL
Elm Slough	121101070201	423	288	135	32%	>95%	FAIL
121101070404	121101070404	390	196	194	50%	>95%	FAIL
Hog Wallow Slough-Hondo Creek	121101070202	2153	1424	729	34%	>95%	FAIL
East Branch Live Oak Creek	121101070203	1578	811	767	49%	>95%	FAIL
West Tehuacana Creek	121101070206	972	536	436	45%	>95%	FAIL
Little Live Oak Creek-Live Oak Creek	121101070204	998	554	444	44%	>95%	FAIL
Brier Branch-Hondo Creek	121101070205	1926	1478	448	23%	>95%	FAIL
East Tehuacana Creek-Tehuacana Creek	121101070207	1234	720	514	42%	>95%	FAIL
Headwaters Seco Creek	121101070301	1174	854	320	27%	>95%	FAIL
Little Seco Creek-Seco Creek	121101070302	1841	1278	563	31%	>95%	FAIL
Rocky Creek-Seco Creek	121101070303	2138	1406	732	34%	>95%	FAIL
Headwaters Hondo Creek	121101070101	1015	713	302	30%	>95%	FAIL
Live Oak Creek-Seco Creek	121101070304	2147	1335	812	38%	>95%	FAIL

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	HUC12 ID						
Parkers Creek	121101070305	1614	1019	595	37%	>95%	FAIL
Twin Hollow	121101070103	903	724	179	20%	>95%	FAIL
Martin Creek-Verde Creek	121101070105	1360	1088	272	20%	>95%	FAIL
Middle Verde Creek	121101070104	3115	2487	628	20%	>95%	FAIL
Second Creek-Verde Creek	121101070106	2408	1387	1021	42%	>95%	FAIL
Main Quihi Creek-Elm Creek	121101070107	2373	1932	441	19%	>95%	FAIL

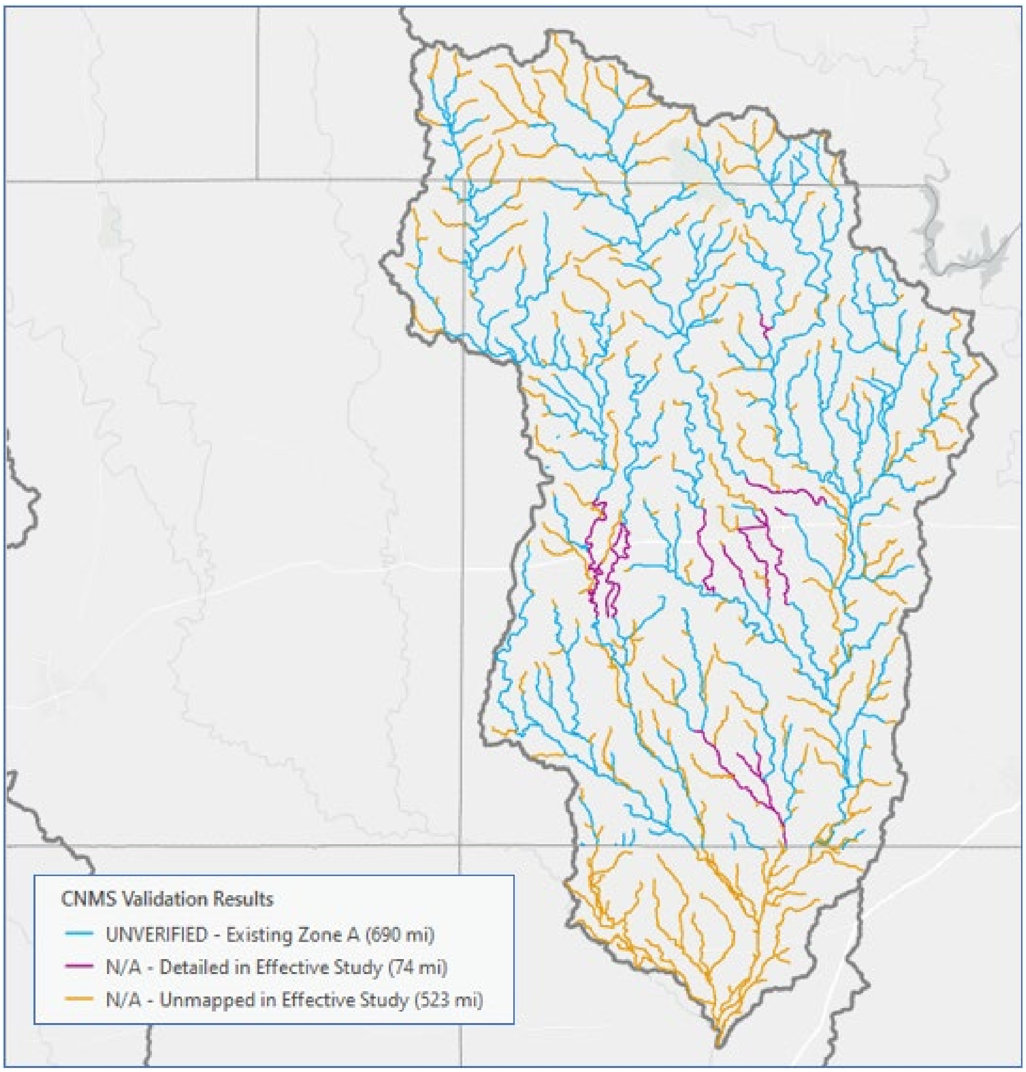


Figure 7-1. CNMS Validation Results

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Appendix A – PeakFQ Output File

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  Version 7.3         Annual peak flow frequency analysis      Run Date / Time
  10/25/2019                                                  11/12/2021 16:45

                         --- 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)  -
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TXT
                         specifications -
C:\Users\snarkhede\Documents\PROJECTS\TWDB\HUC107\1211010701\08200000\PKFQWPSF.TMP

                      Output file(s):
                         main -
C:\Users\snarkhede\Documents\PROJECTS\TWDB\HUC107\1211010701\08200000\08200000_PEAK.
PRT


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

1


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  Version 7.3         Annual peak flow frequency analysis      Run Date / Time
  10/25/2019                                                  11/12/2021 16:45

                  Station - 08200000  Hondo Ck nr Tarpley, TX


                     TABLE 1 - INPUT DATA SUMMARY

                Number of peaks in record           =       69
                Peaks not used in analysis          =        0
                Gaged peaks in analysis             =       68
                Historic peaks in analysis          =        1
                Beginning Year                      =     1932
                Ending Year                         =     2020
                Historical Period Length            =       89
                Skew option                         =   WEIGHTED
                Regional skew                       =   -0.483
```

```
1
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  10/25/2019                                                   11/18/2021 14:07

                        --- PROCESSING OPTIONS ---

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                     Basin char output   = None
                     Print option        = Yes
                     Debug print         = No
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Skew\HUC107\1211010701\08200700\08200700_PEAK.TXT
                        specifications -
C:\Users\snarkhede\Documents\PROJECTS\TWDB\Gage Analysis\With
Skew\HUC107\1211010701\08200700\PKFQWPSF.TMP
                     Output file(s):
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  ***  User responsible for assessment and interpretation of the following analysis
***

1


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  Version 7.3        Annual peak flow frequency analysis      Run Date / Time
  10/25/2019                                                   11/18/2021 14:07

        Station - 08200700  Hondo Ck at King Waterhole nr Hondo, TX


                    TABLE 1 - INPUT DATA SUMMARY

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               Peaks not used in analysis         =       0
               Gaged peaks in analysis            =      44
               Historic peaks in analysis         =       0
               Beginning Year                     =    1962
               Ending Year                        =    2005
               Historical Period Length           =      44
               Skew option                        =   WEIGHTED
               Regional skew                      =  -0.459
                    Standard error                =   0.465
```

```
1
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  Version 7.3        Annual peak flow frequency analysis      Run Date / Time
  10/25/2019                                                  11/12/2021 17:18

                         --- 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\HUC107\1211010703\08202700\08202700_PEAK.
TXT
                         specifications -
C:\Users\snarkhede\Documents\PROJECTS\TWDB\HUC107\1211010703\08202700\PKFQWPSF.TMP

                      Output file(s):
                         main -
C:\Users\snarkhede\Documents\PROJECTS\TWDB\HUC107\1211010703\08202700\08202700_PEAK.
PRT


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

1


  Program PeakFq          U. S. GEOLOGICAL SURVEY           Seq.001.001
  Version 7.3        Annual peak flow frequency analysis      Run Date / Time
  10/25/2019                                                  11/12/2021 17:18

             Station - 08202700  Seco Ck at Rowe Rh nr D'Hanis, TX


                    TABLE 1 - INPUT DATA SUMMARY

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                Peaks not used in analysis          =        0
                Gaged peaks in analysis             =       60
                Historic peaks in analysis          =        0
                Beginning Year                      =     1961
                Ending Year                         =     2020
                Historical Period Length            =       60
                Skew option                         =   WEIGHTED
                Regional skew                       =   -0.461
```

Appendix B – Supplemental Hydrology Data

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

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

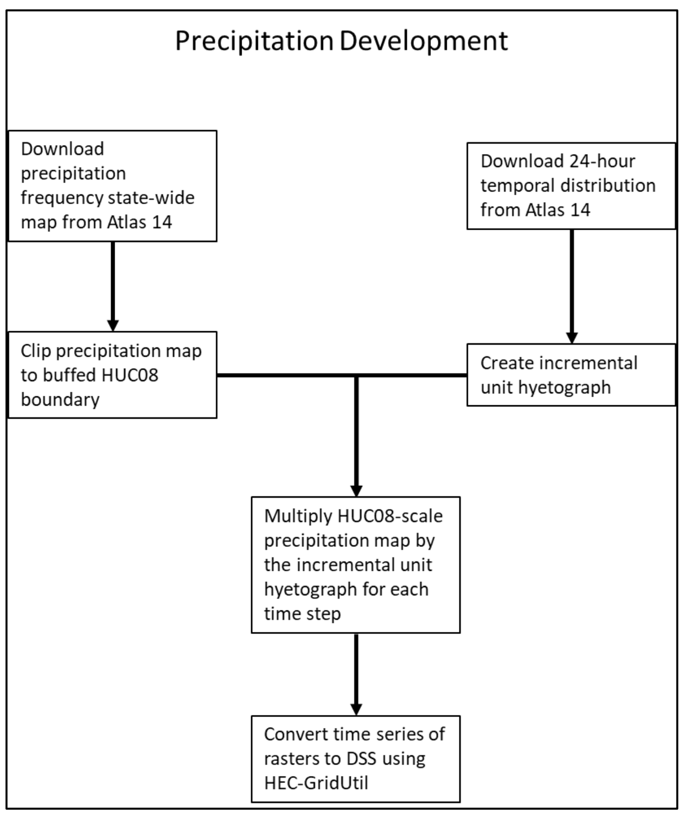

Figure B.1 - Flow chart demonstrating Stantec's precipitation dataset derivation process

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

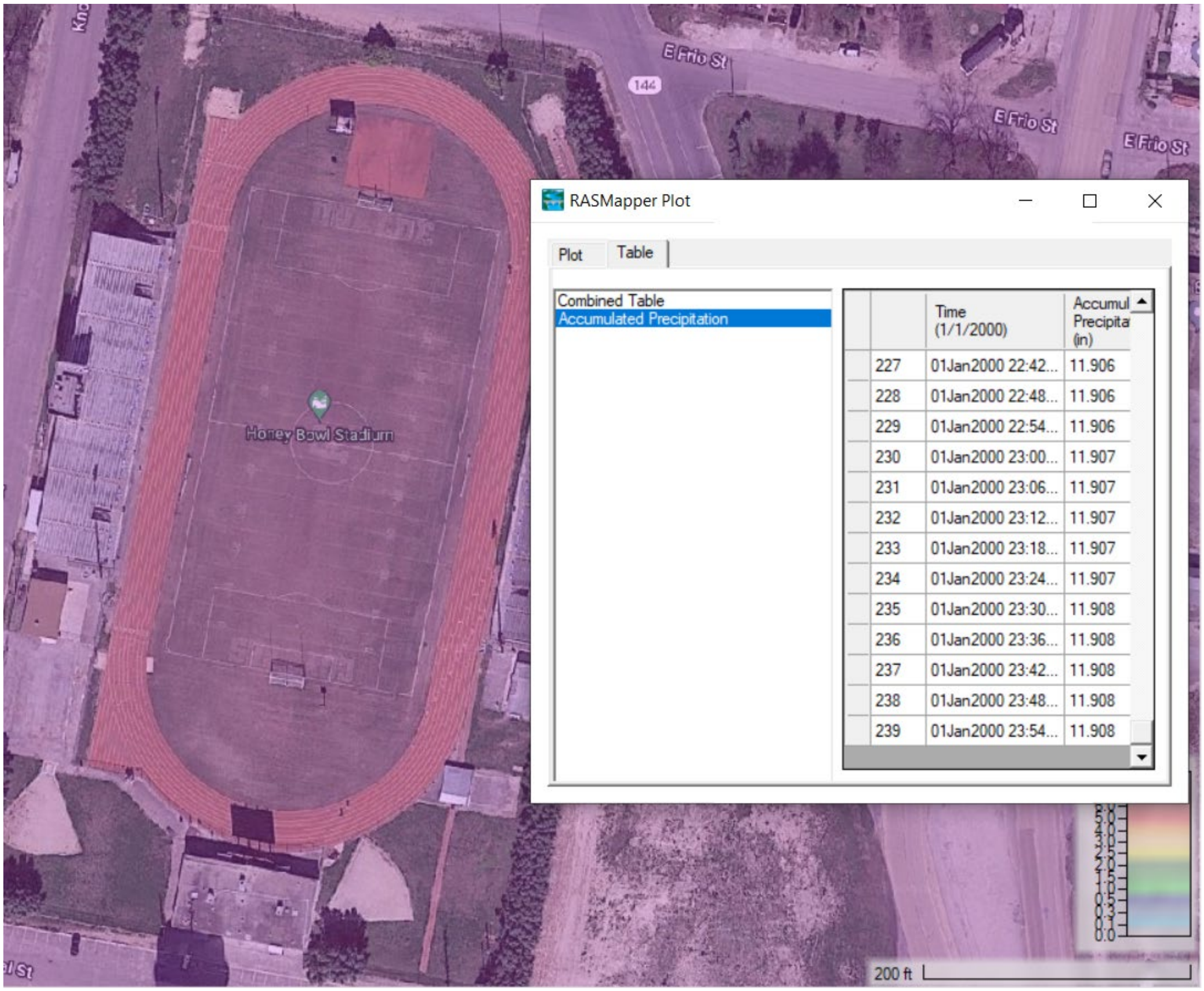

Figure B.2 – Cumulative 100-year, 24-hour precipitation at Honey Badger Stadium in Uvalde, TX

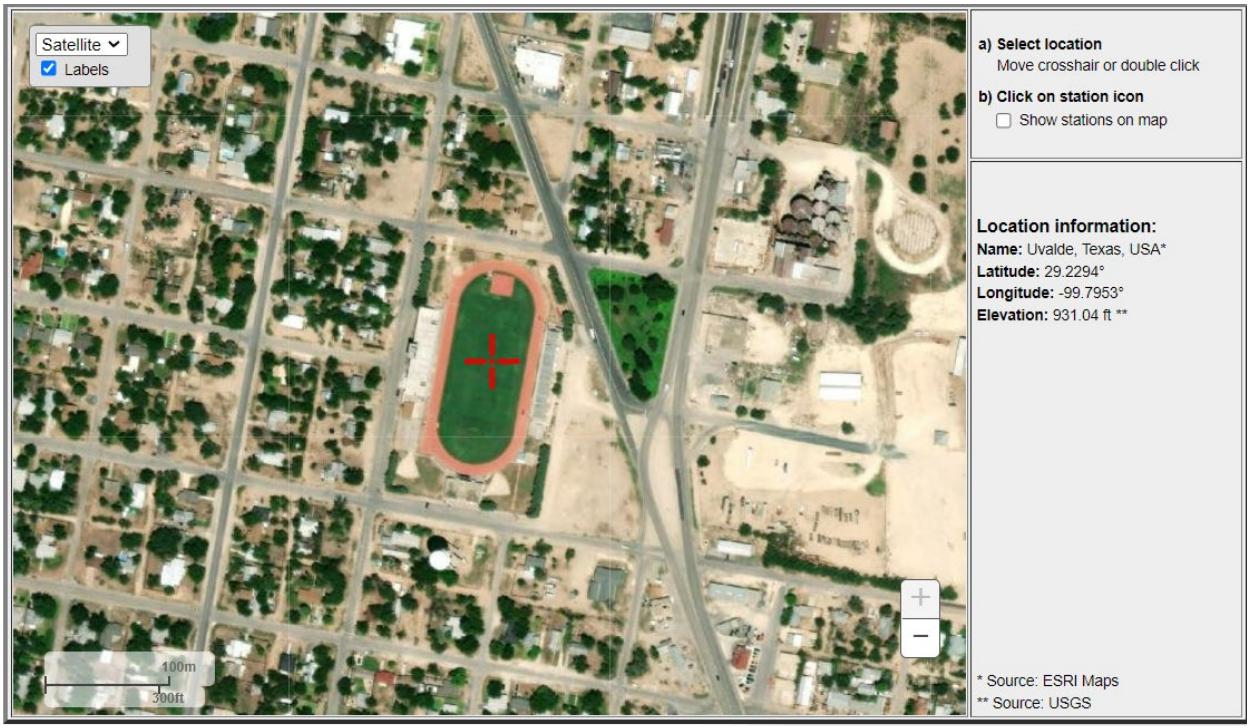

Figure B.3 –Honey Badger Stadium view from Atlas 14 browser

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

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

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

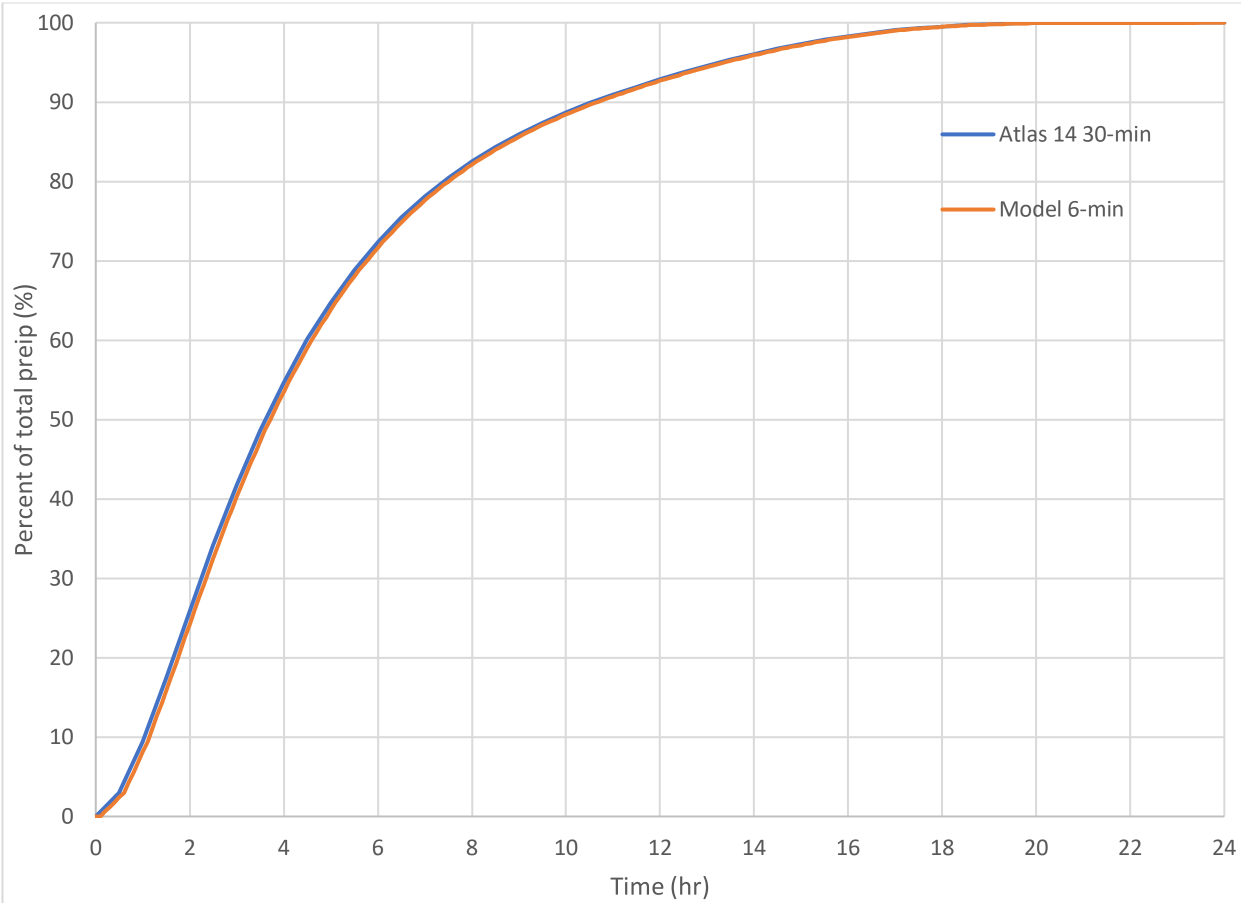

Figure B.00-1. Comparison of Atlas 14 and normalized model cumulative precipitation.

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

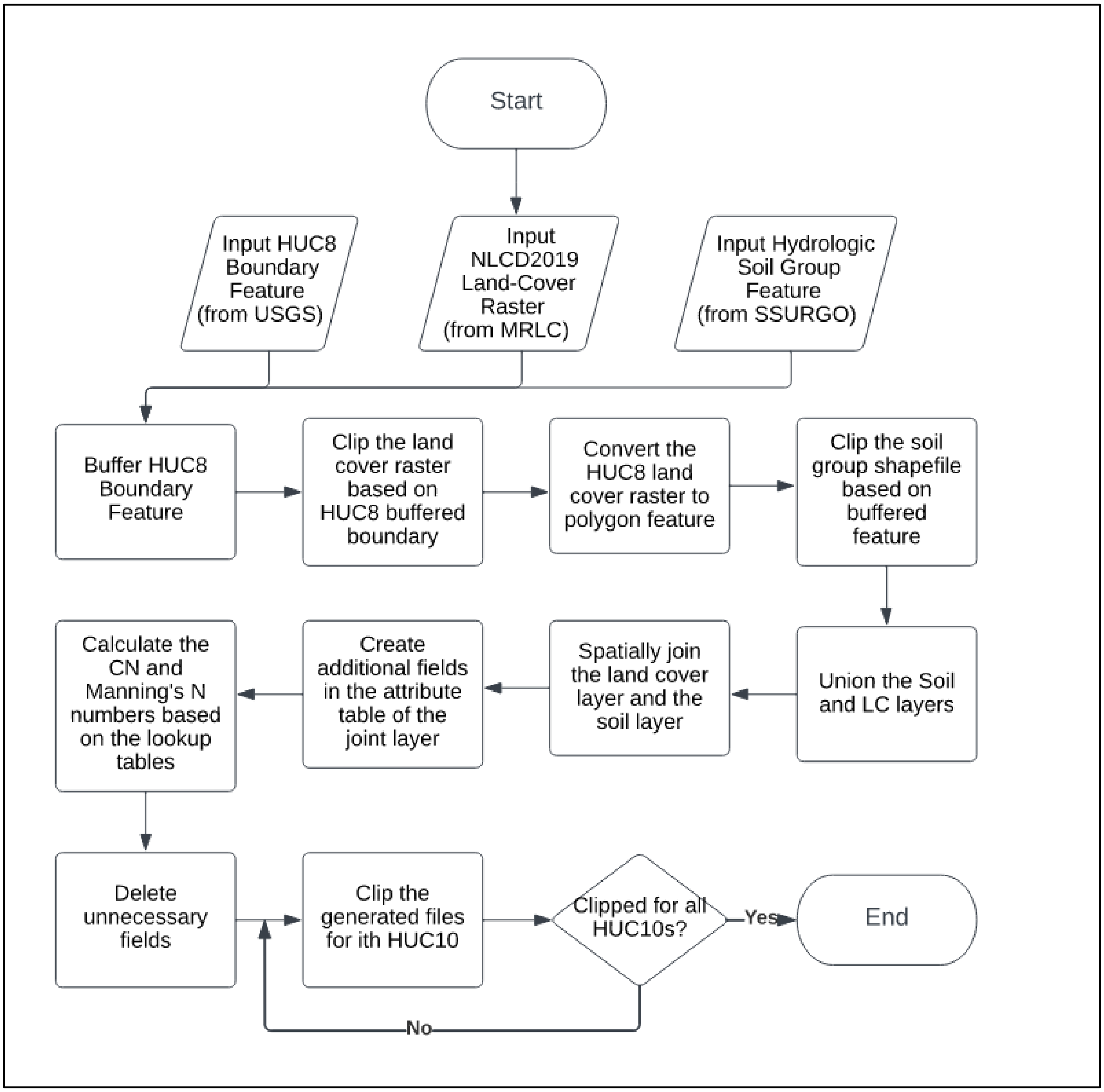

Figure B.1 Flow chart demonstrating Stantec's curve number spatial dataset derivation process