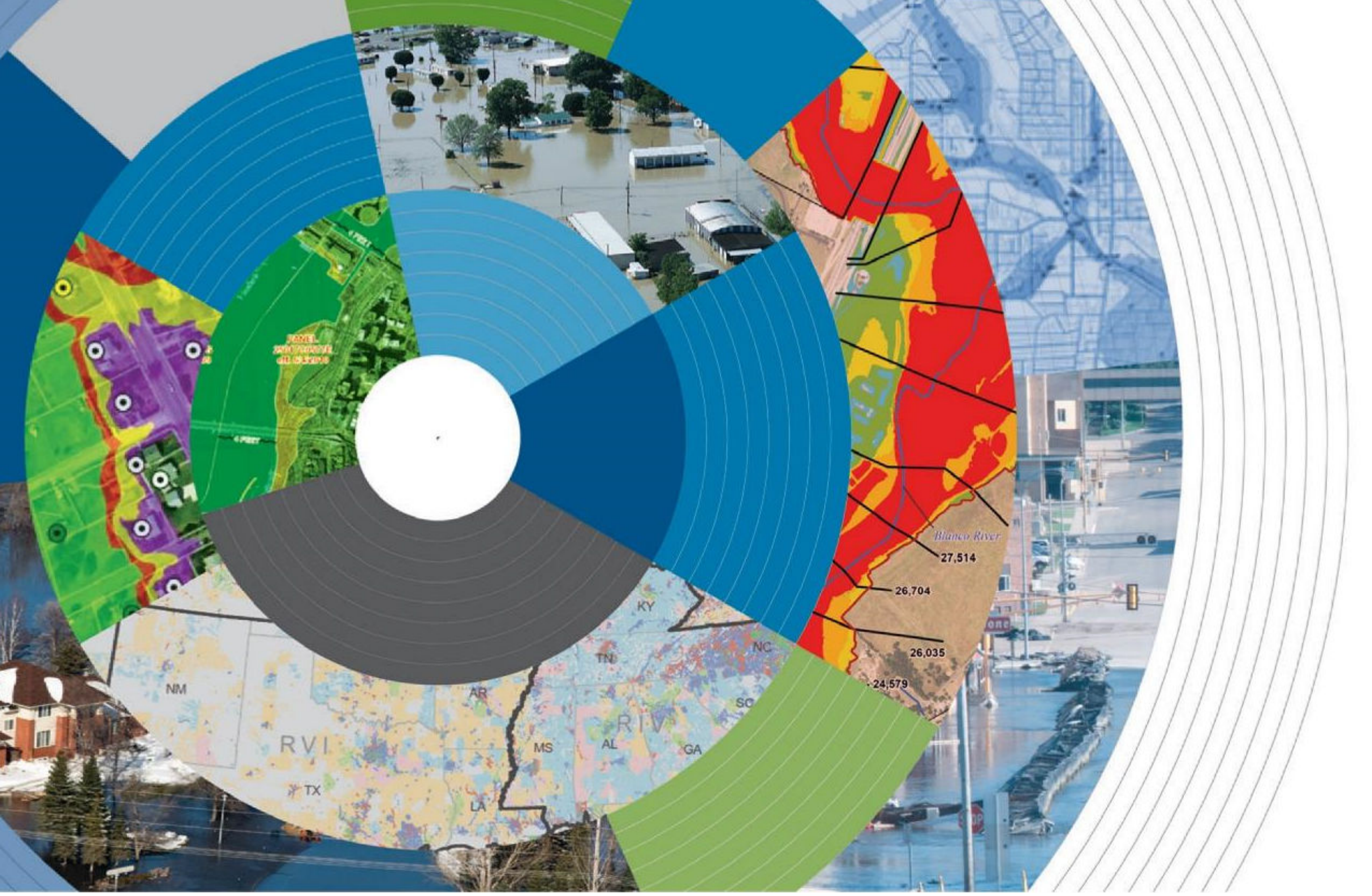

Base Level Engineering Report

Austin-Travis Lakes (12090205)

Texas Water Development Board

November 30, 2024

Version 1.0

Report Prepared for:

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Version No.	Version Date	Summary of Changes	Author
1.0	November 30, 2024	Initial report for the Estimated Base Flood Elevation viewer	AtkinsRéalis USA, Inc.

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Executive Summary

The Texas Water Development Board (TWDB) contracted with AtkinsRéalis USA, Inc. (AtkinsRéalis) to complete two-dimensional (2D) Base Level Engineering (BLE) in the Austin-Travis Lakes HUC-8 watershed (12090205). This watershed is located in Central Texas, between Horseshoe Bay and Austin, Texas. The watershed area is 1,241 square miles (mi^2). Approximately 1,608 miles of stream centerlines were modeled. The information produced during this assessment is available on the U.S. Department of Homeland Security's Federal Emergency Management Agency's (FEMA) Mapping Information Platform (MIP) under case number 22-06-0047S.

The following guidance documents provided the methodologies for this project:

- *Base Level Engineering – Region 6 Submittal Guidance* (FEMA, January 2019)
- *Base Level Engineering – Region 6 Submittal Guidance – Appendix A: 2-D Base Level Engineering Guidance* (FEMA, January 2019)
- *Texas Two-Dimensional Base Level Engineering Guidelines, Version 1.0* (TWDB, May 2022)

Light Detection And Ranging (LiDAR) topographic data available for download from the Texas Natural Resources Information System (TNRIS) were leveraged to build a 3D terrain surface for the watershed.

The hydrologic and hydraulic modeling was completed using the U.S. Army Corps of Engineers' Hydrologic Engineering Center River Analysis System (HEC-RAS), Version 6.2. In accordance with FEMA's Standard Identification Number (SID) 84, the 10%, 4%, 2%, 1%, 0.2%, 1% plus, and 1% minus annual-chance events were simulated. Precipitation data from the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 were leveraged to develop the 24-hour rainfall distribution for each event. A rain-on-grid methodology was applied to distribute the rainfall across the extents of the 2D hydraulic model area. Infiltration losses were computed using the Natural Resources Conservation Service's (NRCS) Curve Number (CN) loss rate method.

The Austin-Travis Lakes watershed was divided into ten HEC-RAS model domains — 0501_A1, 0502_A2, 0503_A3, 0503_A4, 0504_A5, 0504_A6, 0504_A7, 0503_A8, 0503_A9, and 0504_A10. Per TWDB guidance, a 200-foot by 200-foot nominal cell spacing was used for the 2D area and a finer 100-foot by 100-foot cell spacing was used along the breaklines and within the refinement regions. Breaklines were added to capture roadways, railroads, dam crests, and embankments to force the terrain surface to drain properly. Refinement regions were defined in and near urban areas, major reservoirs, and dam overflow areas to enhance the identification of the flood hazards in these higher-risk areas.

Model results were validated using stream gage data, regression flows, effective FEMA data, and outcomes from other studies in the project area.

Floodplain mapping was developed for the 10%, 1%, and 0.2% annual chance events. Raw mapping output from HEC-RAS was post-processed to delineate floodplains that aligned with the TWDB's 2D BLE mapping standards.

A summary of FEMA's Coordinated Needs Management Strategy (CNMS) data for the Austin-Travis Lakes watershed is in Table 1 and Table 2 and shown on Figure 1.

Table 1: Summary of Stream Miles

Source	Stream Miles
Current Inventory -- CNMS	1,394.8
New Study Streams – CNMS	213.6
Total (BLE) Stream Miles	**1,608.4**

Table 2: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment
VALID	NVUE COMPLIANT	500.6	0
	BEING STUDIED	181.6	345.6
UNVERIFIED	BEING STUDIED	0	338.3
	TO BE STUDIED	4.1	0

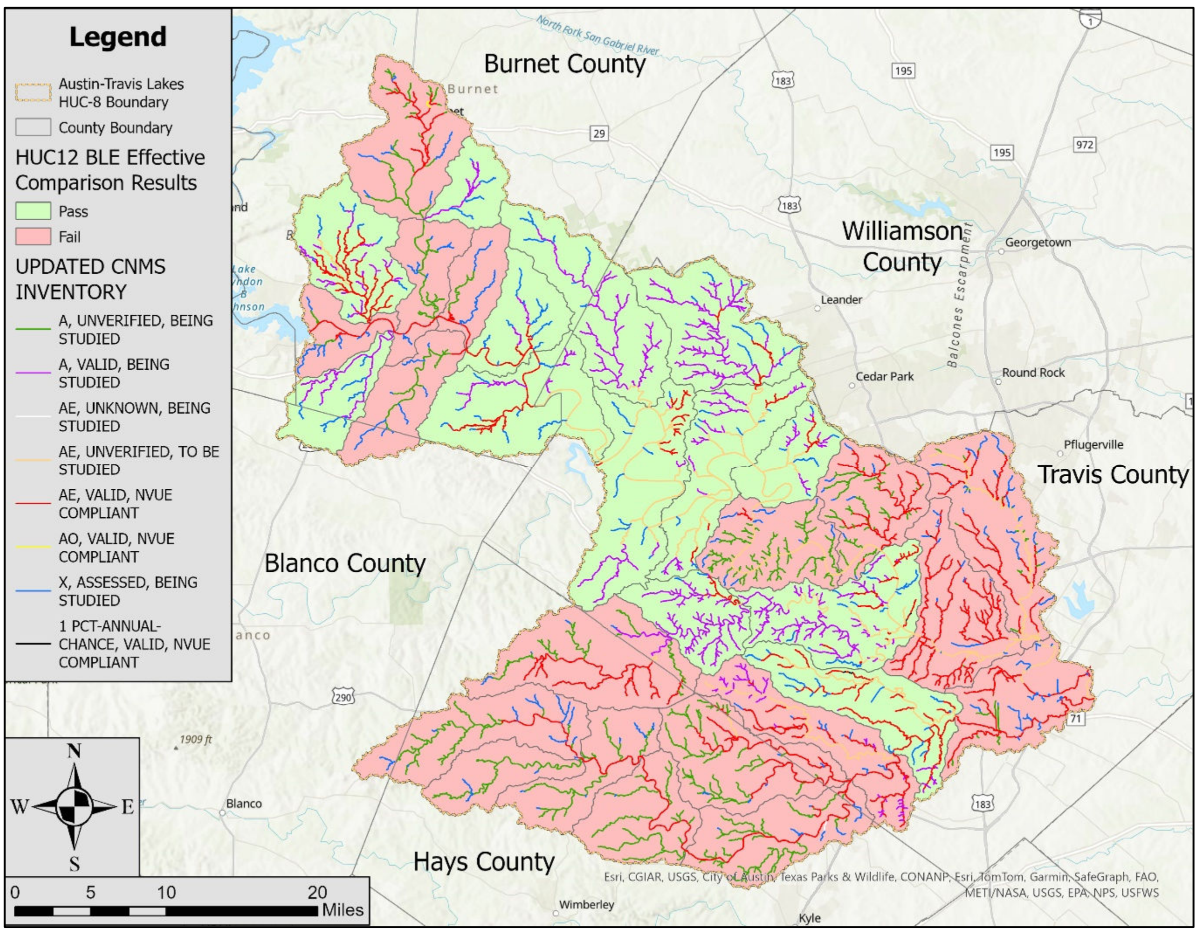


Figure 1: Austin-Travis Lakes - 12090205 CNMS Validation Results

1.0 Base Level Engineering (BLE) Methodology

Recent innovations and increased efficiency in floodplain mapping have allowed FEMA to develop a process called BLE, which can be used to address current program challenges, including the validation of Zone A studies and the availability of flood risk data in the early stages of a Flood Risk Project. The BLE process involves using best available data and incorporating automated techniques with traditional model development procedures to produce regulatory-quality flood hazard boundaries for the 1% annual chance event, as well as estimates of flood hazard boundaries for multiple recurrence intervals. The cost for developing the data and estimates resulting from the BLE process are lower than standard flood production costs. The BLE results may be used for eventual production of regulatory and non-regulatory products.

As described in Title 42 of the *Code of Federal Regulations*, Chapter III, Section 4101(e), once every 5 years, FEMA must determine whether the information on its Flood Insurance Rate Maps (FIRMs) reflects the current risks in flood-prone areas. FEMA makes this determination of flood hazard data validity by examining flood study attributes and change characteristics, as specified in the Validation Checklist of the *CNMS Technical Reference*. The CNMS Validation Checklist provides a series of critical and secondary checks to determine the validity of flood hazard areas studied by detailed methods (e.g., Zone AE, AH, or AO). While the critical and secondary elements in CNMS provide a comprehensive method of evaluating the validity of Zone AE studies, a cost-effective approach for evaluating Zone A studies has been lacking.

In addition to the need for Zone A validation guidance, FEMA standards require flood risk data to be provided in the early stages of a flood risk project. FEMA Program SID 29 requires that during the Discovery process, data must be identified that illustrates potential changes in flood elevation and mapping that may result from the proposed project scope. If available data does not clearly illustrate the likely changes, then an analysis is required that estimates the likely changes. This data and any associated analyses should be shared, and the results should be discussed with stakeholders.

An important goal of the BLE process is the scalability of the results. Scalability means that the results of a BLE analysis cannot only be used for CNMS evaluations of Zone A studies, but can also be leveraged throughout the Risk MAP program. The data resulting from a BLE analysis can be updated as needed and used for the eventual production of regulatory and non-regulatory products, outreach and risk communication, and MT-1 processing. Leveraging this data outside the Risk Mapping, Assessment, and Planning (Risk MAP) program may also be valuable to external stakeholders.

The TWDB contracted with AtkinsRéalis to complete a BLE analysis for the Austin-Travis Lakes watershed (HUC-8 12090205). The western half of the watershed is mostly rural and the land is predominantly used for ranching. The eastern half of the watershed falls within the Austin metropolitan area and is highly developed. Parts of Blanco, Burnet, Hays, Llano, Travis, and Williamson counties fall within the watershed. The cities of Austin, Bee Cave, Buda, Burnet, Cedar Park, Cottonwood Shores, Creedmoor, Dripping Springs, Granite Shoals, Hays, Horseshoe Bay, Jonestown, Kyle, Lago Vista, Lakeway, Leander, Marble Falls, Meadowlakes, Mountain City, Rollingwood, Sunset Valley, and West Lakes Hills reside within the watershed. The town of Round Mountain and the villages of Bear Creek, Briarcliff, Point Venture, San Leanna, Village of the Hills, and Volente also fall within the watershed. See Figure 2 for a map of the Austin-Travis Lakes watershed.

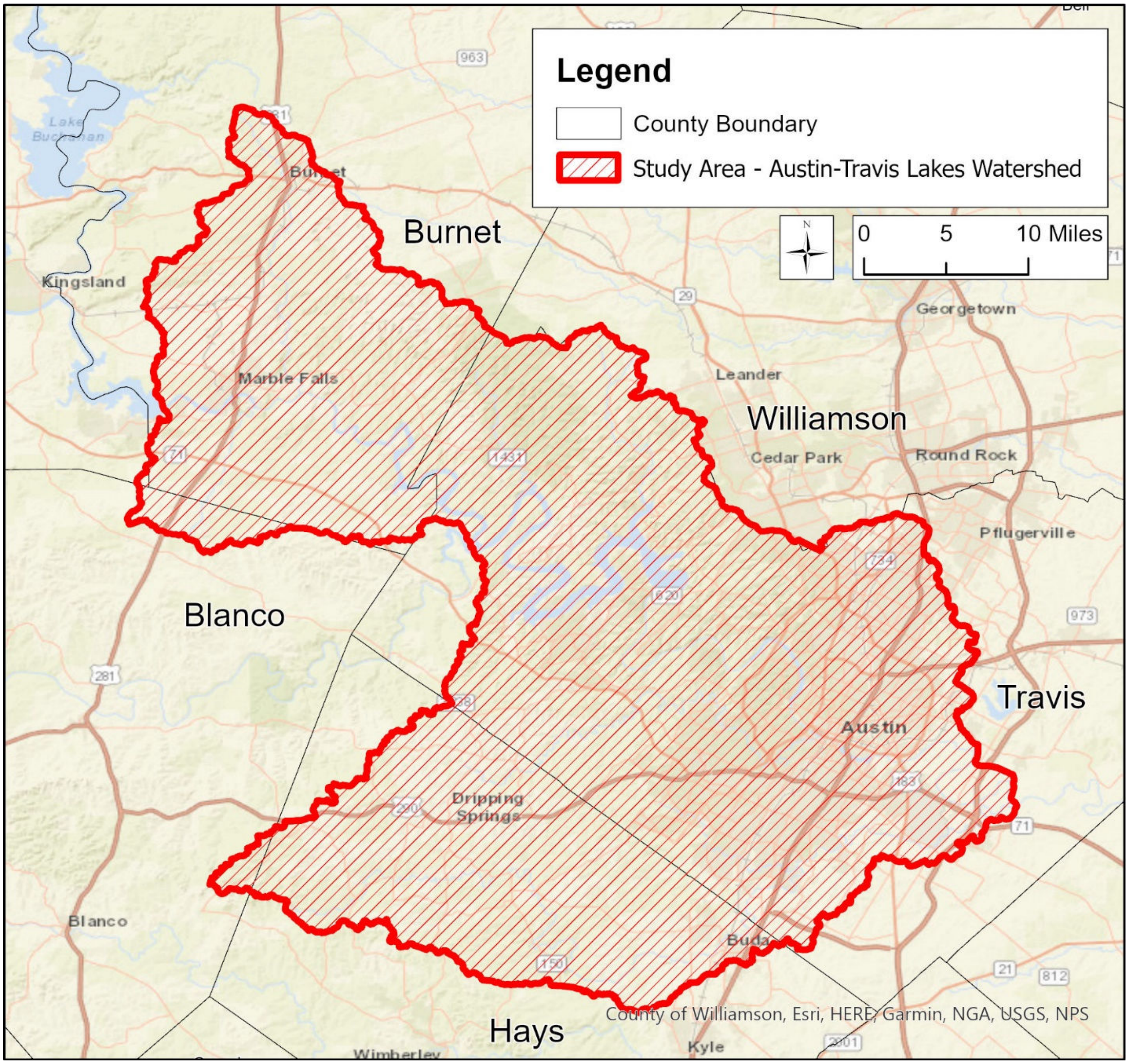


Figure 2: Austin-Travis Lakes Watershed – HUC-8 12090205

The BLE assessment prepared a cursory engineering analysis for approximately 1,608 miles of stream reaches within the Austin-Travis Lakes watershed, with a minimum drainage area tolerance of 1 mi^2. The selection and extent of the stream reaches studied were based on the number of stream miles meeting the minimum drainage area of 1 mi^2 and not the number of effective Zone A stream miles. Study reaches were extended above this 1-mi^2 threshold as appropriate so the entire effective Zone A floodplain received an updated analysis. The following sections summarize the BLE process and discuss the results, along with their recommended use.

1.1 Topographic Data

1.1.1 Development of the Seamless HUC-8 Digital Elevation Model (DEM)

The topographic data used to develop the terrain surface for the Austin-Travis Lakes watershed included three primary data sources in the form of Digital Elevation Models (DEMs). These datasets were provided by the TWDB or downloaded directly from the TNRIS website.

Some of the topographic datasets overlapped one another. Therefore, a priority hierarchy was established to determine which dataset took precedent over the others in the overlap areas. Factors used to establish the hierarchy included the age of the terrain data and its accuracy. This hierarchy is as follows:

- Hurricane LiDAR
- Central Texas LiDAR
- North and Central Texas LiDAR

A description of the terrain data sources used in this study is in Table 3.

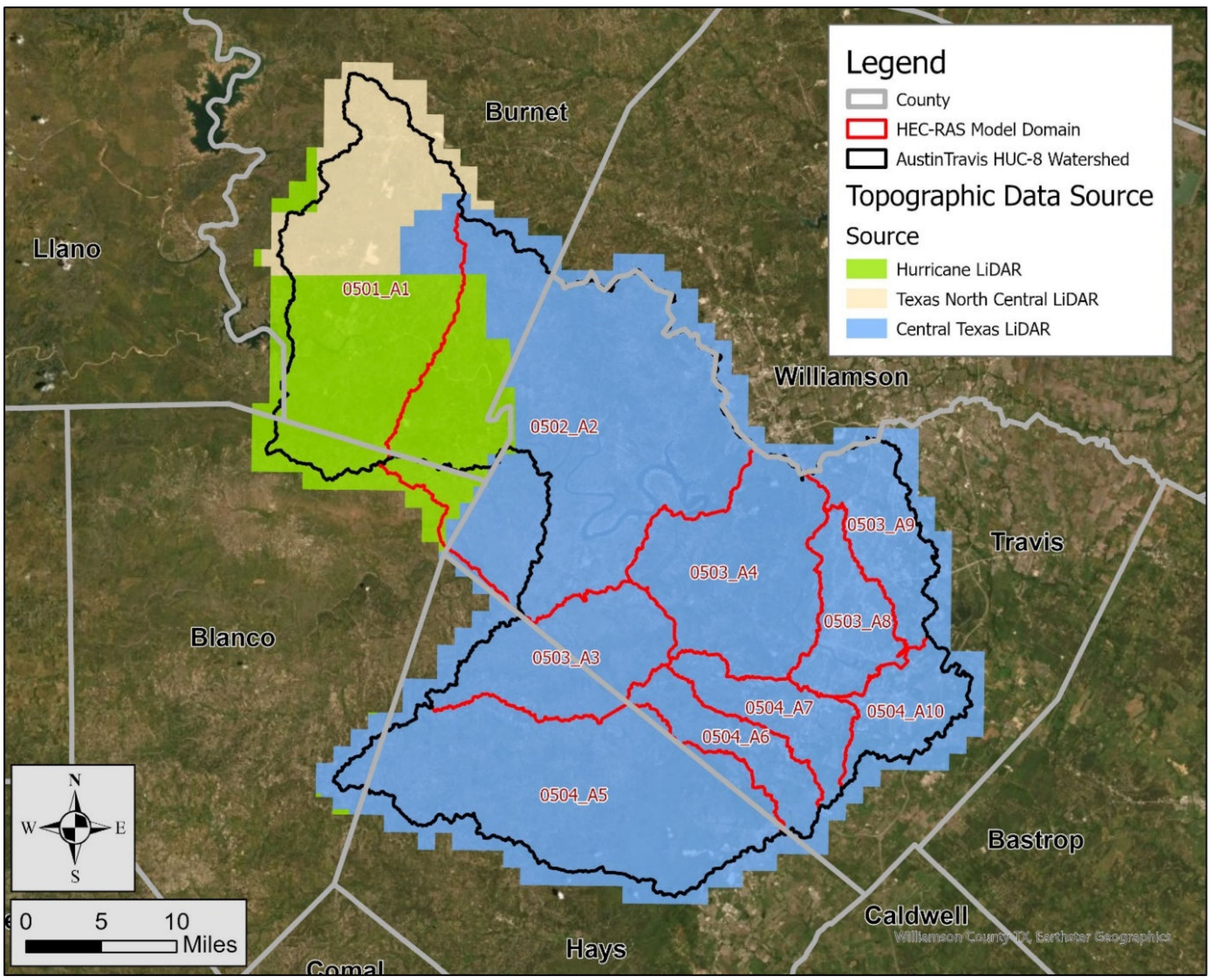


Figure 3: Topographic Data Extents in the Austin-Travis Lakes Watershed

Table 3: Topographic Data Sources

County	Year Acquired	Vertical Accuracy	Source	Approximate Footprint (mi^2)
Hurricane LiDAR (Blanco, Burnet, Hays, Travis, and Williamson Counties)	2019	3.8 cm	USGS	239
Central Texas LiDAR (Blanco, Burnet, and Llano Counties)	2017	3.4 cm	StratMap	1,186
North & Central Texas LiDAR (Burnet County)	2020	3.9 cm	StratMap	117

An overview of each topographic dataset follows. The vertical datum of all LiDAR datasets was the North American Vertical Datum of 1988 (NAVD 88).

Dataset One – Hurricane LiDAR

The United States Geological Survey's (USGS) Hurricane LiDAR dataset captured in 2019 contains data for 14,512 mi^2 across 45 counties in Texas. In the Austin-Travis Lakes watershed, this dataset includes parts of Blanco, Burnet, Hays, Travis, and Williamson counties. The vertical accuracy (RMSEz, or root mean square error in the z direction) of this dataset is 3.8 centimeters (cm). The native cell size of the data is 1 square meter (m^2).

Dataset Two – Central Texas LiDAR

The StratMap Central Texas LiDAR dataset captured in 2017 contains data for 6,522 mi^2 across 24 counties in Texas. In the Austin-Travis Lakes watershed, this dataset includes parts of Blanco, Burnet, and Llano counties. The vertical accuracy (RMSEz) of this dataset is 3.4 cm. The native cell size of the data is 1 m^2.

Dataset Three – North & Central Texas LiDAR

The StratMap Central Texas LiDAR dataset captured in 2020 contains data for 6,330 mi^2 across 21 counties in Texas. In the Austin-Travis Lakes watershed, this dataset includes part of Burnet County. The vertical accuracy (RMSEz) of this dataset is 3.9 cm. The native cell size of the data is 1 m^2.

The above-mentioned LiDAR data sets were used to create a seamless set of tiled 5-foot DEMs for the Austin-Travis Lakes watershed and a buffered area around the watershed. Each DEM tile measured 6,000 feet by 6,000 feet. This tile size was used because tiles this size can easily be resampled by other users to 1-, 2-, 3-, 5-, 10-, 20-, or 25-foot rasters, since 6,000 is evenly divisible by all of these numbers. A 1,000-meter buffer was included since the watershed divide was outside the HUC-8 watershed extents in some areas. A 5-foot cell size was used in accordance with the 10-foot cell size criterion outlined in FEMA's Region 6 BLE guidance from 2019. After projecting the terrain into the Texas State Plane Zone 3 (Central) projection (North American Datum [NAD] 1983 [2011]) with units of U.S. feet, the tiles were mosaicked into one DEM. The source and extents of the original DEMs used to create the mosaicked DEM are shown on Figure 3.

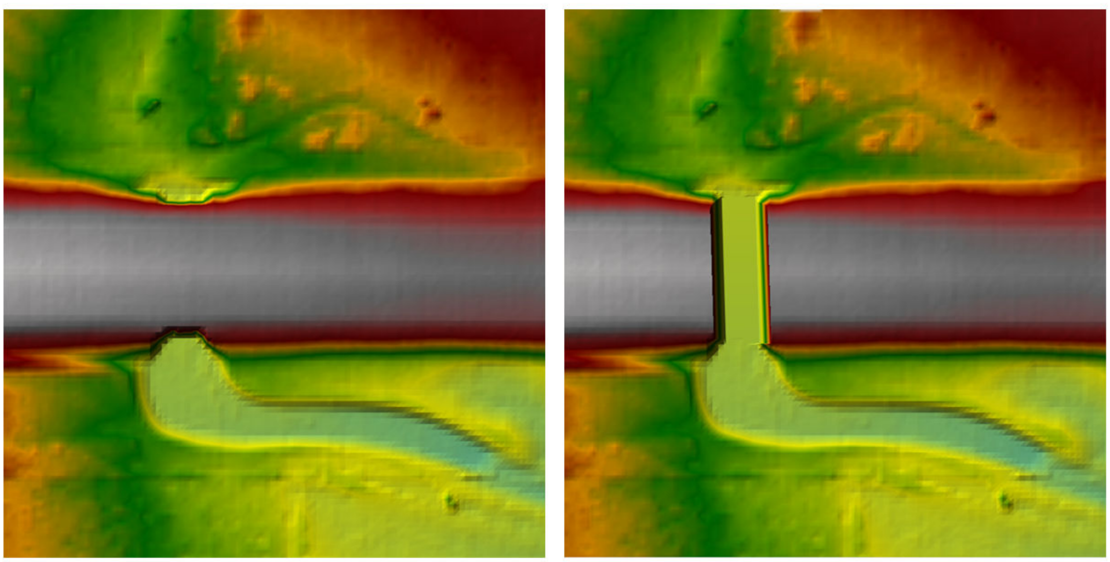
No modifications were made to this terrain surface. The goal was to use this terrain 'as is' in the hydraulic modeling, floodplain mapping, and grid development tasks. Maintaining the source terrain data in an unmodified state avoids customized changes to the terrain dataset that future users may not be able to replicate. It also reduces the chance of future users applying an outdated version of the terrain. Any changes that were required in the hydraulic model phase were made in the HEC-RAS terrain, not in the processed tiles.

1.1.2 Development of the Stream Networks and Drainage Basins

A hydro-conditioned terrain surface was developed to define the stream networks and drainage basins. A 1,000-meter buffer was applied to the HUC-8 boundary to capture the watershed divide. A 5-meter mosaicked DEM was developed from the source LiDAR data in the same projection as the source data. Using a 5-meter DEM for hydrologic network development maintained sufficient accuracy and produced datasets that were smaller in size and easier to manipulate.

The process for terrain preparation and network and basin delineation is outlined below:

- The flow direction grid, flow accumulation grid, hydrologic stream network, and hydrologic basins were developed.
- Burn lines were defined as needed at roadway/railroad crossings or where reservoirs/ponds artificially diverted the flow path from the natural alignment. The bridge/culvert crossing burn lines developed in this task were subsequently incorporated into the HEC-RAS terrain as terrain modification features. Terrain modifications, when applied, allowed flow through roadways.



(a) without terrain modifications (b) with terrain modifications

Figure 4: HEC-RAS Terrain Modification at a Culvert Crossing to Allow Flow through a Roadway

- The streamlines and watershed delineations were reviewed and burn lines were continually added and adjusted until the flow paths, basins, and computed drainage areas were reasonable and justifiable.
- A drainage area grid was computed along the flow paths. The drainage areas from the Pedernales and Buchanan-Lyndon B Johnson Lakes HUC-8 watersheds were added to the drainage area grid.
- There were 21 USGS gages and 1 Lower Colorado River Authority (LCRA) gage with drainage areas greater than one square mile in the watershed. The table below summarizes the

differences between the reported and computed values for the drainage area. The differences are less than 10 percent, which is considered acceptable.

Table 4: Reported and Computed Drainage Areas at Each USGS Gage

USGS Gages			BLE Computed Drainage Area	
Site No.	Site Name	Drainage Area (mi^2)	Drainage Area (mi^2)	Difference
08152700	Little Flatrock Ck nr Marble Falls, TX	3.20	3.29	2.8%
08154700	Bull Ck at Loop 360 nr Austin, TX	22.3	22.4	0.3%
08154950	Bee Ck at Westlake Dr, Austin, TX	3.28	3.31	0.9%
08155200	Barton Ck at SH 71 nr Oak Hill, TX	89.7	89.9	0.2%
08155240	Barton Ck at Lost Ck Blvd nr Austin, TX	107.0	107.8	0.7%
08155300	Barton Ck at Loop 360, Austin, TX	116.0	116.9	0.7%
08155400	Barton Ck abv Barton Spgs at Austin, TX	125.0	119.9	-4.1%
08158000	Colorado Rv at Austin, TX	39,009	39,020	0.0%
08158600	Walnut Creek at Webberville Road, Austin, TX	51.3	51.7	0.8%
08158700	Onion Ck nr Driftwood, TX	124.0	123.7	-0.2%
LCRA 4595	Onion Ck at Buda, TX	166.0	166.4	0.2%
08158810	Bear Ck bl FM 1826 nr Driftwood, TX	12.2	12.2	-0.3%
08158819	Bear Ck nr Brodie Lane nr Manchaca, TX	23.8	23.6	-1.0%
08158820	Bear Ck at FM 1626 nr Manchaca, TX	24.0	24.34	1.4%
08158825	Little Bear Ck at FM 1626 nr Manchaca, TX	21.0	21.1	0.3%
08158827	Onion Ck at Twin Creeks Rd nr Manchaca, TX	181.0	175.0	-3.3%
08158840	Slaughter Ck at FM 1826 nr Austin, TX	8.24	7.70	-6.6%
08158860	Slaughter Ck at FM 2304 nr Austin, TX	23.1	23.1	0.0%
08158880	Boggy Ck (S) at Circle S Rd, Austin, TX	3.58	3.46	-3.4%
08158922	Williamson Ck at Brush Cntry Blvd, Oak Hill, TX	6.79	6.76	-0.4%
08158927	Kincheon Br at William Cannon Blvd, Austin, TX	6.73	6.96	3.3%
08159000	Onion Ck at US Hwy 183, Austin, TX	321.0	323.9	0.9%

The following information has been placed in the terrain supplemental data folder:

- The computed watershed boundaries at the HUC-8, HUC-10, and HUC-12 levels developed during the terrain processing task.
- The 1-mi^2 stream network developed during the terrain processing task. These lines represent locations where the drainage area is 1 mi^2 or greater.
- Additional supporting layers such as roads, NHD waterbodies, and NHD flow lines.

1.2 Hydrologic and Hydraulic Analysis

A 2D BLE analysis of the Austin-Travis Lakes watershed was completed using HEC-RAS Version 6.2. The analysis applied a rain-on-grid methodology over a 3D terrain. Average basin rainfall was applied to the 2D computational mesh, and losses were computed using the spatially varied infiltration capabilities of HEC-RAS. In accordance with SID 84, the 10%, 4%, 2%, 1%, 0.2%, 1% plus, and 1% minus annual-chance events were simulated.

Model Layout

The Austin-Travis Lakes watershed was split into ten model domains — 0501_A1, 0502_A2, 0503_A3, 0503_A4, 0504_A5, 0504_A6, 0504_A7, 0503_08, 0503_A09, and 0504_A10, as shown on Figure 5. The first 4 numbers in the model domain name are the final 4 numbers in the name of the HUC-10 watershed number. A1, A2, etc. in the model domain name is just a linear naming convention for the domains. Per recommendation from the TWDB, the model domains (work areas) were no larger than roughly 300 mi^2, which is the size of a typical HUC-10 watershed. The primary reason for having a domain size equal to or smaller than a HUC-10 watershed was to satisfy the assumption that the rainfall across the domain was uniform.

A significant portion of the watershed is urban, and a nominal cell spacing of 100 feet by 100 feet was applied in and near the City of Austin. Because smaller cells lead to longer run times, the sizes of the model domains downstream of Lake Travis were smaller, ranging from 44 mi^2 to 129 mi^2, to keep the run times manageable.

The initial model domain boundaries were derived from revised HUC-10 watershed delineations that were established using the LiDAR data. A buffer of 1,000 feet was applied to each HUC-10 watershed boundary to create overlapping domain boundaries. The purpose of the overlap areas was to facilitate clean floodplain and Base Flood Elevation (BFE) transitions between models, to capture the full extent of the floodplain within the watershed, and to minimize the impact of model boundary conditions on model results. At the confluences of model domains, the overlap areas along the main channel were increased in some locations to facilitate tie-ins between model domains.

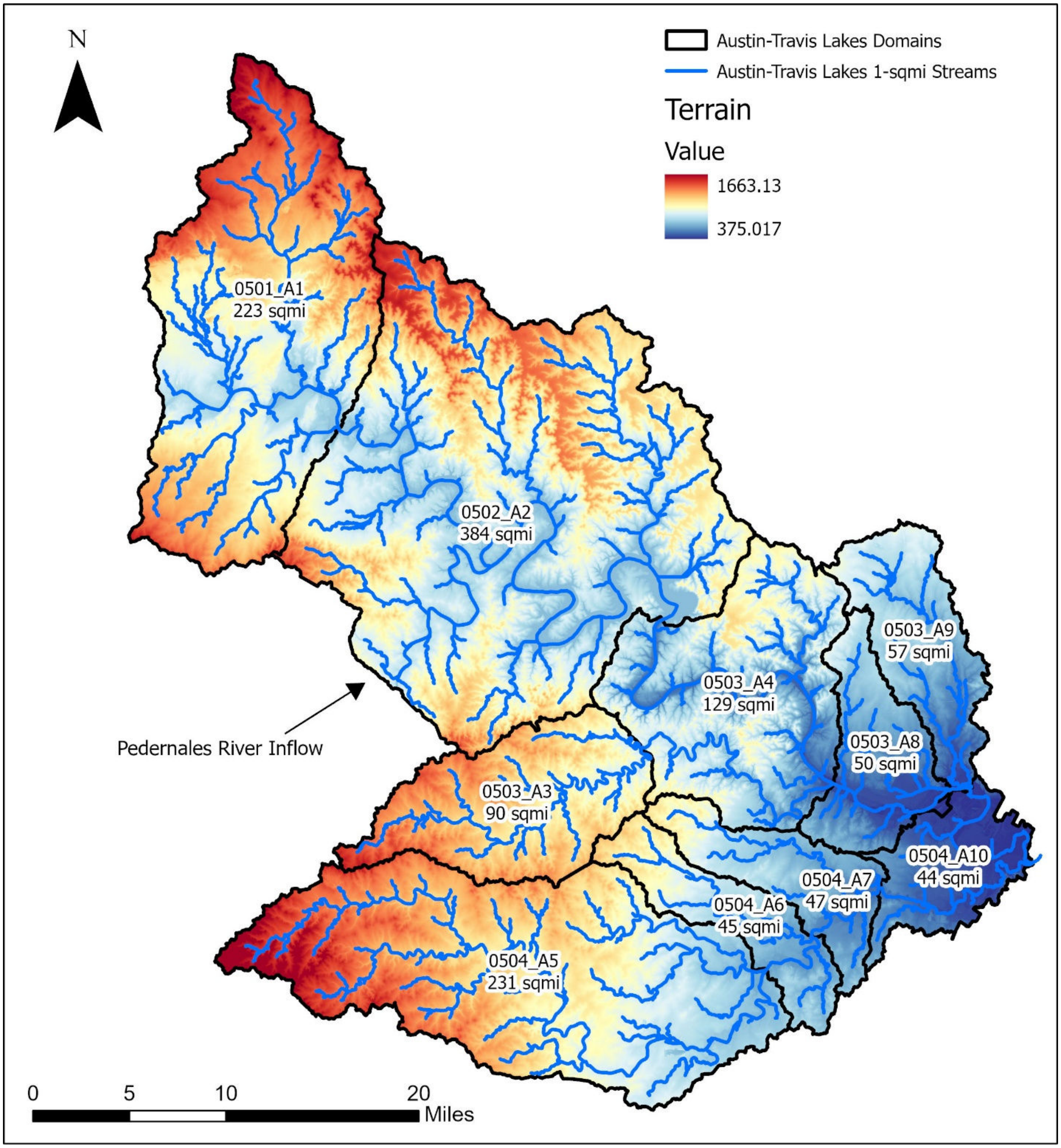


Figure 5: Austin-Travis Lakes Model Domains and Linkages

1.2.1 Total Precipitation

Using NOAA's Atlas 14 precipitation statistics, an area-averaged precipitation frequency table was computed for each event in each model domain. For all events, a 24-hour rainfall distribution was calculated using an NRCS nested temporal distribution. The NRCS rainfall distribution development methodology is documented in Title 210, Part 630, Chapter 4, Section 630.0407 of the *National Engineering Handbook* (August 2019). To create the 24-hour rainfall distribution for an event, the model domain-averaged rainfall totals for the 5-minute, 10-minute, 15-minute, 30-minute, 1-hour, 2-hour, 3-hour, 6-hour, 12-hour, and 24-hour durations were calculated for that event. The ratio of each duration's precipitation total to the 24-hour duration's precipitation total was calculated to produce a preliminary symmetric rainfall distribution. These rain ratios were manipulated as described in Section 630.0407 to obtain the final 24-hour rainfall distribution for the event. This process was repeated for all events in the model domain. The results were exported to DSS (data storage system) files for input into the HEC-RAS models.

The 1% plus and 1% minus annual-chance rainfall totals were computed using the approach provided in subsection 2.2.3 of the TWDB's *2D BLE Guidance Version 1.0* (May 2022). The 1% plus and 1% minus storms were based on the NRCS temporal distribution described in Section 630.0407 of the *National Engineering Handbook* (August 2019). Additional checks were performed to confirm the 1% plus and 1% minus hyetographs did not cross the hyetographs for other events. The precipitation data used in this study have been included in the supplemental data folder.

When the precipitation values were initially assembled for this project, domains 0503_A4, 0503_A8, and 0503_A9 were in a single domain. After the model development task was well underway, this domain was split into the three domains to reduce model run times. The point rainfall totals from NOAA Atlas 14 for the single large domain and the three separate domains were similar. Therefore, instead of building unique hyetographs for the three domains, the hyetographs for the combined domain were used in domains 0503_A4, 0503_A8, and 0503_A9.

City of Austin local rainfall regulations were not considered.

1.2.2 Infiltration Losses

The NRCS CN loss rate method was used to account for infiltration losses. A spatially varying infiltration layer for the study area was developed in HEC-RAS by using gridded soils and gridded land cover data sets.

To develop the soils dataset, the 2021 Gridded Soils Survey Geographic (gSSURGO) Database was downloaded from NRCS's website (https://data.nal.usda.gov/dataset/gridded-soil-survey-geographic-database-gssurgo). The SSURGO database contained hydrologic soil type information, which was used to develop the gridded soils layer in HEC-RAS.

To develop the land cover dataset, the 2019 National Land Cover Database (NLCD) was downloaded from the Multi-Resolution Land Characteristics Consortium (MRLC) website (https://www.mrlc.gov/data/nlcd-2019-land-cover-conus). The land cover dataset provided land use classification codes and the extent of each land use. This information was used to create the gridded land cover dataset.

The infiltration layer was created in HEC-RAS by combining the soils and land cover gridded datasets. The CN values required for the loss rate computations were obtained from Table 2.4 of the TWDB's *2D Base Level Engineering Guidance Version 1.0* (May 2022) and are shown below in Table 5. An initial abstraction ratio of 0.2 was used to obtain the initial loss. During the model validation phase, the CN values were adjusted to bring the model results into alignment with the validation data (e.g., stream gage data, effective discharges, etc.). The CN values presented in Table 5 are based on average Antecedent Moisture Condition II (AMC II) and during validation, the values were revised by no more than ±10% of their initial values. In some cases, however, a 10% reduction of the AMC II CN values produced flows that continued to be too high to be considered valid. For these model domains, CN values corresponding to AMC I conditions were used to achieve model validation. AMC I CN values are shown in Table 6.

Research completed for this project revealed that antecedent moisture conditions in Texas vary from AMC II in the east to AMC I in the west, and the Austin-Travis Lakes watershed resides within the transition from AMC II to AMC I. Therefore, the application of AMC I conditions in some domains to support validation was appropriate. Including AMC I CN values in these domains produced flows that were able to be validated while avoiding adjustments to the AMC I CN values. See Section 1.2.10 for more information about the use of AMC I and AMC II CNs in the Austin-Travis Lakes watershed.

Table 5: AMC II Curve Number Values

Land Use Grid Code	NLCD Land Use Description	CN for Each Hydrologic Soil Group			
		A	B	C	D
11	Open Water	99	99	99	99
21	Developed, Open Space	49	69	79	84
22	Developed, Low Intensity	61	75	83	87
23	Developed, Medium Intensity	81	88	91	93
24	Developed, High Intensity	89	92	94	95
31	Barren Land	39	61	74	80
41	Deciduous Forest	30	55	70	77
42	Evergreen Forest	30	55	70	77
43	Mixed Forest	30	55	70	77
52	Shrub Scrub	30	48	65	73
71	Herbaceous	49	62	74	85
81	Hay Pasture	39	61	74	80
82	Cultivated Crops	51	67	76	80
90	Woody Wetlands	72	80	87	93
95	Emergent Herbaceous Wetlands	72	80	87	93

Table 6: AMC I Curve Number Values

Land Use Grid Code	NLCD Land Use Description	CN for Each Hydrologic Soil Group			
		A	B	C	D
11	Open Water	98	98	98	98
21	Developed, Open Space	29	48	61	69
22	Developed, Low Intensity	40	56	67	74
23	Developed, Medium Intensity	64	75	81	85
24	Developed, High Intensity	77	83	87	89
31	Barren Land	21	40	54	63
41	Deciduous Forest	15	34	49	58
42	Evergreen Forest	15	34	49	58
43	Mixed Forest	15	34	49	58
52	Shrub Scrub	15	28	44	53
71	Herbaceous	29	41	54	70
81	Hay Pasture	21	40	54	63
82	Cultivated Crops	30	46	57	63
90	Woody Wetlands	52	63	74	85
95	Emergent Herbaceous Wetlands	52	63	74	85

Manning's n values were defined within the infiltration layer. These values were used to compute the energy losses as the flow was routed through the 2D computational mesh in the HEC-RAS model. For this study, the overbank Manning's roughness coefficients were obtained from Table 2.2 of the TWDB's *2D Base Level Engineering Guidance Version 1.0* (May 2022) and are presented in Table 7.

Manning's n values for the main channel areas were refined by adding Manning's n override regions. The extents of the override regions in the channels were established by adding a typical buffer of 100 feet to the streamlines. For larger streams, where the channel polygon widths were wider than 200 feet, the channel polygons were adjusted by reviewing the typical channel widths on the terrain surface and aerial photography. Manning's n values in the main channels ranged from 0.040 to 0.065.

Table 7: Manning's n Values for Overland and Overbank Areas

Land Use Grid Code	NLCD Land Use Description	Typical N Value	N Value Range
11	Open Water	0.038	0.025–0.050
21	Developed, Open Space	0.040	0.030–0.050
22	Developed, Low Intensity	0.090	0.060–0.12
23	Developed, Medium Intensity	0.12	0.080–0.14
24	Developed, High Intensity	0.16	0.12–0.20
31	Barren Land	0.025	0.023–0.030
41	Deciduous Forest	0.15	0.10–0.20
42	Evergreen Forest	0.12	0.080–0.16
43	Mixed Forest	0.14	0.080–0.20
52	Shrub Scrub	0.115	0.070–0.16
71	Herbaceous	0.038	0.025–0.050
81	Hay Pasture	0.038	0.025–0.050
82	Cultivated Crops	0.035	0.020–0.050
90	Woody Wetlands	0.098	0.045–0.15
95	Emergent Herbaceous Wetlands	0.068	0.050–0.085

1.2.3 2D Computational Mesh

The 2D computational mesh is one of the key components of a rain-on-grid 2D model, and it has a significant impact on model outcomes. Per the TWDB's 2D BLE guidelines, a 200-foot by 200-foot nominal cell spacing was used for the 2D area and a finer 100-foot by 100-foot cell spacing was used along the breaklines and within the refinement regions. Breaklines were included in the model to capture linear features in the topographic data that represented high ground or streamlines. Breaklines were added to capture roadways, railroads, dam crests, and embankments to force the terrain surface to drain properly. For main channel areas where flow depths and velocities are higher and in urban areas, refinement regions were added to enhance the identification of the flood hazards in these higher-risk areas. In addition, for model domains in and around the City of Austin, a 100-foot by 100-foot nominal cell spacing was used since this part of the watershed is highly developed.

The following list provides additional details of the mesh refinement that was performed:

- The stream centerlines defined during the hydro-enforcement task were applied as breaklines to align the mesh cells with the direction of flow. For undeveloped/rural areas, the 1 mi^2 stream centerlines were used to create the breaklines. For urban areas, the 0.5 mi^2 stream centerlines were used.
- Texas Department of Transportation (TxDOT) road lines (https://gis-txdot.opendata.arcgis.com/) were used as breaklines.
- Breaklines were placed on the spillways and crests of significant reservoirs.
- Polygons computed by buffering the streamlines were used to establish channel refinement regions. The buffers were 200 feet wide for small streams (100 feet on either side) and increased for wider streams with larger drainage areas.

- Refinement regions were defined in urban areas, major reservoirs, and dam overflow areas.
- Breaklines were split into multi-parts at all intersections using the planarize tool in ArcGIS Pro.
- Since the model runtime increases as more breaklines and refinement regions are added, all breaklines and refinement regions were reviewed to confirm that they improved the quality of the model. Those that did not improve the quality were removed.
- The 2D perimeter, refinement regions, and breaklines were smoothed and cleaned using Geographic Information Systems (GIS) software to minimize mesh generation errors.
- As discussed in Section 1.1.2, the bridge/culvert crossing burn lines developed for this study were incorporated into the HEC-RAS terrain as terrain modification features to allow flow to pass through the bridges and culverts at the roadway embankments in the watershed.

1.2.4 Model Boundary Conditions

The BLE analysis included four types of model boundary conditions—precipitation, flow hydrograph, stage, and normal depth. The following is a summary of where each type of boundary condition was applied.

Precipitation Boundary Conditions

As described previously, basin-averaged NOAA Atlas 14 precipitation depths were calculated for each model domain and were temporally distributed using an NRCS distribution. The precipitation hyetographs were applied to the 2D area using a precipitation boundary condition for the rain-on-grid analysis.

Flow Hydrograph Boundary Conditions

Flow hydrograph boundary conditions were added at major stream inflow locations. In this study, a direct-flow approach was used to transfer flows from upstream watersheds to downstream watersheds. In the direct-inflow method, the precipitation and upstream inflows assume the same annual-chance event is occurring simultaneously. So, for each event, the outflows from the upstream watersheds were directly applied as inflows to the model of interest without adjustments to the timing of the peaks.

Storage Area-2D (SA/2D) connections were added near the main channel outflow location in the upstream HEC-RAS model to compute the outflow from the upstream model. A flow boundary condition line was then added in the downstream model at a location that coincided with the SA/2D line to maintain consistency. The breaklines were enforced at the SA/2D connections and flow boundary condition lines to align the cell faces with the boundary. The purpose of adding SA/2D connections was to limit the impact of the boundary conditions on the inflow applied to the downstream models and to clearly document the flow transfer locations and hydrographs, as this information is stored in the DSS output files. The lengths of the inflow boundary condition lines for the downstream model were shortened to a length between the widths of the 1% and 10% floodplain limits to mimic the distribution of the inflow in the upstream model.

Inflow from the Pedernales River

The Pedernales River, with a drainage area of 1,280 mi^2, enters the Austin-Travis Lakes BLE study area in domain 0502_A2. This domain was extended upstream into the Pedernales River watershed to where Cypress Creek enters the Pedernales River; however, no mapping was prepared for the Pedernales River watershed since it falls outside of the boundaries of the Austin-Travis Lakes watershed.

Near the end of the modeling task for this project, the InFRM WHA team shared with the TWDB its completed HEC-HMS model for the Colorado River watershed. This HEC-HMS model included the Pedernales River watershed. Hydrographs for the 10%, 4%, 2%, 1%, and 0.2% event were available at the confluence of Cypress Creek with the Pedernales River at HEC-HMS model element PD_Pedernales_J130. These hydrographs were extracted from the HEC-HMS model and included in the BLE model to model the Pedernales River inflows. The 1% plus and 1% minus peak flows were determined by multiplying the 1% peak flow by 1.648 and dividing the 1% peak flow by 1.648, respectively, as described in Subsection 1.2.8. The shape of the 1% hydrograph in the HEC-HMS was scaled up to create the 1% plus hydrograph and scaled down to create the 1% minus hydrograph.

The figure below shows this area. The red line is the Austin-Travis Lakes watershed boundary. The black line shows the extent of domain 0504_A2. The black dot is the confluence of Cypress Creek with the Pedernales River. This is where model element PD_Pedernales_J130 is located in the HEC-HMS model. Note that the discharges at this location were compared with the discharges at the downstream end of the Pedernales River, and they were very similar (e.g., 1% flows within 0.1%).

Figure 6: Pedernales River Inflow into the Domain 0504_A2

Stage Hydrograph Boundary Conditions

Stage hydrographs were applied at the main stem outflow locations to account for the downstream backwater elevations. This approach served two purposes. First, it facilitated the tie-ins of the water surface elevations at the model domain boundaries, which were required to be within 0.5 foot. Second, the application of the stage hydrograph boundaries accounted for the timing of the tailwater conditions in the downstream model. In short, the stage hydrograph in the upstream model was obtained from the downstream model at the upstream main channel's outflow location.

Figure 7 and Figure 8 show an example of the iterative process used to extract and apply a stage hydrograph at the transition of two model domains (which overlap) in the nearby Jim Ned watershed. These figures show the location used to obtain the stage hydrograph between domains 0801_A2 (upstream domain) and 0802_A3 (downstream domain). A stage hydrograph was iteratively extracted from the downstream model results and applied to the upstream model as a boundary condition. This boundary condition was based upon the hydrograph results calculated from a SA/2D connection in the upstream model applied as a discharge in the downstream model. The iterative process was necessary to balance the upstream model's peak outflow within 5% of the downstream model's peak inflow while also achieving a WSEL tie-in of 0.5 foot or less at the transition location.

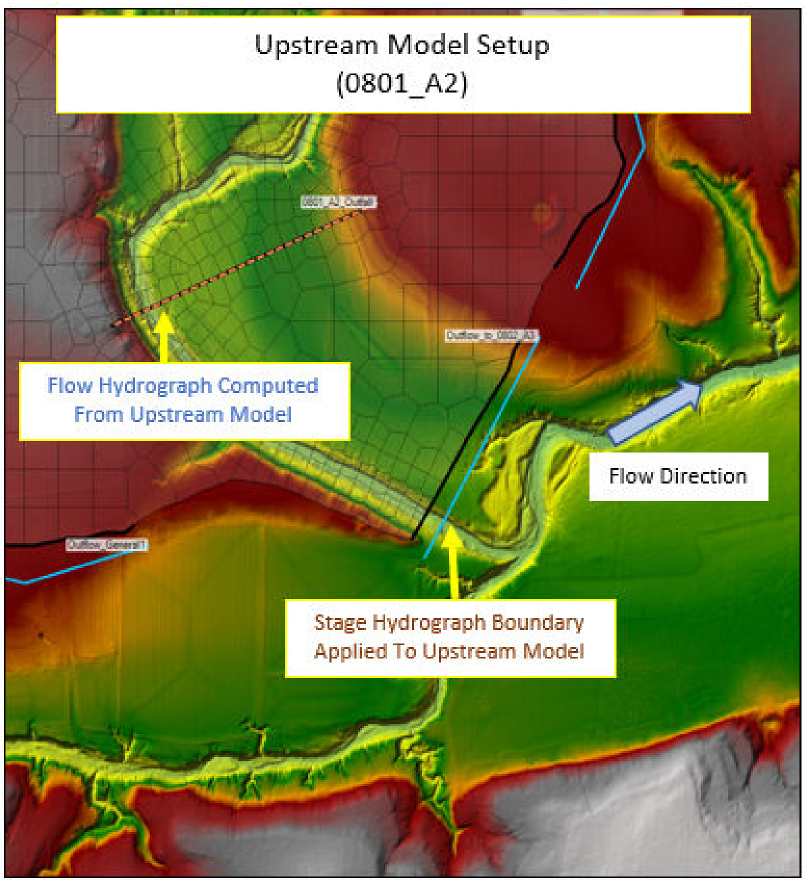


Figure 7: Extraction of Flow Hydrograph from the SA/2D Connection in the Upstream Domain for Use in the Downstream Domain

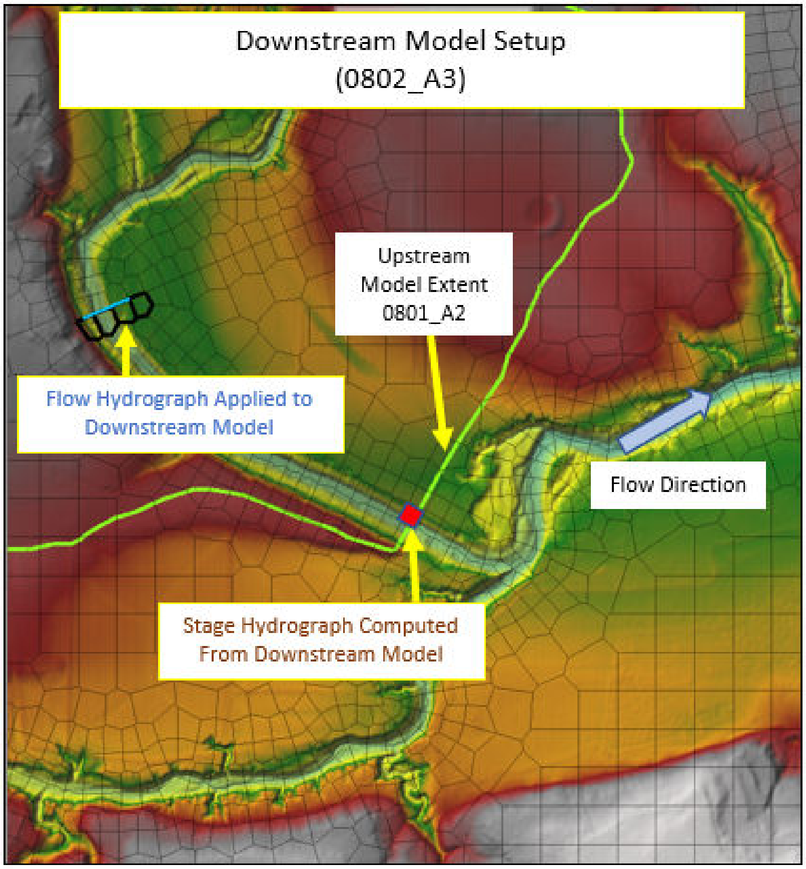


Figure 8: Application of Upstream Flow Hydrograph in the Downstream Domain

See Table 8 through Table 15 for a summary of the upstream and downstream peak discharges and WSELs at the downstream end of each domain in the Austin-Travis Lakes watershed. These tables have been included to demonstrate that at the downstream end of each model domain, the peak discharges are within 5% of one another and the WSELs are within 0.5 feet for each profile.

Note that a table for domain 0502_A2 has not been included. The downstream end of this model domain is at Mansfield Dam, which is the outlet for Lake Travis. The flows downstream of the dam were decoupled from the flows that exited this domain in the BLE model. Therefore, the upstream and downstream flows were not required to be within 5% of each other. Furthermore, because of the dam, the water surface elevations were not required to be within 0.5 feet of one another.

Table 8: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0501_A1

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	65,579	65,579	0.00%	706.21	706.54	-0.33
4%	138,623	139,472	-0.61%	718.22	718.24	-0.02
2%	226,930	226,930	0.00%	726.33	726.18	0.15
1%	348,414	348,414	0.00%	734.62	734.24	0.38
0.2%	594,987	594,987	0.00%	750.78	750.30	0.48
1% minus	213,329	213,329	0.00%	724.36	723.90	0.46
1% plus	565,239	565,239	0.00%	747.19	746.72	0.47

Table 9: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0503_A3

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	10,016	10,017	-0.01%	751.97	751.83	0.14
4%	22,204	22,207	-0.01%	756.19	755.95	0.24
2%	37,107	37,132	-0.07%	759.56	759.36	0.20
1%	55,578	55,628	-0.09%	763.05	762.83	0.22
0.2%	122,672	122,916	-0.20%	772.40	772.16	0.24
1% minus	31,395	31,399	-0.01%	758.27	758.05	0.22
1% plus	81,701	81,825	-0.15%	767.11	766.88	0.23

Table 10: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0503_A4

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	26,749	26,680	0.26%	442.57	442.56	0.01
4%	28,224	27,147	3.97%	443.10	443.05	0.05
2%	68,309	68,244	0.10%	449.55	449.54	0.01
1%	85,310	85,270	0.05%	451.65	451.64	0.01
0.2%	252,813	252,580	0.09%	464.47	464.56	-0.09
1% minus	50,682	50,597	0.17%	447.02	447.03	-0.01
1% plus	142,335	142,219	0.08%	457.10	457.14	-0.04

Table 11: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0504_A5

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)*	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	16,641	16,693	-0.31%	598.92	598.71	0.21
4%	33,839	33,881	-0.12%	603.20	602.98	0.22
2%	54,909	54,878	0.06%	606.93	606.69	0.24
1%	81,026	80,750	0.34%	610.69	610.44	0.25
0.2%	166,856	164,009	1.74%	619.55	619.27	0.28
1% minus	46,904	46,870	0.07%	605.61	605.38	0.23
1% plus	116,159	115,545	0.53%	614.82	614.55	0.27

* The flow between domain 0504_A5 and 0504_A6. Discharges in this table are the sum of the split flows.

Table 12: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0504_A6

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	23,020	23,163	-0.62%	553.82	553.77	0.05
4%	46,261	46,610	-0.75%	559.23	559.17	0.06
2%	73,595	74,267	-0.90%	563.70	563.64	0.06
1%	107,207	108,457	-1.15%	567.67	567.60	0.07
0.2%	216,620	218,892	-1.04%	576.10	575.99	0.11
1% minus	63,015	63,663	-1.02%	562.15	562.09	0.06
1% plus	152,073	153,261	-0.78%	571.64	571.56	0.08

Table 13: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0504_A7

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	23,020	23,163	-0.62%	491.74	491.61	0.13
4%	46,261	46,610	-0.75%	499.28	499.13	0.15
2%	73,595	74,267	-0.90%	505.63	505.47	0.16
1%	107,207	108,457	-1.15%	511.62	511.44	0.18
0.2%	216,620	218,892	-1.04%	524.82	524.67	0.15
1% minus	63,015	63,663	-1.02%	503.40	503.24	0.16
1% plus	152,073	153,261	-0.78%	517.55	517.42	0.13

Table 14: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0503_A8

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)*	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	26,316	26,316	0.00%	422.91	423.13	-0.22
4%	31,379	31,379	0.00%	426.47	426.57	-0.10
2%	67,008	67,008	0.00%	431.88	431.88	0.00
1%	82,638	82,638	0.00%	434.51	434.44	0.07
0.2%	153,127	153,127	0.00%	443.67	443.58	0.09
1% minus	49,731	49,731	0.00%	429.07	429.13	-0.06
1% plus	117,150	117,139	0.01%	438.67	438.58	0.09

* The flow between domain 0503_A8 and 0504_A10. Discharges in this table are the sum of the split flows.

Table 15: Upstream and Downstream Discharges and WSELs at the Downstream End of Domain 0503_A9

Profile (AEP)	Upstream Outflow (cfs)	Downstream Inflow (cfs)	Difference (%)	Upstream WSEL (ft)	Downstream WSEL (ft)	Difference (ft)
10%	3,293	3,293	0.00%	433.98	434.05	-0.07
4%	10,396	10,396	0.00%	436.11	436.51	-0.40
2%	19,747	19,747	0.00%	438.20	438.34	-0.14
1%	31,351	31,351	0.00%	440.03	440.00	0.03
0.2%	68,161	68,161	0.00%	443.91	443.67	0.24
1% minus	15,229	15,229	0.00%	437.41	437.63	-0.22
1% plus	46,247	46,247	0.00%	441.94	441.79	0.15

* The flow between domain 0503_A9 and 0504_A10. Discharges in this table are the sum of the split flows.

Normal Depth Boundary Conditions

Normal depth downstream boundary conditions were applied at the main stem outflow locations for most model domains. Normal depth slope values for the main stem boundary were iteratively changed such that the water surface elevations were within 0.5 foot between the upstream and downstream model at the model boundary. Normal depth also permitted the simulation of realistic backwater effects at the main channel outfall. Normal depth boundary conditions were also applied along each 2D area perimeter to avoid ponding along the perimeter.

1.2.5 Reservoir Modeling

Wirtz Dam, at the downstream end of Lake Lyndon B. Johnson (LBJ), forms the boundary between the Buchanan-LBJ Lakes HUC-8 watershed and the Austin-Travis Lakes HUC-8 watershed. The discharges from the dam drive the inflows from the Colorado River into the Austin-Travis Lakes watershed. Lake Travis, also on the Colorado River, is a major reservoir within the watershed and is controlled by

Mansfield Dam, located at the downstream end of the reservoir. The modeling approaches for Wirtz Dam and Mansfield Dam are discussed in this subsection.

Lake LBJ (Wirtz Dam) Discharges into Domain 0501_A1

The lake and the dam are owned and operated by the LCRA primarily for hydroelectric power. Construction of the dam was completed in 1951. The dam is a concrete and earthfill structure. The top-of-dam elevation is 838 feet above mean sea level (NGVD assumed). The spillway, controlled by 9 tainter gates each 50 feet high by 30 feet wide, has a crest elevation of 796 feet above mean sea level (NGVD assumed).

The outflow from Lake LBJ through Wirtz Dam is the inflow into domain 0501_A1. Lake LBJ was studied by the Interagency Flood Risk Management (InFRM) team's Watershed Hydrology Assessment (WHA) for the Lower Colorado River Basin. As part of the InFRM study, a Reservoir Frequency Analysis (RFA) was completed to develop an updated frequency-discharge curve for the dam. This curve was available on page 61 in Chapter 9 of a draft copy of the WHA report. A copy of this report has been included in the submittal package. The InFRM RFA reported a peak 1% outflow rate of 190,335 cfs.

In October 2022, the TWDB received additional reservoir modeling data for Lake LBJ from the InFRM WHA team and shared this information with AtkinsRéalis. This package included a frequency-discharge table for the outlet of Lake LBJ at Wirtz Dam that was derived from an HEC-HMS model. The TWDB was not able to acquire this model from the InFRM team. This table included information for the 50%, 20%, 10%, 4%, 2%,1%, 0.5%, and 0.2% events. For the 1% event, the peak discharge at Wirtz Dam was 375,055 cfs. After seeking approval from the TWDB, AtkinsRéalis used this table to set the discharges from Wirtz Dam into the Austin-Travis Lakes watershed. Since the HEC-HMS model did not consider the 1% plus and 1% minus events, those discharges were computed by AtkinsRéalis by applying the standard error prediction from the regression equations the USGS has developed for Texas to the 1% discharge. See Subsection 1.2.8 for more information about how the 1% plus and 1% minus discharges were computed from the 1% discharge and the SEP. See Table 16 for the frequency-discharge table for Lake LBJ (Wirtz Dam).

Table 16: Frequency-Discharge Table for Lake LBJ (Wirtz Dam)

Profile (AEP)	Total Release (cfs)
10%	71,100
4%	149,000
2%	242,000
1%	375,055
0.2%	650,000
1% Plus*	618,091
1% Minus*	227,582

* Computed from the 1% discharge using the SEP of the USGS regression equations

To develop shapes for the hydrographs at the outlet of Wirtz Dam, AtkinsRéalis applied a balanced hydrograph approach that leveraged flow data from USGS gage 08147000 (Colorado River near San

Saba, TX) for major events in 1997, 2000, 2004, and 2018. These flow data were averaged together to create a scalable hydrograph shape for flow that exits the dam. This gage was located upstream of Buchanan Lake, downstream of the confluence with the San Saba River. The peak inflows and hydrograph shapes for the Colorado River where it enters domain 0501_A1 have been documented in the supplemental data folder in *Colorado_Riv_Flow_Hydrographs_ATL.xlsx*. These hydrographs have been reproduced in Figure 9.

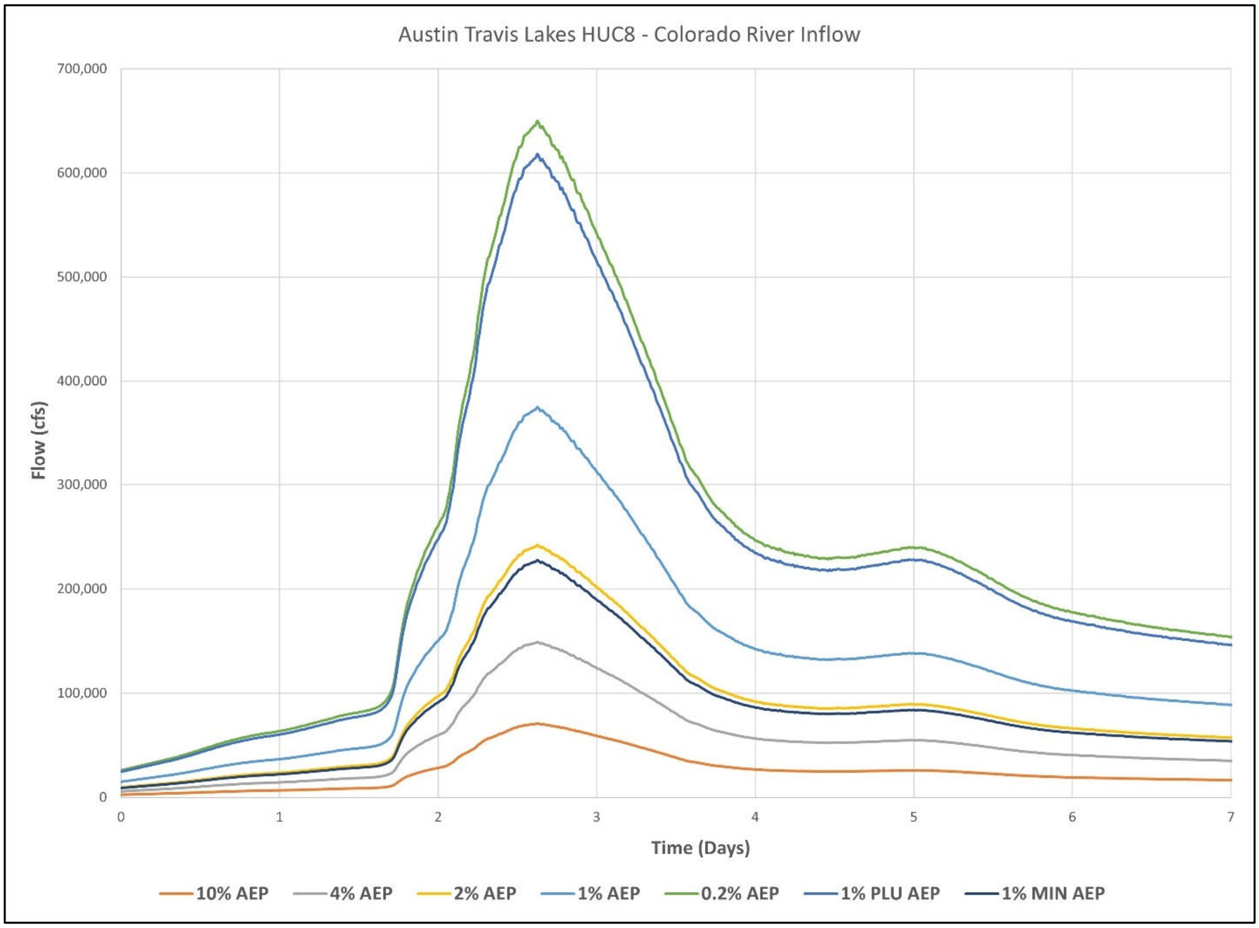


Figure 9: Domain 0501_A1 Colorado River Inflow Hydrographs

Lake Travis

Lake Travis is another major reservoir on the Colorado River. It is located in domain 0502_A2. The model domains for the Austin-Travis Lakes BLE models were split near the Mansfield Dam crest such that the entire reservoir is located in domain 0502_A2 and the area downstream of the dam is in domain 0502_A4. See Figure 10 for the extents of domains 0502_A2 and 0503_A4 in the vicinity of Mansfield Dam.

Lake Travis and Mansfield Dam are owned and operated by the LCRA for flood control, water supply, electrical power generation, and recreational purposes. Construction of Mansfield Dam, at the lake's outlet, was completed in 1939 with additional work completed in 1942. The dam was constructed using concrete, earth, and rockfill. The dam's length is 7,098 feet, and the top-of-dam has an elevation of 750 feet NAVD 88. The flood pool elevation is 714.6 feet NAVD 88. The dam is a concrete gravity dam. Flows passes through the dam via a spillway with an elevation of 714 feet NAVD 88.

Figure 10: Lake Travis Model Configuration

Like Lake LBJ, Lake Travis was studied by the InFRM team's WHA of the Lower Colorado River Basin. The WHA developed an updated pool elevation-frequency-discharge curve for Lake Travis. The results of this analysis were available on page 55 in Chapter 9 of a draft report for the WHA. A copy of this report has been included in the submittal package. This information has been reproduced in Table 17.

Table 17: Pool Elevation-Frequency-Discharge Curve for Lake Travis (Mansfield Dam)

Profile (AEP)	Elevation (ft NGVD 29)*	Spillway Release (cfs)	Gate Release (cfs)	Total Release (cfs)
10%	699.17	0	30,000	30,000
4%	713.35	0	30,000	30,000
2%	715.90	70,000	7,620	72,620
1%	721.23	84,175	5,825	90,000
0.2%	734.13	261,100	0	261,100

* Add 0.29 feet to convert from NGVD 29 to NAVD 88.

SA/2D Connection Setup at Mansfield Dam

Mansfield Dam, located in domain 0502_A2, was initially modeled in HEC-RAS using an SA/2D connection. The pool elevation-frequency-discharge curve in Table 17 was applied at this connection. The model features in domain 0502_A2 in the vicinity of Mansfield Dam are shown on Figure 11. The elevations in the InFRM study were referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). A datum conversion of +0.29 feet was used to convert the elevations to NAVD 88.

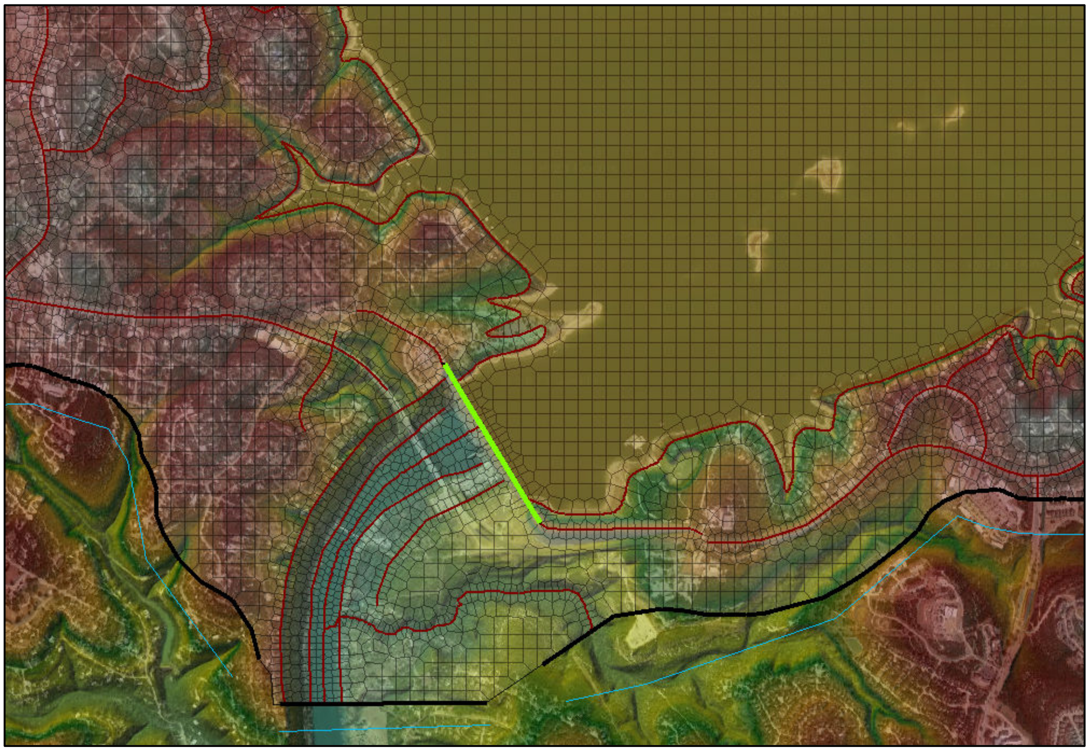


Figure 11: SA/2D Connection for Mansfield Dam

Revisions to the Modeling Approach at Mansfield Dam

Modeling Mansfield Dam with an SA/2D connection produced WSELs at the dam that exceeded the highest WSELs in the dam rating table available in the InFRM WHA. This was primarily caused by the large volume of water entering Lake Travis in the BLE model. The BLE assessment for this watershed assumed that the 1% storm occurred over the entire watershed. In each domain, Atlas 14 rainfall totals were used; no areal-reduction factors were applied, which was reasonable since the domains were relatively small (less than 300 mi^2). This led to generally good BLE results in the tributaries in the watershed. However, along the main stem of the Colorado River, this methodology produced high runoff volumes that entered Lake Travis. A way to reduce these volumes would be to apply an elliptical rainfall distribution or a Joint Probability Analysis in the watershed, but such an analysis was beyond the scope of the BLE project.

After coordination with the TWDB, AtkinsRéalis made the following revisions to the modeling approach for Mansfield Dam:

- Delete the SA/2D connection for the dam and clip the model domain extent to align with the dam.

- Insert a new downstream BC line at the dam. Instead of a rating curve, a stage hydrograph boundary was used at this BC line. The peak stage in the stage hydrograph for each event was based on the InFRM WHA (see Table 17). AtkinsRéalis developed the shape for the stage hydrographs by completing an initial 1% model run that applied a normal depth boundary condition at the dam BC line. This run produce a stage hydrograph for the 1% event. This stage hydrograph shape was then scaled so the peak stages matched the peak stages computed by the WHA.
- Increase the mesh sizes near the downstream end of the model to lower the water surface elevations upstream of the dam.
- Modify the terrain near the dam outlet (under the water surface) to align the BFE lines to the dam outlet and to further lower the water surface elevations.

These modifications lowered the water surface elevations at the dams to realistic levels and better aligned the stages out of the dam with the stages in the WHA. The final model layout in the vicinity of Mansfield Dam is shown on Figure 12. See Figure 13 for the stage hydrographs that were applied at the BC line at Mansfield Dam.

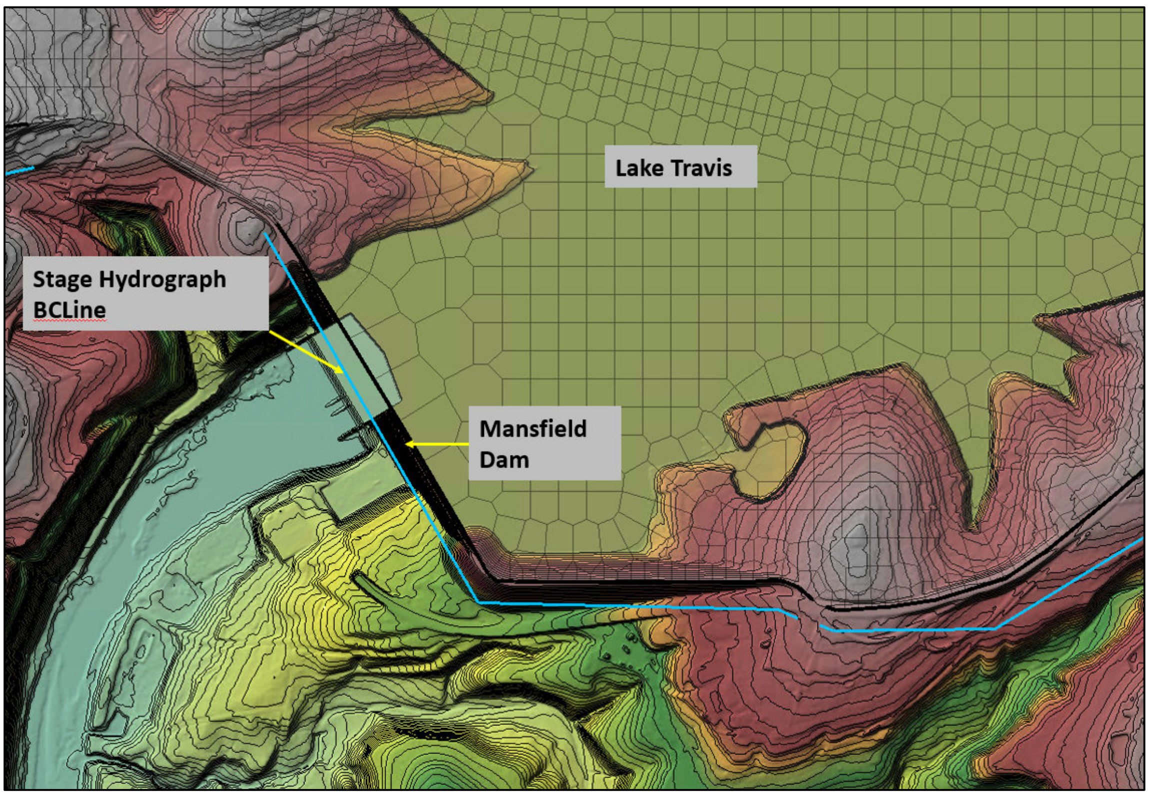


Figure 12: Final Model Layout near Mansfield Dam

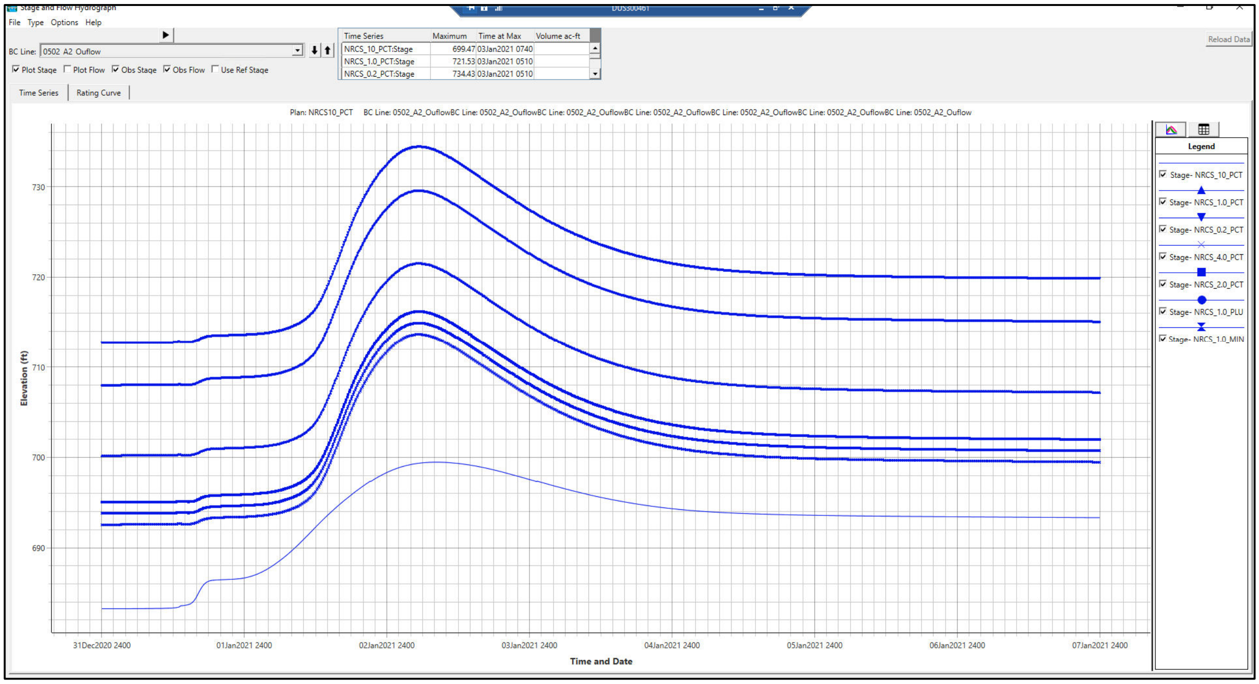


Figure 13: Stage Hydrographs at the BC Line for Mansfield Dam

Crossing Profiles at Mansfield Dam

Once the model was run, the model revisions documented in Figure 12 and the stage hydrographs presented in Figure 13 produced crossing flow hydrographs for the 10% and 4% events at the BC line for Mansfield Dam. These crossing profiles are shown in Figure 14.

At the beginning of the model run, the water surface elevation for each event in Lake Travis is equal to the initial stage in the stage hydrograph in Figure 14. As the model runs, the stage at Mansfield Dam is determined by these stage hydrographs. Upstream of the dam, the water surface elevation changes as water leaves the lake via the BC line at the dam and water enters the lake via local runoff and from upstream via the Colorado River. As the stage hydrographs at the dam rise sharply toward the peak stages from the WHA, there is a dip in the flow hydrographs as the hydraulic head is reduced. For the 10%, 4%, 2%, and 1% minus events, the stages at the BC line become high enough that flow at the BC line is negative, meaning that water is flowing upstream from the dam, not downstream.

In reality, water will never flow upstream into Lake Travis from Mansfield Dam. It is acceptable for there to be negative discharges at the BC line because the flow hydrographs at this BC line are meaningless. The importance of the BC line at the dam is to force the peak stages in Lake Travis to approximate the peak stages computed by the WHA. In addition, the flow hydrographs at the BC line were not used to establish the hydrographs that enter domain 0503_A4, which is the domain downstream from the dam, as discussed below. Regardless, several different modeling scenarios were tried to eliminate the crossing profiles. Unfortunately, none of them were successful. Although these crossing profiles remain in the model, they do not adversely affect the BLE outcomes.

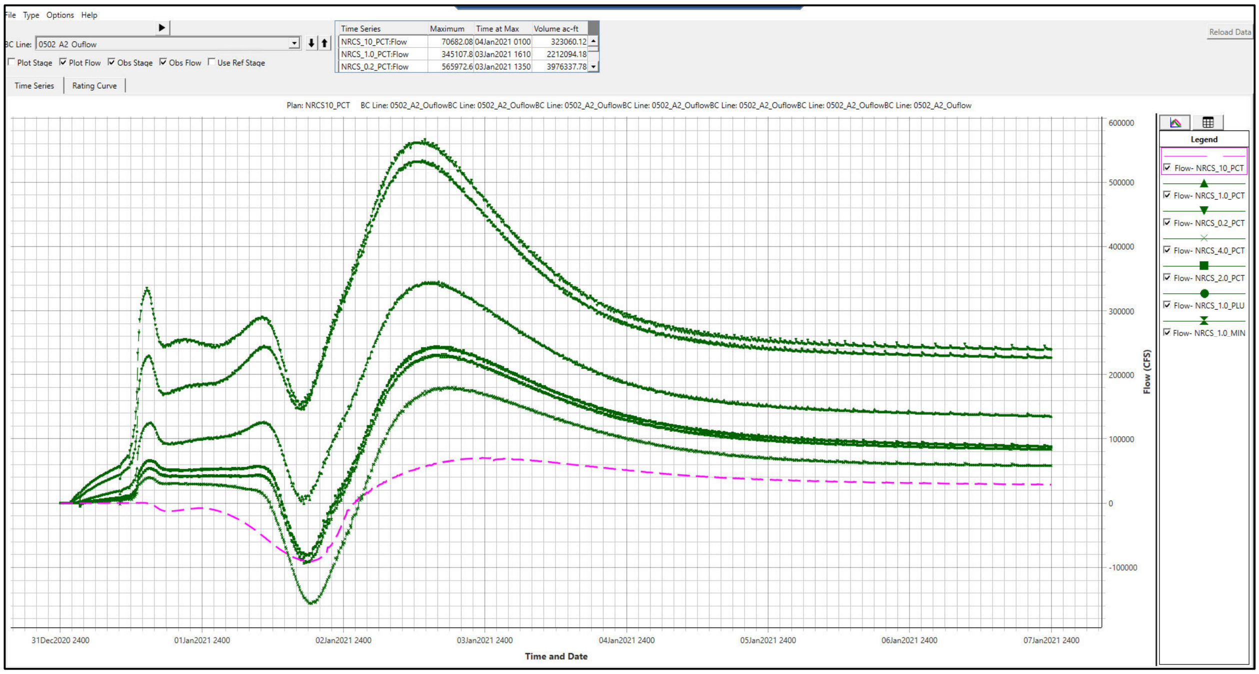


Figure 14: Crossing 10% and 4% Profiles at Mansfield Dam

Lake Travis Discharge into Domain 0503_A4

The discharges from domain 0502_A2 as computed by the HEC-RAS model were not used as the inflows into domain 0503_A4. Instead, a decoupled modeling approach was used to establish the discharges into 0503_A4.

To establish the discharges out of Lake Travis and into domain 0503_A4, the peak flow rates from the RFA in Table 17 were used and hydrographs based on these peaks flows were determined. To develop shapes for the hydrographs at the outlet of Mansfield Dam, AtkinsRéalis applied the balanced hydrograph approach that was also completed for Wirtz Dam (Lake LBJ). This approach leveraged flow data from USGS gage 08147000 (Colorado River near San Saba, TX) for major events in 1997, 2000, 2004, and 2018. These flow data were averaged together to create a scalable hydrograph shape for flow that exits the dam. This gage was located upstream of Buchanan Lake, downstream of the confluence with the San Saba River. The peak inflows and hydrograph shapes for the Colorado River where it enters domain 0502_A2 have been documented in the *Supplemental Data* folder in *Colorado_Riv_Flow_Hydrographs_ATL.xlsx*. These hydrographs have been reproduced in Figure 15. Note the hydrographs for the 10% and 4% events are identical since the RFA reported a peak discharge of 30,000 for both return periods.

Since the RFA did not consider the 1% plus and 1% minus events, those discharges were computed by AtkinsRéalis by applying the standard error prediction from the regression equations the USGS has developed for Texas to the 1% discharge. See Subsection 1.2.8 for more information about how the 1% plus and 1% minus discharges were computed from the 1% discharge and the SEP. This exercise computed a 1% plus discharge of 148,320 cfs and a 1% minus discharge of 54,612 cfs.

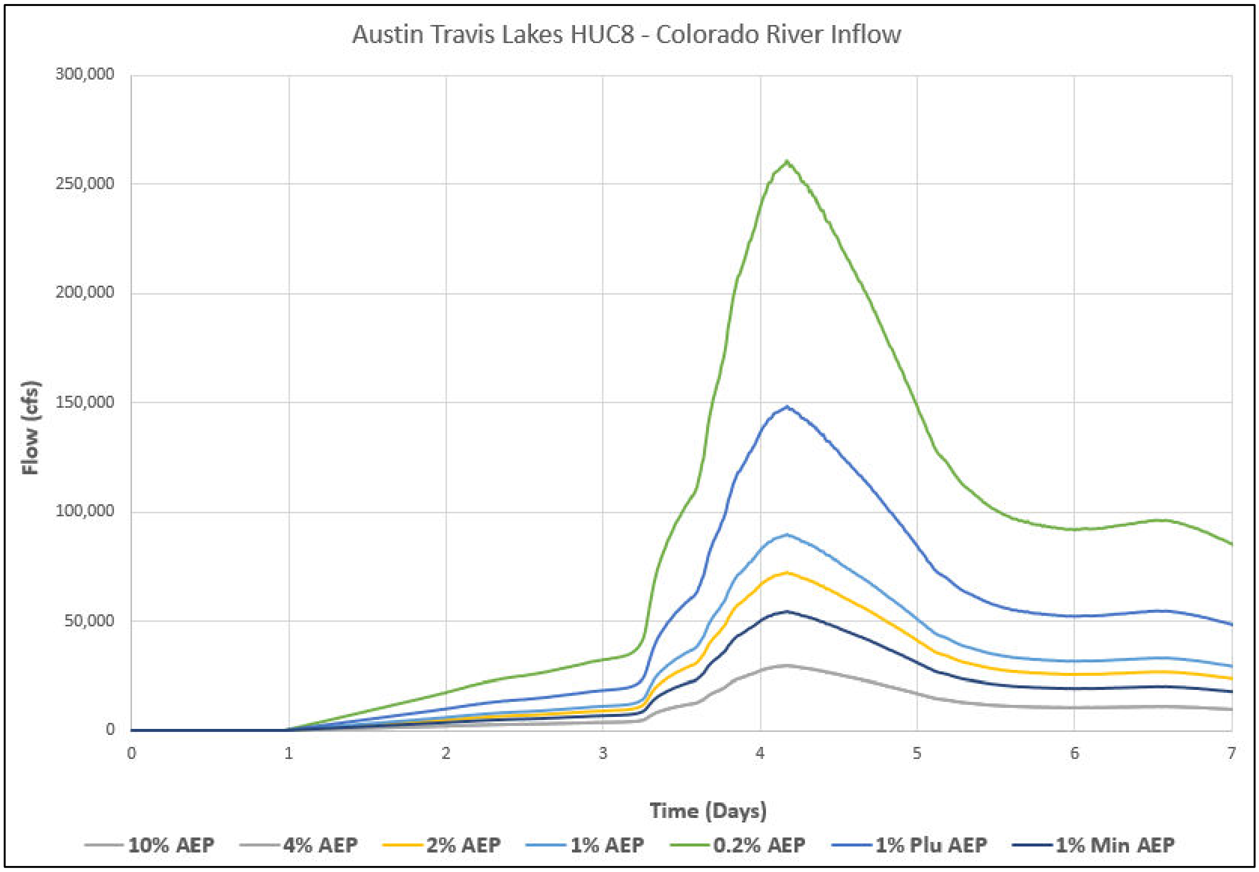


Figure 15: Domain 0503_A4 Colorado River Inflow Hydrograph

Other Dams in the Watershed

Other notable dams in the Austin-Travis Lakes watershed along the Colorado River are Max Starcke Dam, Tom Miller Dam, and Longhorn Dam. Since information about the operations of these dams was not available, they were modeled in HEC-RAS by adding and enforcing a breakline through the dam crest.

1.2.6 Terrain Adjustments in Mining Areas

There were mining sites/borrow pits present in several of the model domains. The sites included large depressions that were typically 30 to 40 feet deep and up to one mile wide. In some instances, the sites were located near streams and had elevations lower than the stream channel's thalweg.

Initially, the HEC-RAS models diverted flow from the streams into these depressions. Since mining areas are not intended for flood control purposes, the pits were filled using the terrain modification feature in HEC-RAS. The fill elevation for each pit was determined by reviewing the topography around the depression and selecting an elevation similar to the surrounding area. A shapefile identifying where the terrain was modified to account for the depressions has been included in the supplemental data folder of this submittal. A screenshot showing the pre- and post-modified terrain for one pit is shown on Figure 16.

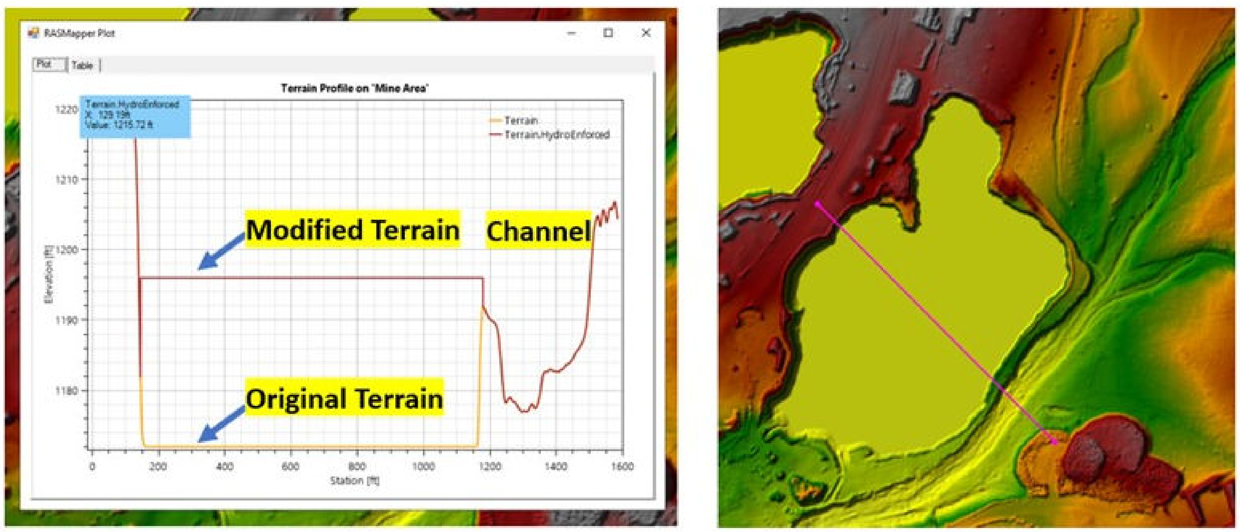


Figure 16:Example of a Terrain Modification at a Mining Pit

1.2.7 Computation Settings

The computation settings applied in the HEC-RAS models are listed below:

- The Diffusion Wave equation was used.
- A 96-hour simulation time was generally applied to capture the peaks and tails of the hydrographs.
- An advanced time step control based on the Courant number was applied as shown below in Figure 17. This option was chosen to decrease run times while generally maintaining Courant number values less than 1.
- Typical model run times with this advanced time step control setting were approximately 2 hours per simulation.
- The mapping and hydrograph output intervals were 10 minutes.

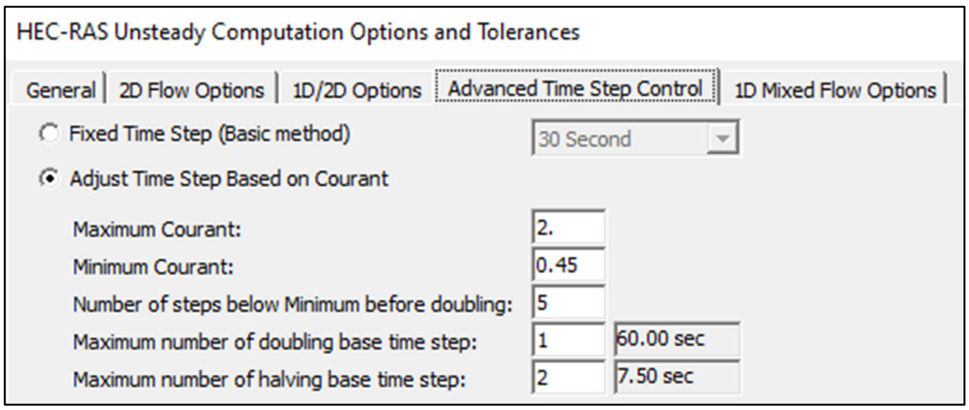


Figure 17: HEC-RAS Unsteady Computation Options and Tolerances

1.2.8 Regression Analysis

Regression flows were used for model validation where gage data was not available. The flow direction and flow accumulation grids created during the hydro-enforcement task were used to develop regression input parameter grids and regression peak flow grids for locations with drainage areas of 1 mi^2 or larger. The peak flows were computed using the regression equations documented in *Regression Equations for Estimation of Annual Peak-Streamflow Frequency for Undeveloped Watersheds in Texas Using an L-moment-Based, PRESS-Minimized, Residual-Adjusted Approach* (Asquith and Roussel, 2009).

The contributing drainage area (A), mean-annual precipitation (P), dimensionless channel slope (S), and the basin-averaged OmegaEM parameter ($\underline{\Omega}$) were the input parameters for the regression equations. The regression equations are shown in Table 3 in the regression report (Asquith and Roussel 2009) and below on Figure 18.

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

Figure 18: Regression Equations for the Austin-Travis Lakes Watershed

The lower and upper limits of the slope in the regression analysis were 0.00023 and 0.0703, respectively. The computed flows are sensitive to the channel slope and unreasonable flows tend to be computed when slopes are outside the range used in the regression analysis. Therefore, when the channel slope was less than 0.00023, 0.00023 foot per mile was used in place of the computed value. Similarly, when the channel slope exceeded 0.0703, 0.0703 was used in place of the computed value.

The average SEP for the 1% annual-chance event was 64.8%, according to the PRESS statistic in Table 3 of the regression report (Asquith and Roussel 2009). The 1% plus and 1% minus gridded flows were computed using the SEP as shown in the equations below. The 1% minus flows were not computed by subtracting the SEP from the 1% flows to avoid unreasonably low flows when the standard errors were large.

$$Q_{1\%Plus} = Q_{1\%} * 1.648$$

$$Q_{1\%Minus} = \frac{Q_{1\%}}{1.648}$$

The flows resulting from the regression analysis were not used downstream of flow-regulating reservoirs or for streams with inflows from other HUC-8 watersheds.

1.2.9 Gage Analysis

There were 13 gages in the Austin-Travis Lakes watershed that had adequate periods of record for a statistical flow-frequency gage analysis. See Table 18 for a list of these gages. Twelve gages were operated by the USGS and one gage was operated by the LCRA. The Austin-Travis Lakes watershed was studied by the InFRM team's WHA for the Lower Colorado River Basin. Ten of the 13 gages were analysed in that study. The flow-frequency analyses for the remaining gages were completed by AtkinsRéalis using PeakFQ, which applies the USGS's Bulletin 17C approach. A description of the InFRM team's analysis, assumptions, and results are available in the report *DRAFT InFRM Watershed Hydrology Assessment for the Lower Colorado River Basin Report, Chapter 5*, Fall 2021. A copy of the pertinent pages from this report has been included in Appendix B. AtkinsRéalis's PeakFQ analyses have been placed in the supplemental data folder.

Table 18. Gages Where a Flow-Frequency Analysis Was Completed

Gage Number	Gage Location	Model Domain	Source of Analysis	Notes
USGS 08155200	Barton Creek at SH 71 near Oak Hill, TX	0503_A3 Outlet	InFRM	Pages 114-115 and 153
USGS 08154700	Bull Creek at Loop 360 near Austin, TX	0503_A4	InFRM	Pages 112-113 and 153
USGS 08155240	Barton Creek at Lost Creek Boulevard near Austin, TX	0503_A4	InFRM	Pages 116-117 and 153
USGS 08155300	Barton Creek at Loop 360, Austin, TX	0503_A4	InFRM	Pages 118-119 and 153
USGS 08155400	Barton Creek above Barton Springs at Austin TX	0503_A4	InFRM	Pages 120-121 and 153
USGS 08158000	Colorado River at Austin, TX	0503_A8	InFRM	Pages 122-124 and 146
USGS 08158700	Onion Creek near Driftwood, TX	0504_A5	InFRM	Pages 127-128 and 153
USGS 08158600	Walnut Creek at Webberville Road, Austin, TX	0503_A9	InFRM	Pages 125-126 and 153
LCRA 4595	Onion Creek at Buda, TX	0504_A5	InFRM	Pages 189-190 and 200
USGS 08158810	Bear Creek below FM 1826 near Driftwood, TX	0504_A5	AtkinsRéalis (Bulletin 17C)	PeakFQ
USGS 08158840	Slaughter Creek at FM 1826 near Austin, TX	0504_A6	AtkinsRéalis (Bulletin 17C)	PeakFQ
USGS 08158860	Slaughter Creek at FM 2304 near Austin, TX	0504_A6	AtkinsRéalis (Bulletin 17C)	PeakFQ
USGS 08159000	Onion Creek at US Highway 183, Austin, TX	0504_A10	InFRM	Pages 129-130 and 153

The gages analyses completed by AtkinsRéalis for Bear Creek, Slaughter Creek, and Onion Creek were performed per Bulletin 17C using the Expected Moments Algorithm (EMA) and Multiple Grubbs-Beck potentially-influential low-flow (PILF) test. The regional skew was derived from the Water-Resources

Investigations Report 96-4117, *Techniques to Estimate Generalized Skew Coefficients of Annual Peak Streamflow for Natural Basins in Texas*.

USGS gage 08158810 (Bear Creek below FM 1826 near Driftwood, TX) had 44 years of data with one single flow in 1939 and then a continuous period of record from 1979 to 2021. Eight PILFs were identified. The single data point from 1939 was not included in the analysis.

USGS gage (08158840 Slaughter Creek at FM 1826 near Austin, TX) had a continuous record of 43 years that spanned from 1979 to 2021. Twenty-one PILFs were identified.

USGS gage 08158860 (Slaughter Creek at FM 2304 near Austin, TX) had a continuous record of 23 years that spanned from 1979 to 2021 except for a gap from 1983 to 2003. There were two PILFs. A perceptible range with an upper bound of 30,000 cfs was used and tested for sensitivity from 10,000 cfs to 30,000 cfs with no change in the results.

The discharges computed by the InFRM WHA and PeakFQ are summarized in Table 19.

Table 19: Results of the Flow-Frequency Analysis

Site No.	Site Name	Computed Drainage Area (mi^2)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)
USGS 08155200	Barton Creek at SH 71 near Oak Hill, TX	89.9	23,700	41,600	135,000
USGS 08154700	Bull Creek at Loop 360 near Austin, TX	22.4	14,500	23,500	82,100
USGS 08155240	Barton Creek at Lost Creek Boulevard near Austin, TX	107.8	25,600	46,000	92,000
USGS 08155300	Barton Creek at Loop 360, Austin, TX	116.9	26,800	52,500	221,000
USGS 08155400	Barton Creek above Barton Springs at Austin TX	119.9	20,200	45,200	192,000
USGS 08158000	Colorado River at Austin, TX	39,020	48,100	62,600	144,000
USGS 08158700	Onion Creek near Driftwood, TX	123.7	18,800	32,500	143,000
USGS 08158600	Walnut Creek at Webberville Road, Austin, TX	51.7	13,800	17,700	28,600
LCRA 4595	Onion Creek at Buda, TX	166.4	36,500	67,100	185,000
USGS 08158810	Bear Creek below FM 1826 near Driftwood, TX	12.2	27,640	43,890	80,210

Site No.	Site Name	Computed Drainage Area (mi^2)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)
USGS 08158840	Slaughter Creek at FM 1826 near Austin, TX	7.7	8,665	12,460	22,710
USGS 08158860	Slaughter Creek at FM 2304 near Austin, TX	23.1	38,100	75,040	189,600
USGS 08159000	Onion Creek at US Highway 183, Austin, TX	323.9	98,600	179,000	468,000

1.2.10 Model Validation

The Austin-Travis Lakes hydraulic models were validated using peak flow information available in the draft InFRM WHA and the effective Flood Insurance Study (FIS) report. For the streams where no InFRM or FIS flow information were available, the regression analysis previously discussed was used to validate the HEC-RAS models.

Validation checks were made at 125 locations throughout the Austin-Travis Lakes HUC-8 watershed. The locations may be grouped as follows:

- Sixty-three validation locations compared the 1% BLE flows with the 1% FIS flows.
- Forty-one validation locations compared the 1% BLE flows with the 1% FIS flows and the 1%, 1% plus, and 1% minus regression flows.
- Eleven validation locations compared the 1% BLE flows with the 1%, 1% plus, and 1% minus gage flows.
- Nine validation locations compared the 1% BLE flows with the 1%, 1% plus, and 1% minus regression flows.
- One validation location compared the 1% BLE flow with the 1% FIS flow and the 1%, 1% plus, and 1% minus gage flows.

The validation locations were scattered throughout the watershed in locations that provided a comprehensive coverage of drainage areas and stream characteristics. Validation points were placed where gage and FIS flow information were available. The drainage areas of the validation points ranged from approximately 1 mi^2 to 39,020 mi^2.

When validating the BLE outcomes, gage data took precedence over FIS data, and FIS data took precedence over regression data. At the 13 validation locations where gage data were available, the BLE results were between the 1% minus gage discharge and the 1% plus gage discharge at 11 locations. At the 106 locations where FIS discharges were available, the BLE 1% discharge was within 25% of the 1% FIS discharge at 72 locations. At the 9 validation locations where only regressions discharges were available, the 1% BLE discharges were between the 1% minus regression discharge and the 1% plus regression discharge at 3 locations.

The 1% BLE flows, the 1% regression flows, the 1% gage flows, and the 1% FIS flows applied during the validation process are shown in Table 21.

The first step of the validation effort was to review the initial 1% BLE results. When the initial BLE flows fell outside of the range between the 1% minus and 1% plus gage discharges or were not within ±25% of the FIS discharges or, where gage and FIS discharges were not available, were outside of the range between the 1% minus and 1% plus regression flows, the Manning's n and CN values were adjusted iteratively until the computed flows at as many validation points as possible were within these ranges. The Manning's n values were revised as needed, provided they remained within the ranges specified in Table 7. The AMC II CN values were adjusted by no more than ±10% of their initial values. Following these adjustments, if the computed flows were between the 1% minus and 1% plus flows or were similar to the 1% flow, then the revised Manning's n and AMC II CN values were used in the final model. Areal reduction of the precipitation data was not completed during the validation process.

There were some model domains where these adjustments to the Manning's n and AMC II CN values did not sufficiently reduce the flows. In these domains, the Manning's n values were reset to their initial values and the baseline antecedent moisture conditions were revised from AMC II to AMC I. According to *Engineering Technical Note No. 210-18-TX5,* published by the Soil Conservation Service (SCS) in October 1990, antecedent moisture conditions in Texas vary from AMC II in the east to AMC I in the west. Since the Austin-Travis Lakes watershed resides within the transition zone from AMC II to AMC I, it was reasonable to assume AMC I conditions were present in the watershed for validation purposes. See Figure 19 and Appendix B for a map from the SCS report showing the average antecedent moisture conditions across Texas. The application of AMC I CN values in the BLE models increased the number of locations where valid 1% BLE flows were computed to an acceptable level (85 out of 126).

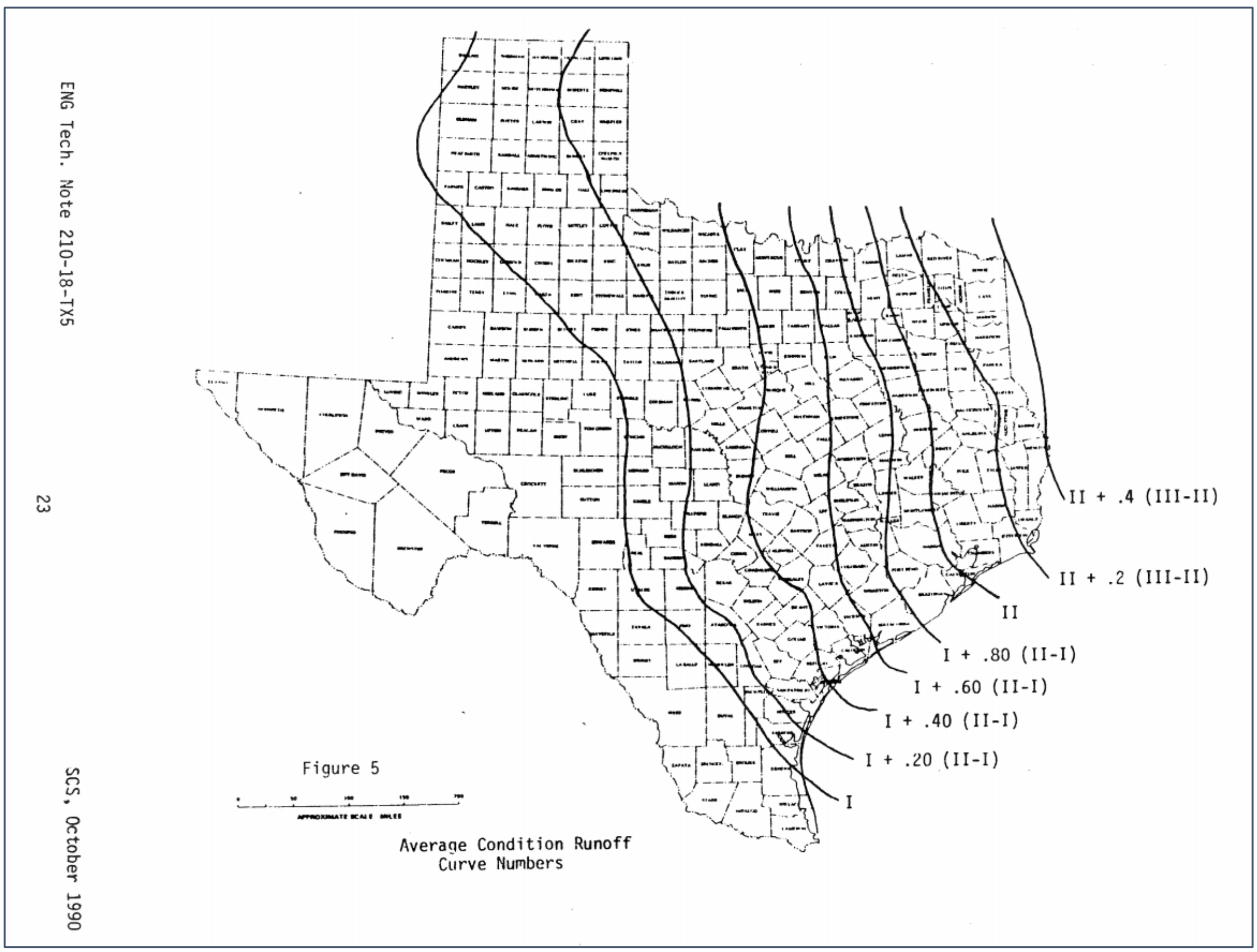


Figure 19: Typical Antecedent Moisture Conditions in Texas

A summary of the parameter adjustments made during the validation task is shown in Table 20.

Table 20: Summary of Parameter Adjustments Made During Validation in the Austin-Travis Lakes Watershed

Model Domain	CN Adjustment	Overland n Adjustment	Channel n Adjustment	Number of Validation Locations	Within Validation Range	Outside Validation Range
0501_A1	Weighted CN – 70% AMC I and 30% AMC II	None	No Change	15	9	6
0502_A2	AMC I	Max	Increased to 0.045	12	7	5
0503_A3	AMC I	Max	Increased to 0.065	12	7	5
0503_A4	AMC I	None	Increased to 0.045	13	13	0
0504_A5	AMC I	Max	Increased to 0.065 on Onion and Little Bear Creeks, and 0.045 everywhere else	11	7	4
0504_A6	Weighted CN – 70% AMC I and 30% AMC II	None	Increased to 0.045	12	8	4
0504_A7	AMC I	Max	None	10	6	4
0503_A8	AMC I	Max	Increased to 0.045	17	14	3
0503_A9	AMC I	Max	Increased to 0.065	12	6	6
0504_A10	AMC I	None	Increased to 0.055	12	8	4
			Total	126	85	41

During the validation process, domain-wide parameter adjustments were applied to the CN values and the Manning's n values to maximize the number of streams where the 1% BLE flows fell between the 1% minus and 1% plus flows. No particular area or tributary in a domain was considered a priority over the others when these adjustments were made. As a result, in areas where the stream/watershed characteristics were significantly different from the rest of the domain, some of the 1% BLE flows might fall outside of the range of acceptable flows. Other factors that contributed to the 1% BLE flows falling outside of the range acceptable flows included differences in the regression, effective, gage, and 2D BLE analysis methodologies; the use of updated topographic data in the BLE analysis; and the higher NOAA Atlas 14 rainfall totals that were used in the BLE analysis.

The BLE 1% discharges were compared to the 1%, 1% plus, and 1% minus discharges computed by the flow-frequency analyses that were completed for the 13 USGS/LCRA flow gages in the watershed. The differences between the 1% BLE flows and the 1% gage flows ranged from -49% to 268%. At 11 of the 13 gages, the 1% BLE flow was between the 1% plus and 1% minus discharges and at 2 gages it was not. One of these gages was along Walnut Creek in domain 0504_A9. At this gage (USGS gage 08158600), the 1% FIS flow was available, and the 1% BLE discharge was within 25% of the effective discharge. In addition, there was a split flow at this location, and it is possible the gage only measures part of the total flow. At the other gage, which was USGS gage 08158810 along Bear Creek, although the 1% BLE discharge was less than the 1% minus gage discharge, the BLE mapping was a little more extensive than the effective mapping.

At the 104 locations where 1% FIS discharges were available, the 1% BLE discharge was within 25% of the 1% FIS discharge at 71 locations. In general, the locations where the 1% BLE discharges were more than 25% different from the 1% FIS discharges were scattered throughout the watershed. However, there was a cluster of locations in Hays County where the differences exceeded 25%. The countywide study was completed in 1998 using regression equations, surveyed cross sections, and the HEC-2 hydraulic modeling program. These differences in methodology likely explain the differences between the BLE and effective outcomes. There were also some failures points along Slaughter Creek. This urbanized watershed was studied in 2016 using HEC-HMS and HEC-RAS. The different hydrology and the level of urbanization likely explain the differences between the BLE and effective outcomes along this creek.

Along the Colorado River, the 1% BLE discharge at Max Starcke Dam (371,733 cfs) was within 4% of the 1% FIS discharge (356,100 cfs). Downstream of Mansfield Dam, at USGS gage 08158000 (Colorado River at Austin, TX), the BLE 1% flow rate of 84,353 cfs was 36% higher than the WHA gage estimate of 62,600 cfs but less than the 1% plus discharge of 144,000 cfs.

Along Barton Creek, the 1% BLE flows compared favorably with the gage flows. The 1% BLE discharges were between the 1% plus and 1% minus gage discharges at all four gages. In the upstream reach of Barton Creek, the BLE 1% flows were 23% to 45% higher than the 1% FIS flows. The effective study along Barton Creek was from 1990. The FIS report did not specify which software was used to model the creek, so it was difficult to ascertain why the BLE outcomes were higher than the effective outcomes.

Along Onion Creek, the 1% BLE flows compared favorably with the 1% FIS flows. The 1% BLE discharges varied from the 1% FIS discharges by -10% to 29%. There were three gages along Onion Creek, and the differences between the 1% BLE discharges and the 1% gage discharges ranged from -28% to 92%. At all three gages, the 1% discharge was between the 1% plus and 1% minus discharges.

Overall, when comparing the 1% FIS discharges with the 1% BLE discharges, there are a few important considerations to keep in mind:

- As discussed above, the effective studies tend to be older. These include the Hays County study from 1998 and the Barton Creek analysis from 1990. These studies applied methodologies and terrain data sources significantly different from what was applied in this BLE analysis. This is leading to differences in the outcomes between these studies and the BLE study.
- All of the effective studies in this watershed were completed before the Atlas 14 rainfall dataset for Texas was released in 2018. The point rainfall totals in this dataset are higher than the rainfall totals used in the effective studies. The application of higher rainfall totals in the BLE study is leading to higher discharges in this watershed, especially along some of the major streams.
- At the time this report was written, the City of Austin was restudying all of the watersheds in the city. In addition, Hays County was restudying the Onion Creek watershed. These studies will include Atlas 14 rainfall data, which will lead to higher effective FIS discharges in most locations in these watersheds. Once these studies are complete, the BLE outcomes should be compared to the results of these studies.
- While the studies in Austin and Hays County were progressing, both communities directed the local floodplain management community to apply the 0.2% FIS discharges in lieu of the 1% FIS discharges because it was assumed that the revised 1% discharges will be similar to the effective 0.2% discharges.

Table 21: Comparison of 1% BLE, Gage, and FIS Flows in the Austin-Travis Lakes Watershed

Gage ID	Location	Area (mi²)	BLE 1% Flow	InFRM Bulletin 17C Analysis Gage Flows (cfs)			FIS 1% Flow (cfs)	% Difference	
				1% Minus	1%	1% Plus		BLE Vs. Gage	BLE Vs. FIS
USGS 08155200	Barton Creek	89.9	55,578	23,700	41,600	135,000	n/a	33.6	
USGS 08154700	Bull Creek	22.4	31,726	14,500	23,500	82,100	n/a	35.0	
USGS 08155240	Barton Creek	107.8	58,770	25,600	46,000	92,000	n/a	27.8	
USGS 08155300	Barton Creek	116.9	60,352	26,800	52,500	221,000	n/a	15.0	
USGS 08155400	Barton Creek	119.9	60,749	20,200	45,200	192,000	n/a	34.4	
USGS 08158700	Onion Creek	123.7	62,267	18,800	32,500	143,000	n/a	91.6	
LCRA 4595	Gage at Buda, TX (Onion Creek)	166.4	66,864	36,500	67,100	185,000	n/a	-0.4	
USGS 08158810	Bear Creek	12.2	22,600	27,640	43,890	80,210	n/a	-48.5	
USGS 08158840	Slaughter Creek U/S	7.7	21,059	8,665	12,460	22,710	n/a	69.0	
USGS 08158860	Slaughter Creek D/S	23.1	40,269	38,100	75,040	189,600	n/a	-46.3	
USGS 08158000	Colorado River	39,020	84,353	48,100	62,600	144,000	n/a	34.7	
USGS 08158600	Walnut Creek	51.7	65,082	13,800	17,700	28,600	50,000	267.7	30.2
USGS 08159000	Onion Creek	323.9	129,049	98,600	179,000	468,000	n/a	-27.9	

The model overview and results spreadsheet (*AustinTravis_Model_Overview_And_Results.xlsx*) has been placed in the task documentation folder of this submittal. The validation locations are included in the HEC-RAS models and may also be found on the validation location maps in the model overview and results spreadsheet for each domain.

See Figure 20 and Table 22 on the following pages for a summary of the 1% validation results at the validation points in the Austin-Travis Lakes watershed.

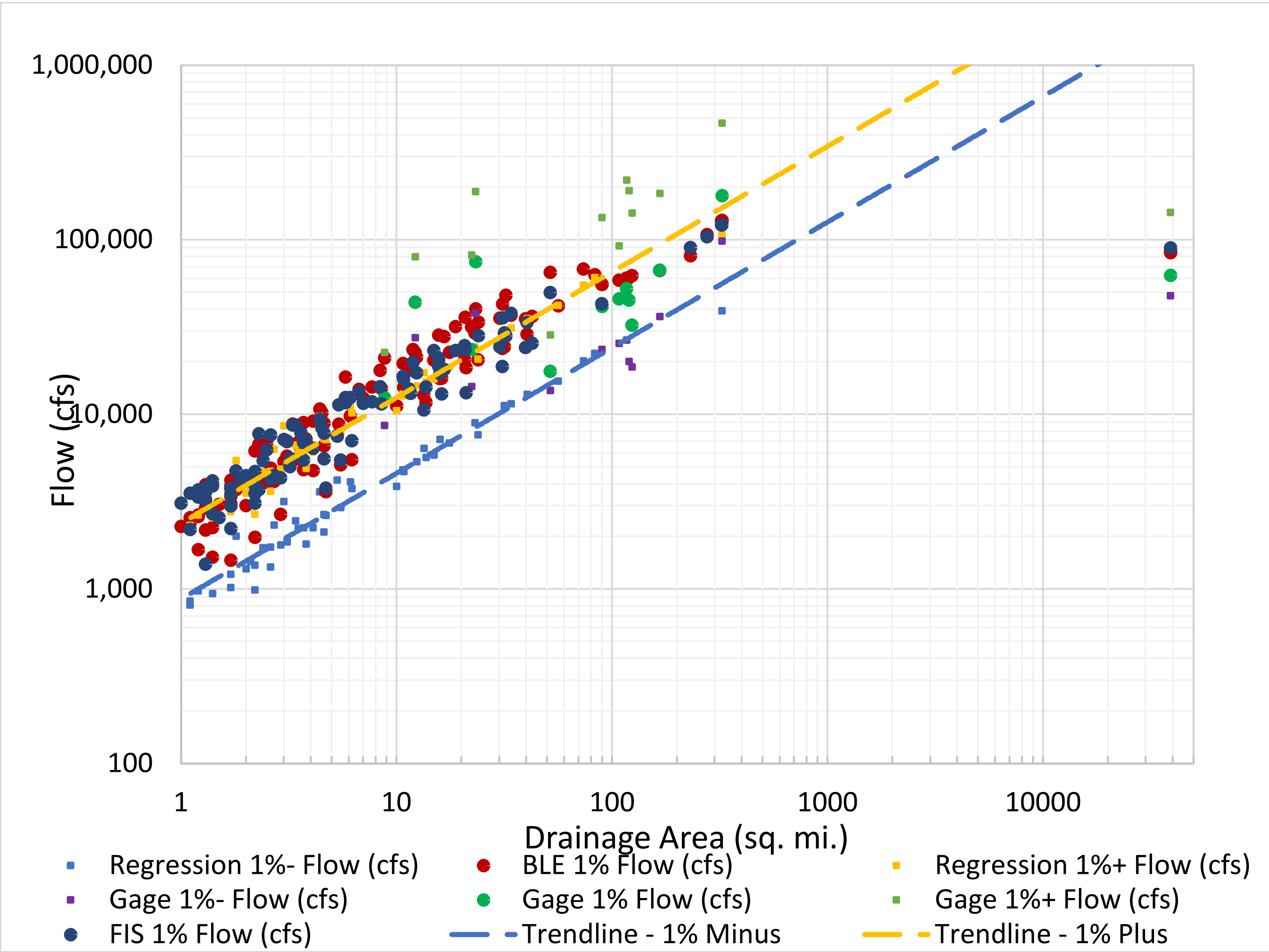


Figure 20: Computed Flow vs Drainage Area for Select 1% BLE, Regression, FIS, and Gage Flows

Table 22: 1% Peak Flow Validation Results for the Austin-Travis Lakes Watershed

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Domain 0501_A1										
FIS1	Backbone Creek – Approx. 3200 ft above Railroad	5.3	4,218	6,952	11,452	7,568	-	-	-	7,500
FIS2	Backbone Creek – Below Confluence of Sparerib Creek	15.9	7,226	11,908	19624.8	16,047	-	-	-	17,200
FIS3	Backbone Creek – At Confluence with Colorado River (Lake Marble Falls)	40.3	13,086	21,566	35,541	28,775	-	-	-	33,710
FIS4	Whitman Branch – Approx 290 ft downstream of Commerce St.	3.8	1,815	2,992	4,930	7,242	-	-	-	7,120
FIS5	Williams Creek – Above the confluence with Backbone Creek	2.2	992	1,635	2,695	1,979	-	-	-	3,100
FIS6	Backbone Creek - Approx. 1375 ft downstream of confluence with Backbone Creek Trib 2	31.6	11,289	18,604	30,659	24,338	-	-	-	29,330
FIS7	Hamilton Creek – Downstream of confluence of Haynie Branch	13.7	5,695	9,386	15,467	11,745	-	-	-	14,350

Point ID	Validation Point Name	Drainage Area (mi²)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
FIS8	Hamilton Creek – Upstream of the confluence of the right bank tributary located approximately 900 feet upstream of the confluence of Stream HC(B)-3	6.2	3,778	6,226	10,260	5,502	-	-	-	7,070
FIS9	Colorado River at Max Starcke Dam	-	-	-		371,733	-	-	-	356,100
Pt1	Hamilton Creek	83.1	22,470	37,031	61,027	63,069	-	-	-	-
Pt2	Hamilton Creek	73.7	20,362	33,556	55,301	67,990	-	-	-	-
Pt3	Hairston Creek	17.6	6,885	11,346	18,698	22,746	-	-	-	-
Pt4	Double Horn Creek	3.5	2,236	3,685	6,072	6,936	-	-	-	-
Pt5	Double Horn Creek	23.1	8,982	14,803	24,395	29,236	-	-	-	-
Pt6	Unnamed	4.1	2,251	3,710	6,115	4,771	-	-	-	7,500
Domain 0502_A2										
FIS1	Big Sandy Creek – At confluence of Big Sandy Creek Tributary 2 (Bloody Hollow)	34.0	11,550	19,035	31,369	37,107	-	-	-	38,000
FIS2	Big Sandy Creek - At confluence of Big Sandy Creek Tributary 3 (Bingham Creek)	3.4	2,472	4,074	6,713	5,547	-	-	-	8,700

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
FIS3	Little Cypress Creek – Approximately 2.23 miles upstream of confluence with sycamore creek	2.7	2,332	3,843	6,334	4,137	-	-	-	4,470
FIS4	Little Cypress Creek Approximately 1.93 miles of the confluence with the Colorado River (Lake Travis)	13.4	6,404	10,554	17,393	12,914	-	-	-	10,616
FIS5	Sycamore Creek – Approx. 95 feet downstream of State Highway 71	2.9	1,796	2,960	4,878	2,677	-	-	-	4,338
FIS6	Lime Creek – At Confluence with Like Creek Trib. 2	3.0	3,188	5,254	8,658	5,370	-	-	-	7,200
FIS7	Yaupon Creek – At confluence with Hurst Creek	1.8	2,017	3,324	5,478	3,716	-	-	-	4,750
FIS8	Hurst Creek - At Lohmann Crossing Road	4.4	3,612	5,953	9,810	10,726	-	-	-	9,400
FIS9	Little Cypress Creek Tributary 2 - Approx. 40 ft downstream of CR 408N	1.7	1,025	1,690	2,785	1,460	-	-	-	2,225
FIS10	Lime Creek - At Lake Travis	6.1	4,124	6,796	11,200	9,815	-	-	-	12,500
Pt1	Unnamed	56.3	15,601	25,711	42,372	41,870	-	-	-	-

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Pt2	Unnamed	10.0	3,880	6,394	10,538	11,192	-	-	-	-
Domain 0503_A3										
Pt 1	Barton Creek	42.6	-	-	-	36,445	-	-	-	25,590
Pt 2	Barton Creek	39.7	-	-	-	35,242	-	-	-	24,230
Pt 3	Barton Creek	16.2	-	-	-	16,124	-	-	-	13,090
Pt 4	Unnamed	1.4	-	-	-	2,252	-	-	-	2,700
Pt 5	Unnamed	1.3	-	-	-	2,178	-	-	-	1,390
Pt 6	Roy Branch	1.5	-	-	-	3,049	-	-	-	2,560
Pt 7	Long Branch	2.2	-	-	-	3,971	-	-	-	3,530
Pt 8	Little Barton Creek	11.4	-	-	-	18,301	-	-	-	14,000
Pt 9	Little Barton Creek	8.5	-	-	-	14,061	-	-	-	11,500
Pt 10	Little Barton Creek	0.4	-	-	-	1,286	-	-	-	1,185
Pt 11	Little Barton Creek	11.6	-	-	-	17,991	-	-	-	13,200
Outfall. USGS Gage 08155200	Barton Creek	89.9	-	-	-	55,578	23,700	41,600	135,000	-
Domain 0503_A4										
Pt 1	Bull Creek	20.7	-	-	-	20,560	-	-	-	24,800
Pt 2. USGS Gage 08154700	Bull Creek	22.4	-	-	-	31,726	14,500	23,500	82,100	-
Pt 4	Bull Creek	15.7	-	-	-	20,551	-	-	-	18,900
Pt 5	Colorado River	-	-	-	-	85,458	-	-	-	90,100
Pt 6	Cow Fork	1.3	-	-	-	2,916	-	-	-	3,810
Pt 7	West Bull Creek	5.8	-	-	-	12,370	-	-	-	12,500
Pt 8	West Bull Creek	6.7	-	-	-	13,931	-	-	-	13,400

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Pt 9	Bull Creek	31.0	-	-	-	42,983	-	-	-	35,800
Pt 10	Unnamed	2.5	-	-	-	6,825	-	-	-	6,282
Pt 11	Bee Creek	3.3	-	-	-	8,797	-	-	-	8,698
Pt 12 USGS Gage 08155240	Barton Creek	107.8	-	-	-	58,770	25,600	46,000	92,800	-
Pt 13 USGS Gage 08155300	Barton Creek	116.9	-	-	-	60,352	26,800	52,500	221,000	-
Pt 14 USGS Gage 08155400	Barton Creek	119.9	-	-	-	60,749	20,200	45,200	192,000	-
Domain 0503_A5										
Pt 1 USGS Gage 08158700	Onion Creek	123.7	-	-	-	62,267	18,800	32,500	143,000	-
Pt 2 – USGS Gage 08158810	Bear Creek	12.2	-	-	-	22,600	27,640	43,890	80,210	-
Pt 3 – LCRA Gage 4595	Onion Creek	166.4	-	-	-	66,864	36,500	67,100	185,000	-
Pt 4	Onion Creek	30.9	-	-	-	23,945	-	-	-	18,830
Pt 5	South Onion Creek	23.9	7,660	12,624	20,804	20,526	-	-	-	-
Pt 6	Onion Creek	89.6	-	-	-	55,602	-	-	-	43,020
Pt 7	Unnamed (Bear Creek Tributary 2)	1.7	-	-	-	3,406	-	-	-	3,770
Pt 8	Little Bear Creek	21.0	-	-	-	18,553	-	-	-	13,310
Pt 9	Bear Creek	24.0	-	-	-	33,734	-	-	-	28,300

Point ID	Validation Point Name	Drainage Area (mi²)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Pt 10	Garlic Creek	5.4	-	-	-	8,795	-	-	-	11,370
0504_A5_ Outfall	Onion Creek	231.1	-	-	-	81,185	-	-	-	90,200
Domain 0504_A6										
Pt 1 – USGS Gage 08158840	Slaughter Creek u/s	7.7	-	-	-	21,059	8,665	12,460	22,710	-
Pt 2 – USGS Gage 08158860	Slaughter Creek d/s	23.1	-	-	-	40,269	38,100	75,040	189,600	-
Pt 3	Slaughter Creek Trib 2	1.9	-	-	-	4,199	-	-	-	4,270
Pt 4	Devils Pen Creek	2.3	-	-	-	6,762	-	-	-	3,709
Pt 5	Danz Creek	3.7	-	-	-	8,975	-	-	-	6,910
Pt 6	Danz Creek	1.3	-	-	-	3,179	-	-	-	3,590
Pt 7	Slaughter Creek Trib 5	1.2	-	-	-	2,658	-	-	-	3,650
Pt 8	Rinard Creek Trib 1	3.2	-	-	-	5,230	-	-	-	5,590
Pt 9	Rinard Creek	2.2	-	-	-	6,186	-	-	-	4,710
Pt 10	Rinard Creek	1.3	-	-	-	3,959	-	-	-	3,250
Pt 11	Rinard Creek	7.0	-	-	-	12,419	-	-	-	11,600
0504_A6_ Outfall	Onion Creek	275.8	-	-	-	107,207	-	-	-	104,400
Domain 0504_A7										
Pt 2	Williamson Creek	30.2	-	-	-	35,621	-	-	-	24,340
Pt 3	Unnamed (Pace Mills Tributary)	1.2	-	-	-	1,683	-	-	-	3,700

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Pt 4	Marble Creek	3.6	-	-	-	6,276	-	-	-	7,870
Pt 5	Boggy Creek	4.5	-	-	-	10,225	-	-	-	8,350
Pt 6	Unnamed (Kincheon Branch)	1.4	-	-	-	3,963	-	-	-	3,900
Pt 7	Unnamed (Kincheon Branch)	7.7	-	-	-	14,375	-	-	-	11,840
Pt 8	Williamson Creek	15.7	-	-	-	28,469	-	-	-	21,080
Pt 9	Williamson Creek	18.8	-	-	-	31,827	-	-	-	23,260
Pt 1	Onion Creek	322.7	-	-	-	128,923	-	-	-	121,900
Domain 0503_A8										
Profile Line 1	Tannehill Branch	2.0	1,309	2,158	3,557	3,011	-	-	-	4,453
Profile Line 2	Fort Branch Creek	3.1	1,892	3,118	5,139	5,630	-	-	-	6,977
Profile Line 3	Tannehill Branch	3.7	2,255	3,717	6,126	4,836	-	-	-	5,475
Profile Line 4	Hancock Branch	1.7	1,222	2,014	3,320	4,200	-	-	-	3,790
Profile Line 5	Shoal Creek	10.7	4,841	7,978	13,148	19,600	-	-	-	16,500
Profile Line 6	Shoal Creek	12.4	5,384	8,874	14,624	21,295	-	-	-	17,350
Profile Line 7	Blunn Creek	1.0	-	-	-	2,284	-	-	-	3,100
Profile Line 8 USGS Gage 08158000	Colorado River	39,020	-	-	-	84,353	48,100	62,600	144,000	-

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Profile Line 10	Boggy Creek	10.8	4,729	7,793	12,843	14,312	-	-	-	16,013
Profile Line 11	Boggy Creek	14.9	5,889	9,706	15,996	20,447	-	-	-	23,207
Profile Line 12	Boggy Creek	2.1	1,440	2,374	3,912	4,422	-	-	-	4,341
Profile Line 13	Waller Creek	4.6	2,679	4,416	7,277	8,923	-	-	-	7,820
Profile Line 14	Waller Creek	2.2	1,374	2,264	3,731	4,078	-	-	-	3,941
Profile Line 15	Hemphill Branch	1.1	855	1,411	2,324	2,561	-	-	-	3,545
Profile Line 17	Country Club Creek West	2.3	-	-	-	6,350	-	-	-	7,740
Profile Line 18	Country Club Creek East	0.5	-	-	-	1,603	-	-	-	1,910
Profile Line 19	Fort Branch Creek	3.1	1,869	3,080	5,076	5,774	-	-	-	7,039
Domain 0504_A9										
Pt 1	Unnamed	1.7	-	-	-	3,886	-	-	-	3,500
Pt 2	Wells Branch	2.6	-	-	-	4,700	-	-	-	4,420
Pt 3	Unnamed	1.7	-	-	-	3,083	-	-	-	2,990
Pt 4	Unnamed	4.1	-	-	-	9,155	-	-	-	6,410
Pt 5	Unnamed	3.2	-	-	-	5,145	-	-	-	5,020
Pt 6	Little Walnut Creek	11.9	-	-	-	23,514	-	-	-	19,890
Pt 7	Little Walnut Creek	8.4	-	-	-	17,849	-	-	-	14,420
Pt 8	Little Walnut Creek	5.8	-	-	-	16,361	-	-	-	11,690

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Pt 9	Walnut Creek	20.8	-	-	-	36,026	-	-	-	23,530
Pt 10 USGS Gage 08158600	Walnut Creek	51.7	-	-	-	65,082	13,800	17,700	28,600	50,000
Pt 11	Walnut Creek	16.6	-	-	-	27,872	-	-	-	18,060
Pt 12	Walnut Creek	32.2	-	-	-	48,164	-	-	-	28,100
Domain 0504_A10										
Profile Line 1	Cottonmouth Creek	1.1	813	1,340	2,209	2,392	-	-	-	2,198
Profile Line 2	Cottonmouth Creek	2.6	1,343	2,214	3,649	4,926	-	-	-	4,246
Profile Line 3	Cottonmouth Creek	4.6	2,131	3,511	5,786	6,618	-	-	-	5,567
Profile Line 4	Burleson Creek	0.9	-	-	-	1,595	-	-	-	1,870
Profile Line 5	Burleson Creek	2.4	1,733	2,855	4,706	4,057	-	-	-	5,430
Profile Line 6	Burleson Creek	2.6	1,747	2,878	4,744	4,151	-	-	-	7,630
Profile Line 7	Carson Creek	1.4	946	1,560	2,571	1,524	-	-	-	4,171
Profile Line 8	Carson Creek Montopolis Trib	1.2	981	1,617	2,664	2,602	-	-	-	3,358
Profile Line 9	Carson Creek	4.7	2,649	4,366	7,196	3,613	-	-	-	3,793
Profile Line 10	Carson Creek	5.5	2,940	4,845	7,985	5,147	-	-	-	5,481

Point ID	Validation Point Name	Drainage Area (mi^2)	Regression 1%- Flow (cfs)	Regression 1% Flow (cfs)	Regression 1%+ Flow (cfs)	BLE 1% Flow (cfs)	Gage 1%- Flow (cfs)	Gage 1% Flow (cfs)	Gage 1%+ Flow (cfs)	FIS 1% Flow (cfs)
Profile Line 11 USGS Gage 08159000	Onion Creek	323.9	39,412	64,951	107,040	129,049	98,600	179,000	468,000	-
Profile Line 12	Colorado River	39,110	-	-	-	86,302	-	-	-	90,000

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

Floodplains were delineated throughout the entire watershed for the 10%, 1%, and 0.2% annual-chance events. The 1% and 0.2% floodplains may be found in the FLD_HZD_AR feature class in the flood risk database. The 10% floodplain may be found in the TENPCT_FP feature class in the database.

The floodplains were derived from the raw modeled grids using the maximum water surface elevation and depth values in each cell of the mesh. These grids were exported from HEC-RAS as rasters in TIF format with an interpolated rendering that slopes values at the center and along the faces/edges of the computational mesh cells. Using GIS software, the TIF rasters were post-processed into 10%, 1%, and 0.2% annual-chance floodplains.

The following general steps were completed to delineate the floodplains:

- Export the depth rasters and WSEL rasters for the 10%, 1%, and 0.2% ACEs from the HEC-RAS models using a sloping water surface elevation render mode to a GIS environment. When exporting the model results, the “Raster based on terrain” parameter in HEC-RAS was changed from “Terrain.HydroEnforced” to “Terrain.” This change was made so the original terrain surface was used to develop the floodplain mapping, not the hydro-enforced terrain surface. Using the hydro-enforced terrain would have led to mapping that would have incorrectly shown the roadway as being overtopped where the hydro-enforced culverts had been added.
- For each ACE, merge the raw WSEL rasters into a single raster that covers the entire watershed. Do the same for the depth rasters. Where the floodplain mapping needed to tie-in across two model domains, the model domain boundaries overlapped. Tie-in locations were identified in these overlap areas using split line shapefiles. Three split line shapefiles were created, one for each of the mapped events (i.e., 10%, 1%, and 0.2%). Split line alignments for each event were determined by creating difference rasters that subtracted the WSEL rasters from one another in the model domain overlap areas. Split lines were then drawn around the entire perimeter of each model domain through areas where the WSELs in the difference rasters were within 0.5 feet of each other. See the split line shapefiles in the *Supplement Data* folder to understand where the mapping tie-ins are located.
- To understand how a split line is placed, consider Figure 21, which shows two floodplains that overlap along a model domain boundary. The split line must be placed where the WSELs are within 0.5 feet of one another in the overlap area. To determine where the WSELs meet this criterion, a WSEL difference raster was created.

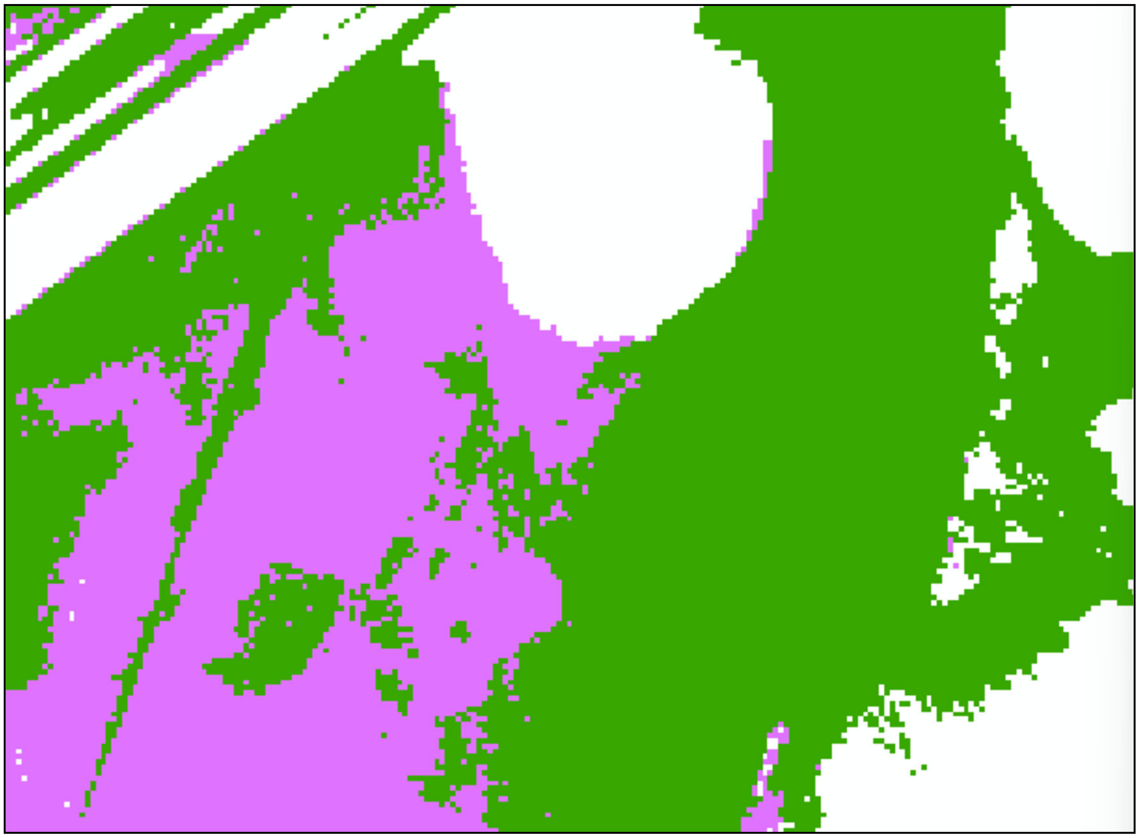


Figure 21: Example of overlapping mapping along a model domain boundary

Figure 22 shows what the difference raster looks like for the area in Figure 21. Light green means the WSELs are within 0.5 feet of each other and red means they are not. The blue-black line is the split line. It has been aligned so that it crosses the difference raster where the raster is light green. To the south of this line, the purple raster in Figure 21 is the source of the floodplain mapping. To the north of the split line, the dark green raster is the source of the floodplain mapping. Along the split line is where the source of the mapping transitions from the purple mapping to the dark green mapping.

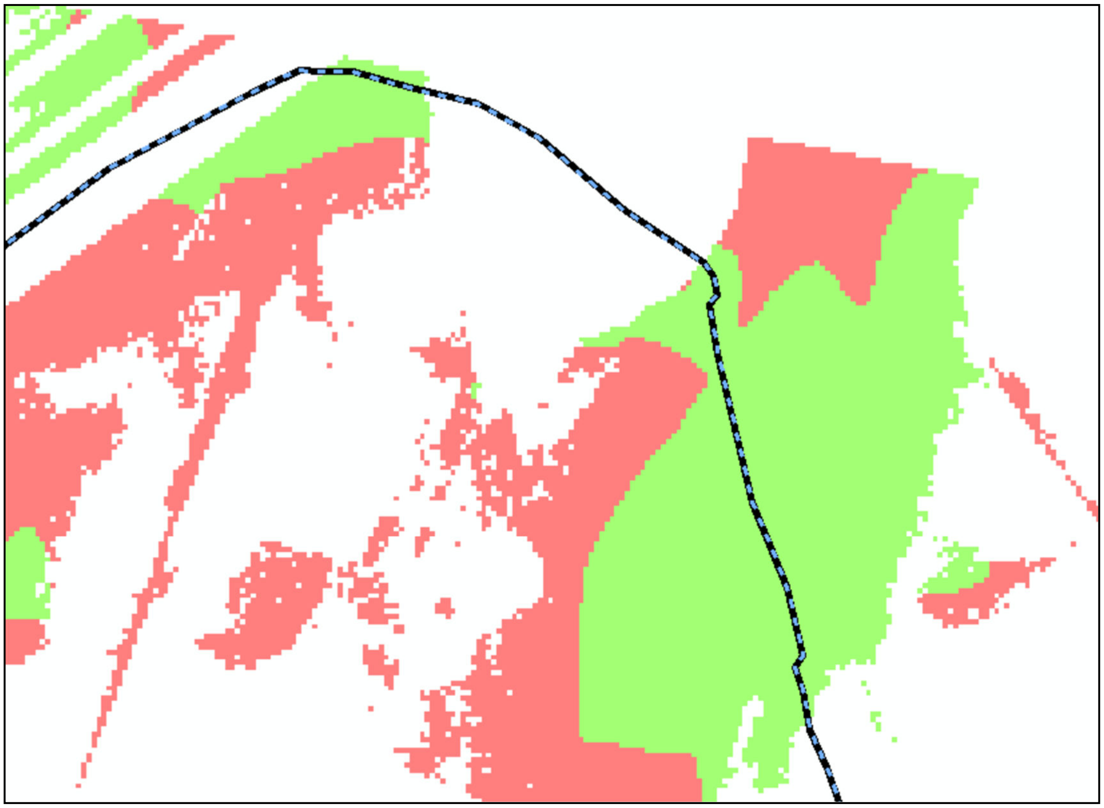


Figure 22: WSEL difference raster and split line for the overlap area

- The merged raw raster grids included connected and disconnected areas of potential flood hazard. To reduce the extent of these disconnected flood areas, process the rasters to filter and remove disconnected small, shallow areas of flooding. To do this, apply the TWDB's mapping threshold matrix to remove shallow depths, small areas of flood risk, and disconnected areas. According to Figure 3.1 in TWDB's 2D BLE guidelines, the watershed falls in the Inland Areas of Texas. Therefore, disconnected areas were removed if they met ***both*** of the criteria in Table 23.

Table 23: Inland mapping threshold matrix

Area (acres)	Depth (feet)
Less than 0.33	Remove all flooding
0.33 to 0.50	Less than 0.33
0.50 to 1.0	Less than 0.25
1.0 to 2.0	Less than 0.10

- Fill the holes (i.e., islands) in the rasters using the Elevation Void Fill routine. For the 1% and 0.2% ACEs, holes in the rasters less than 2 acres were filled. For the 10% ACE, holes in the raster less than 0.5 acres were filled. Application of the Elevation Void Fill routine occasionally produces WSELs that are below the ground elevation. In cases where this phenomenon occurred, the WSELs were not revised from their subterranean values, but the depths at these locations were set to 0.1 feet.
- Convert each WSEL raster to a floodplain polygon.

- Many ponding areas were present throughout the watershed. Due to the large mesh cells used in the 2D modeling, the extent of the smaller ponds was not always mapped properly in the model output. To properly identify the flood hazard in these areas, transfer the ponding extents available in the National Hydrography Dataset into the 1% and 0.2% floodplain polygons. Do not transfer them into the 10% floodplain polygon.
- If any dams are present that have been catalogued by the National Inventory of Dams and include a normal pool storage of 200 acre-feet or more, review the spillway mapping along each dam. If the 1% and/or the 0.2% model output did not include any flooding along the spillway, manually revise the floodplain polygon(s) to flood the spillway.
- Add waterbodies of lake and reservoir inundation areas of 20 acres or greater to the WTR-LN and FLD_HAZ_AR feature classes. The National Inventory of Dams was used to identify dams with inundation areas greater than 20 acres. The areas of inundation were computed by measuring the areas of the normal pools visible on the aerial photography.
- Clean up each polygon by simplifying it and smoothing it. The intent of the simplify and smooth processes is to eliminate unnecessary/erroneous vertices, remove rough edges, and reduce the size and complexity of the raw floodplain polygons. Apply professional judgement to determine the appropriate tolerance for simplifying and smoothing the floodplain polygons. Set initial thresholds to 5 feet for simplifying and 25 feet for smoothing.
- Merge the 1%, and 0.2% ACE polygons into one feature class. Keep the 10% ACE polygon as a separate feature class.
- The extents of the final depth and WSEL grids must match the extents of the flood inundation polygons. Because of the clipping and smoothing procedures applied to the floodplain polygons, they will no longer match the extents of the rasters. Clip the depth and WSEL grids to each respective flood frequency inundation polygon to align the extents of the rasters with the extents of the floodplain polygons.
- Clip the rasters and the floodplain polygons using the HUC-8 watershed boundary.

2.0 Challenges

A handful of challenges were encountered during the Austin-Travis Lakes BLE analysis. These challenges and their solutions are catalogued in the following subsections.

Balancing Flows between Small and Large Streams

The BLE models developed for the Austin-Travis Lakes watershed are watershed-wide models. Each domain is similar in size to a HUC-10 watershed. As a result, streams with both large and small drainage areas are in the same model and cannot be isolated from one another. One of the main challenges of the BLE analysis was adjusting the model input parameters so that valid flows were produced along streams with both large and small drainage areas. For example, when the CN values were revised to increase flows that were too low along the smaller tributaries, this adjustment would occasionally lower the flows along the more-significant streams to a point below the lower end of that which was considered valid, and vice versa. To address this challenge, a range of acceptable CN values and Manning's n values was established for the watershed. The parameters were adjusted only within this set range so that the model results did not skew too heavily in favor of the larger streams or the smaller streams. Balancing the validation needs between the small and large streams was further enhanced by assigning an equal weight to all validation locations and choosing validation locations such that a representative coverage of drainage areas and stream characteristics was included.

Modeling of Hydraulic Structures

Although detailed modeling of hydraulic structures was outside the scope of this BLE analysis, completely ignoring the structures would have produced invalid model results. Therefore, hydraulic structures were modeled using a simplified approach. This included adding breaklines along dam crests, elevated roadways, and railroads to force the terrain surface to drain properly. Bridge and culvert openings were represented by hydro-enforcing burn lines that were roughly equal in width to the bridge and culvert opening sizes. The addition of breaklines at the dam crests throughout AtkinsRéalis's BLE study area typically resulted in an overestimation of the 1% BLE floodplain extents and WSELs on the upstream side of the dam. On the downstream side of the dams, the floodplains and flows tended to be underestimated.

Cupping

Within HEC-RAS, the RAS Mapper interface provides three render modes for visualization of floodplains: Horizontal, Sloping, and Hybrid. Currently, the results of only the horizontal and sloping render modes can be exported. While the horizontal render mode produces "bathtubs" of isolated ponding per cell, the sloping render mode produces "cupping." Cupping is a ramp-up of the depth in the overbanks occurring most often in areas of significant topographic relief. USACE HEC is aware of this issue, which is an error caused by the WSEL projecting to the adjacent cell's average elevation. However, the timeframe for a solution to this error by the HEC is unknown. Since the TWDB mapping process is based on the sloping render mode output, this cupping effect can be identified in the final mapping products produced, as shown by the pink areas in Figure 23. The areas of cupping will not be removed or cleaned beyond the extents of the mapping clean-up process discussed herein. There is significant topographic relief throughout the Austin-Travis Lakes watershed. Therefore, cupping is prevalent throughout the BLE mapping.

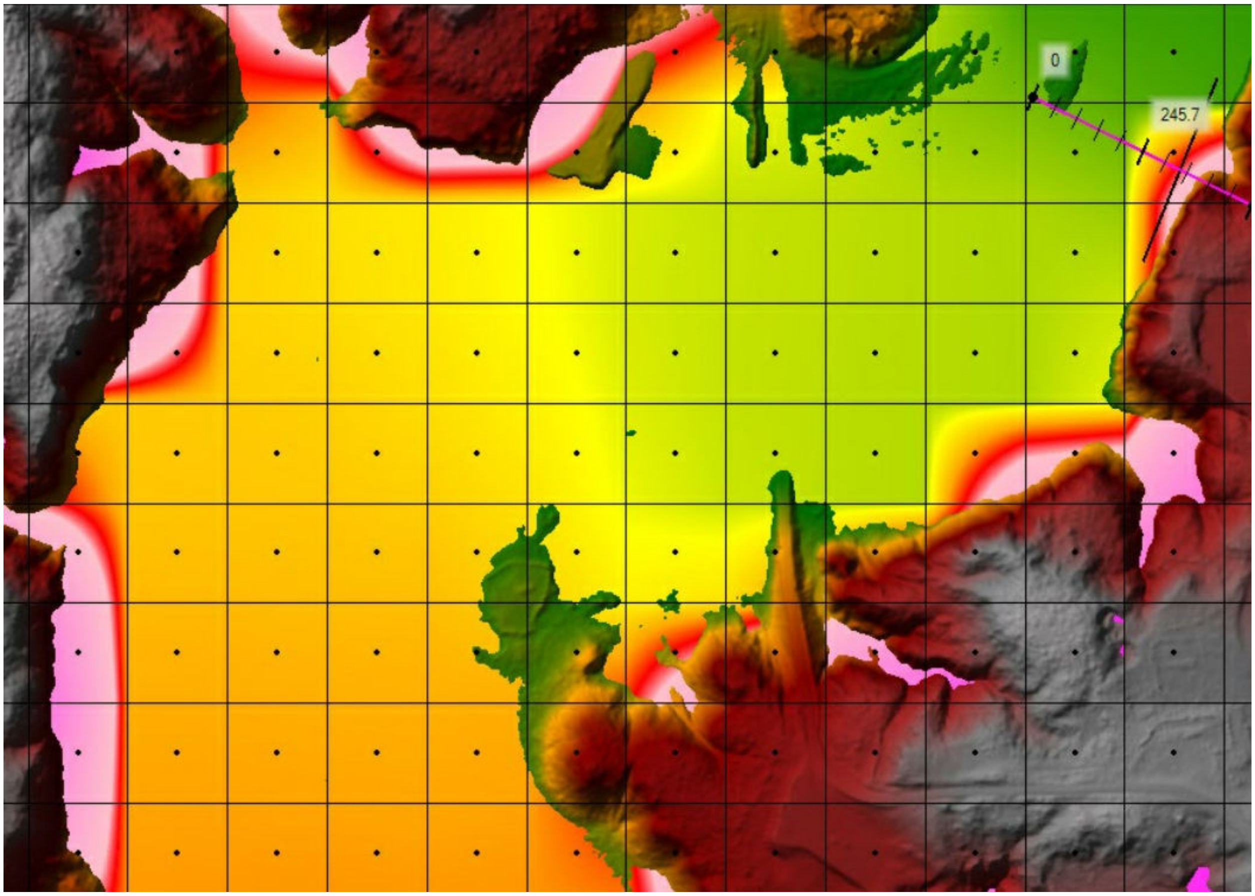


Figure 23: An Example of Cupping in 2D BLE Mapping

Outdated Land Use Information

At limited locations across the watershed, the NLCD land cover database was outdated due to development in the watershed. Since Manning's n values and CN values were derived from this database, some of these parameters in the model may not reflect current conditions. These areas have been documented in the AOMI_AR feature class in the mapping database deliverable.

HEC-HMS Model Produced by the InFRM WHA

Near the end of the project, the InFRM team shared with the TWDB an HEC-HMS model of the Colorado River watershed. Outside of establishing the inflows from the Pedernales River into the Colorado River, this model was received too late in the project workflow to be used in this BLE study. Future updates to the BLE modeling in the Austin-Travis Lakes watershed should review the HEC-HMS model to determine whether any other information could be leveraging from the model to refine the BLE results.

Lake LBJ and Lake Travis

Lake LBJ drains into domain 0501_A1 at Wirtz Dam. Travis Lake drains into domain 0503_A4 at Mansfield Dam. Due to the high flow volumes in the Colorado River, modeling these reservoirs was challenging. See Subsection 1.2.5 for details about how these two dams were modeled during the BLE assessment.

Terrain Adjustments in Mining Areas

There were mining sites and borrow pits present in several of the model domains. Refer to Subsection 1.2.6 for a description of how these areas were modeled during the BLE assessment.

Modeling the Confluence of Domains 0503_A8, 0503_A9, and 0504_A10

The confluence of domains 0503_A8, 0503_A9, and 0504_A10 is a complex area that was challenging to model. Complicating factors included a high level of development, the presence of a number of major mining pits, and generally flat terrain that allowed floodwaters to move easily across the model domain boundaries.

In the vicinity of this confluence, the three domains were drawn in such a way that they all overlapped one another. See Figure 24 for details.

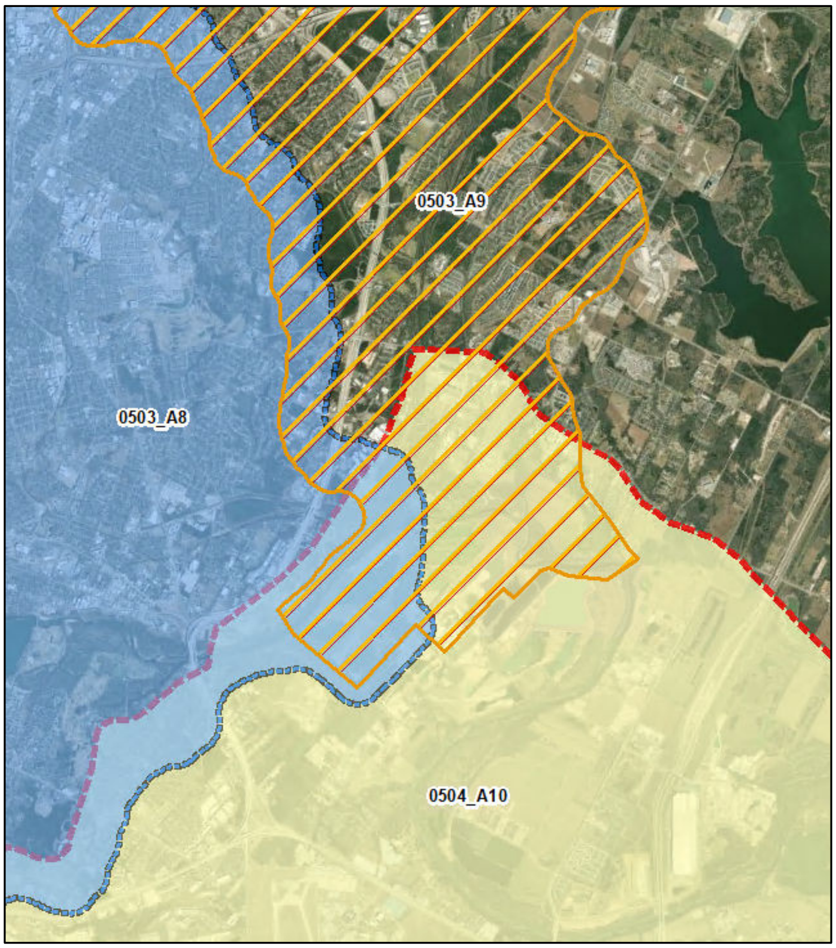


Figure 24: Domain Layout at the Confluence of Domains 0503_A8, 0503_A9, and 0504_A10.

At the downstream end of domain 0503_A8, two SA/2D connections were included in the model, one for the flow in the main channel of the Colorado River and one for the floodwaters in the right overbank. The right overbank experienced patchy flooding for all events except for the 0.2% event, where the flooding in the overbank was extensive. The layout of these SA/2D connections at the downstream end of domain 0503_A8 and the raw 1% floodplain are shown on Figure 25.

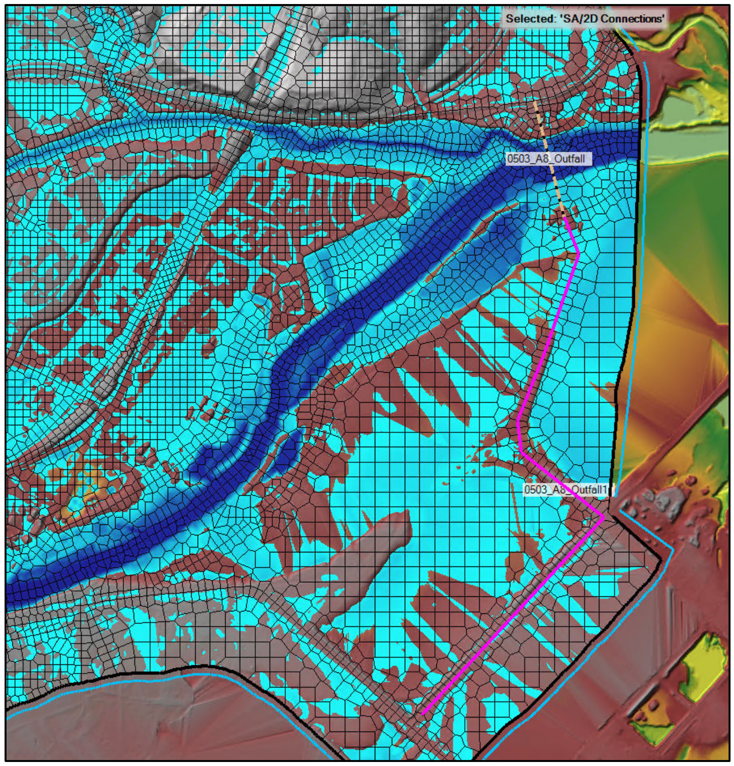


Figure 25: Layout of SA/2D Connections at the Downstream End of Domain 0503_A8

Initial attempts to model this area placed BC lines in domains 0503_A9 and 0504_A10 that were similar in length to the SA/2D connections in domain 0503_A8. However, this approach did not yield WSELs that produced successful mapping tie-ins in the right overbank. Several different BC line alignments and domain layouts were tried, but none of them produced acceptable mapping tie-ins.

The modeling approach that produced successful tie-ins included the placement of a short BC line in a single mesh cell in domains 0503_A9 and 0504_A10. These BC lines were placed along the same alignment in both domains, in a mesh cell in the right overbank near the main channel. This approach produced flooding that looked reasonable and WSEL tie-ins that were within 0.5 feet for all profiles.

See Figure 26 for details regarding the model set-up at the downstream end of domain 0504_A10. Note the presence of the small BC line Inflow_from_0503_A8_Outfall1 in the right overbank of the main channel.

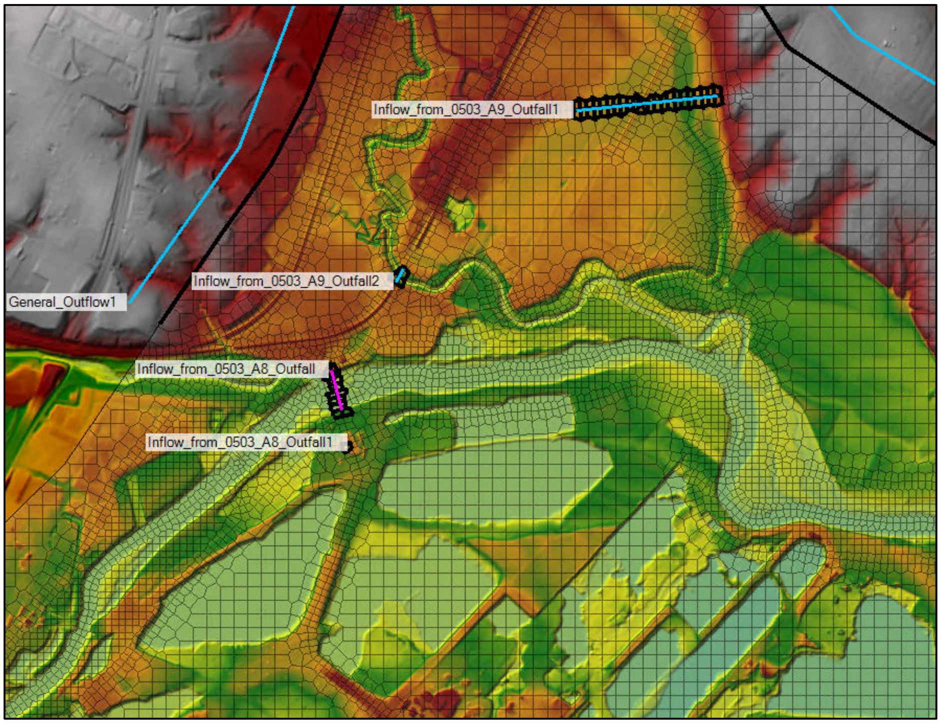


Figure 26: Model Set-up at the Downstream End of Domain 0504_A10

Development in the Watershed since the 2019 NLCD Was Released

The source of land use data for this BLE assessment was the 2019 NLCD. The land uses captured by this database were compared with the land uses shown in the aerial imagery available in Google Earth when the floodplain mapping was being developed. Areas where the land use had changed significantly since 2019 were documented in the S_AOMI_AR feature class in the mapping database.

Crossing Profiles in the Perimeter BC Lines

When establishing the extents of each model domain, a buffer of 1,000 feet was applied to each HUC-10 watershed boundary to create overlapping domain boundaries. The purpose of these overlap areas was to facilitate clean floodplain and BFE transitions between domains, to capture the full extent of the floodplain within the watershed, and to minimize the impact of model boundary conditions on model results.

BC lines were placed around the perimeter of the buffered domain. Breakout areas where runoff left the domain received their own BC lines. For the rest of the domain, long BC lines were placed along the perimeter of the domain. Because of the buffering of the domain and the rain-on-grid approach applied in the model, some rainfall fell outside of the HUC-10 watershed ridgeline, in the area between the ridgeline and the edge of the buffered domain. This runoff needed to leave the domain or else it would have ponded up against the domain boundary. To allow this runoff to leave, long BC lines were placed around the perimeter of each domain. These BC lines assumed a normal depth boundary condition with a slope of 0.01 feet/foot.

At some of these perimeter BC lines, the stage hydrographs cross during the model run. An example of where this occurred is in domain 0503_A4 along the perimeter BC line called General Outflow3. See Figure 27 for the orientation of General Outflow3 in the domain. See Figure 28 for the stage hydrographs at this BC line. Note the crossing profiles during the simulation.

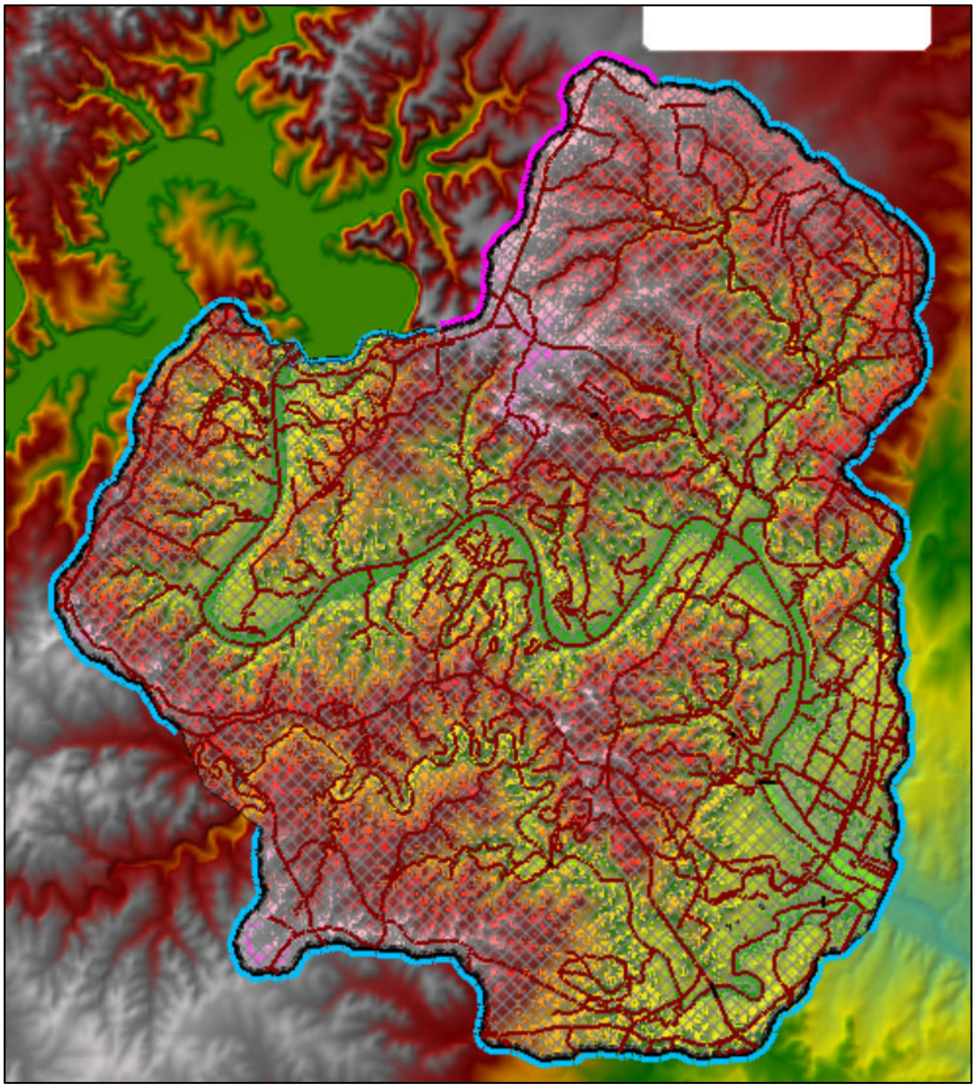


Figure 27: Layout of General Outflow3 in Domain 0504_A4

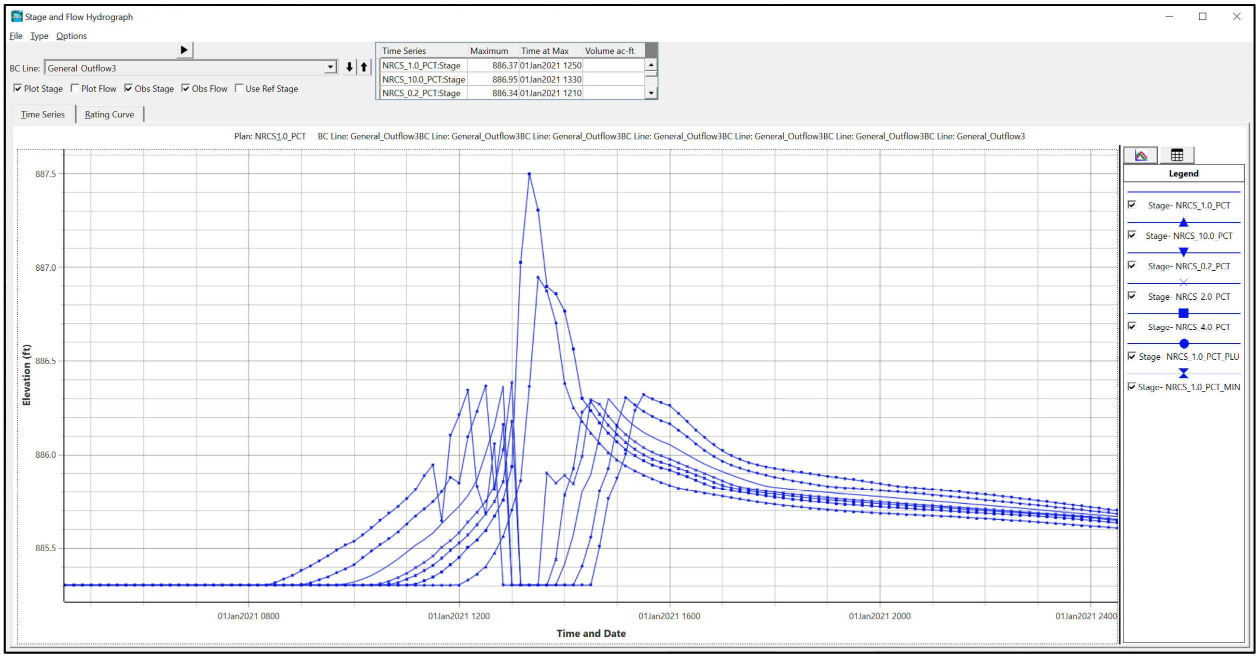


Figure 28: Crossing Stage Hydrographs at General Outflow3 in Domain 0504_A4

These profiles are crossing due to model instabilities during the simulation. The BC line is long (7 miles) and the stage hydrograph is only able to report a single WSEL at each time step even though the elevation along the BC line varies significantly across the line. Note that WSELs are computed at each cell face along the BC line, but HEC-RAS consolidates them into a single stage at each time step for the stage hydrograph.

These crossing profiles are acceptable because the stages in the stage hydrographs are not used to support any BLE outcomes. The BC lines with these stage hydrographs exist only to allow rain that falls outside of the HUC-10 watershed to leave the model without ponding.

Comparison of 1% BLE Study Outcomes with Effective FEMA Study Outcomes

The Austin-Travis Lakes Watershed is a highly urbanized watershed, especially downstream of Lake Travis. Because of the high amount of development, FEMA has extensively studied and mapped the watershed. Please see Subsection 1.2.10 for a comparison between the BLE outcomes and the FEMA study outcomes in the Austin-Travis Lakes watershed as well as a discussion about why the BLE and FEMA results are different in some locations.

3.0 Results and Recommendations

The BLE floodplain mapping was compared with other floodplain mapping products available in the Austin-Travis Lakes watershed. All of the effective FEMA mapping for the watershed was captured in the in the National Flood Hazard Layer (NFHL) for the watershed, so the BLE mapping was compared with the NFHL mapping.

In general, there was good agreement throughout the watershed between the BLE mapping and the NFHL mapping. For example, Figure 29 shows the area near Lake Travis. The BLE mapping and NFHL mapping in this area line up well.

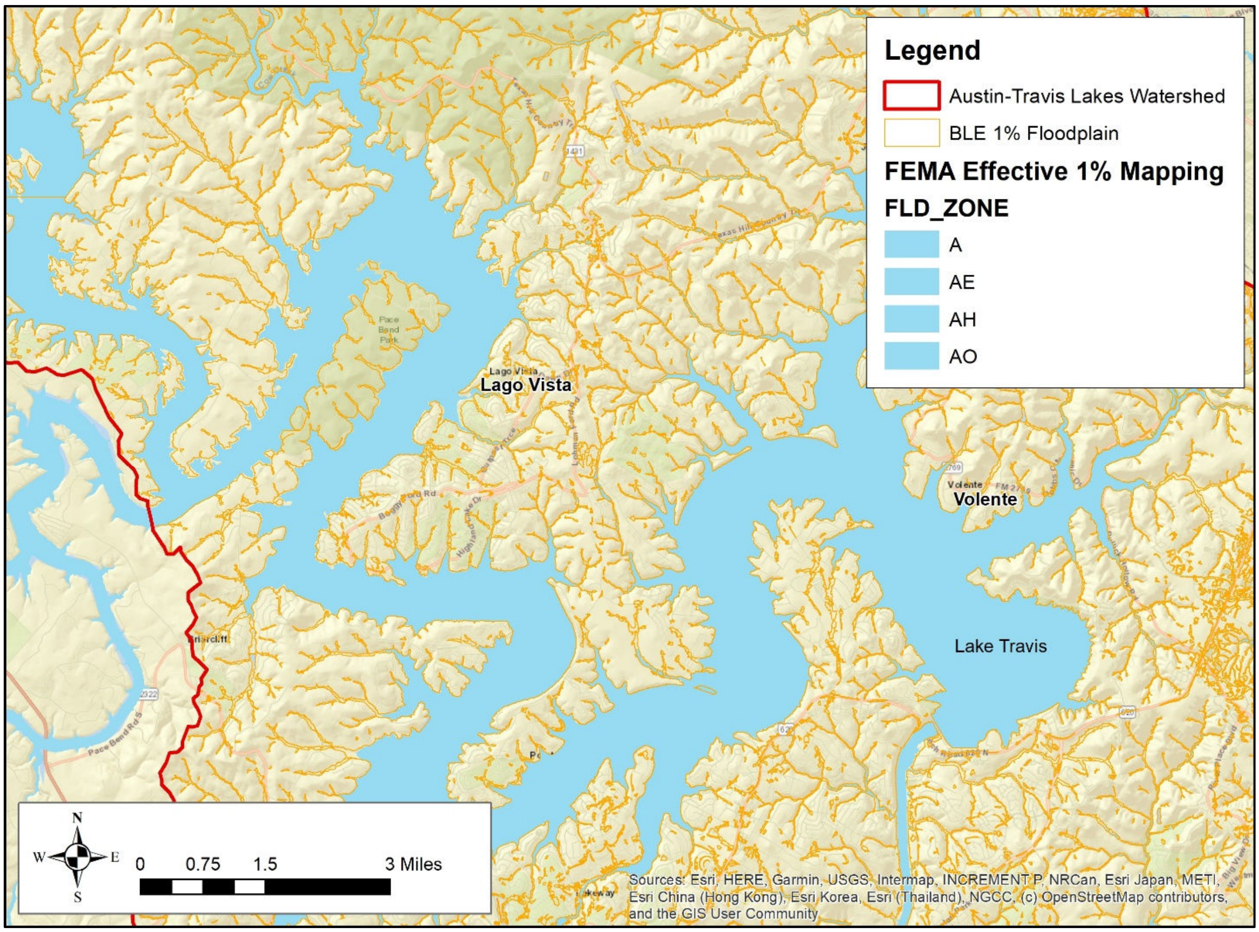


Figure 29: 1% BLE Mapping and 1% NFHL Mapping for Lake Travis

Figure 23 shows the downstream end of the watershed. Again, there is good agreement between the BLE mapping and the NFHL mapping.

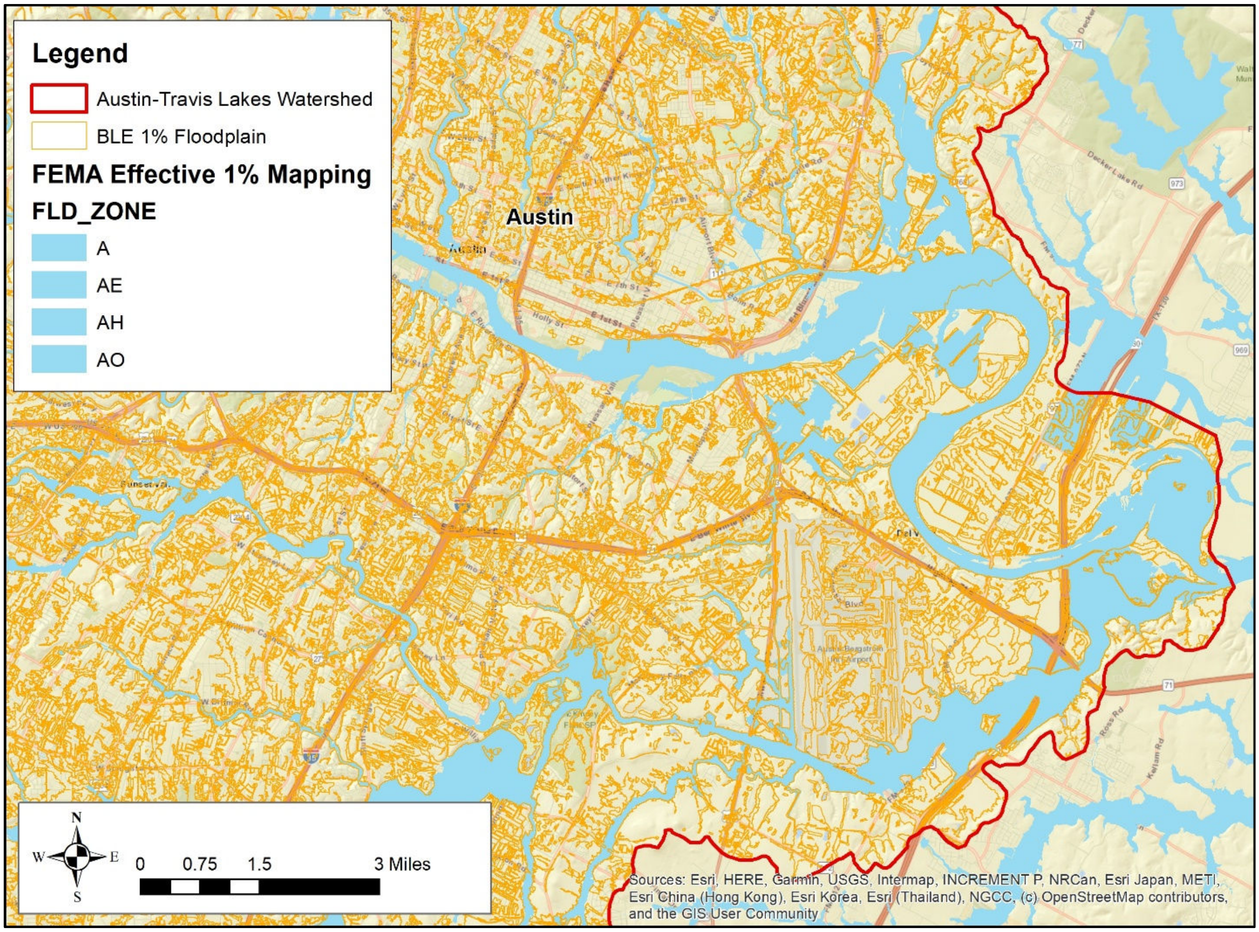


Figure 30: 1% BLE Mapping and 1% NFHL Mapping for Near the Downstream End of the Watershed

Finally, Figure 31 shows the south end of the watershed, including the communities of Bee Cave, Buda, Driftwood, and Dripping Springs. As in the previous two figures, the BLE and NFHL mapping are in good agreement.

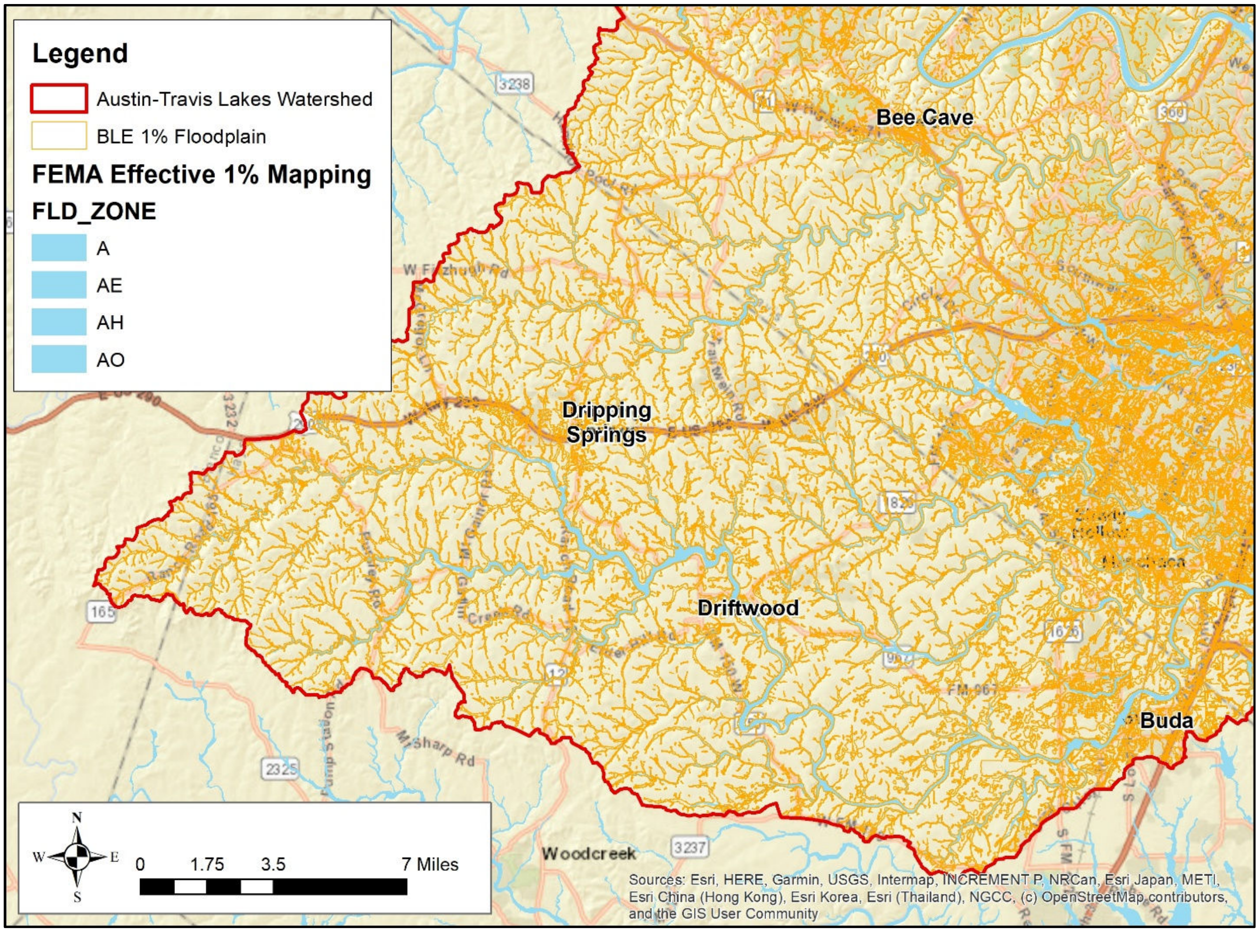


Figure 31: 1% BLE Mapping and 1% NFHL Mapping for in the South End of the Watershed

Floodplain mapping for the Austin-Travis Lakes watershed was also available from a contractor called Fathom. The TWDB acquired cursory floodplain data from Fathom to fill gaps in areas where no floodplain mapping was available in Texas. The Fathom floodplain dataset included pluvial, fluvial, and coastal storm surges produced using models developed at a 30-meter resolution for the entire state of Texas. The 30-meter produced Fathom models incorporated LiDAR data provided by the TWDB and NOAA Atlas 14 rainfall data in all areas of the state. Fathom model results were mapped to a 3-meter resolution. Fluvial and pluvial cells with depths less than 0.5 feet were removed from the results of the mapping dataset. The use of this dataset should be limited to areas where no other data source has been identified or areas where flood hazard information is outdated or unreliable. Limited use of this dataset is recommended due to limitations with accuracy, resolution, and age of the underlying datasets.

The Austin-Travis Lakes watershed has been studied extensively by FEMA so there were not too many places where NFHL mapping was not available. Nonetheless, Figure 32 shows a comparison between the 1% BLE mapping and the 1% Fathom in the area near Buda, Texas. Once again, there is good agreement between the two data sources. The BLE mapping tends to be a little more extensive since it maps pluvial flooding more aggressively than the Fathom mapping does.

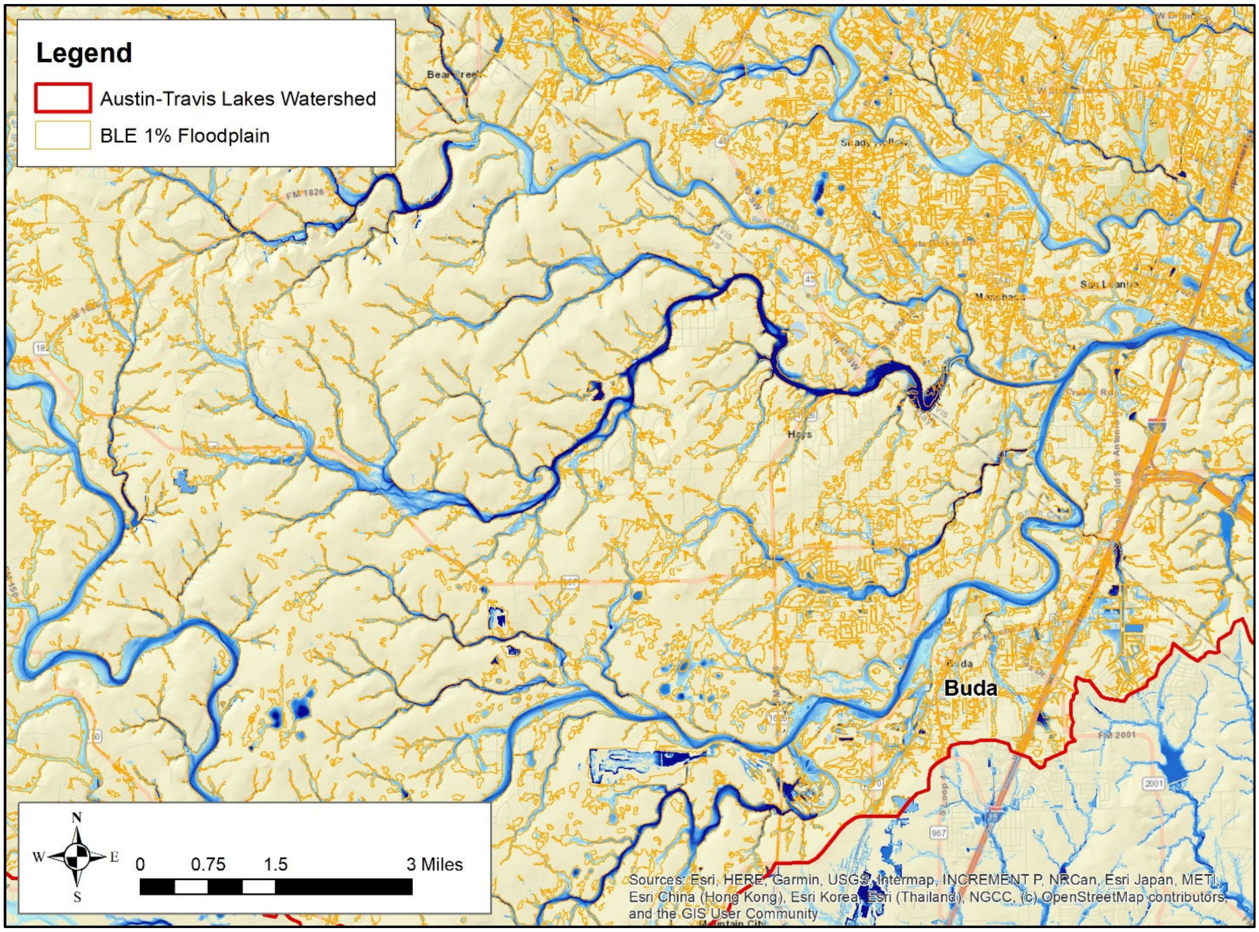


Figure 32: 1% BLE Mapping (Orange) and 1% Fathom Mapping (Blue) Near Buda

A map showing the BLE results for the Austin-Travis Lakes watershed has been included as Appendix A.

As part of the BLE assessment effort, a polygon file was prepared to detail areas where model refinements may be warranted. These areas may be found in the feature class S_AOMI_AR in the mapping database.

3.1 Quality Control

To guide its quality control (QC) reviews, AtkinsRéalis developed three custom QC checklists for its TWDB 2D BLE studies. The checklists were for the terrain processing, the modeling, and the mapping tasks. The terrain processing checklist included 17 items and the modeling checklist included 51 items. The mapping checklist included 20 checks for the spatial data and 244 checks for the attributes in the mapping database. These robust checklists documented the QC review process, capturing reviewer comments and originator feedback throughout the comment resolution process. Checklists were not considered final until reviewed and approved by project leadership.

A major component of the QC process was an automated check that identified locations where the 1% annual-chance WSELs were crossed by another frequency or by the 1% plus or 1% minus profile. Significant effort was made to reasonably resolve all of these instances.

An Independent Technical Review (ITR) was completed on all BLE deliverables by a representative of the TWDB. AtkinsRéalis resolved all ITR comments prior to uploading the project deliverables to the MIP.

3.2 CNMS Validation of Effective Zone A Special Flood Hazard Area

Approximately half (338.3 miles) of the Zone A streams in the Austin-Travis Lakes watershed were classified as “UNVERIFIED” with a status type of “BEING STUDIED.” The other 345.6 miles of Zone A streams were classified as “VALID” with a status type of “BEING STUDIED.” No streams were classified as “VALID” with a status type of “NVUE COMPLIANT.”

Initial Assessment A1 – Significant Topography Update Check

This check involved determining whether a topographic data source was available that was significantly better than that used for the effective Zone A modeling and mapping. For the Austin-Travis Lakes watershed, USGS 1:24,000-scale topographic maps were used for the effective Zone A analysis. The LiDAR data used in the BLE analysis was a significant improvement over the effective data. Therefore, the A1 check failed for all effective Zone A reaches.

Initial Assessment A2 – Check for Significant Hydrology Changes

This check involved first determining whether regression equations were used in the effective study. If they were, then it was determined whether new regression equations had become available since the date of the effective Zone A study. If newer regression equations existed for the area of interest, then an engineer determined whether these regression equations would significantly affect the 1% annual-chance flow. Most of the effective hydrologic analysis (495.7 miles) was based on a regression analysis, therefore the A2 check was set to fail. The rest of the effective reaches were set to pass.

Initial Assessment A3 – Check for Significant Development

This check involved using the National Urban Change Indicator (NUCI) dataset to assess increased urbanization in the HUC-12 watersheds with Zone A studies. If the percentage of urban area within the watershed containing the effective Zone A study was 15% or more, and had increased by 50% or more since the effective analysis, then the study would fail this check. Although the NUCI data provided year-to-year changes in urbanization, the NLCD also was needed to establish a baseline of urban land cover for this analysis. This watershed is generally rural with few villages, and there has not been significant development in the watershed. A significant development check for the study areas was carried out using the NUCI dataset, which did not meet the urban change criteria. Therefore, the A3 check was set to pass for all reaches.

Table 24: Zone A Initial Assessment Results

Assessment Check	Pass/Fail	Comments/Notes
A1 - Topography	Fail	The LiDAR terrain data is a significant improvement over the terrain data used to develop the effective mapping.
A2 - Hydrology	Pass 19.5% Fail 80.5%	Most of the effective hydrologic analysis was regression based.
A3 - Development	Pass	No significant development has occurred in the study area.

Initial Assessment A4 – Check of Studies Backed by Technical Data

Zone A studies that passed all of the initial assessment checks described above were categorized as "Valid" in the CNMS Inventory when the effective Zone A study was supported by modeling or sound engineering judgment and all regulatory products were in agreement. If the effective Zone A study passed all initial assessment checks but was not supported by modeling, or if the original engineering method used was unsupported or undocumented, then a comparison of the BLE results and effective Zone A mapping was performed. Approximately 185.8 miles of effective reaches had no adequate documentation regarding how the engineering analysis supported the effective study. Therefore, the A4 check was marked as fail. The majority (498.1 miles) of the effective reaches were set to pass as there was adequate documentation for the engineering analysis.

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

A comparison was made between the effective Zone A mapping in the watershed and the BLE 1% ACE mapping. This comparison leveraged the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach used the 1% plus and 1% minus flood extents and the horizontal and vertical tolerances described in the *CNMS Technical Reference*. For the comparison of the BLE mapping and effective Zone A mapping in the study area, the following vertical and horizontal tolerances were used to conduct the modified FBS procedure. These comparisons were made at points spaced at a 100-foot interval along the outer extents of the effective Zone A mapping.

Vertical Tolerance: Plus or minus 2.5 or 5 feet (one-half contour interval of assumed effective topographic source). See the shapefile USGS_24K_Index.shp in the Supplemental data folder to see how the vertical tolerance varied throughout the watershed.

Horizontal Tolerance: Plus or minus 75 feet (standard horizontal tolerance for BLE comparison testing).

The terrain data used to complete Initial Assessment A5 was the terrain surface created from the LiDAR data that was acquired for the Austin-Travis Lakes BLE analysis.

The contour interval for the vertical tolerance was taken from the USGS 1:24,000-scale topographic maps of the Austin-Travis Lakes watershed.

The source of the effective Zone A mapping was FEMA's NFHL and mapping that was digitized from FEMA's paper FIRMs.

See Table 26 for a summary of the outcomes of Initial Assessment A5.

CNMS Validation Results

Based on the validation assessments and BLE comparisons described above, the CNMS inventory of the Zone A studies in the Austin-Travis Lakes watershed has been updated. The total miles in each of these categories are summarized in Table 25 and illustrated on Figure 33. The findings from Initial Assessment A5 are in Table 26.

Table 25: Zone A Validation Results

Validation Status	CNMS Validation Status	CNMS Project Start	CNMS Post-BLE Assessment
VALID	NVUE COMPLIANT	500.6	0
	BEING STUDIED	181.6	345.6
UNVERIFIED	BEING STUDIED	0	338.3
	TO BE STUDIED	4.1	0

Table 26: BLE Comparison Results

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>95%)
Watershed Name	HUC-12 ID					
Backbone Creek	120902050101	7,393	260	7,133	96.5%	Pass
Flatrock Creek-Lake Travis	120902050102	2,381	19	2,362	99.2%	Pass
Lake Marble Falls	120902050103	1,642	130	1,512	92.1%	Fail
Headwaters Hamilton Creek	120902050104	4,756	267	4,489	94.4%	Fail
Hairston Creek	120902050105	1,309	3	1,306	99.8%	Pass
Hamilton Creek-Lake Travis	120902050106	2,415	401	2,014	83.4%	Fail
Sycamore Creek-Lake Travis	120902050107	1,328	194	1,134	85.4%	Fail
Double Horn Creek-Lake Travis	120902050108	2,022	271	1,751	86.6%	Fail
Hickory Creek-Lake Travis	120902050201	2,410	83	2,327	96.6%	Pass
Little Cypress Creek-Lake Travis	120902050202	4,370	58	4,312	98.7%	Pass
Post Oak Creek-Lake Travis	120902050203	4,819	87	4,732	98.2%	Pass
Bee Creek-Lake Travis	120902050204	1,400	15	1,385	98.9%	Pass
Big Sandy Creek	120902050205	6,059	72	5,987	98.8%	Pass
Hurst Creek-Lake Travis	120902050206	2,166	45	2,121	97.9%	Pass
Cypress Creek-Lake Travis	120902050207	983	9	974	99.1%	Pass
Headwaters Lake Austin	120902050301	4,498	405	4,093	91.0%	Fail
Bull Creek-Lake Austion	120902050302	2,686	151	2,535	94.4%	Fail
Headwaters Barton Creek	120902050303	5,720	768	4,952	86.6%	Fail

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass? (>95%)
Watershed Name	HUC-12 ID					
Little Barton Creek-Barton Creek	120902050304	4,799	59	4,740	98.8%	Pass
Lake Austin-Town Lake	120902050305	5,446	259	5,187	95.2%	Pass
Town Lake-Colorado River	120902050306	45	4	41	91.1%	Fail
Walnut Creek-Colorado River	120902050307	768	139	629	81.9%	Fail
Headwaters Onion Creek	120902050401	3,624	803	2,821	77.8%	Fail
South Onion Creek	120902050402	1,923	545	1,378	71.7%	Fail
Gatlin Creek-Onion Creek	120902050403	2,677	469	2,208	82.5%	Fail
Yorks Creek-Onion Creek	120902050404	4,122	1,286	2,836	68.8%	Fail
Mustang Branch-Onion Creek	120902050405	5,254	1,482	3,772	71.8%	Fail
Bear Creek	120902050406	6,017	1,286	4,731	78.6%	Fail
Slaughter Creek-Onion Creek	120902050407	1,492	77	1,415	94.8%	Fail
Williamson Creek-Onion Creek	120902050408	321	5	316	98.4%	Pass
Carson Creek-Colorado River	120902050409	1,610	419	1,191	74.0%	Fail

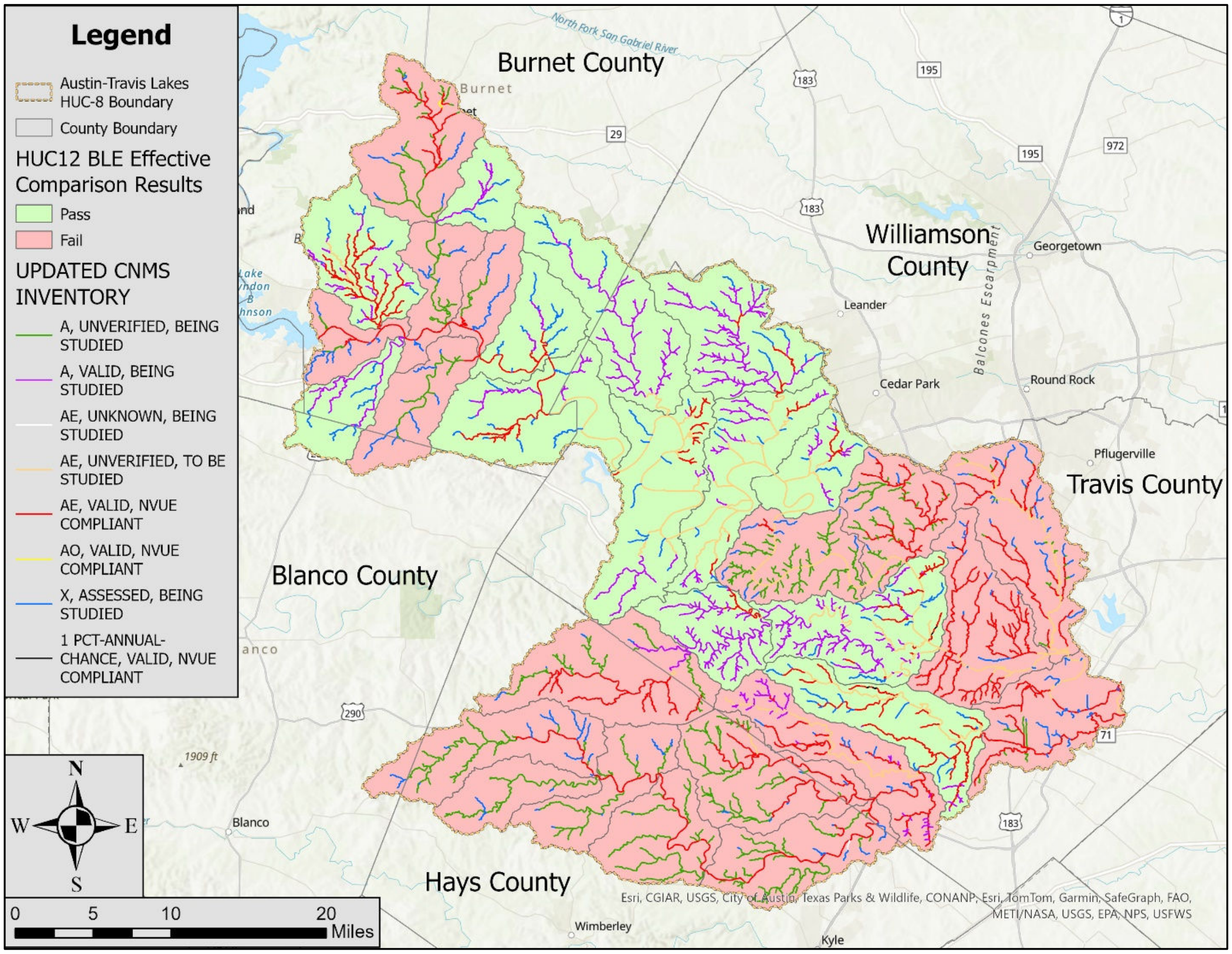


Figure 33: CNMS Validation Results

3.3 Flood Risk Analysis

A flood risk analysis was performed for the Austin-Travis Lakes watershed. This analysis was completed using Hazus Version 5.1. Flood losses were based on the 1% annual-chance depth grids from the BLE analysis.

Additional inputs for the analysis were as follows.

S_AOMI_Ar

AoMIs are Areas of Mitigation Interest. This polygon feature class is intended to be used as a communication tool to direct users to areas that warrant further investigation or research for possible mitigation. The intent of this coverage area is to allow a visualization and depiction of areas that may be refined in future local, state, regional, or federal modeling efforts.

Areas typically identified by this feature class include:

- Areas of significant land use change – The source of land use data for this BLE assessment was the 2019 NLCD. The land uses captured by this database were compared with the land uses shown in the aerial imagery available in Google Earth when the floodplain mapping was being developed. Areas where the land use had changed significantly since 2019 were documented in the feature class.

- Intersections of significant streams with major roadways – Since structures were not explicitly included in the BLE models, these areas were identified as areas where additional analysis may be useful for refining the outcomes of the BLE study.
- Floodplain mapping tie-ins along the HUC-8 watershed boundary – Along the HUC-8 watershed boundaries where AtkinsRéalis completed BLE assessments for both watersheds, the floodplain mapping includes smooth tie-ins across the watershed boundaries. Along those HUC-8 watershed boundaries where AtkinsRéalis did not study both watersheds, the mapping tie-ins could not be smoothed since the BLE floodplain mapping in the neighboring watershed was not available. AoMIs were placed along these HUC-8 watershed boundaries to identify those tie-ins that potentially could be refined by a future modeling effort.

S_AOMI_Pt

This point feature class depicts hydraulic structures (e.g., bridges, culverts, dams, etc.), highwater marks, and low water crossings. Hydraulic structures data was obtained from available Texas GIS data sites. Essential facilities such as schools, police stations, and emergency centers were obtained from the Hazus essential facilities inventory.

Outputs from the analysis were as follows.

S_FRACT_Ar

This is the flood risk assessment polygon feature class. It is the output for a flood level 2 analysis using Hazus Version 5.1, which is based on a 1% annual-chance depth grid. The calculated loss results from Hazus are stored in the polygon feature and are based on dasymetric census blocks. Dasymetric census blocks have had additional “undeveloped” land areas (primarily wetlands and forest) clipped out of the original census block boundaries based on USGS land use/land cover data. Loss values are reported in whole dollar amounts. See Table 27 below for a summary of the losses computed by Hazus.

L_Source_Cit

The data sources used for S_AOMI_Pt and S_AOMI_AR are documented in the L_Source_Cit table.

Table 27: Hazus Results for the Austin-Travis Lakes Watershed

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Blanco County	$2,031,000	$56,139,000	$29,023,000
Burnet County	$594,529,000	$2,519,124,000	$1,536,534,000
Hays County	$499,283,000	$5,503,388,000	$3,086,098,000
Llano County	$0	$197,000	$98,000
Travis County	$25,619,813,000	$103,827,578,000	$66,304,045,000
Williamson County	$91,701,000	$1,318,320,000	$808,523,000
Total	**$26,807,357,000**	**$113,224,746,000**	**$71,764,321,000**

4.0 References

This section includes a bibliographic list of the documents referenced throughout this document or used in the preparation of the BLE analysis.

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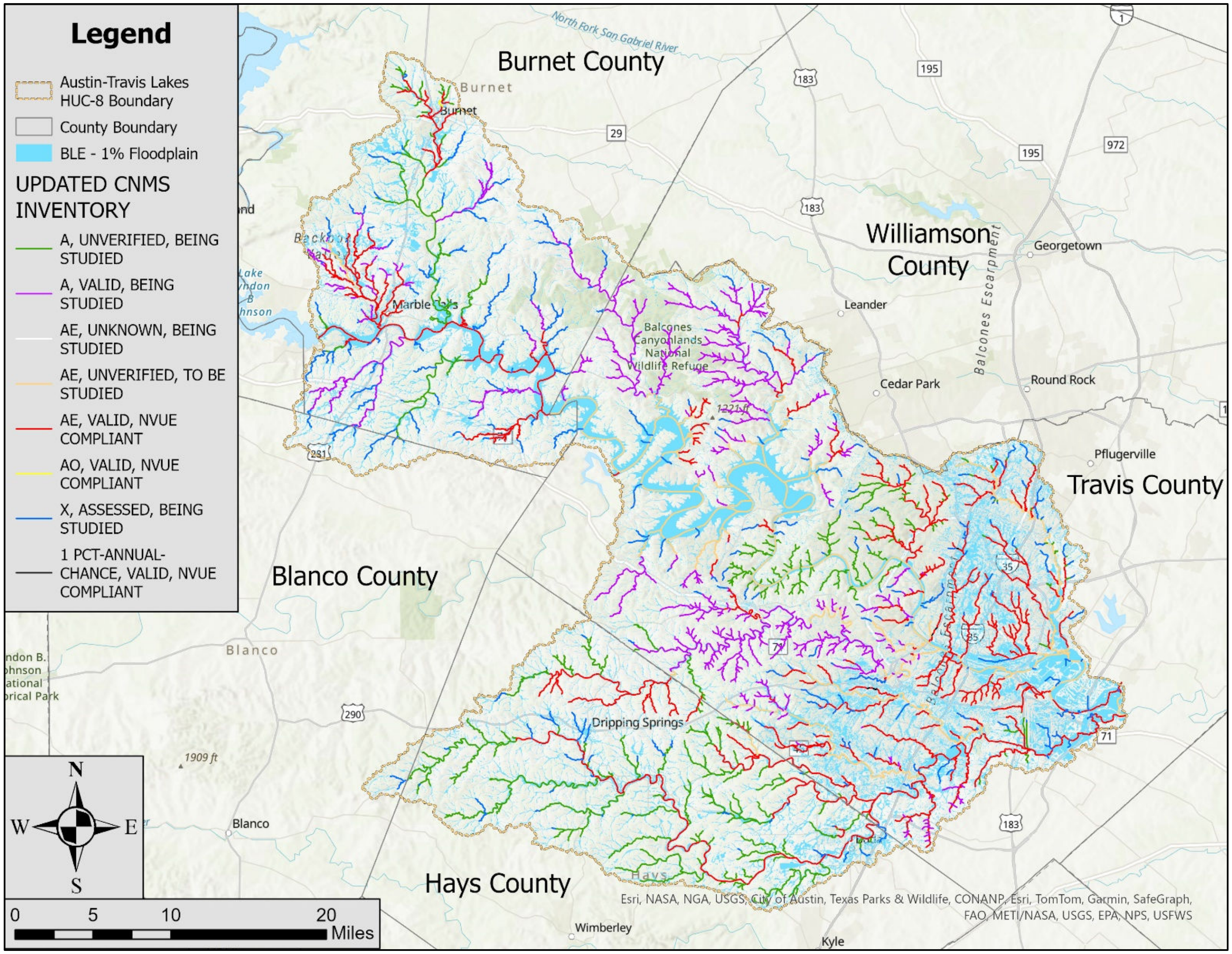
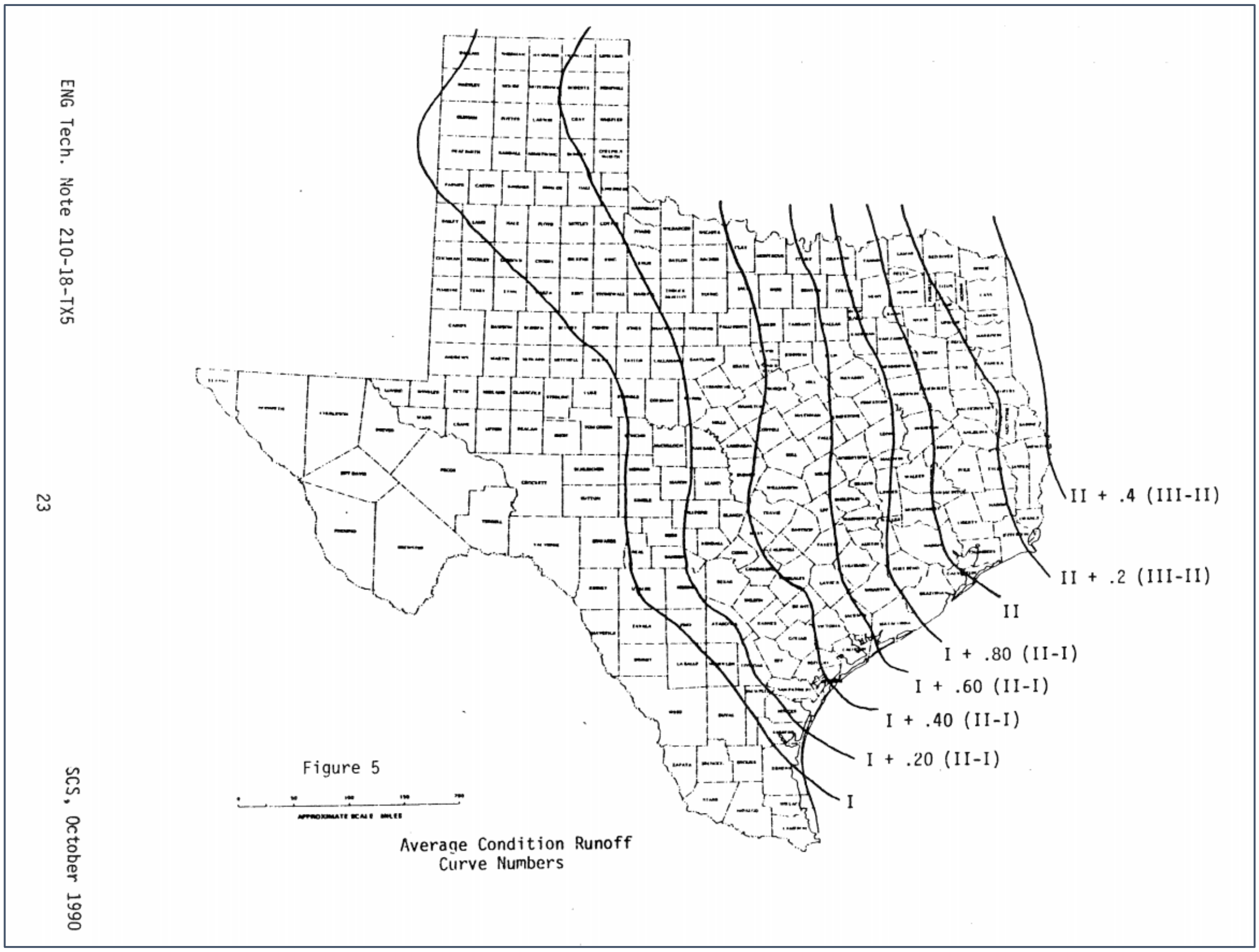
Appendix A: Base Level Engineering Results



Appendix B: Supporting Documentation

The following information may be found in Appendix B. These documents provide further details regarding the methodology and outcomes of the BLE analysis for the Austin-Travis Lakes watershed.

- Page 23 from Engineering Technical Note No. 210-18-TX5 titled Estimating Runoff For Conservation Practices – This is an excerpt showing a map of Average Runoff Conditions (ARC) across Texas. The term Antecedent Runoff Condition (ARC) used in the older literature is analogous to Antecedent Moisture Condition (AMC), which is the term that is commonly accepted today.



- Pages 112-130, 146, 153, 189, 190, and 200 from Chapter 5 of the InFRM team's draft *Watershed Hydrology Assessment for the Lower Colorado River Basin.* This is an excerpt from a draft copy of this report. This excerpt includes the gages analysis for thirteen of the USGS gages included in the Austin-Travis Lakes analysis.

- Pages 55 through 57 and 61 through 63 from the Colorado RFA draft report. This is an excerpt from a draft copy of this report. This excerpt includes the data for the Lake Buchanan and Lake LBJ Reservoirs. The HEC-HMS Peak Outflow analysis for Lake LBJ is shown in the table below.

Return Int (yrs)	ACE (%)	Estimated Peak Outflow (cfs)
500	0.2	650,000
200	0.5	480,000
100	1	375,000
50	2	242,000
25	4	149,000
10	10	71,000
5	20	48,000

08154700 Bull Creek at Loop 360 near Austin, Tex.

The period of record at USGS station 08154700 Bull Creek at Loop 360 near Austin, Tex. (hereinafter referred to as the "Bull Creek near Austin gage") was from 1979 through 2020 (USGS, 2020). The Pettitt test does not detect a change point in the gaged record, nor does the Kendall's Tau test find a statistically significant trend in the annual peak streamflow data.

The largest peak in the gaged record for the Bull Creek near Austin gage is the 2010 peak discharge of 16,900 cfs at a stage of 14.97 ft. The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.88. The flood flow frequency for the Bull Creek near Austin gage is shown in Figure 5.89. The figure is exported from PeakFQ (USGS, 2014), and plots annual peak discharge vs. AEP in percent. The low-outlier threshold was manually set at 1,270 cfs, and nine PILFs were removed.

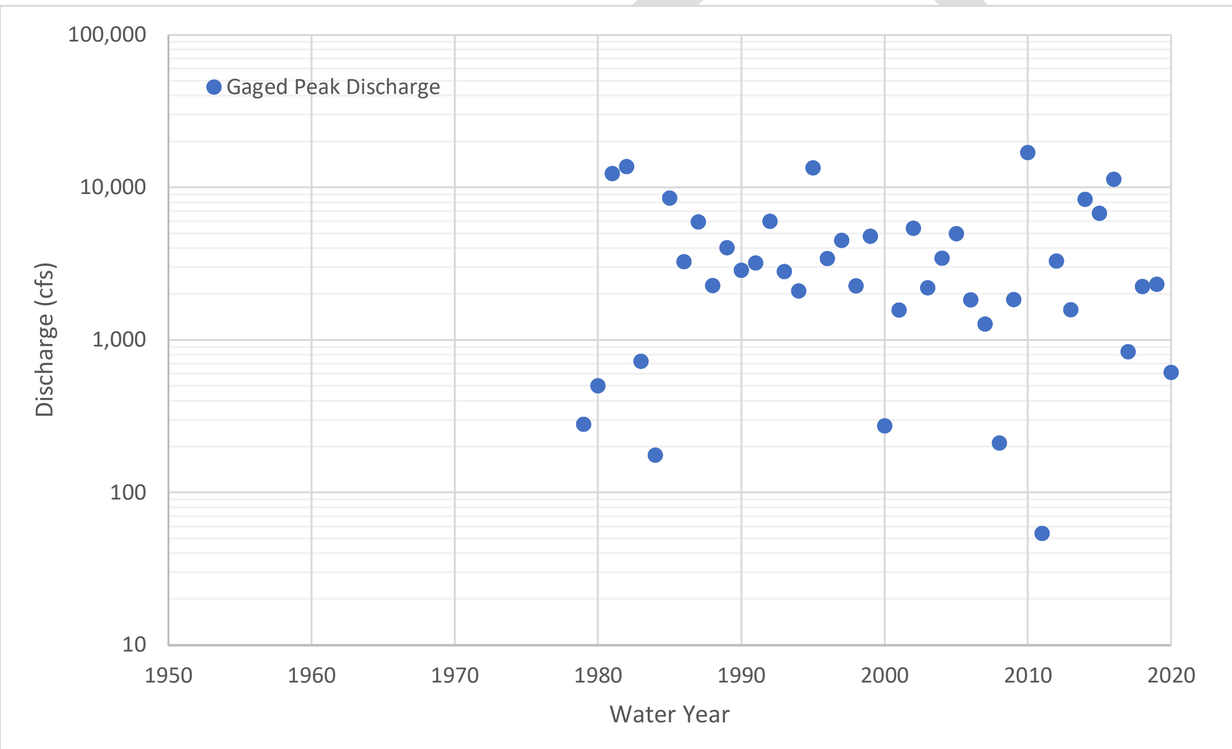


Figure 5.88: Annual Peak Discharge Data for U.S. Geological Survey Streamgaging Station 08154700 Bull Creek at Loop 360 near Austin, Tex.

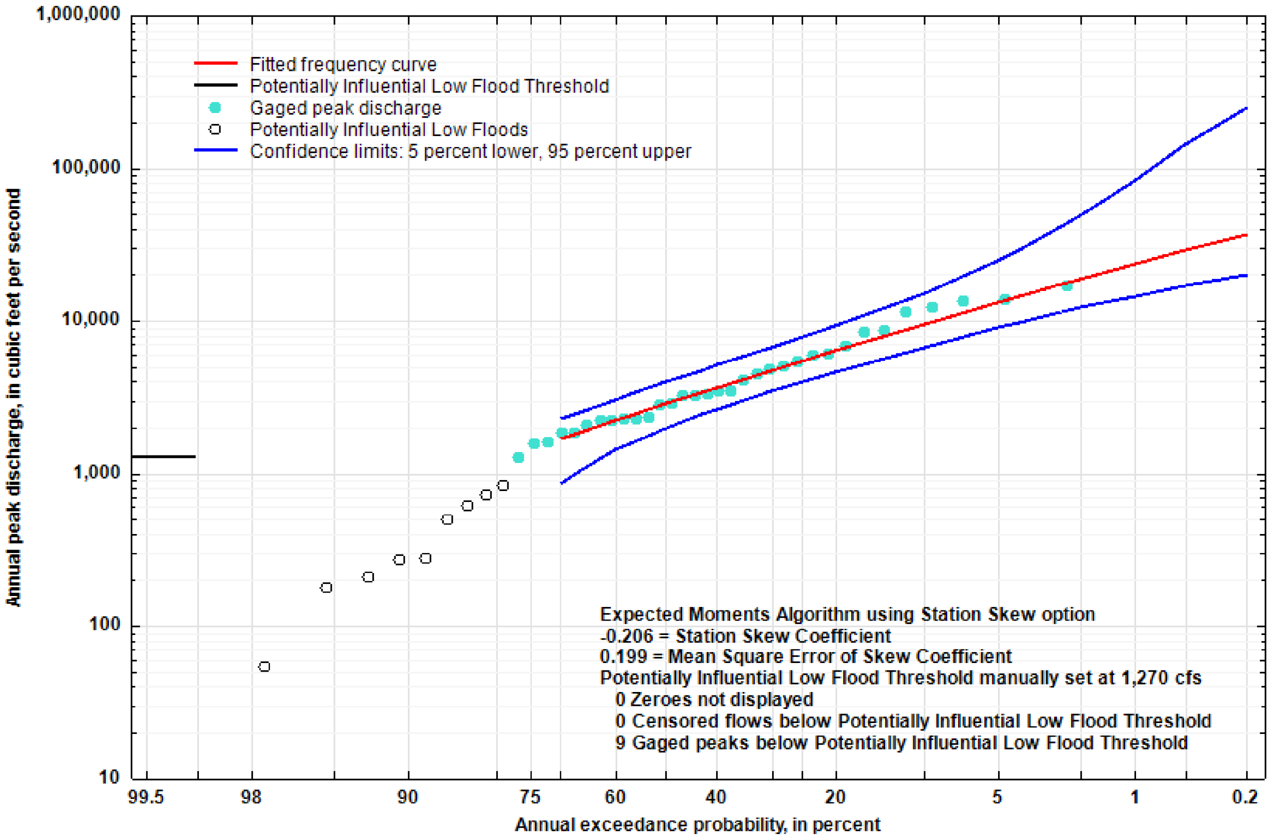


Figure 5.89: Flood Flow Frequency Curve for U.S. Geological Survey Streamgaging Station 08154700 Bull Creek at Loop 360 near Austin, Tex.

08155200 Barton Creek at SH 71 near Oak Hill, Tex.

The period of record at USGS station 08155200 Barton Creek at SH 71 near Oak Hill, Tex. (hereinafter referred to as the "Barton Creek near Oak Hill gage") was from 1976 through 2020 (USGS, 2020). The gaged record is missing from 1983 through 1998, and a perception threshold of 25,300 cfs was set for that time period to fill that gap. The Pettitt test does not detect a change point in the gaged record, nor does the Kendall's Tau test find a statistically significant trend in the annual peak streamflow data.

The largest peak in the gaged record for the Barton Creek near Oak Hill gage is the 2019 peak discharge of 24,400 cfs at a stage of 24.24 ft. The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.90. The flood flow frequency for the Barton Creek near Oak Hill gage is shown in Figure 5.91. The figure is exported from PeakFQ (USGS, 2014), and plots annual peak discharge vs. AEP in percent. The low-outlier threshold was manually set at 363 cfs, and six PILFs were removed.

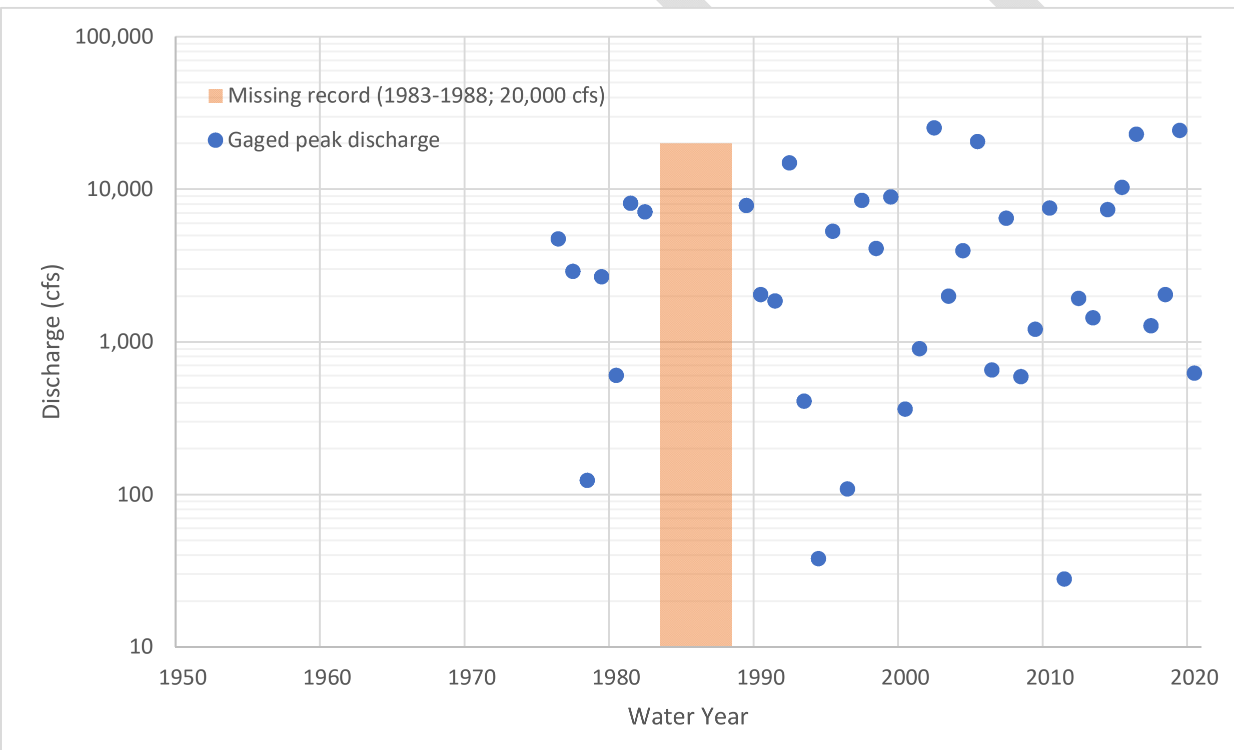


Figure 5.90: Annual Peak Discharge Data for U.S. Geological Survey Streamgaging Station 08155200 Barton Creek at SH 71 near Oak Hill, Tex.

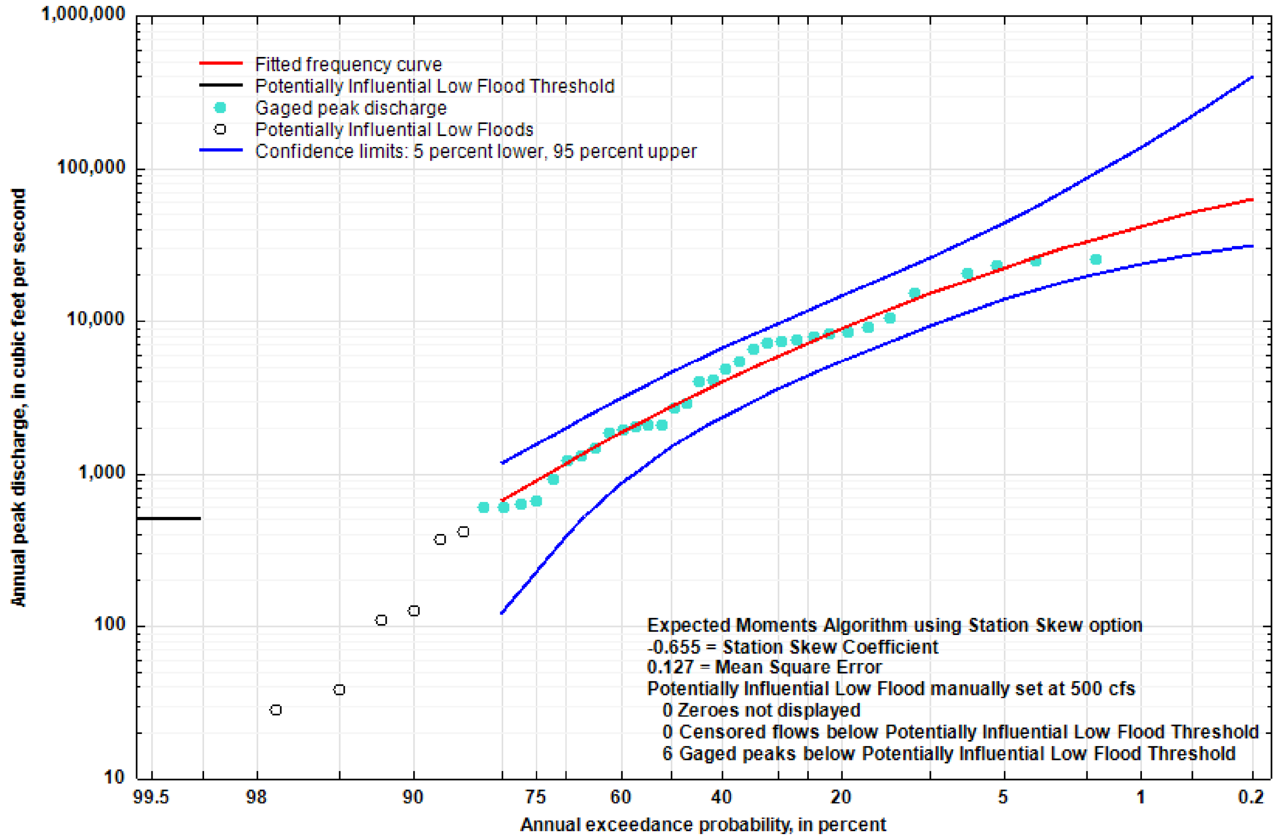


Figure 5.91: Flood Flow Frequency Curve for U.S. Geological Survey Streamgaging Station 08155200 Barton Creek at SH 71 near Oak Hill, Tex.

08155240 Barton Creek at Lost Creek Blvd. near Austin, Tex.

The period of record at USGS station 08155240 Barton Creek at Lost Creek Blvd. near Austin, Tex. (hereinafter referred to as the "Barton Creek at Lost Creek Blvd. gage") was from 1989 through 2020 (USGS, 2020). A historical peak discharge of 39,400 cfs is available for 1929, and a perception threshold of that value was set for the time period between that historic peak and the beginning of gaged record in 1989. The Pettitt test does not detect a change point in the gaged record, nor does the Kendall's Tau test find a statistically significant trend in the annual peak streamflow data.

The largest peak in the gaged record for the Barton Creek at Lost Creek Blvd. gage is the 2002 peak discharge of 26,600 cfs at a stage of 15.90 ft. The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.92. The flood flow frequency for the Barton Creek at Lost Creek Blvd. gage is shown in Figure 5.93. The figure is exported from PeakFQ (USGS, 2014), and plots annual peak discharge vs. AEP in percent. No PILFs were identified by the PeakFQ software.

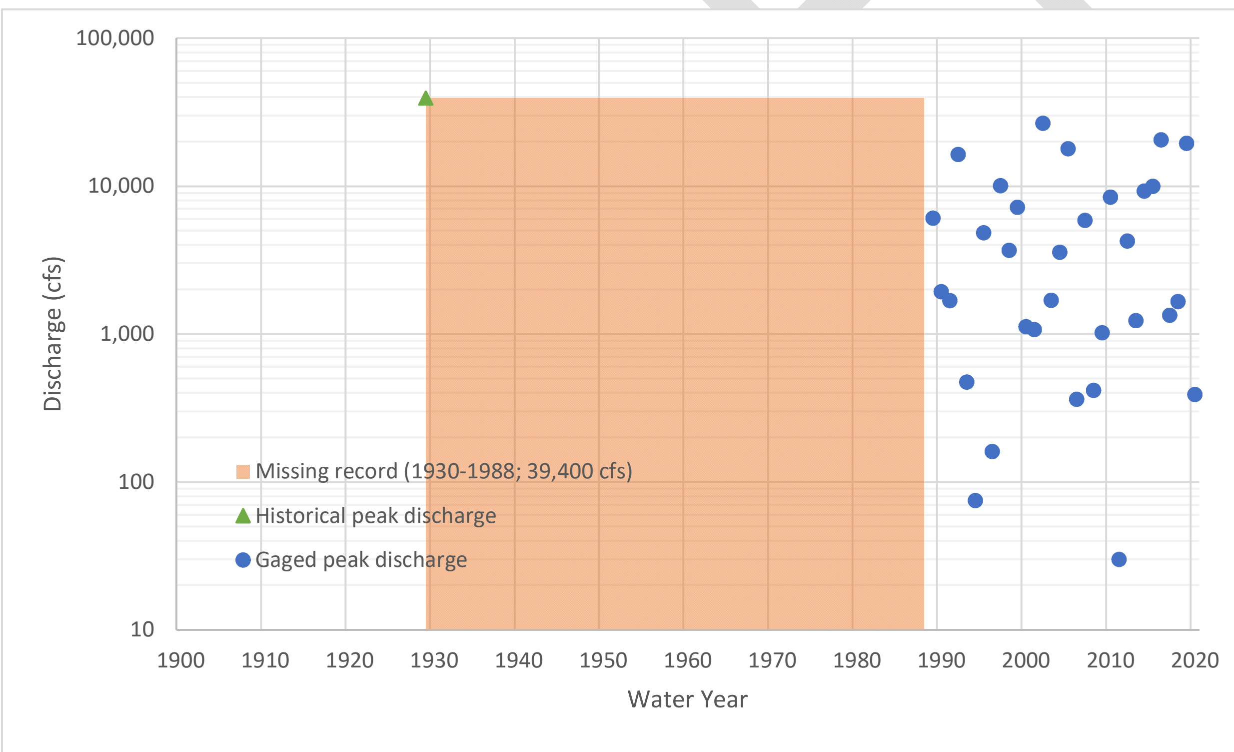


Figure 5.92: Annual Peak Discharge Data for U.S. Geological Survey Streamgaging Station 08155240 Barton Creek at Lost Creek Boulevard near Austin, Tex.

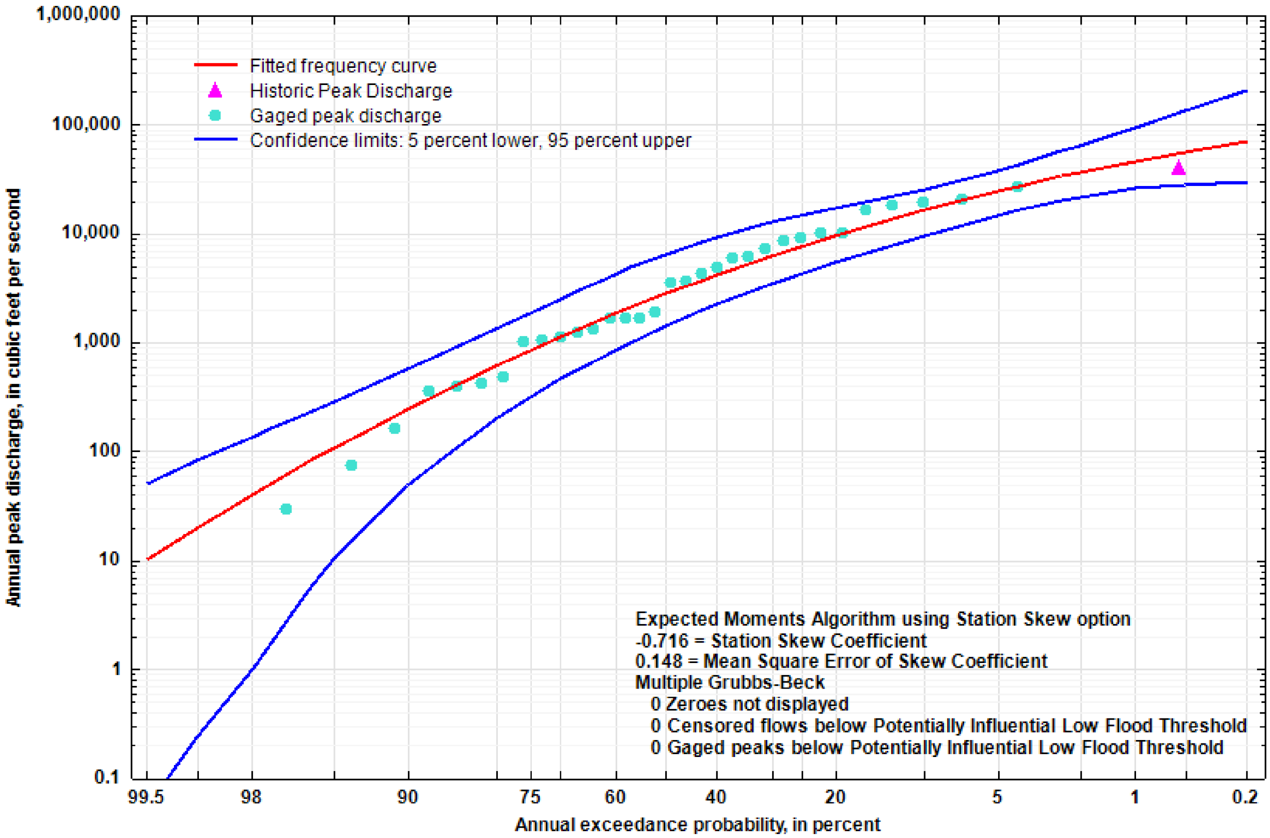


Figure 5.93: Flood Flow Frequency Curve for U.S. Geological Survey Streamgaging Station 08155240 Barton Creek at Lost Creek Boulevard near Austin, Tex.

08155300 Barton Creek at Loop 360, Austin, Tex.

The period of record at USGS station 08155300 Barton Creek at Loop 360, Austin, Tex. (hereinafter referred to as the "Barton Creek at Loop 360 gage") was from 1976 through 2020 (USGS, 2020). A historical peak discharge of 39,400 cfs is available for 1929, and a perception threshold of that value was set for the time period between that historic peak and the beginning of gaged record in 1989. The Pettitt test does not detect a change point in the gaged record, nor does the Kendall's Tau test find a statistically significant trend in the annual peak streamflow data.

The largest peak in the gaged record for the Barton Creek at Loop 360 gage is the 2016 peak discharge of 20,100 cfs at a stage of 19.38 ft. The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.94. The flood flow frequency for the Barton Creek at Loop 360 gage is shown in Figure 5.95. The figure is exported from PeakFQ (USGS, 2014), and plots annual peak discharge vs. AEP in percent. The low-outlier threshold was set by PeakFQ at 2,080 cfs, and 18 PILFs were removed.

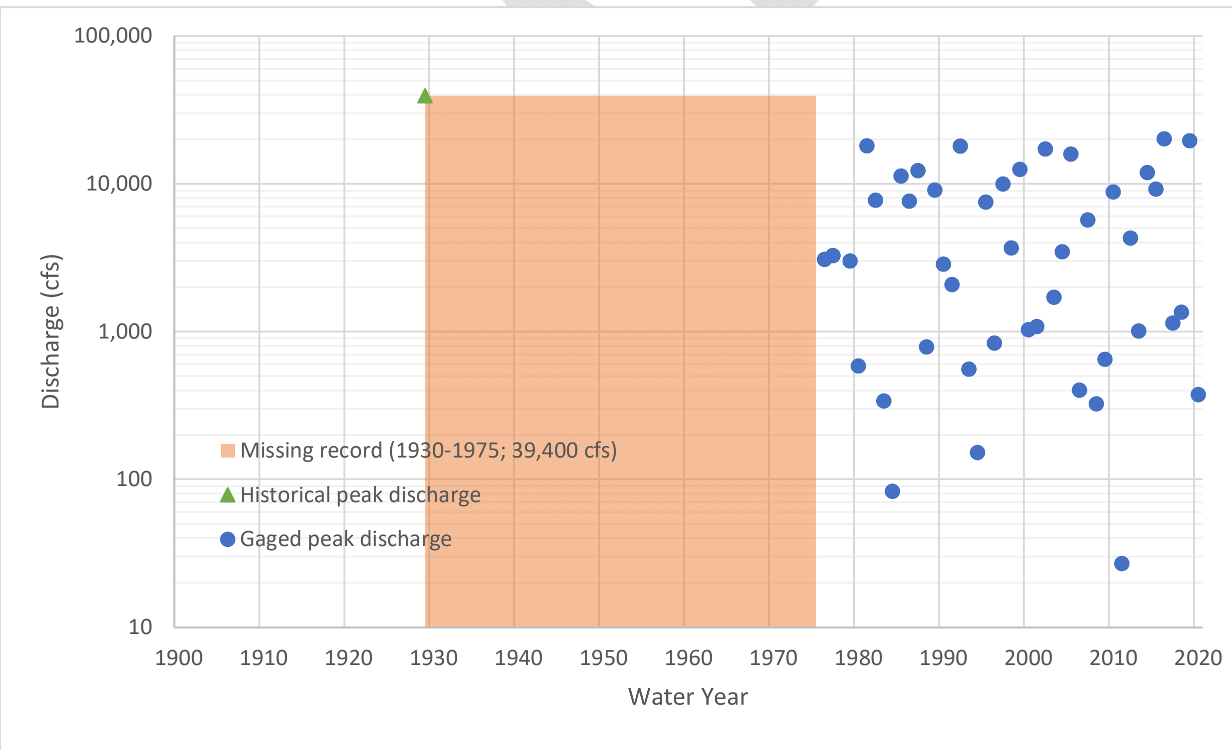


Figure 5.94: Annual Peak Discharge Data for U.S. Geological Survey Streamgaging Station 08155300 Barton Creek at Loop 360, Austin, Tex.

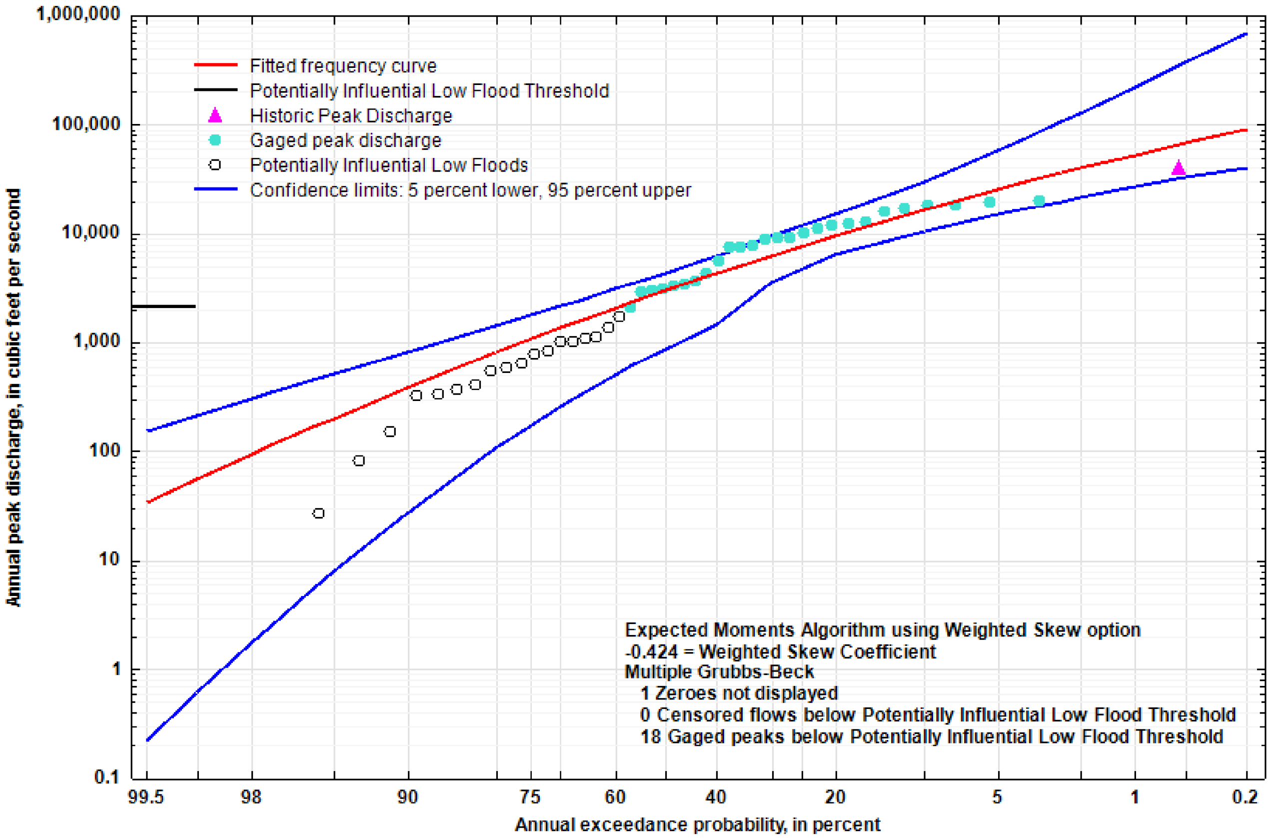


Figure 5.95: Flood Flow Frequency Curve for U.S. Geological Survey Streamgaging Station 08155300 Barton Creek at Loop 360, Austin, Tex.

08155400 Barton Creek above Barton Springs at Austin, Tex.

The period of record at USGS station 08155400 Barton Creek above Barton Springs at Austin, Tex. (hereinafter referred to as the “Barton Creek above Barton Springs gage”) was from 1999 through 2020 (USGS, 2020). The Pettitt test does not detect a change point in the gaged record, nor does the Kendall’s Tau test find a statistically significant trend in the annual peak streamflow data.

The largest peak in the gaged record for the Barton Creek at Loop 360 gage is the 2016 peak discharge of 19,400 cfs at a stage of 18.90 ft. The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.96. The flood flow frequency for the Barton Creek above Barton Springs gage is shown in Figure 5.97. Because the period of record is so short (22 years), the skew was weighted by a regional skew value (Table 5.1). The figure is exported from PeakFQ (USGS, 2014), and plots annual peak discharge vs. AEP in percent. No low outliers were identified by the PeakFQ software.

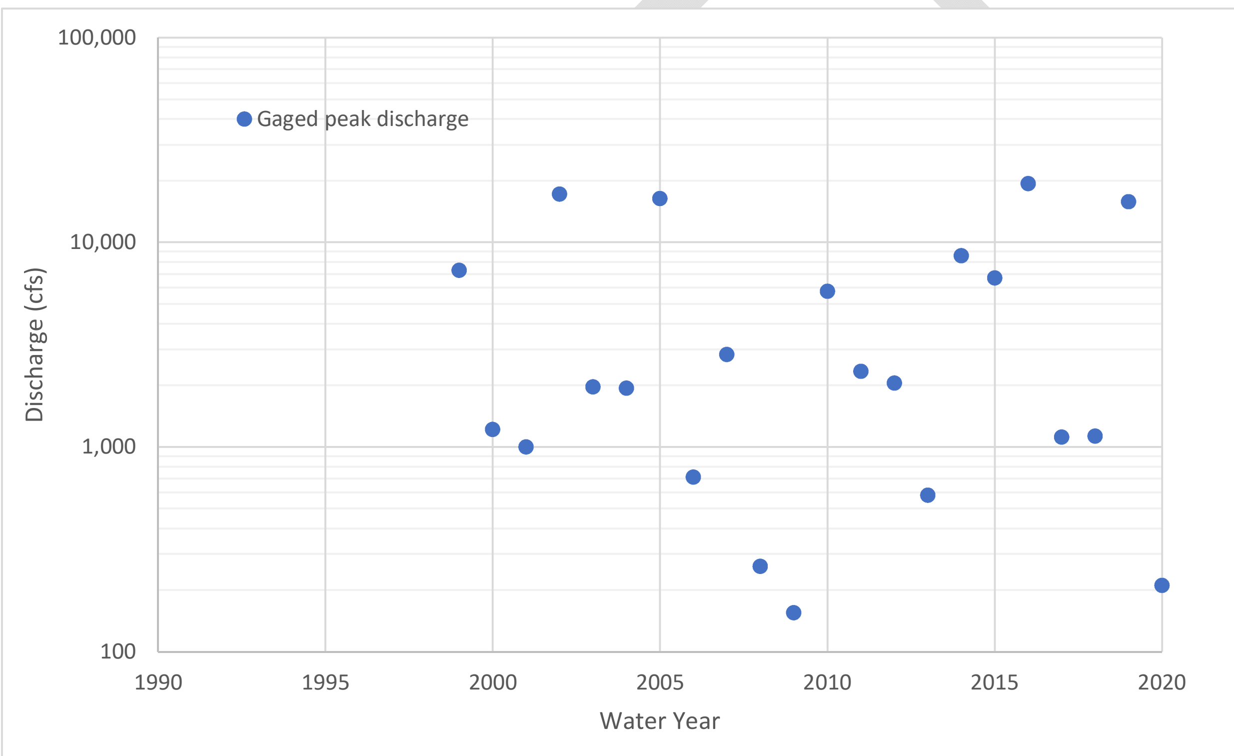


Figure 5.96: Annual Peak Discharge Data for U.S. Geological Survey Streamgaging Station 08155400 Barton Creek above Barton Springs at Austin, Tex.

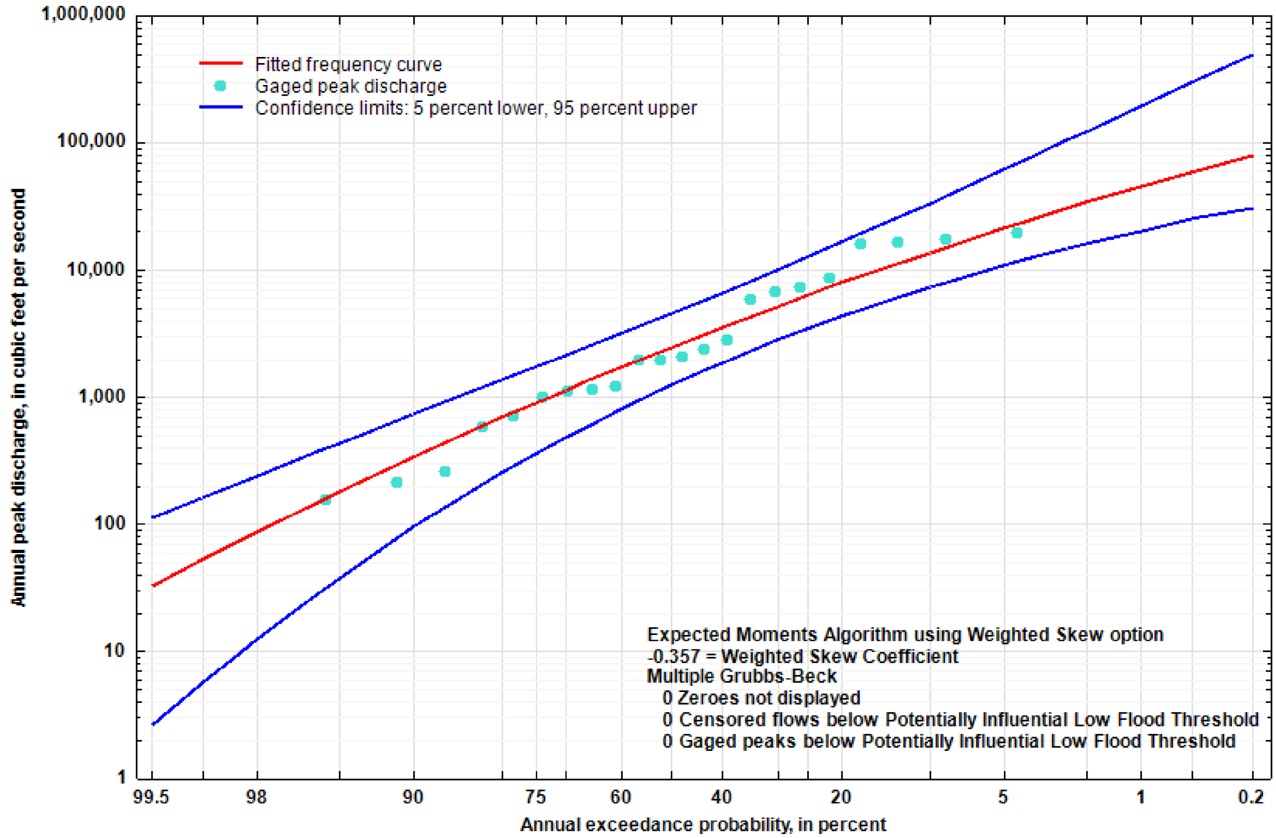


Figure 5.97: Flood Flow Frequency Curve for U.S. Geological Survey Streamgaging Station 08155400 Barton Creek above Barton Springs at Austin, Tex.

08158000 Colorado River at Austin, Tex.

The period of record at USGS station 08158000 Colorado River at Austin, Tex. (hereinafter referred to as the "Colorado River at Austin gage") was from 1898 through 2020 (USGS, 2020). The Pettitt test detects a change point in water year 1942, somewhat coincident with the construction of Lake Travis, which went into service in September of 1940, which had a noticeable effect on annual peak discharge at the gage. A historic peak is available in 1869, but this peak as well as the gaged record prior to 1941 were removed from the record to maintain a homogenous record coinciding with the regulated basin associated with Lake Travis. The Kendall's Tau test detects a statistically significant increasing trend in annual peak discharge at the gaged location.

The largest peak in the gaged record for the Colorado River at Austin gage is the 1941 peak discharge of 47,600 cfs at a stage of 18.55 ft. The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.98. The flood flow frequency for the Colorado River at Austin gage is shown in Figure 5.99. The figure is exported from PeakFQ (USGS, 2014), and plots annual peak discharge vs. AEP in percent. The low-outlier threshold was manually set at 10,000 cfs, and 35 PILFs were removed. Because of the regulation that occurs immediately upstream of the gage, the observed flows do not appear to follow a typical Log Pearson III distribution. Peak flows begin to plateau around 30,000 to 40,000 cfs. Releases from Lake Travis are typically regulated such that discharge at Austin does not exceed 30,000 cfs until the lake elevation exceeds a certain level (USACE, 2013). Therefore, the computed flood flow frequency curve at the Colorado River at Austin gage may not be as reliable as a result of the stringent regulation from Lake Travis.

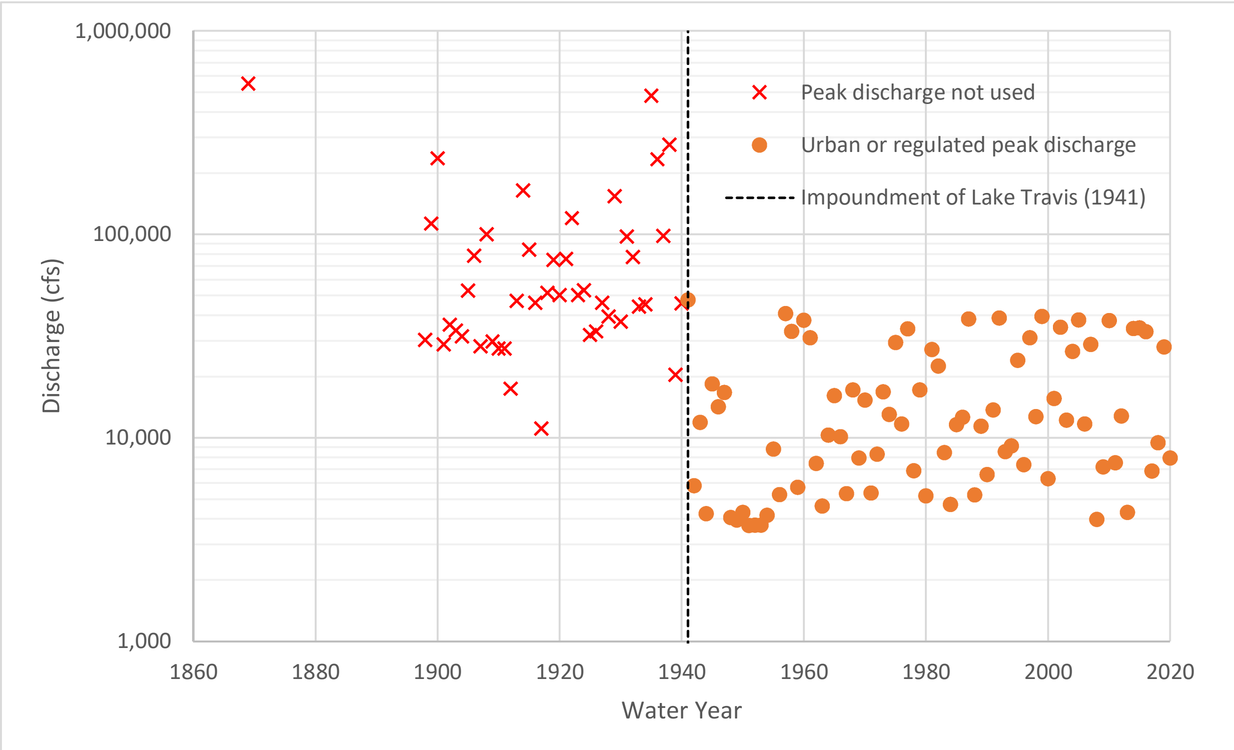


Figure 5.98: Annual Peak Discharge Data for U.S. Geological Survey Streamgaging Station 08158000 Colorado River at Austin, Tex.

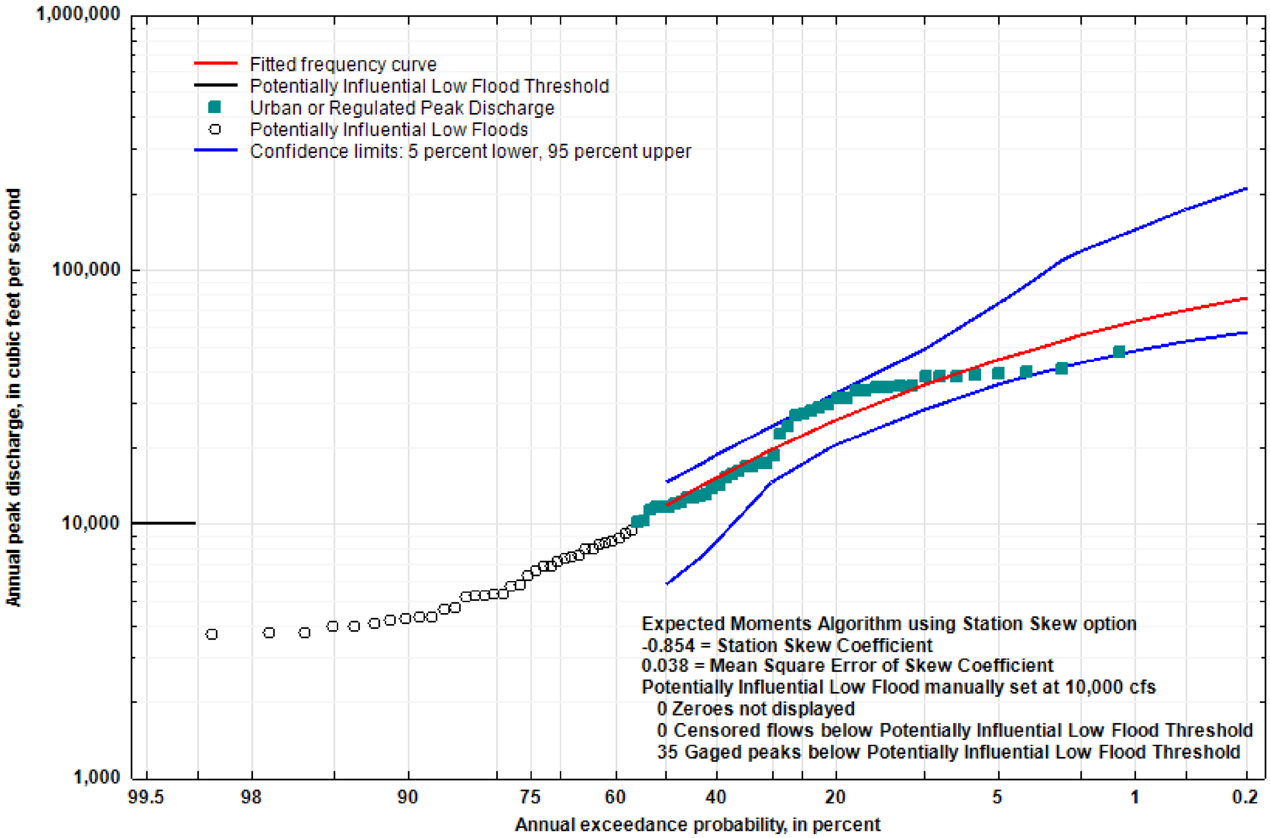


Figure 5.99: Flood Flow Frequency Curve for U.S. Geological Survey Streamgaging Station 08158000 Colorado River at Austin, Tex.

08158600 Walnut Creek at Webberville Road, Austin, Tex.

The period of record at USGS station 08158600 Walnut Creek at Webberville Road, Austin, Tex. (hereinafter referred to as the “Walnut Creek at Webberville Road gage”) was from 1966 through 2020 (USGS, 2020). The largest peak in the gaged record for the Walnut Creek at Webberville Road gage is the 2007 peak discharge of 16,400 cfs at a stage of 26.30 ft. The Pettitt test does not detect a change point in the gaged record, nor does the Kendall’s Tau test find a statistically significant trend in the annual peak streamflow data.

The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.100. The flood flow frequency for the Colorado River at Austin gage is shown in Figure 5.101. The figure is exported from PeakFQ (USGS, 2014), and plots annual peak discharge vs. AEP in percent. The low-outlier threshold was set by PeakFQ at 2,520 cfs, and seven PILFs were removed.

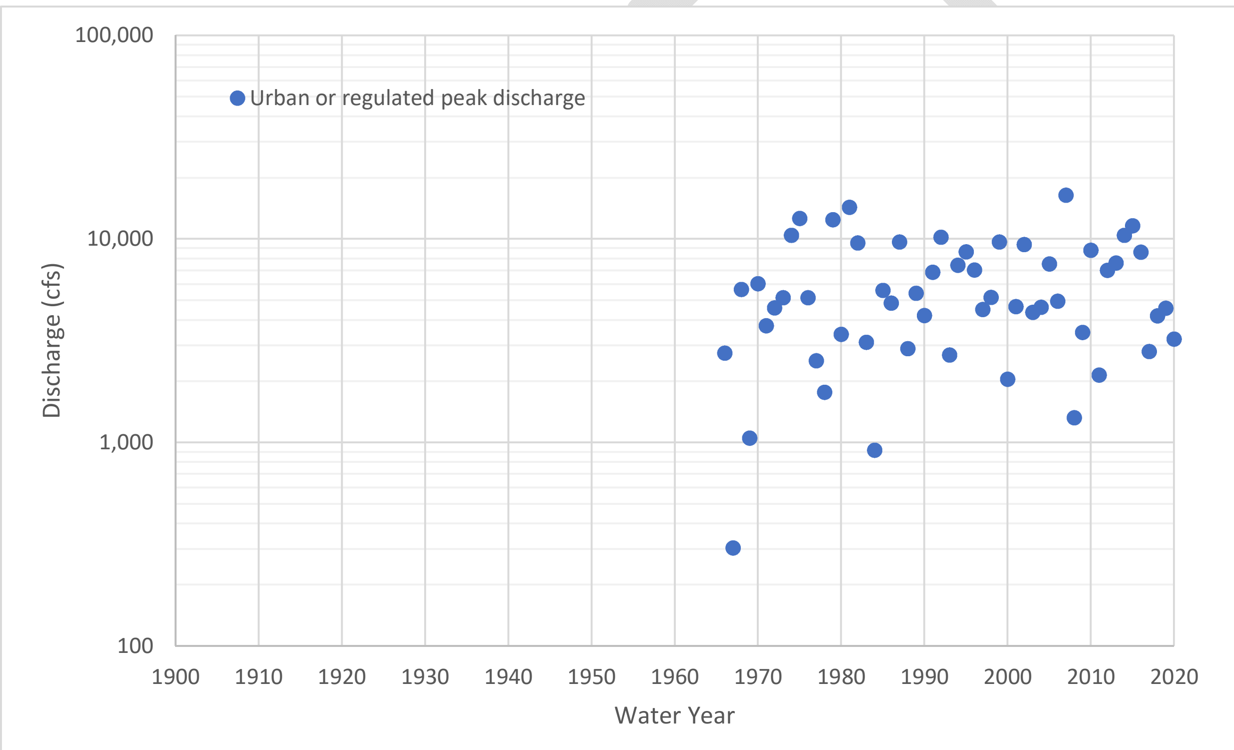


Figure 5.100: Annual Peak Discharge Data for U.S. Geological Survey Streamgaging Station 08158600 Walnut Creek at Webberville Road, Austin, Tex.

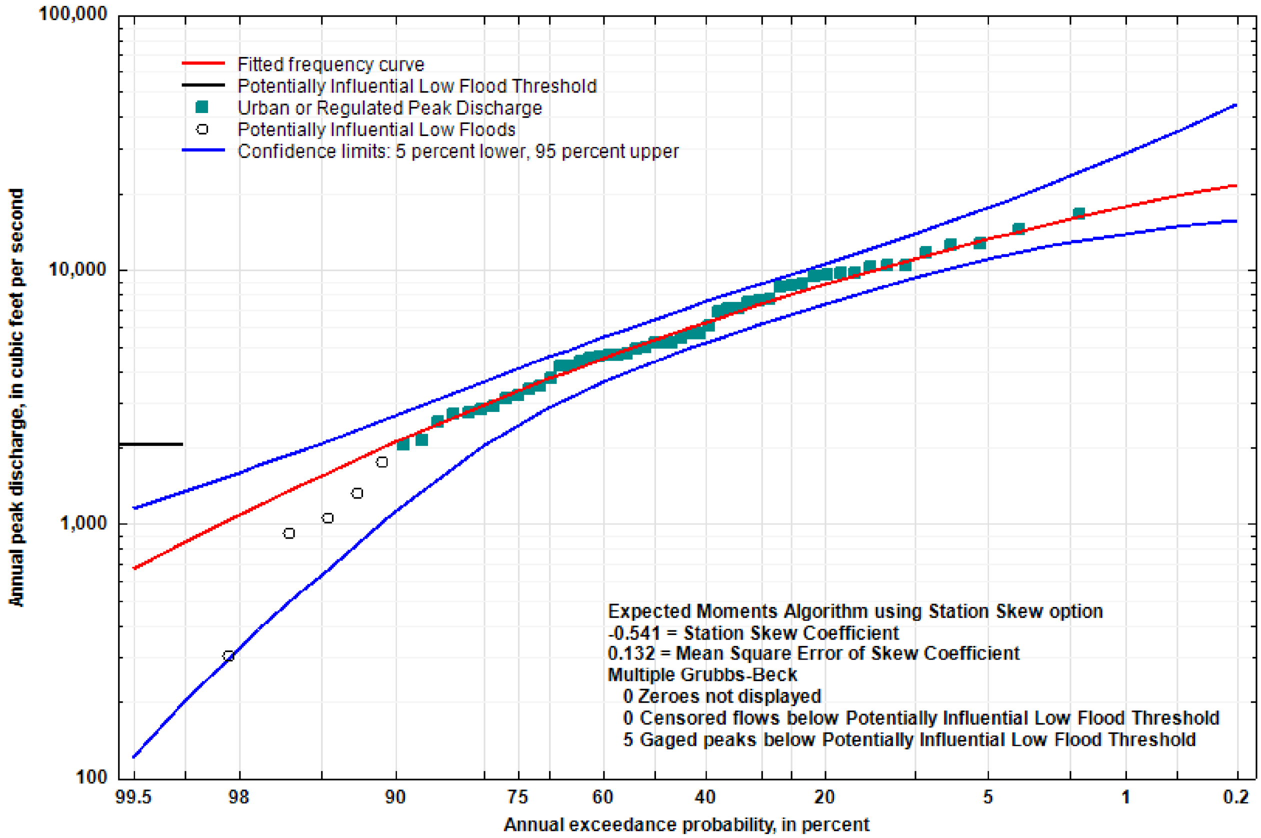


Figure 5.101: Flood Flow Frequency Curve for U.S. Geological Survey Streamgaging Station 08158600 Walnut Creek at Webberville Road, Austin, Tex.

08158700 Onion Creek near Driftwood, Tex.

The period of record at USGS station 08158700 Onion Creek near Driftwood, Tex. (hereinafter referred to as the “Onion Creek near Driftwood gage”) was from 1980 through 2020 (USGS, 2020). The Pettitt test does not detect a change point in the gaged record, nor does the Kendall’s Tau test find a statistically significant trend in the annual peak streamflow data.

The largest peak in the gaged record for the Onion Creek near Driftwood gage is the 2015 peak discharge of 16,600 cfs at a stage of 26.21 ft. The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.102. The flood flow frequency for the Onion Creek near Driftwood gage is shown in Figure 5.103. Because the period of record is short and the station skew is a relatively high negative skew, the skew was weighted by a regional skew value (Table 5.1). The figure is exported from PeakFQ (USGS, 2014), and plots annual peak discharge vs. AEP in percent. The low-outlier threshold was set by PeakFQ at 2,420 cfs, and 15 PILFs were removed.

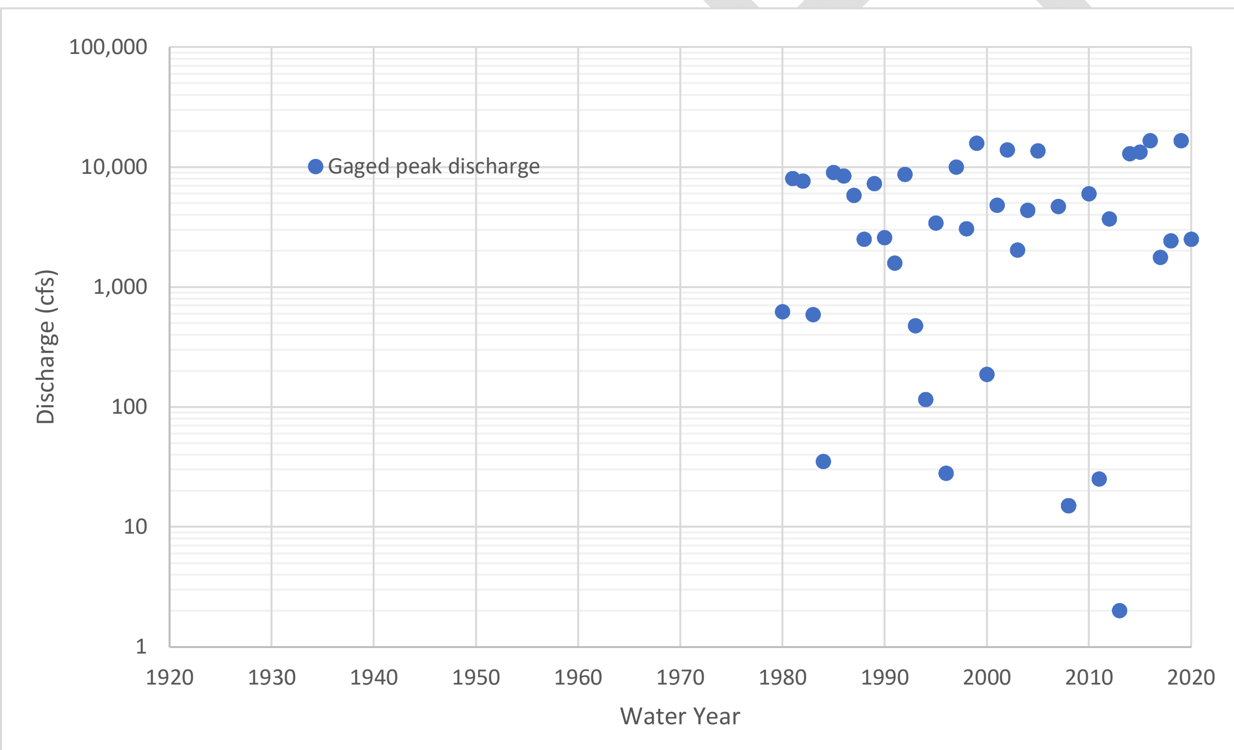


Figure 5.102: Annual Peak Discharge Data for U.S. Geological Survey Streamgaging Station 08158700 Onion Creek near Driftwood, Tex.

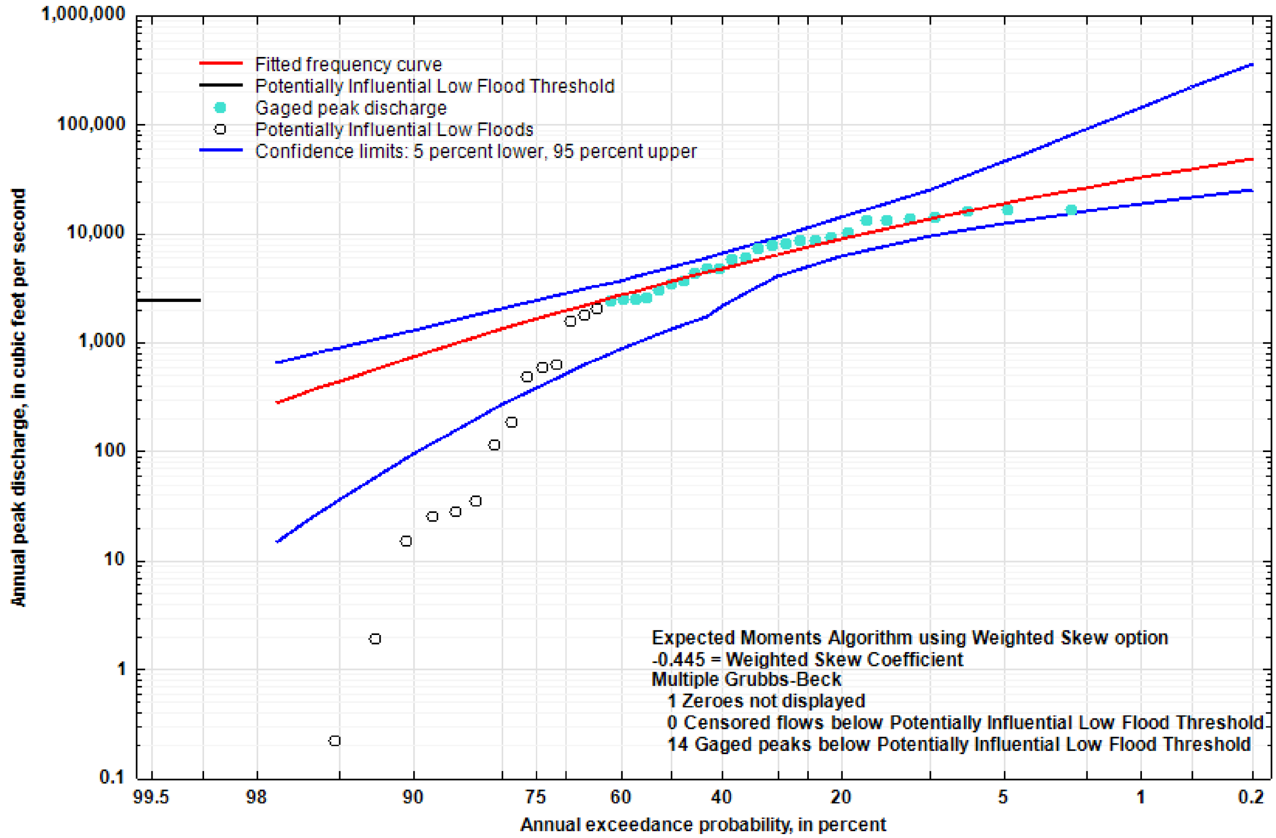


Figure 5.103: Flood Flow Frequency Curve for U.S. Geological Survey Streamgaging Station 08158700 Onion Creek near Driftwood, Tex.

08159000 Onion Creek at US Hwy 183, Austin, Tex.

The period of record at USGS station 08159000 Onion Creek at US Hwy 183, Austin, Tex. (hereinafter referred to as the "Onion Creek at Austin gage") was from 1924 through 2020 (USGS, 2020). A historical peak discharge of 138,000 cfs is available for 1921, and a perception threshold of that value was set for the time period between that historic peak and the beginning of gaged record in 1924. A large gap in the gaged record exists from 1930 through 1975, with a historical peak discharge of 100,000 cfs recorded in 1941. A perception threshold of 100,000 cfs was set for the time periods before and after the 1941 historical peak to fill the gap in the gaged record. When gaged record begins again in 1976, it is coded as 'C' in NWIS, which means that the discharge is "affected by urbanization, mining, agricultural changes, channelization, or other" (NWIS, 2020). Because little to no difference is observed between the gaged record with and without this code, the entire period of record is used in the analysis. The Pettitt test does not detect a change point in the gaged record, nor does the Kendall's Tau test find a statistically significant trend in the annual peak streamflow data.

The largest peak in the gaged record for the Onion Creek at Austin gage is the 2013 peak discharge of 135,000 cfs at a stage of 40.13 ft. The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.104. The flood flow frequency for the Onion Creek at Austin gage is shown in Figure 5.105. The figure is exported from PeakFQ (USGS, 2014), and plots annual peak discharge vs. AEP in percent. No PILFs were identified by the PeakFQ software.

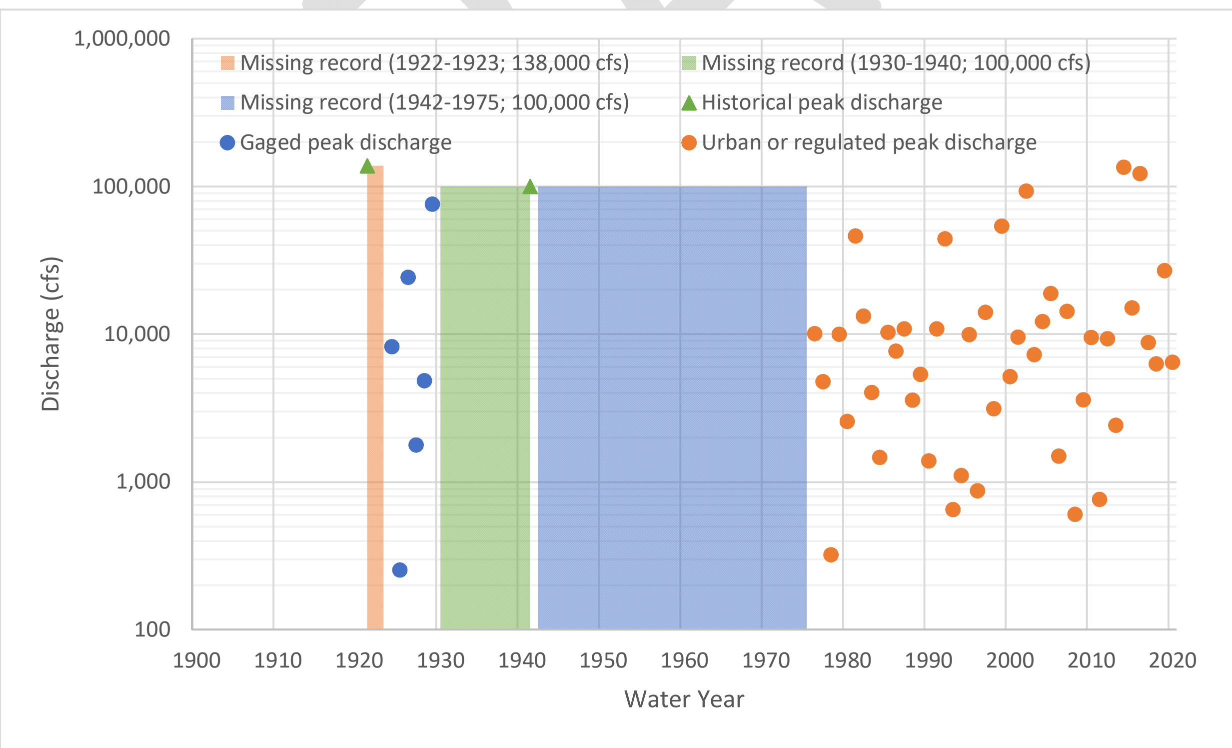


Figure 5.104: Annual Peak Discharge Data for U.S. Geological Survey Streamgaging Station 08159000 Onion Creek at US Hwy 183, Austin, Tex.

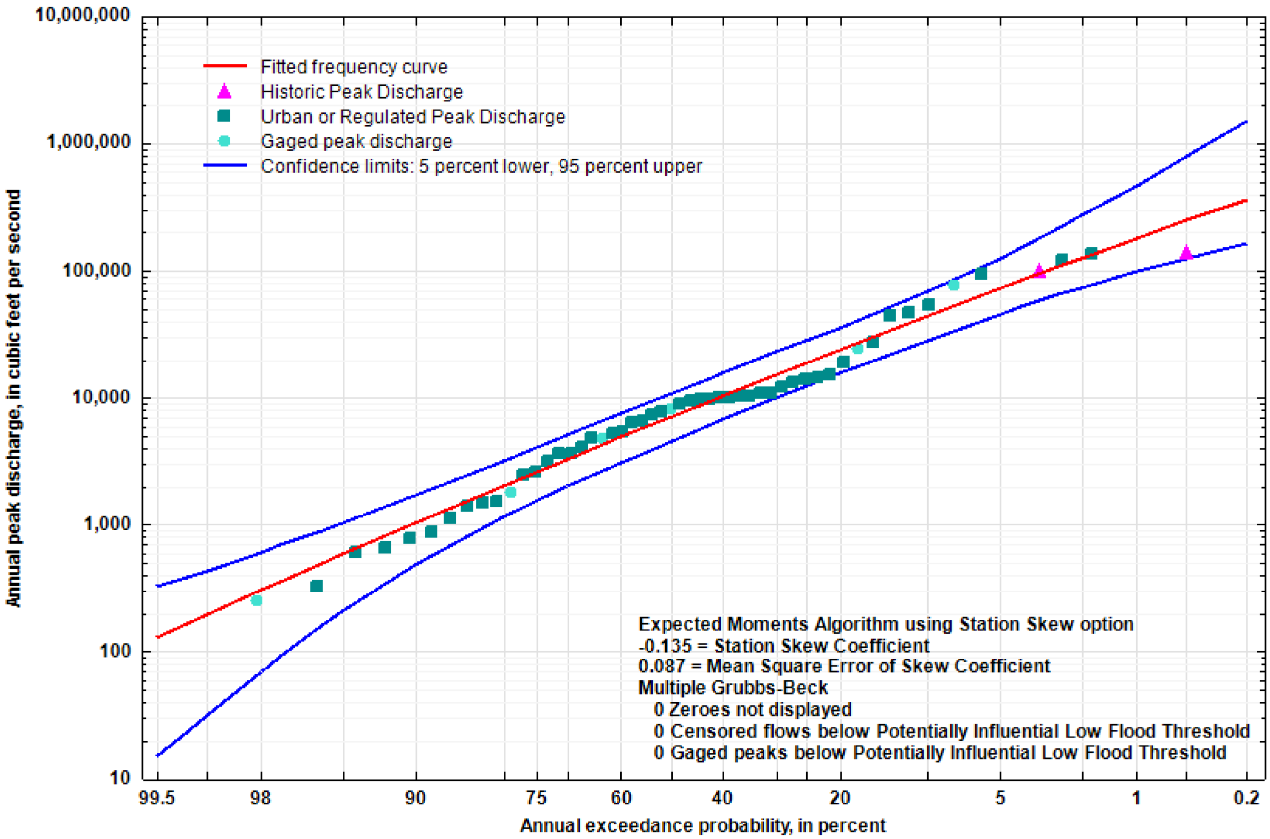


Figure 5.105: Flood Flow Frequency Curve for U.S. Geological Survey Streamgaging Station 08159000 Onion Creek at US Hwy 183, Austin, Tex.

Table 5.3: Statistically Estimated Annual Flood flow frequency Results and Confidence Intervals for the Twelve U.S. Geological Survey Streamgaging Stations on the main-stem of the Lower Colorado River basin, Texas Based on USGS-PeakFQ Software

[cfs, cubic feet per second; %, percent; CI, confidence limit; Note, table contents derived from EXP file (file extension name) of USGS-PeakFQ software output (USGS, 2014). The estimates are of primary interest and are accentuated using a bold typeface.]

Station number and name	Flood flow frequency by corresponding average return period (recurrence interval) in years							
	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)
08124000 Colorado River at Robert Lee, Tex.								
Lower 95%-CI	180	795	1,610	3,270	5,020	7,260	10,000	14,600
Estimate	**304**	**1,340**	**2,840**	**6,260**	**10,300**	**16,100**	**24,200**	**39,200**
Upper 95%-CI	502	2,490	6,060	16,400	31,900	58,900	105,000	214,000
08126380 Colorado River near Ballinger, Tex.								
Lower 95%-CI	1,780	4,630	6,960	10,300	12,900	15,400	17,800	20,600
Estimate	**2,620**	**6,370**	**9,730**	**14,900**	**19,200**	**24,000**	**29,100**	**36,400**
Upper 95%-CI	3,630	9,090	14,900	26,800	41,400	64,000	99,100	178,000
08136700 Colorado River near Stacy, Tex.								
Lower 95%-CI	306	1,370	2,740	5,440	8,240	11,700	16,000	22,700
Estimate	**604**	**2,630**	**5,540**	**12,000**	**19,600**	**30,300**	**44,800**	**71,500**
Upper 95%-CI	1,160	5,940	15,000	42,100	84,300	160,000	291,000	612,000
08138000 Colorado River at Winchell, Tex.								
Lower 95%-CI	6,120	15,000	19,500	24,600	28,400	32,100	35,900	40,900
Estimate	**10,600**	**17,900**	**23,500**	**31,300**	**37,500**	**44,200**	**51,300**	**61,300**
Upper 95%-CI	12,200	22,400	31,800	50,200	71,000	99,200	136,000	201,000
08147000 Colorado River near San Saba, Tex.								
Lower 95%-CI	12,400	25,400	34,900	46,200	52,600	57,400	61,000	64,600
Estimate	**16,200**	**32,300**	**44,000**	**59,100**	**70,200**	**80,900**	**91,300**	**105,000**
Upper 95%-CI	21,000	40,800	58,100	87,500	114,000	145,000	183,000	246,000
08147000 Colorado River near San Saba, Tex. (Alternate Analysis)								
Lower 95%-CI	18,800	39,100	55,700	79,000	97,200	115,000	133,000	157,000
Estimate	**22,700**	**47,200**	**68,200**	**100,000**	**128,000**	**158,000**	**192,000**	**242,000**
Upper 95%-CI	27,400	57,500	85,600	136,000	188,000	254,000	338,000	483,000
08158000 Colorado River at Austin, Tex.								
Lower 95%-CI	5,740	20,500	28,300	37,300	43,100	48,100	52,300	56,800
Estimate	**11,800**	**25,400**	**35,100**	**47,000**	**55,100**	**62,600**	**69,400**	**77,500**
Upper 95%-CI	14,500	32,300	48,700	83,100	117,000	144,000	172,000	209,000
08159200 Colorado River at Bastrop, Tex.								
Lower 95%-CI	11,800	33,900	45,300	57,600	66,400	75,000	83,300	93,900
Estimate	**22,700**	**41,700**	**55,900**	**75,300**	**90,400**	**106,000**	**122,000**	**144,000**
Upper 95%-CI	27,000	53,500	80,500	137,000	201,000	292,000	392,000	544,000
08159500 Colorado River at Smithville, Tex.								
Lower 95%-CI	16,900	36,800	52,600	74,300	90,900	108,000	124,000	145,000
Estimate	**22,000**	**47,000**	**68,100**	**99,100**	**125,000**	**153,000**	**183,000**	**226,000**
Upper 95%-CI	27,900	60,500	91,200	143,000	191,000	250,000	320,000	433,000

Table 5.7: Statistically Estimated Annual Flood flow frequency Results and Confidence Intervals for the Six U.S. Geological Survey Streamgaging Stations in the Barton Creek, Walnut Creek, and Onion Creek tributaries of the Colorado River, Texas Based on USGS-PeakFQ Software

Station number and name	Flood flow frequency by corresponding average return period (recurrence interval) in years							
	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)
08154700 Bull Creek at Loop 360 near Austin, Tex.								
Lower 95%-CI	1,990	4,600	6,720	9,780	12,200	14,500	16,900	19,800
Estimate	**2,840**	**6,350**	**9,490**	**14,400**	**18,700**	**23,500**	**28,800**	**36,800**
Upper 95%-CI	3,940	9,260	15,200	29,000	48,100	82,100	143,000	249,000
08155200 Barton Creek at SH 71 near Oak Hill, Tex.								
Lower 95%-CI	1,480	5,400	9,240	15,200	19,700	23,700	27,200	30,900
Estimate	**2,730**	**8,870**	**15,000**	**24,600**	**32,800**	**41,600**	**50,800**	**63,400**
Upper 95%-CI	4,580	14,300	25,600	51,400	84,200	135,000	214,000	395,000
08155240 Barton Creek at Lost Creek Boulevard near Austin, Tex.								
Lower 95%-CI	1,410	5,460	9,470	16,300	21,700	25,600	28,000	29,700
Estimate	**2,780**	**9,570**	**16,500**	**27,300**	**36,400**	**46,000**	**56,000**	**69,400**
Upper 95%-CI	6,470	16,900	25,200	42,700	63,800	92,800	132,000	205,000
08155300 Barton Creek at Loop 360, Austin, Tex.								
Lower 95%-CI	870	6,270	10,400	16,300	21,400	26,800	32,500	40,400
Estimate	**2,990**	**9,540**	**16,500**	**28,500**	**39,600**	**52,500**	**67,300**	**89,400**
Upper 95%-CI	4,310	15,100	30,100	70,400	127,000	221,000	368,000	681,000
08155400 Barton Creek above Barton Springs at Austin, Tex.								
Lower 95%-CI	1,240	4,260	7,270	12,000	16,000	20,200	24,700	30,800
Estimate	**2,460**	**7,820**	**13,700**	**23,900**	**33,600**	**45,200**	**58,700**	**79,600**
Upper 95%-CI	4,520	16,500	33,500	72,900	121,000	192,000	293,000	493,000
08158600 Walnut Creek at Webberville Road, Austin, Tex.								
Lower 95%-CI	4,350	7,320	9,250	11,500	12,800	13,800	14,700	15,500
Estimate	**5,300**	**8,760**	**11,000**	**13,800**	**15,800**	**17,700**	**19,400**	**21,700**
Upper 95%-CI	6,390	10,500	13,700	18,800	23,300	28,600	34,600	44,400
08158700 Onion Creek near Driftwood, Tex.								
Lower 95%-CI	1,320	6,260	9,300	13,100	16,000	18,800	21,600	25,200
Estimate	**3,600**	**8,810**	**13,400**	**20,400**	**26,200**	**32,500**	**39,200**	**48,600**
Upper 95%-CI	4,880	13,900	25,600	53,700	89,700	143,000	220,000	354,000
08159000 Onion Creek at US Hwy 183, Austin, Tex.								
Lower 95%-CI	4,560	15,500	28,200	51,400	73,600	98,600	126,000	163,000
Estimate	**7,070**	**23,700**	**43,700**	**83,000**	**125,000**	**179,000**	**247,000**	**365,000**
Upper 95%-CI	10,800	35,600	68,000	151,000	270,000	468,000	789,000	1,530,000

4595 Onion Creek at Buda, Tex.

The period of record at LCRA station 4595 Onion Creek at Buda, Tex. was from 2003 through 2020. The largest peak in the gaged record for the Onion Creek at Buda gage is the 2014 peak discharge of 41,400 cfs. A USGS streamflow gaging station was located near the present site and provides annual peak discharge from 1980 through 1983 and 1993 through 1995. Additionally, a historical event was recorded at the gage in 1929 at 53,200 cfs. Therefore, a perception threshold for the missing record until 2002 was set at 53,200 cfs. The LCRA gage was discontinued from 2005 through 2006 because of bridge construction. During this time, the downstream USGS streamgage 08158827 Onion Creek at Twin Creeks Road near Manchaca, Tex. did not record a peak above 19,200 cfs. Therefore, a perception threshold of 19,200 cfs was set for those two missing years. The Kendall's Tau test was not run on this dataset because of its incongruity.

The data as set up for statistical frequency analysis are shown in a log-normal plot of annual peak discharge vs. water year in Figure 5.153. The flood flow frequency for the Onion Creek at Buda gage is shown in Figure 5.154. The figure is exported from HEC-SSP (USACE, 2016), and plots annual peak discharge vs. AEP in percent. Because the period of record is relatively short (18 years), the skew was weighted by a regional value from Asquith and others (2020; Table 5.8). The low-outlier threshold was set by HEC-SSP at 1,504.2 cfs, and 6 PILFs were removed.

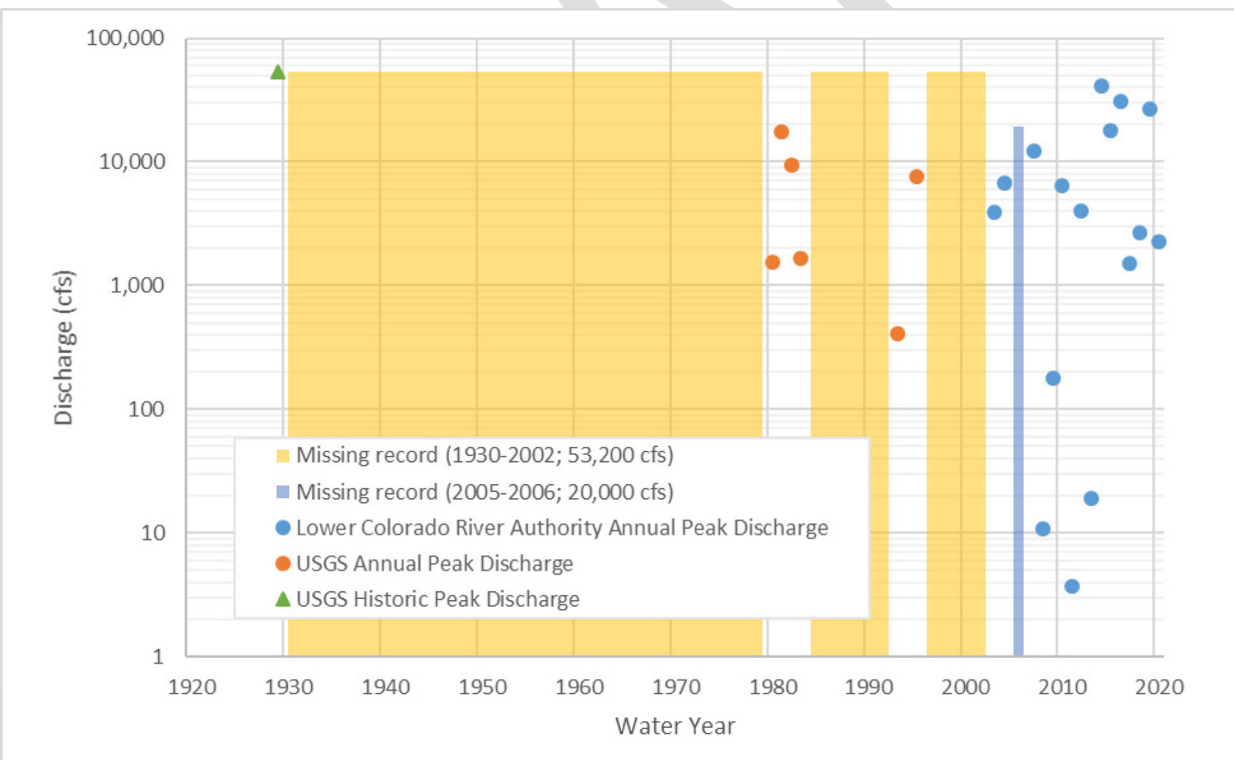


Figure 5.154: Annual Peak Discharge Data for Lower Colorado River Authority Streamgaging Station Onion Creek at Buda, Tex.

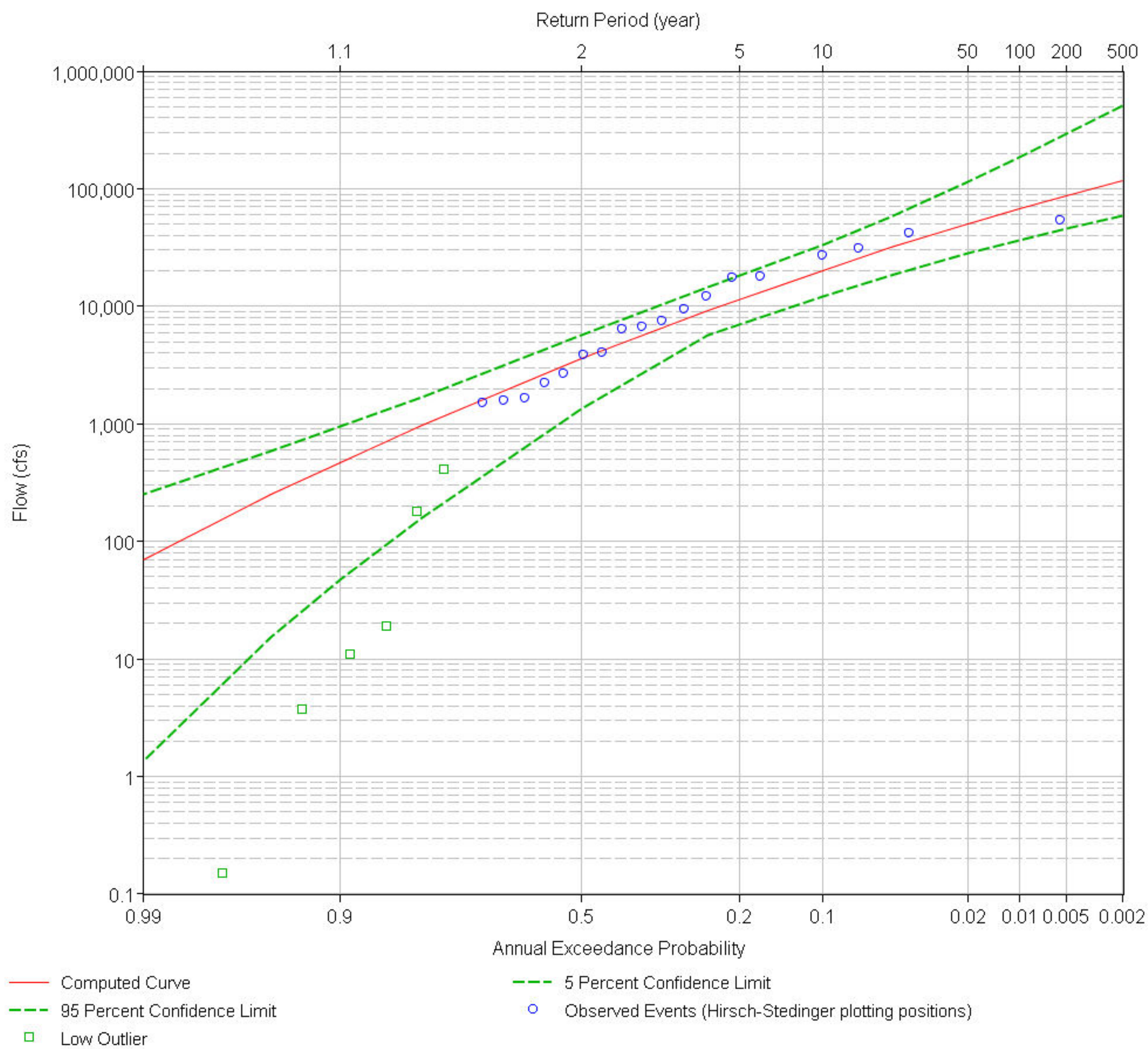


Figure 5.155: Flood Flow Frequency Curve for Lower Colorado River Authority Streamgaging Station Onion Creek at Buda, Tex.

Table 5.9 (continued): Peak-streamflow frequency quantiles and 90-percent prediction limits for Lower Colorado River Authority streamflow-gaging stations (streamgages) in the Lower Colorado River basin, Texas.

Station name	Flood flow frequency by corresponding average return period (recurrence interval) in years							
	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)
Sandy Creek near Willow City, Tex.								
Lower 95%-CI	1,060	3,960	6,680	10,700	13,800	16,900	19,800	23,500
Estimate	**2,230**	**6,980**	**11,900**	**20,200**	**27,800**	**36,400**	**46,100**	**60,300**
Upper 95%-CI	3,940	13,800	28,300	63,300	107,000	173,000	269,000	461,000
Sandy Creek near Click, Tex.								
Lower 95%-CI	2,590	10,400	17,800	28,600	36,900	44,700	52,000	60,700
Estimate	**5,600**	**18,500**	**31,900**	**54,300**	**74,300**	**96,800**	**121,000**	**157,000**
Upper 95%-CI	10,000	36,600	75,800	170,000	286,000	456,000	699,000	1,180,000
Backbone Creek at Marble Falls, Tex.								
Lower 95%-CI	159	2,660	5,380	9,560	13,100	16,900	20,700	25,800
Estimate	**1,140**	**5,210**	**10,500**	**21,000**	**31,700**	**44,900**	**60,700**	**85,500**
Upper 95%-CI	2,060	12,000	32,000	112,000	280,000	672,000	1,520,000	3,360,000
Hamilton Creek near Marble Falls, Tex.								
Lower 95%-CI	1,580	5,360	9,170	15,400	20,900	26,900	33,300	42,300
Estimate	**3,020**	**9,430**	**16,700**	**30,200**	**43,900**	**61,100**	**82,300**	**117,000**
Upper 95%-CI	5,310	19,300	41,400	99,800	182,000	318,000	537,000	1,040,000
Pedernales River at LBJ Ranch near Stonewall, Tex.								
Lower 95%-CI	3,670	15,500	27,500	47,000	64,000	82,200	101,000	126,000
Estimate	**7,250**	**26,600**	**48,200**	**85,500**	**120,000**	**159,000**	**203,000**	**268,000**
Upper 95%-CI	12,600	46,500	87,000	165,000	249,000	358,000	498,000	746,000
North Grape Creek near Johnson City, Tex.								
Lower 95%-CI	774	5,630	9,280	14,200	18,000	21,700	25,200	29,600
Estimate	**3,180**	**9,500**	**15,800**	**26,100**	**35,300**	**45,600**	**56,900**	**73,300**
Upper 95%-CI	5,200	18,400	38,100	93,100	175,000	315,000	544,000	1,060,000
Cypress Creek near Cypress Mill, Tex.								
Lower 95%-CI	1,230	8,220	14,300	23,200	30,300	37,400	44,300	53,000
Estimate	**4,280**	**14,500**	**25,800**	**45,200**	**63,300**	**84,300**	**108,000**	**144,000**
Upper 95%-CI	7,370	29,700	66,200	173,000	333,000	607,000	1,050,000	2,040,000
Onion Creek at Buda, Tex.								
Lower 95%-CI	1,340	7,150	12,200	20,400	28,000	36,500	45,700	58,600
Estimate	**3,600**	**11,600**	**20,300**	**35,500**	**50,000**	**67,100**	**86,900**	**117,000**
Upper 95%-CI	5,650	18,200	33,200	68,100	114,000	185,000	291,000	504,000
Gilleland Creek near Manor, Tex.								
Lower 95%-CI	1,540	3,010	4,000	5,120	5,800	6,350	6,800	7,270
Estimate	**2,090**	**3,900**	**5,180**	**6,800**	**7,980**	**9,120**	**10,200**	**11,600**
Upper 95%-CI	2,730	5,170	7,270	10,600	13,400	16,700	20,400	26,200

9.10.1 Lake Travis

Table 9.14 2019 Lake Travis Computed Pool-Frequency Comparison with Previous Estimates

Lake Travis		RMC-RFA Best Estimate	Effective FIS	Change in Pool	2002 FDEP	Change in Pool	Easement Pool	Easement 1% ACE (100-year) Freeboard
N-Years	ACE %	Feet-NGVD	Feet-NGVD	Feet	Feet-NGVD	Feet	Feet-NGVD	Feet
2	50	683.40			685.00	-1.60		
5	20	691.20			690.90	+0.30		
10	10	699.17	696.80	+2.37	696.80	+2.37		
25	4	713.35			713.50	-0.15		
50	2	715.90	716.50	-0.60	716.50	-0.60		
100	1	721.23	721.80	-0.57	721.80	-0.57	715.00	-7.81
250	0.4	729.26						
500	0.2	734.13	732.50	+1.63	736.40	-2.27		

Table 9.15 2019 Lake Travis Computed Frequency Discharge Release

Lake Travis		RMC-RFA Best Estimate			
N-Years	ACE %	Elevation-NGVD	Spillway Release (CFS)	Gate Release (CFS)	Total Release (CFS)
2	50	683.40	0	5,000	5,000
5	20	691.20	0	30,000	30,000
10	10	699.17	0	30,000	30,000
25	4	713.35	0	30,000	30,000
50	2	715.90	70,000	7,620	72,620
100	1	721.23	84,175	5,825	90,000
250	0.4	729.26	161,970	0	161,970
500	0.2	734.13	261,100	0	261,100

Note: Release is according to release schedule (Table 7-2) WCM.

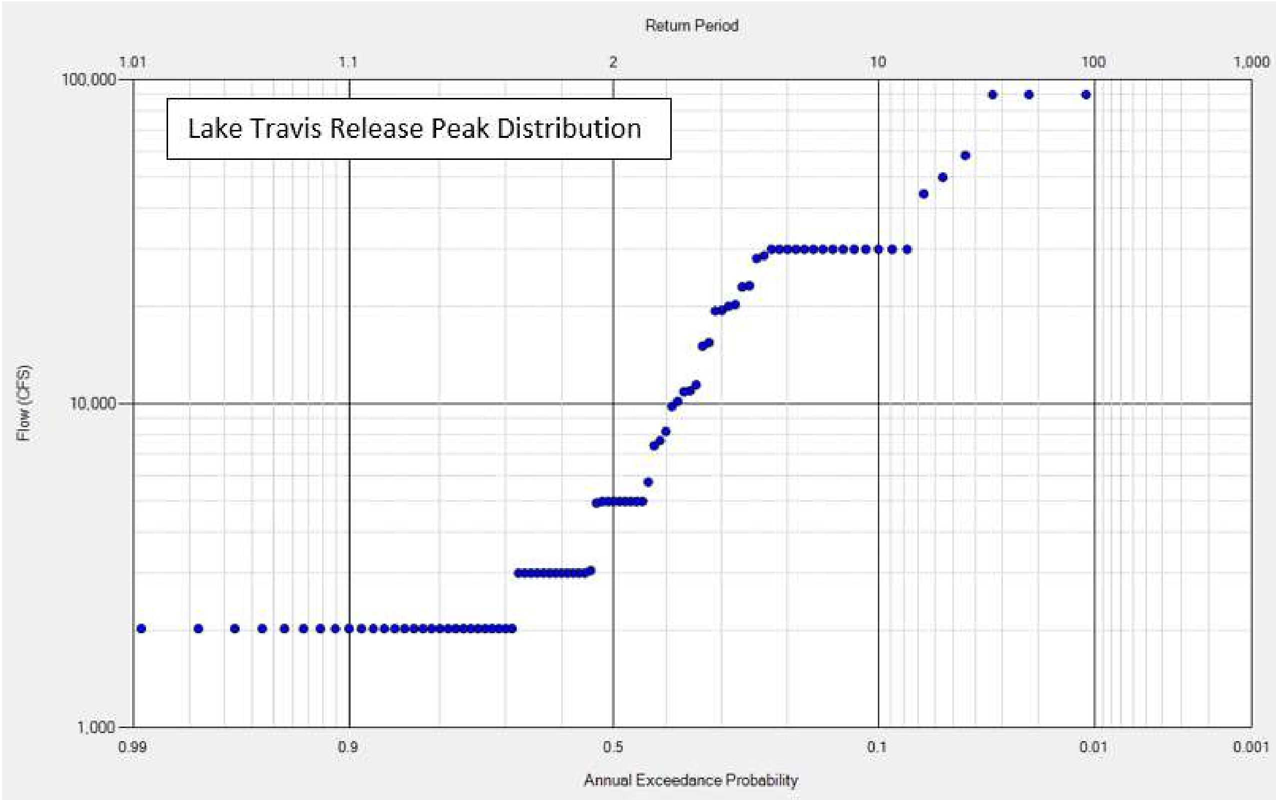


Figure 9.38 Lake Travis Simulated Total Release Following Weibull Plotting Distribution

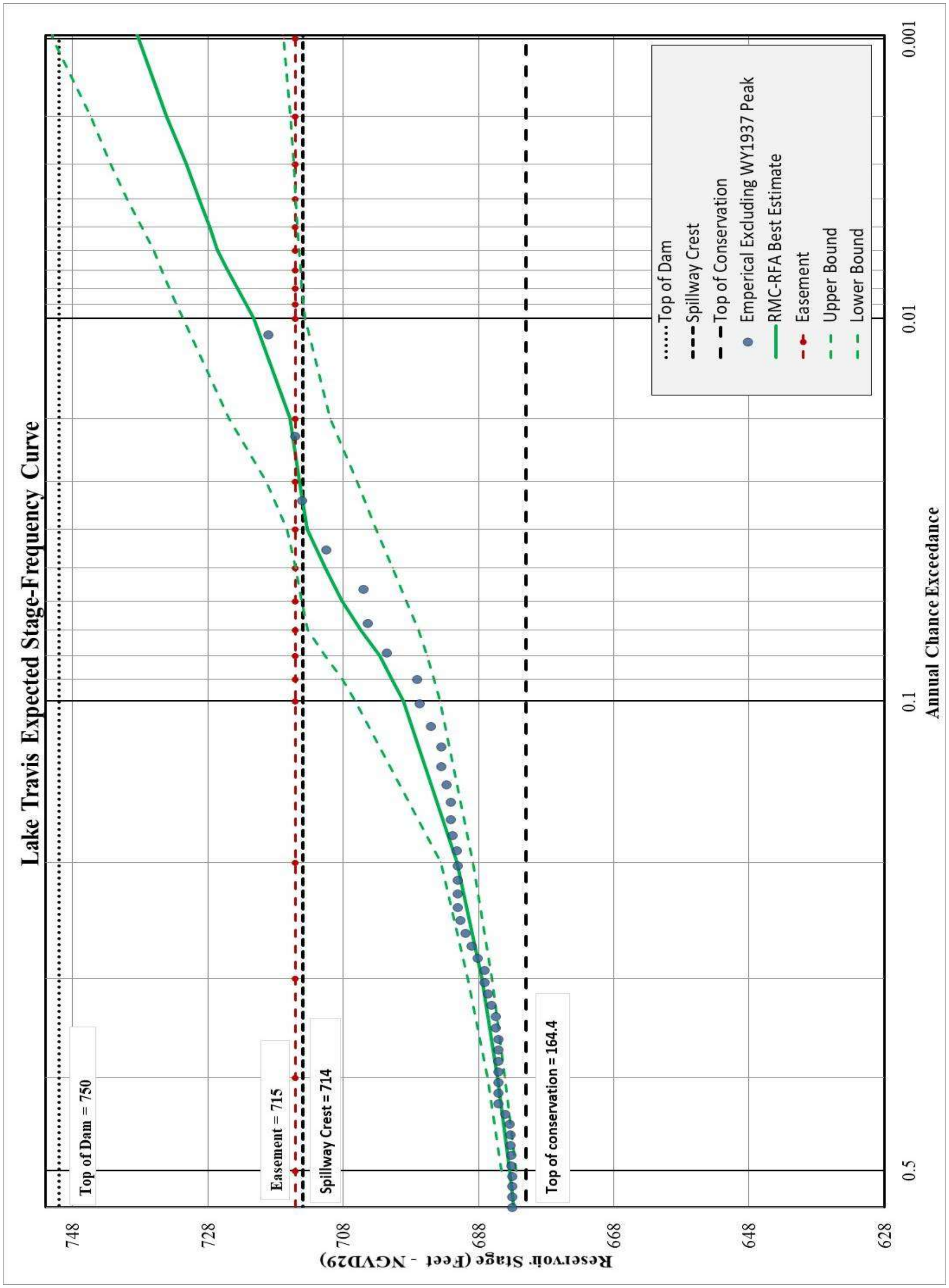


Figure 9.39 Lake Travis (Mansfield Dam) Current Condition (2019) Stage-Frequency Curve for Rainfall

9.10.3 Lake L.B.J

Table 9.18 2019 Lake L.B.J Computed Pool-Frequency Comparison with Previous Estimates

Lake L.B.J		RMC-RFA Best Estimate	2002 FDEP	Change in Pool	Easement Pool	Easement 1% ACE (100-year) Freeboard
N-Years	ACE %	Feet-NGVD		Feet	Feet-NGVD	Feet
2	50	825.47	824.84	+0.63		
5	20	825.81	824.84	+0.97		
10	10	826.60	824.84	+1.76		
25	4	827.93	824.84	+3.09		
50	2	828.31	825.24	+3.07		
100	1	828.70	827.94	+0.76	825.00	-3.70
250	0.4	829.35				
500	0.2	830.00	829.24	+0.76		

Table 9.19 2019 Lake L.B.J Computed Frequency Discharge Release

Lake L.B.J		RMC-RFA Best Estimate			
N-Years	ACE %	Elevation-NGVD	Spillway Release (CFS)	Gate Release (CFS)	Total Release (CFS)
2	50	825.47	20,300	0	20,300
5	20	825.81	50,490	0	50,490
10	10	826.60	70,975	0	70,975
25	4	827.93	102,195	0	102,195
50	2	828.31	147,270	0	147,270
100	1	828.70	190,335	0	190,335
250	0.4	829.35	258,610	0	258,610
500	0.2	830.00	328,990	0	328,990

Note: Since spillway crest elevation is at 825.0 ft, all release is through uncontrolled spillway.
Total release is according to free spillway design curve.

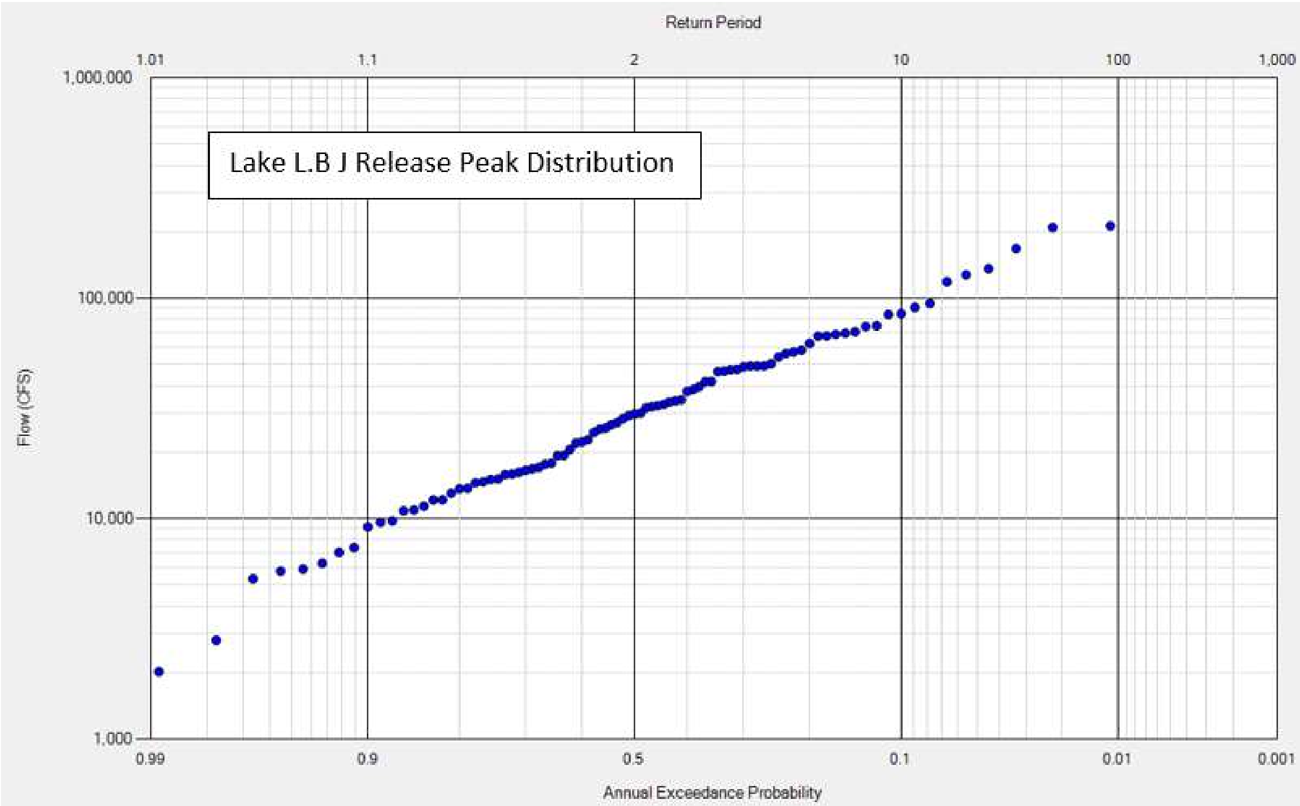


Figure 9.41 Lake L.B.J Simulated Release Following Weibull Plotting Distribution

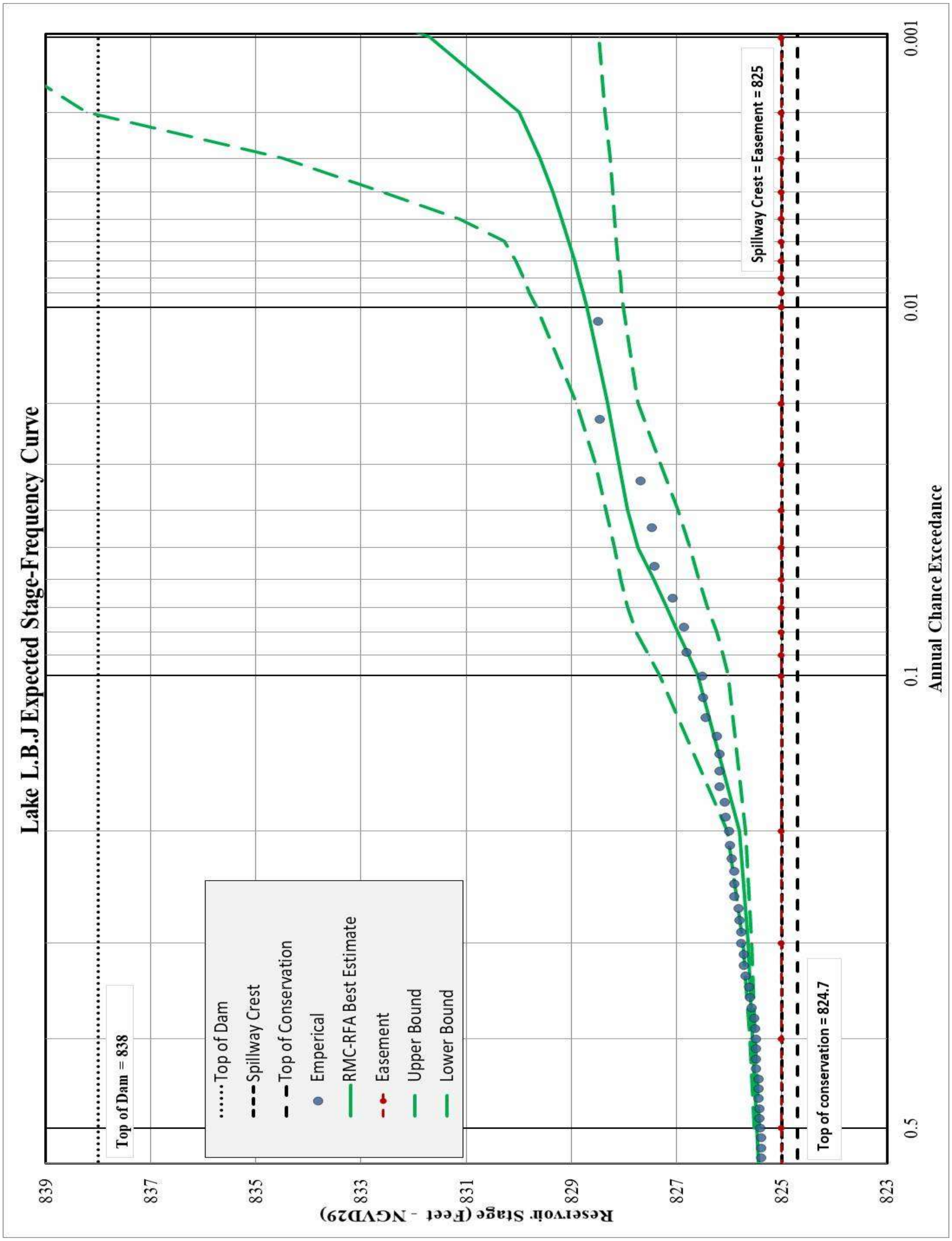


Figure 9.42 Lake L.B.J Current Condition (2019) Stage-Frequency Curve for Rainfall Simulations