Middle Brazos-Palo Pinto Watershed, Texas
2D Base Level Engineering and Mapping Methods and Results

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Prepared for:

Texas Water Development Board
Attn: Manuel Razo, GISP, CFM
1700 N. Congress Avenue
Austin, Texas 78701

Prepared By:

AECOM Technical Services
13640 Briarwick Drive, Suite 200
Austin, TX 78729
aecom.com

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Role	Name	Phone	Title (CLIN/RMC)	Review Date	Approved Date
Project Manager	Sean Sutton	512.457.7745	Project Manager	August 26, 2022	September 13, 2022

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Name	Title/Organization	Location
Manuel Razo	Contract Manager, TWDB	Austin, Texas

Table of Contents

List of Figures

List of Tables

1. Introduction

Base Level Engineering (BLE) provides technically credible flood data for various geographies - community, county, watershed and/or state level. BLE data can be shared with Federal, State, local and tribal governments, this data sharing provides stakeholders at all levels the necessary data to make informed decisions to reduce future flood losses. Without the mapping of flood prone areas, there can be a lack of information to effectively communicate flood risk to community officials, citizens, and businesses.

BLE is a riverine hydrologic and hydraulic modeling approach that builds on lessons learned to produce a baseline understanding of flood risk to communities, produced to support the assessment and maintenance of the national flood hazard inventory. Engineering models are created during a BLE assessment, producing information that meets the mapping Standards for Flood Risk Projects (FEMA Policy Memo FP 204-078-1) to produce Zone A (1-percent-annual-chance flood) information. BLE data is intended to represent the base level of investment needed for all flood study efforts FEMA will undertake. The Middle Brazos-Palo Pinto watershed BLE documented here was designed to use two-dimensional (2D) modeling techniques with enhancements and calibration to develop products that can be communicated and shared with stakeholders, and transitioned into FEMA regulatory data development workflows.

The intent of BLE is to provide communities technically credible flood hazard information in a cost efficient and timely manner. Additionally, BLE provides communities a chance to review draft modeling information, reflecting the potential changes in risk within their community. Providing additional flood risk datasets, like water surface elevation (WSEL) grids and flood depth grids, delivers alternative information that reinforces the variability of flood risk within a designated floodplain and supports historic community requests for a source to determine a Base Flood Elevation in Zone A areas.

For floodplain management purposes, BLE data may be used as best available information in areas that are designated as Zone A floodplain. It may also be used to regulate development in areas where no Special Flood Hazard Area (SFHA) has been mapped before. Communities may adopt BLE data to support local regulations, which facilitates use of the data in local floodplain management activities, including in the post disaster environment where a need for updated and/or enhanced flood hazard information may be necessary.

BLE provides information to communities who are currently unmapped and provides a digital entry to communities that are currently un-modernized. BLE acts as a measuring tool to allow FEMA to assess the current Zone A inventory identified as unknown or unverified in FEMA's Coordinated Needs Management Strategy (CNMS), which FEMA is required to evaluate once every five years, as described in Title 42 of the Code of Federal Regulations, Chapter III, Section 4101(e). 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 Coordinated Needs Management Strategy (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. Another important goal of the BLE process is scalability of the results, meaning that the model produced during the BLE assessment may be refined to produce a more enhanced model with additional manual correction and on the ground survey. If BLE modeling exists, FEMA will recommend that it be used as the base model for any detailed studies performed in those areas.

BLE practices leverage high-resolution topography that meets or exceeds the United States Geological Survey (USGS) 3-D Elevation Program (3DEP) standards and often applies flood engineering at a large scale as opposed to targeting stream reaches within a watershed. BLE can be conducted at any scale, commonly for larger areas (Hydrologic Unit Code (HUC)-8 watershed) but may be produced at the county or local level too. It is encouraged to do BLE for wider areas in order to build on efficiencies in modeling and ensure cost efficiency. Using current technologies, multiple watersheds or watersheds with large land areas can be analyzed at a more efficient rate to produce water-surface elevations and site-specific hazard data replacing outdated flood studies shown in existing Flood Insurance Rate Maps (FIRMs). All flood prone areas within a watershed will have an engineering model calculating multiple flood recurrence intervals and defining floodplains with elevation grids using high-resolution topography.

Per standard identification SID #84 and #133, BLE will include all recurrence intervals (0.2-percent, 1-percent, 1-percent plus, 1-percent minus, 2-percent, 4-percent, and 10-percent-annual-chance floods). As such, hydrologic and hydraulic analysis should be performed to determine the expected WSELs for each of the seven recurrence intervals previously identified.

The Middle Brazos-Palo Pinto (MBPP) watershed 2D BLE project was scoped as described in the Texas Water Development Board (TWDB) Task Order 10. In an effort to increase and enhance the flood risk products in Texas, the study was contracted through the TWDB's Cooperative Technical Partner (CTP) program to AECOM Technical Services, Inc. This report documents the BLE process, products, and results for this watershed. Figure 1 depicts the MBPP watershed footprint.

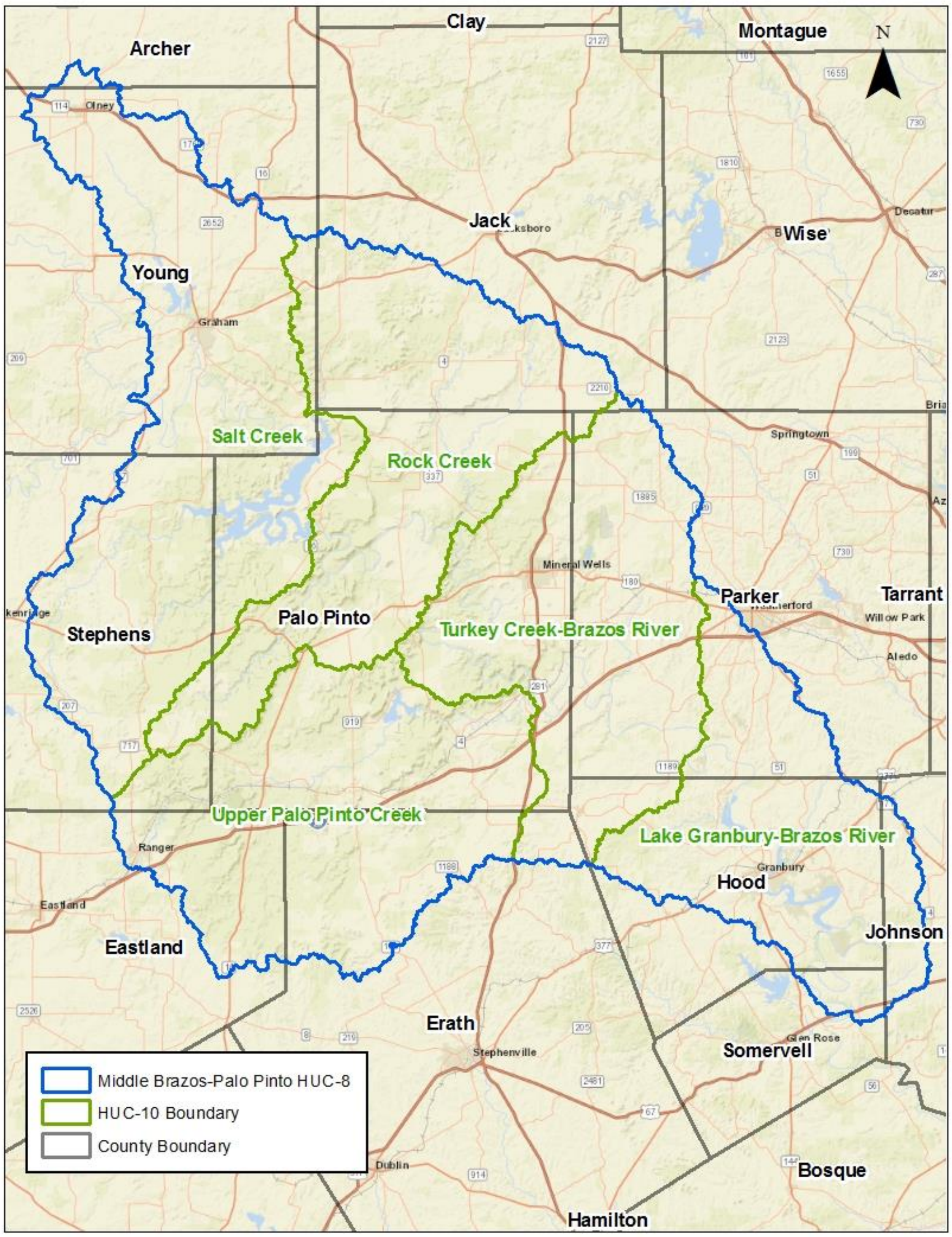

Figure 1: Middle Brazos-Palo Pinto Watershed

2. 2D BLE Modeling Inputs and Controls

Section 2 presents fundamental components required to execute a 2D hydraulic engineering analysis for the MBPP watershed. Inputs such as elevation data, hydrology from rain-on-grid and inflow hydrographs, and hydraulic analyses and variables are defined herein. HEC-RAS 6.1 rain-on-grid utility was applied in the production of the 2D BLE products produced for this watershed.

2.1 Topographic Data

A high resolution Digital Elevation Model (DEM) is a fundamental component for 2D engineering analyses by providing a detailed representation of the surface for hydraulic routing through the model area. As such, DEMs were developed for the MBPP BLE project by leveraging available high resolution gridded elevation data derived from Light Detection and Ranging (LiDAR) collections throughout the States of Texas. The 1 meter DEM developed to support the 2D BLE modeling and analysis, within the MBPP watershed, was executed using the following steps:

1. Available elevation data for the project area were inventoried and collected.
2. Leveraged elevation data were evaluated and prioritized based on source vertical accuracy, year of collection, and resolution.
3. Seamless DEMs were processed using Geographic Information Systems (GIS).
4. Quality was assured using quantitative and qualitative assessment.

Documentation regarding leveraged data including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables and text within Section 2.1.2. All vertical accuracy specifications were obtained from the metadata or survey reports provided with the leverage datasets. All available metadata, survey reports, and other leverage documentation are included in the FEMA Data Capture Technical Reference compliant submittal content for the MBPP watershed.

2.1.1 Inventory

An inventory of existing topographic data was conducted for the MBPP BLE watershed footprint. Figure 2 depicts the datasets identified and leveraged across the project area. FEMA, National Oceanic and Atmospheric Administration (NOAA), USGS, Texas Natural Resources Information System (TNRIS) and other State and Federal agencies were queried to build the inventory with the most current and available data sources.

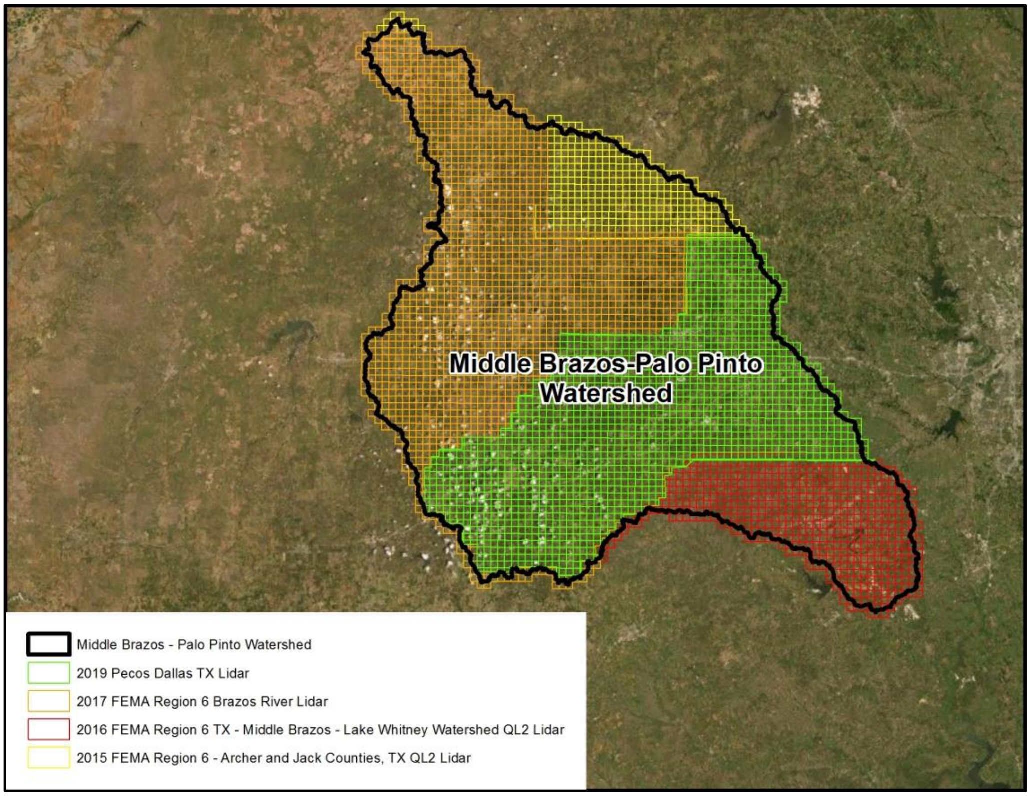

Figure 2: Middle Brazos-Palo Pinto Watershed BLE Source Terrain Data

2.1.2 Evaluation

A data coverage assessment was conducted to check for data gaps, extent, accuracy, and completeness. A review of related documentation, reports, indexes, and metadata associated with the leveraged datasets ensured each dataset meets FEMA accuracy requirements for topographic data. Decisions to leverage or exclude a dataset (or portion of it), were based generally on the following criteria coupled with engineering judgment:

- Data meet FEMA vertical accuracy standards (Table 1)
- Date of origination
- Data density and coverage

Table 1 depicts the Risk MAP SID #43 vertical accuracy requirements based on flood risk and terrain slope within the floodplain being mapped.

Table 1: FEMA Vertical Accuracy Requirements for Leveraged Data

Level of Flood Risk	Typical Slopes	Specification Level	Vertical Accuracy*	LiDAR Nominal Pulse Spacing (NPS)
High (Deciles 1,2,3)	Flattest	Highest	24.5 cm / 36.3 cm	≤ 2 meters
High (Deciles 1,2,3)	Rolling or Hilly	High	49.0 cm / 72.6 cm	≤ 2 meters
High (Deciles 2,3,4,5)	Hilly	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Flattest	High	49.0 cm / 72.6 cm	≤ 2 meters
Medium (Deciles 3,4,5,6,7)	Rolling	Medium	98.0 cm / 145 cm	≤ 3.5 meters
Medium (Deciles 3,4,5,6,7)	Hilly	Low	147 cm / 218 cm	≤ 5 meters
Low (Deciles 7,8,9,10)	All	Low	147 cm / 218 cm	≤ 5 meters

*Vertical Accuracy at 95% Confidence Level (FVA or NVA)/(CVA or VVA)

Table 2 depicts the complete list of source elevation data and attributes leveraged for the MBPP watershed. All datasets used for hydraulic analyses and mapping meet the highest specification level defined in Table 1. The following datasets were evaluated and prioritized as best available:

Table 2: LiDAR Topographic Data Available for the Middle Brazos-Palo Pinto Watershed

Year	Description	Source/Owner	Accuracy[1]	Approximate Footprint (mi^2)[2]
2019	2019 Pecos Dallas TX LiDAR	TNRIS/TWDB	7.3 cm	1251
2017	2017 FEMA Region 6 TX – Brazos River QL2 LiDAR	FEMA	7.9 cm	1251.5
2016	2016 FEMA Region 6 TX – Middle Brazos – Lake Whitney Watershed QL2 LiDAR	FEMA	3.7 cm	461.4
2015	2015 FEMA Region 6 – Archer and Jack Counties, TX QL2 LiDAR	FEMA	5.5 cm	277.2

[1]RMSEz reported at the 95% confidence level

[2]Size of LiDAR DEM footprint utilized for BLE study

2.1.2.1 Middle Brazos-Palo Pinto Watershed Source Terrain Data

The source elevation data for the MBPP watershed are DEMs derived from the 2019 Pecos Dallas TX LiDAR; the 2017 FEMA Region 6 TX – Brazos River QL2 LiDAR; the 2016 FEMA Region 6 TX – Middle Brazos – Lake Whitney Watershed QL2 LiDAR; and the 2015 FEMA Region 6 – Archer and Jack Counties, TX QL2 LiDAR. Only points classified as “ground” points (i.e., bare earth) were imported from the LiDAR and used for development of the project DEMs. Bare-earth LiDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the raw laser returns. Figure 2 depicts the extent of the data defined in Table 2.

2019 Pecos Dallas TX LiDAR

Digital Aerial Solutions LLC was tasked to collect and process lidar for three areas of interest (AOIs) covering approximately 9,557 square miles in the following Texas counties: Collin, Crane, Culberson, Dallas, Denton, Eastland, Ellis, Erath, Johnson, Kaufman, Loving, Palo Pinto, Parker, Reeves, Rockwall, Smith, Stephens, Tarrant, Ward, Winkler, and Wise. The lidar aerial acquisition was conducted between January 26, 2019 and July 12, 2019. The horizontal datum for the data was North American Datum of 1983 (NAD83 2011) Universal Transverse Mercator (UTM) Zone 14N with units in meters and the vertical datum is North American Vertical Datum of 1988 (NAVD88) with the elevation units in meters realized with GEOID12B.

For the 2019 Pecos Dallas TX Lidar, the tested Root Mean Square Error (RMSEz) of the classified lidar data is 7.3cm.

2017 FEMA Region 6 TX – Brazos River QL2 LiDAR

The area covered by the Brazos portion of the Texas Red River FEMA Region 6 Lidar project includes the counties of Archer, Baylor, Bell, Bosque, Brown, Callahan, Coleman, Comanche, Coryell, Dickens, Eastland, Erath, Fisher, Hamilton, Jack, Jones, King, Knox, Lampasas, McLennan, Mills, Palo Pinto, Runnels, Shackelford, Stephens, Stonewall, Taylor, Throckmorton, and Young. The lidar aerial acquisition was conducted between January 1, 2017 and May 28, 2018. The horizontal datum for the data was NAD83 (CORS 2011) UTM Zone 14N with units in meters and the vertical datum is NAVD88 with the elevation units in meters realized with GEOID12B.

For the Brazos Basin Texas FEMA R6 Lidar Project, the tested RMSEz of the classified lidar data is 7.9cm.

2016 FEMA Region 6 TX – Middle Brazos – Lake Whitney Watershed QL2 LiDAR

The area covered by the 2016 FEMA Region TX – Middle Brazos – Lake Whitney Watershed QL2 Lidar project is approximately 2,398 square miles and includes portions of Bosque, Erath, Hill, Hood, Johnson, McLennan, Palo Pinto, and Parker counties. The lidar aerial acquisition was conducted between March 1 and March 21, 2016. The horizontal datum of the data was NAD83 (2011) UTM Zone 14N with units in meters and the vertical datum of the data was NAVD88 with elevation units in meters realized with GEOID12B. The lidar data tested at 3.7cm RMSEz.

2.1.3 Data Processing

ArcGIS software was utilized in order to create a digital surface model for the MBPP HUC-8 watershed project area. The LiDAR datasets were added to a mosaic dataset and prioritized by date with the most recent dataset taking the first priority. If two datasets are from the same year or flown at similar dates, the accuracy was reviewed to determine the priority. The mosaic dataset was exported to make a seamless bare earth DEM.

The exported DEM was reviewed through automated quality control (QC) to check for anomalies and outlier locations based on slope and cells that exceed z value differences from surrounding cells. Visual review was also performed to check for ground differences at the extents of the datasets for differences in ground values.

2.1.4 DEM QA/QC

DEMs developed for use in the MBPP watershed BLE analysis were developed and independently assured to meet quality standards of the project. The data were developed using a controlled process, were evaluated and assured by a topographic data development team, and were evaluated and assured by the engineering team. Quality assurance (QA) during the data development process includes, but is not limited to the following QC checks:

- Horizontal Projection Check
- Vertical Datum Check
- Resolution Check
- Format Check
- Seamless Data Check to ensure the DEM files are consistent and seamless along source data edges

The QC after the development process by the DEM development team included visual observations using hillshade, contouring, color rendering, and/or other visual aids to review and identify potential impactful anomalies within the DEM surface. This QC step included, but was not limited to the following QC checks:

- Seamless Data Check to ensure no voids along the edges and between the prioritized datasets
- NoData Value Check to ensure no null values
- Manual Elevation Check using hillshade rasters to find erroneous elevation issues
- Unit Consistency Check
- Legacy Cell Value Anomalies

QA conducted after the seamless DEM development conducted by the engineering team included visual or automated assessments to identify potentially impactful anomalies or slope changes that may adversely impact hydraulic analysis.

The final DEM data developed for the MBPP watershed is assured to meet FEMA standards and present a representative surface developed from leveraged elevation data for the purposes of this BLE project.

2.2 2D BLE Methods

HEC-RAS 6.1 (RAS6) rain-on-grid utility was applied in the Texas 2D BLE products workflow. The following sections describe the engineering methods and model inputs used.

2.2.1 2D Computational Mesh and Settings

Due to the size of the MBPP watershed (approximately 3,151 sqmi), presence of populated and urbanized areas, and due to computational and modeling limitations, the HUC-8 watershed was split into five separate HEC-RAS geometries as shown in Figure 3. The HUC-8 was split into modeling areas as Middle Brazos-Palo Pinto 1 (MBPP1), Middle Brazos-Palo Pinto 2 (MBPP2), Middle Brazos-Palo Pinto 3 (MBPP3), Middle Brazos-Palo Pinto 4 (MBPP4), and Middle Brazos-Palo Pinto 5 (MBPP5). Modeling areas were initially split by using HUC-10 boundaries. Minor adjustments have been made to HUC-10 boundaries to improve modeling efficiency. The RAS6 watershed boundaries were created for the MBPP model areas using ArcGIS toolsets, which reduce the need for manual edits to mesh cells within RAS6 that result in error generation. The MBPP1, MBPP2, MBPP3, MBPP4, and MBPP5 2D meshes contain 748,902; 572,212; 615,766; 789,422; and 874,050 cells respectively, consisting of 200 foot cells, with the exception of 100 foot along the 1 square mile streams and 50 foot cells within community boundaries using refinement regions. Within community boundaries the streamlines were also extended to the 0.5 square mile extent and assigned 50 foot cell spacing in order to be more detailed. Internal connections were used to extract flow readings for gage locations throughout the model, while profile lines were used for all other flow extractions. An adaptive 1 minute time step was used to allow the model to lower the time step, as necessary, to keep the maximum courant number under 3 for the duration of the simulation. The time step was allowed to reach 240 seconds for a maximum and 7.50 seconds for the minimum. The RAS6 model was run with Diffusion Wave (simplified Full Momentum) equations.

2.2.2 Model and Boundary Condition Setup

Using RAS6 rain-on-grid modeling requires a 2D computational mesh boundary and often requires defining inflow boundary conditions and application of excess precipitation. Excess precipitation was applied to the 2D mesh as a precipitation boundary condition. The process to determine the excess precipitation to be applied is outlined in the hydrology section.

Figure 3 depicts the model boundaries, flow transition points between models, and USGS stream gages used in the study.

The MBPP HUC-8 was split into five work areas and the outflow from the MBPP1 model along the Brazos River was used as an inflow hydrograph for the MBPP2 work area. This hydrograph was extracted from the MBPP1 model using a 2D connection, and then placed as a flow hydrograph external boundary condition for the MBPP2 model. The outflows from MBPP2 and MBPP3 models were used as an inflow hydrographs for the MBPP4 model. The MBPP2 hydrograph for inflow model to MBPP4 was extracted using a 2D connection and then placed as a flow hydrograph external boundary condition for MBPP4 model. The MBPP3 hydrograph for inflow model to MBPP4 was extracted using a 2D connection and then placed as a stage hydrograph external boundary condition for MBPP4 model. The stage hydrograph was used for mapping tie in purposes between MBPP3 and MBPP4. The outflow from MBPP4 model was used as an inflow hydrograph for the MBPP5 model. The hydrograph for the inflow model to MBPP5 was extracted using a 2D connection and then placed as a flow hydrograph external boundary condition for MBPP5 model.

An inflow hydrogaph based on USGS gage 08088000 data is also applied at the Brazos river at the upstream end of MBPP1. Since the gage is downstream of the confluence of Brazos river and Lower Clear Fork tributary, the data was extrapolated based on *Statewide Analysis of the Drainage-Area Ratio Method for 34 Streamflow Percentile Ranges in Texas* (*USGS SIR 2006-5286)* to make is applicable at the upstream end of MBPP1 model extent. The final inflow hydrograph was also implemented using a flow hydrograph external boundary condition that represents both Brazos river and Lower Clear Fork tributary. All flow transition points summarized above are shown in Figure 3 below.

Outflow boundary conditions (from the computational 2D mesh) were used at the outlet location. Any other outflow boundaries were deemed unnecessary because MBPP HUC-8 is a fully self-contained area that did not have any outflow transfer at the border.

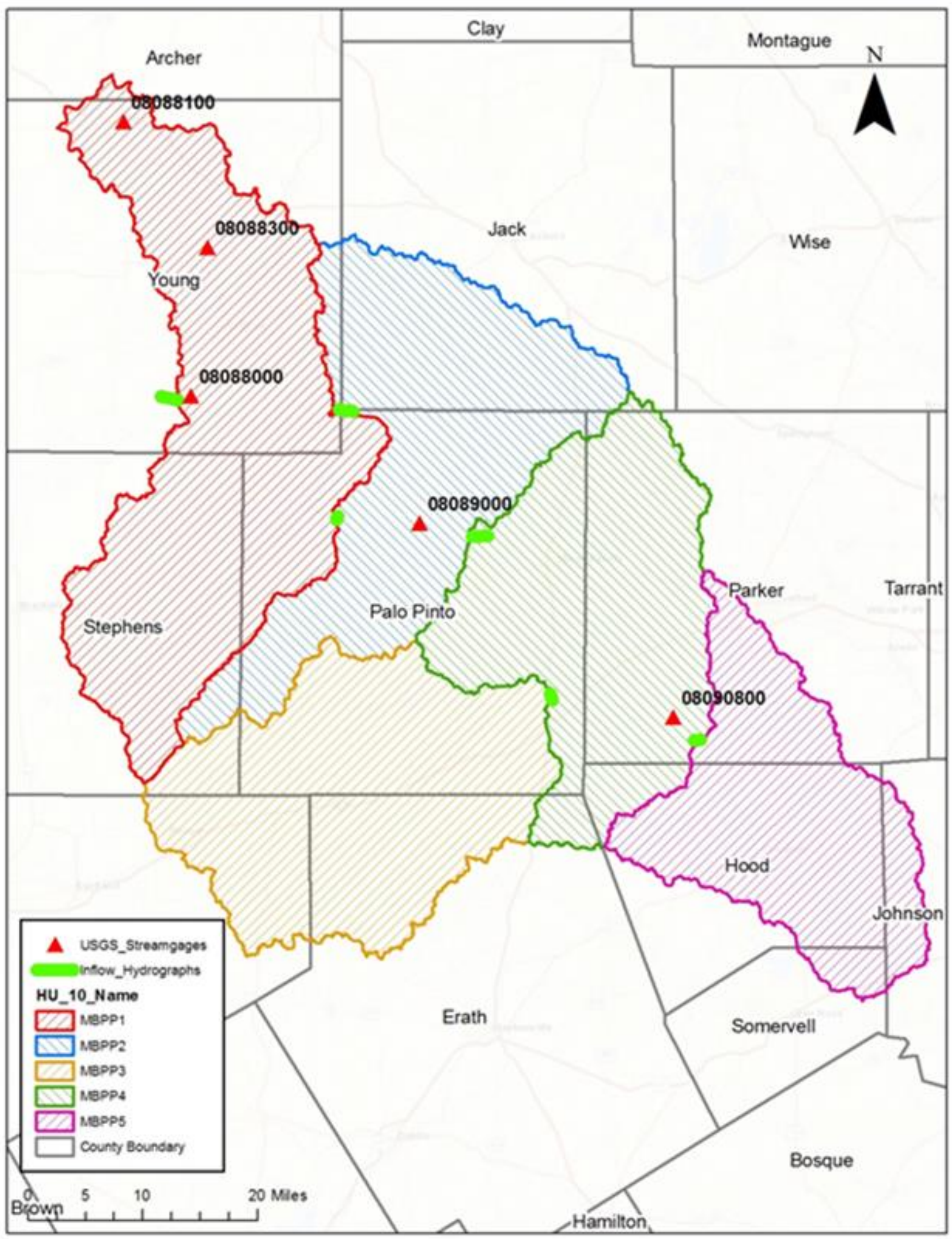

Figure 3: RAS6 2D Computational Mesh, Boundary Conditions and USGS Peak Streamflow Gages

2.2.3 Hydrology

Precipitation frequency data (NOAA, 2018) was used for this study. These data were obtained from NOAA's Precipitation Frequency Data Server (PFDS) (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html), and appropriate values for all sub-basin elements were determined considering spatial variation and a representative total for the MBPP study area. Excess precipitation for the 2D meshes were developed as described in Section 2.2.3.1. USGS streamflow gage data were leveraged to estimate peak flows for downstream gages within each work area for calibration purposes, as discussed in Section 3.1. The 10-, 4-, 2-, 1-, and 0.2-percent annual chance 24-hour precipitation depths for all sub-basin elements were determined by area-weighted intersection of gridded PFDS data with sub-basins.

USGS streamflow gage data were leveraged to estimate peak flows for downstream gages within each model for calibration purposes. Model flows are compared to known USGS peak flows to validate the model results. There are eight gages present in MBPP study area, five were used for this study. USGS stream gages with less than 10 years of record were not considered for this study. Gages 08088450, 08088610 and 08090500 were not considered in this study as well.The flow at gage 08088450 in MBPP1 was just out of calibrated range. MBPP1 contains three calibrated gages. Given the scope of this study, it was determined that extensive efforts to calibrate to this gage were no necessary. The flow values for gage 08088610 are controlled by the release rate of Morris Sheppard Dam, and due to the scope of this study the extensive efforts required to calibrate to this gage is not feasible.Gage 08090500 in MBPP3 is located a confluence, where calibration in the model will be difficult due to backwater effects. As gage 08090500 is the only gage in MBPP3, regression analysis was required to provide additional calibration points. Due to the scope of this study the extensive efforts required to calibrate to this gage were deemed unnecessary, and sole regression analysis calibration acceptable. USGS gages 08088000, 08088100, 08088300, 08089000, and 08090800, the gages used for analysis in this study are listed in Table 3.

Table 3: USGS Peak Streamflow Gages

Gage ID	Flooding Source and Location	Published Drainage Area (mi^2)	Period of Record
08088000	Brazos Rv nr South Bend, TX	22,637	1939-2021
08088100	Salt Ck at Olney, TX	11.8	1958-1976
08088300	Brian Ck nr Graham, TX	24.2	1959-1989
08089000	Brazos Rv nr Palo Pinto, TX	23,811	1924-2021
08090800	Brazos Rv nr Dennis, TX	25,237	1969-2020

2.2.3.1 Excess Precipitation for 2D Computational Mesh

HEC-HMS version 4.8 was used to apply the Soil Conservation Service (SCS) Curve Number (CN) method to calculate losses and define excess precipitation for this watershed. Temporal distributions of point rainfall totals were defined using 24-hour, frequency-based storm distributions. The plus and minus standard error for the 1-percent annual chance precipitation depths were determined as the upper and lower 84% confidence limits on the nominal 1-percent depth, assuming a normal distribution of the logarithms for the precipitation depths. An areal reduction as per Technical Paper 40 (TP-40) was used in HEC-HMS on all recurrence interval total precipitation depths in order to determine the effective precipitation for the sub-basin representing 2D mesh.

In addition to recurrence interval precipitation estimates, NOAA Atlas 14 provides 90% confidence intervals of reported precipitation values. On a normal distribution curve, 90% confidence intervals (i.e. the upper and lower 95% confidence limits) correspond to +/- 1.645 standard deviations. The 1-percent plus and minus events are defined to be one standard deviation above and below the 1-percent event. It should be noted that the standard errors for the 1-percent rainfall depth were based on the depth used post-areal reduction. The estimated 1-percent plus and minus rainfall depths are shown, alongside the other events, in Table 6 later in this section.

CNs were computed by intersecting the National Land Cover Dataset (NLCD) 2019 coverage and NRCS soils data based on the matrix presented in Table 4.

Table 4: Land Use(LU)-Soils-CN Matrix for Defining Initial Curve Number

LU_GridCode	NLCD LU Description	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	84
82	Cultivated Crops	51	67	76	80
90	Woody Wetlands	72	80	87	93
95	Emergent Herbaceous Wetlands	72	80	87	93

In addition to rainfall, the 1-percent plus and minus event estimates were further refined by adjustment of their respective CNs. A CN can be considered a parameter, exhibiting variability that follows some frequency distribution. While Antecedent Runoff Condition (ARC) II CNs were used for a 1-percent event, the range between ARC I and ARC III for the ARC II CN was assumed to correspond to an 80% confidence interval of the ARC II CN. The CN loss method assumes a maximum potential retention parameter, S, is inversely related to a CN by S = 1000 / CN – 10; this relationship is based on a median value of S determined from plotting a large number of observations.

Chapter 5 of the NRCS National Engineering Handbook (NEH) Part 630 provides an example of computing a CN for a watershed based on annual peak gage observations. The example involves computing a CN and corresponding S value for each event, then taking the logarithms of the S values. Further, the logarithm of S is assumed to vary normally, and the mean of the logarithms corresponds to the arithmetic median. Therefore, 10% (S10) and 90% (S90) extremes of lognormally distributed S values can be assumed to correspond to ARC III and ARC I condition CN values, respectively. This range represents an 80% confidence interval, corresponding to +/- 1.282 standard deviations from the mean. The following procedure was used to estimate one standard deviation of a given CN (in fact, one standard deviation of the logarithm of S) for the purposes of modeling 1-percent plus and minus events. First, ARC III (corresponding to S10) and ARC I (corresponding to S90) CN values can be estimated from a 1-percent CN (ARC II) by:

$$\mathrm{CNI} = 4.2 * \mathrm{CNII} \,/\, (10 - 0.058 * \mathrm{CNII})$$

$$\mathrm{CNIII} = 23 * \mathrm{CNII} \,/\, (10 + 0.13 * \mathrm{CNII})$$

Next, S90 and S10 can be computed by:

$$\mathrm{S10} = 1000 \,/\, \mathrm{CNIII} - 10$$

$$\mathrm{S90} = 1000 \,/\, \mathrm{CNI} - 10$$

The following relationship can then be used to compute one standard deviation of the logarithm of S:

$$\log(S10) = \text{mean}(\log(S)) + 1.282\ \text{std. dev.}(\log(S))$$

$$\log(S90) = \text{mean}(\log(S)) - 1.282\ \text{std. dev.}(\log(S))$$

$$1\ \text{std. dev.}(\log S) = (\log S10 - \log S90)\ /\ 1.282$$

Therefore, 1-percent plus and minus S values can be estimated by:

$$\log \text{SPlus} = \log S + [1\ \text{std. dev.}(\log S)]$$

$$\log \text{SMinus} = \log S - [1\ \text{std. dev.}(\log S)]$$

Finally, 1-percent plus and minus CNs can be computed by:

$$\text{CNPlus} = 1000\ /\ (\text{SPlus} + 10)$$

$$\text{CNMinus} = 1000\ /\ (\text{SMinus} + 10)$$

Since the 1-percent plus and minus events represent plus and minus one standard deviation of a 1-percent event, CNs used in a rainfall-runoff simulation for modeling 1-percent plus and minus events were developed, as described above. A single basin was used in HEC-HMS for simulation to estimate excess precipitation.

Table 5 shows the curve numbers both initially computed and revised/verified values based on reasonability check revisions.

Table 5: Rainfall-Runoff Curve Numbers

Sub-basin Description	CN (initial)	CN (verified)	CN 1-percent Minus	CN 1-percent Plus
Middle Brazos-Palo Pinto 1	77.50	77.50	64.89	86.65
Middle Brazos-Palo Pinto 2	75.90	82	70.1	89.80
Middle Brazos-Palo Pinto 3	72.43	72.43	58.55	83.09
Middle Brazos-Palo Pinto 4	72.25	82	70.1	89.80
Middle Brazos-Palo Pinto 5	75.18	85	74.5	91.70

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including CNs for defining rainfall losses. No routing was considered in the rainfall-runoff modeling. Frequency-based storm with 50% storm centering were used for-defining temporal distributions of point rainfall totals. Table 6 provides the precipitation totals applied to the model including areal reduction-factor (ARF).

Table 6: Precipitation Totals estimated in HEC-HMS (post ARF)

Percent Annual Chance Precipitation Depths (in.)							
Sub-Basin Description	1-percent	0.2-percent	2-percent	4-percent	10-percent	1-percent Plus	1-percent Minus
Middle Brazos-Palo Pinto 1	7.73	10.47	6.72	5.81	4.70	9.21	6.24
Middle Brazos-Palo Pinto 2	8.01	10.74	6.96	5.99	4.83	9.64	6.38
Middle Brazos-Palo Pinto 3	8.47	11.65	7.35	6.34	5.11	10.16	6.79
Middle Brazos-Palo Pinto 4	8.28	11.01	7.17	6.15	4.97	9.89	6.67
Middle Brazos-Palo Pinto 5	8.31	10.92	7.34	6.44	5.28	9.89	6.67

Table 7 shows the excess precipitation totals determined from the HMS model. These values are a factor of the average CN and precipitation depths for each model area. Note that CNs were modified during the calibration process and the excess precipitation depths were recalculated to install confidence in the final model results.

Table 7: Total Excess Precipitation Applied to 2D Mesh

Percent Annual Chance Precipitation Depths (in.)							
Sub-Basin Description	1-percent	0.2-percent	2-percent	4-percent	10-percent	1-percent Plus	1-percent Minus
Middle Brazos-Palo Pinto 1	5.08	7.64	4.17	3.36	2.41	7.59	2.52
Middle Brazos-Palo Pinto 2	5.87	8.49	4.88	3.98	2.93	8.40	3.12
Middle Brazos-Palo Pinto 3	5.16	8.07	4.18	3.32	2.32	8.06	2.32
Middle Brazos-Palo Pinto 4	6.13	8.75	5.08	4.13	3.05	8.65	3.36
Middle Brazos-Palo Pinto 5	6.51	9.06	5.58	4.72	3.63	8.88	3.81

Figure 4- Figure 8 show the excess precipitation hyetograph used for MBPP1 – MBPP5. CN and precipitation depth are the two factors used by the HMS model to determine the magnitude of the excess precipitation event. The excess precipitation hyetograph is calculated in 6-minute increments. All models in this study have excess hyetograph shapes that closely resemble this one, but with varying maximum excess precipitation values.

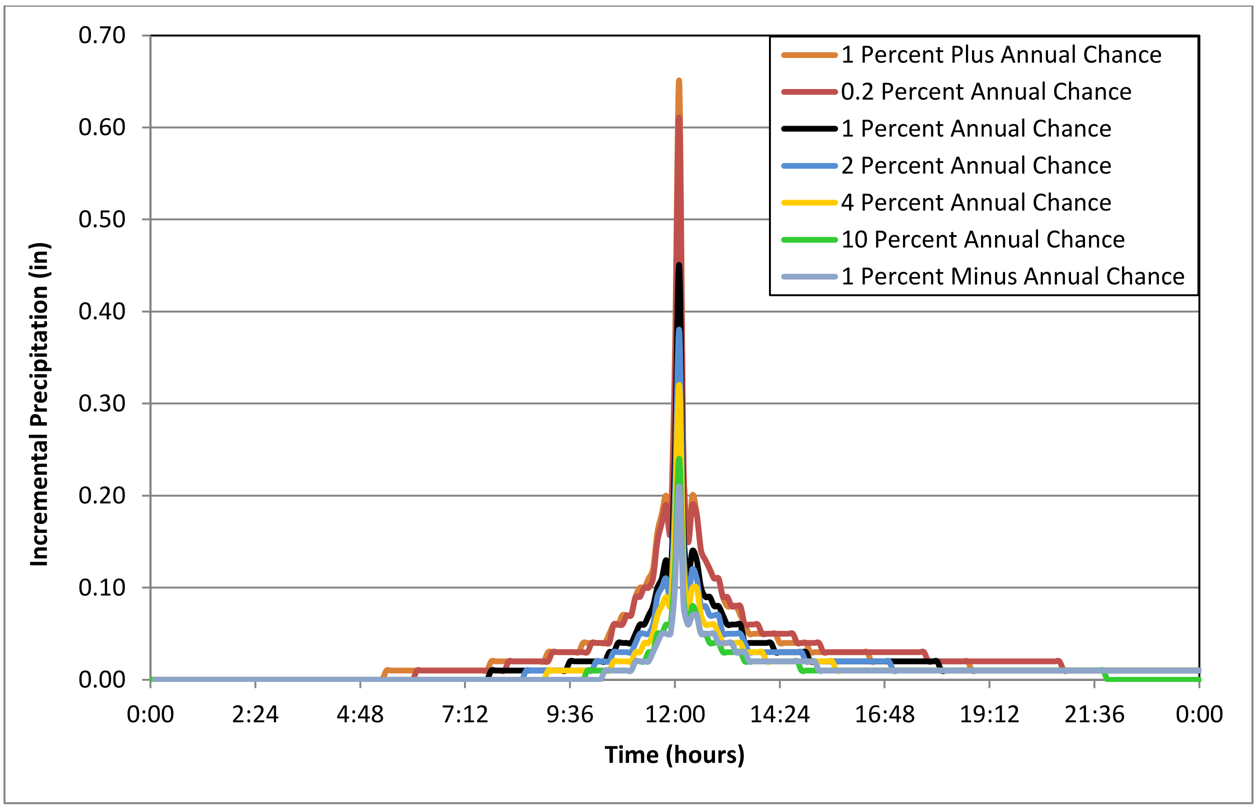

Figure 4: Excess Precipitation Hyetograph Applied to 2D Mesh – Middle Brazos-Palo Pinto 1

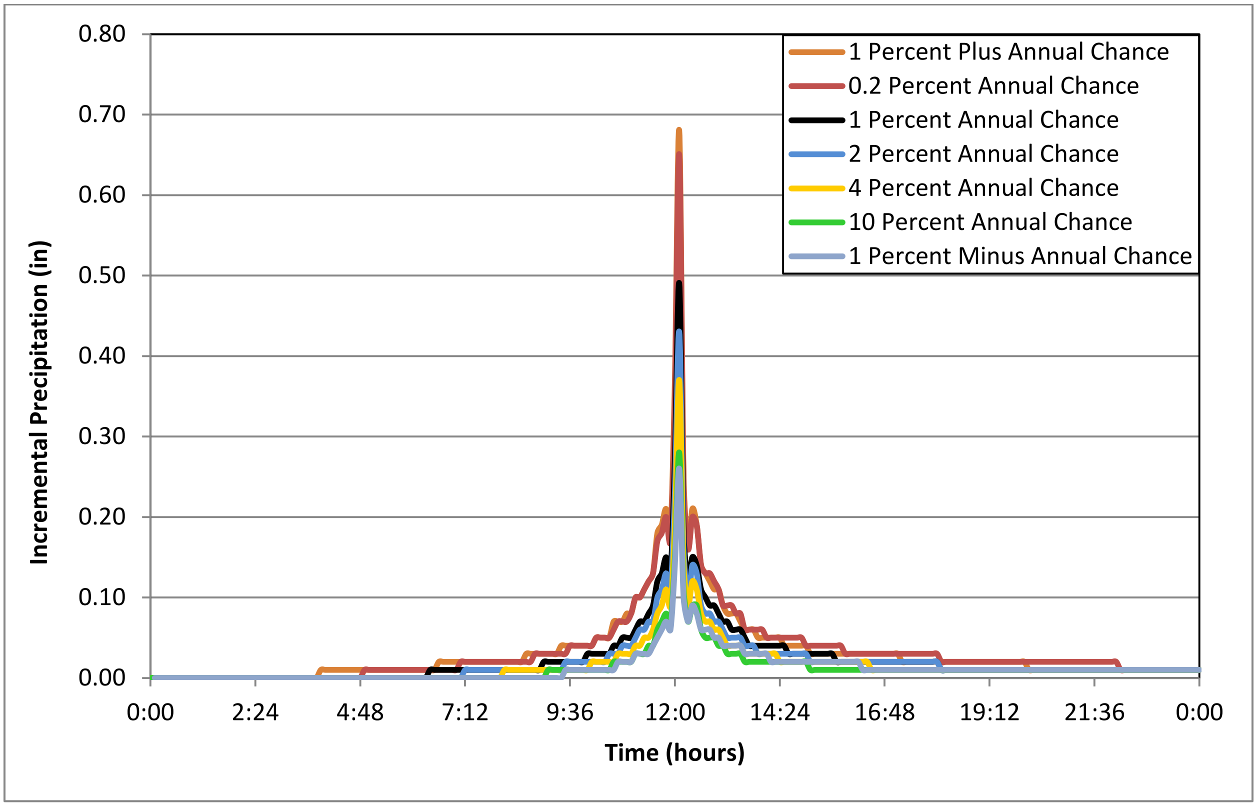

Figure 5: Excess Precipitation Hyetograph Applied to 2D Mesh – Middle Brazos-Palo Pinto 2

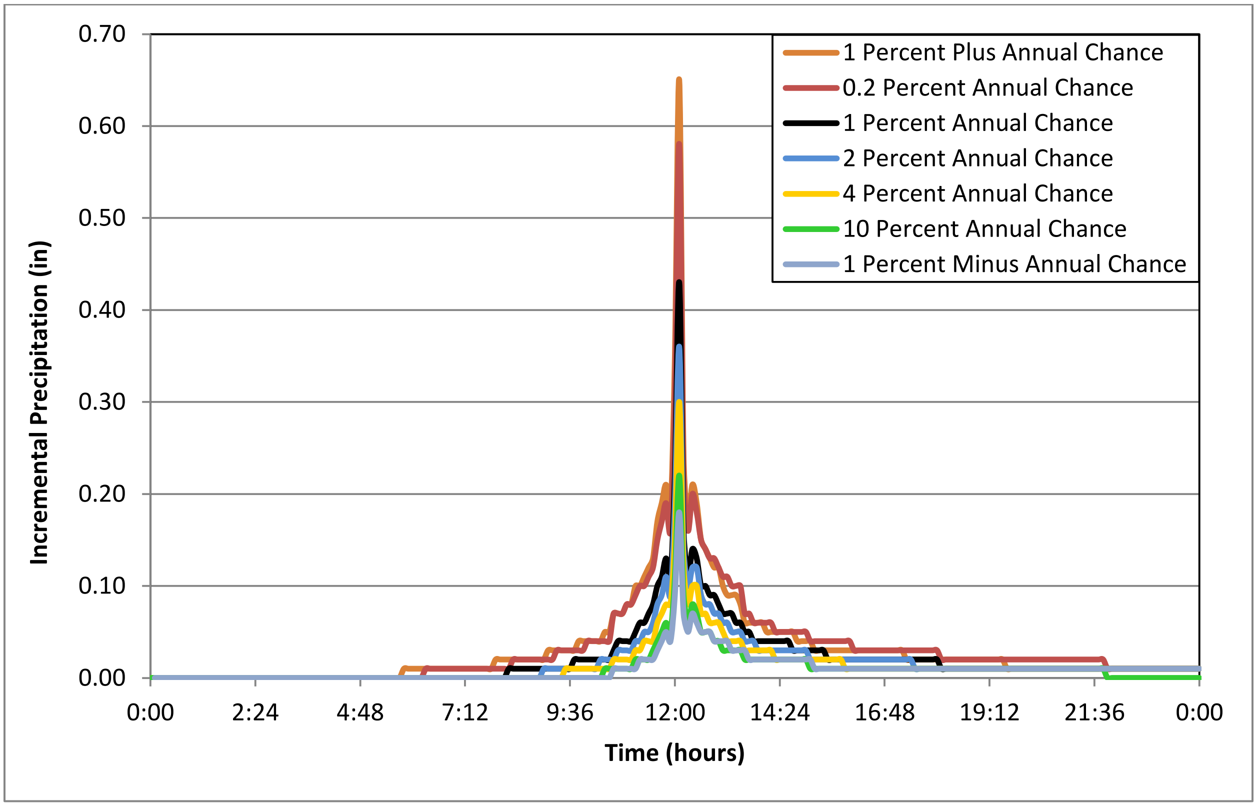

Figure 6: Excess Precipitation Hyetograph Applied to 2D Mesh – Middle Brazos-Palo Pinto 3

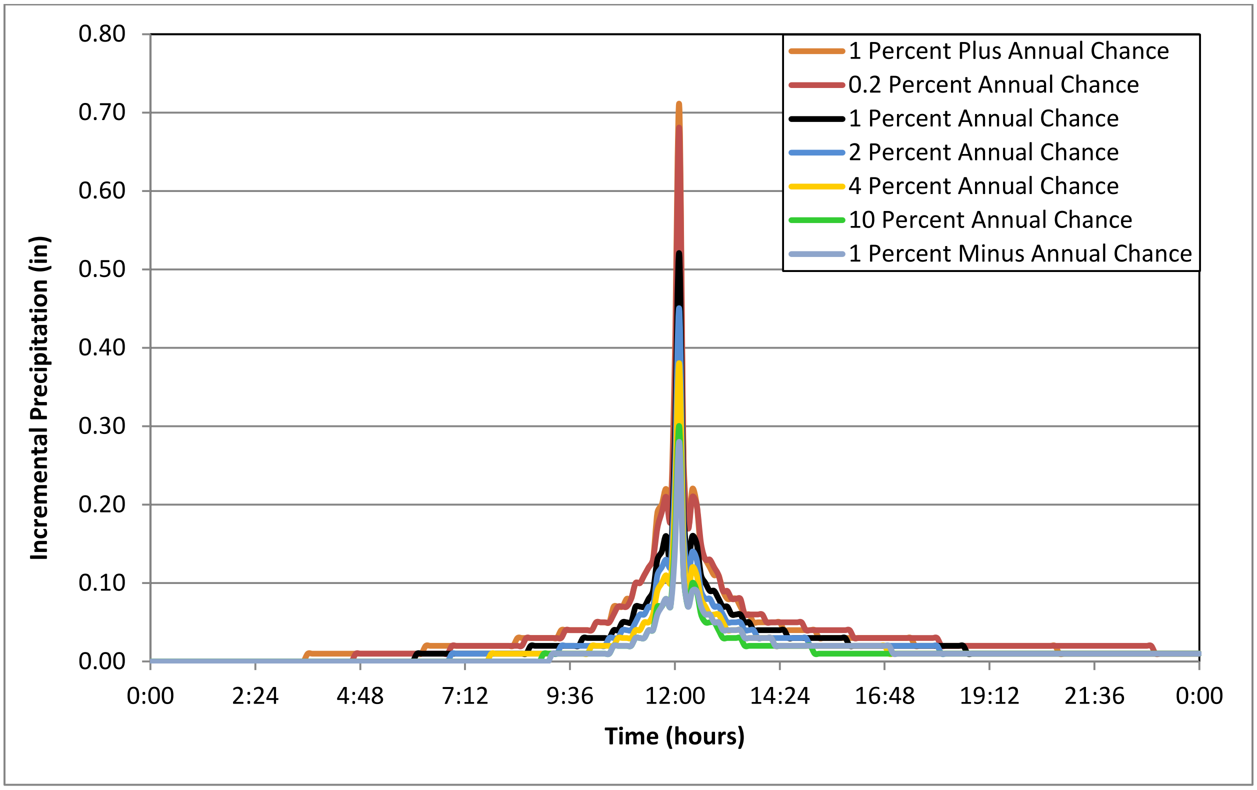

Figure 7: Excess Precipitation Hyetograph Applied to 2D Mesh – Middle Brazos-Palo Pinto 4

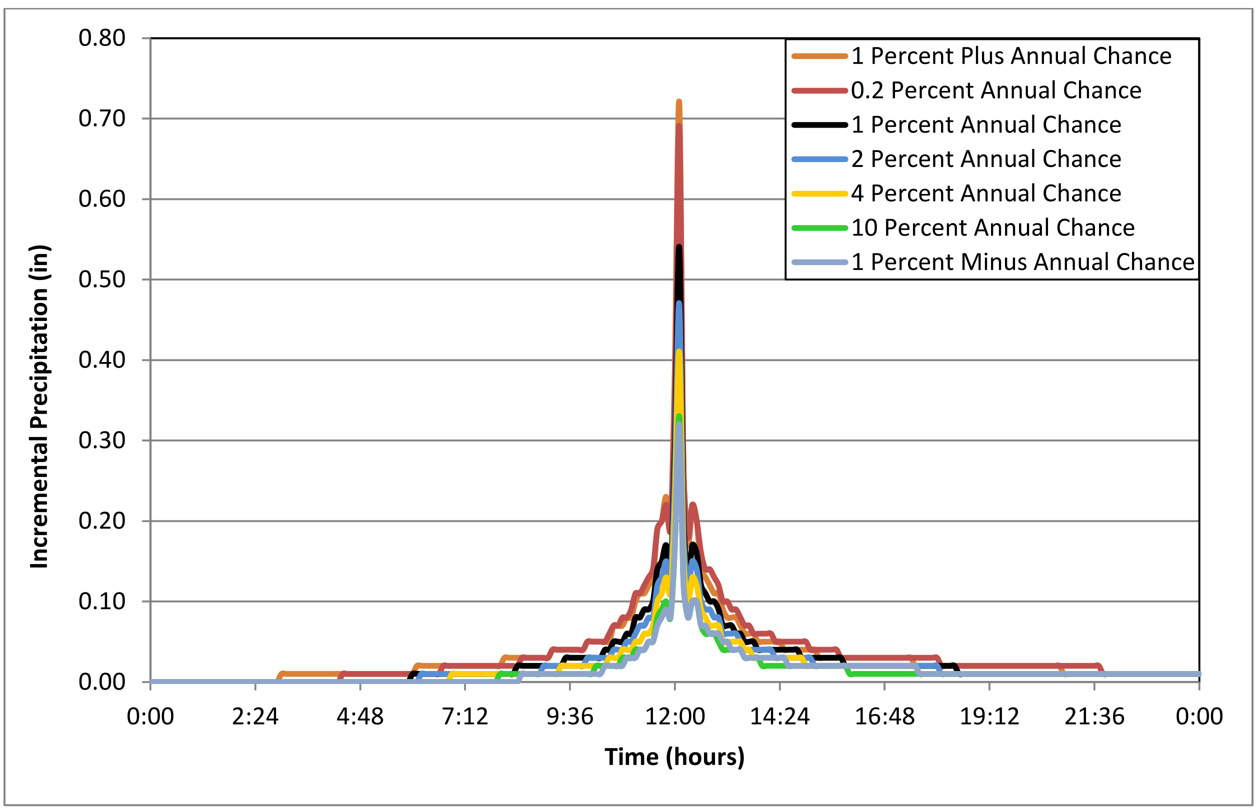

Figure 8: Excess Precipitation Hyetograph Applied to 2D Mesh – Middle Brazos-Palo Pinto 5

2.2.3.2 Inflow Hydrograph Boundary Conditions

Flow from the Brazos River upstream of MBPP HUC-8 watershed was used as an inflow into the MBPP1 model. The inflow hydrograph was derived using a gage transfer approach from gage 08088000 peak flow data at the gage location just downstream of the MBPP1 inflow. This inflow hydrograph is represented in Figure 9.

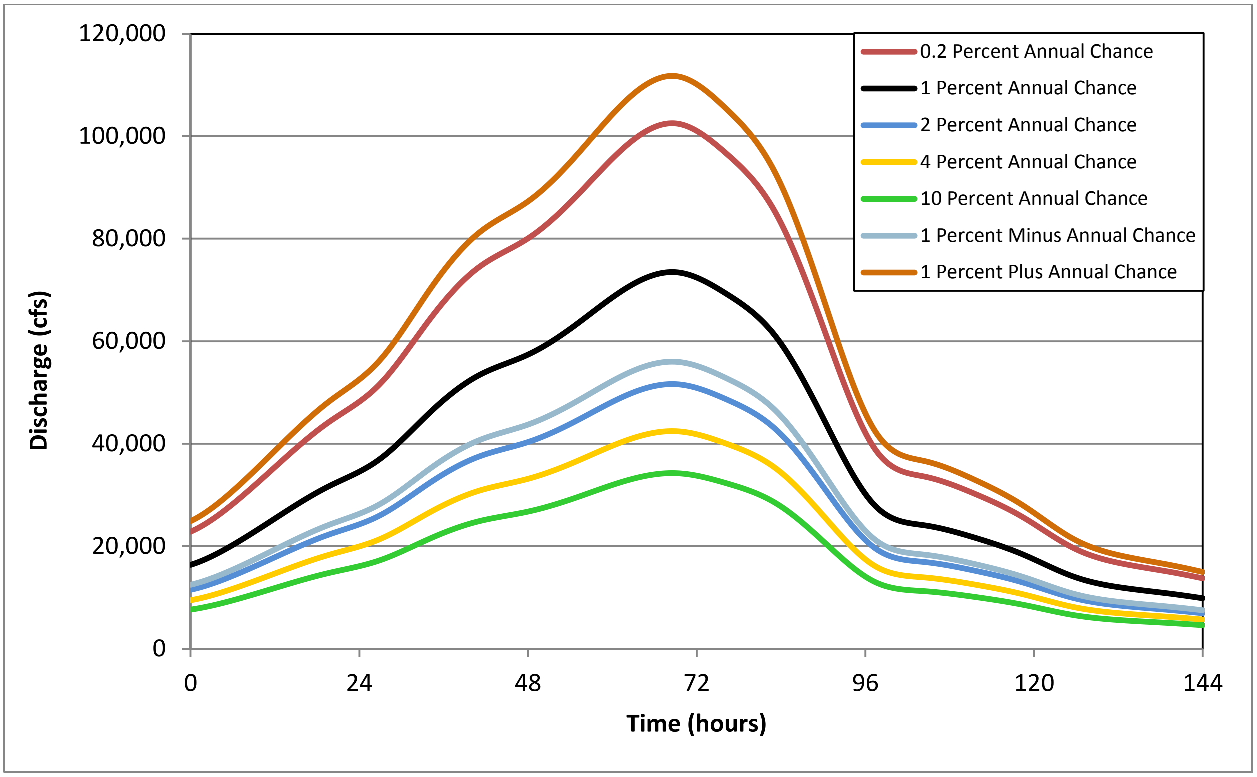

Figure 9: Inflow Hydrograph for Middle Brazos-Palo Pinto 1 from Brazos River

Rock Creek, a stream at the upstream end of MBPP1, is split between the MBPP1 and MBPP2 modeling areas. A modeling decision was made to place an inflow stage hydrograph at the boundary location in MBPP1. The inflow stage hydrograph was extracted from MBPP2 model using a 2D connection. The inflow stage hydrograph applied to MBPP1 RAS model is represented in Figure 10.

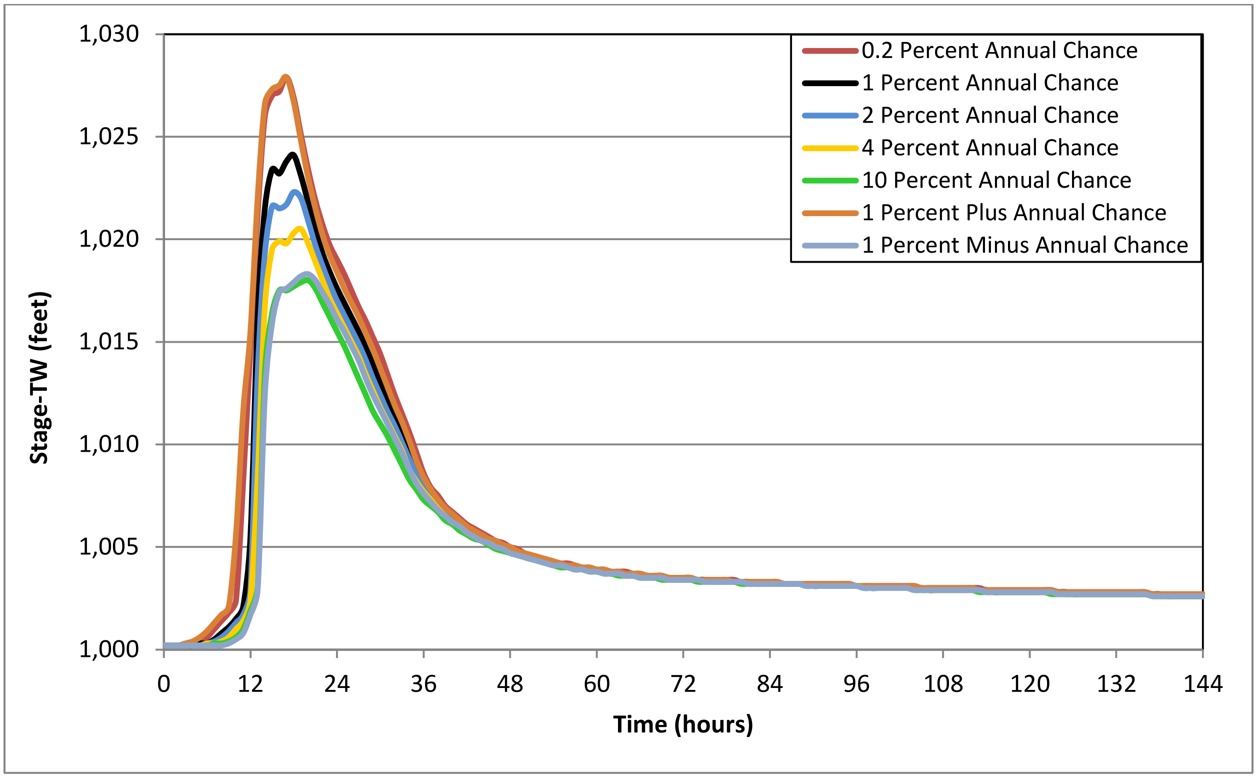

Figure 10: Inflow Hydrograph for Middle Brazos-Palo Pinto 1 from Middle Brazos-Palo Pinto 2

The resulting data from upstream models were used as inflow hydrographs for the downstream models to allow the five separate HEC-RAS models to act as one continuous model for the larger Middle Brazos-Palo Pinto watershed area. The inflow hydrograph from MBPP1, applied as a flow hydrograph in MBPP2, is shown in Figure 11.

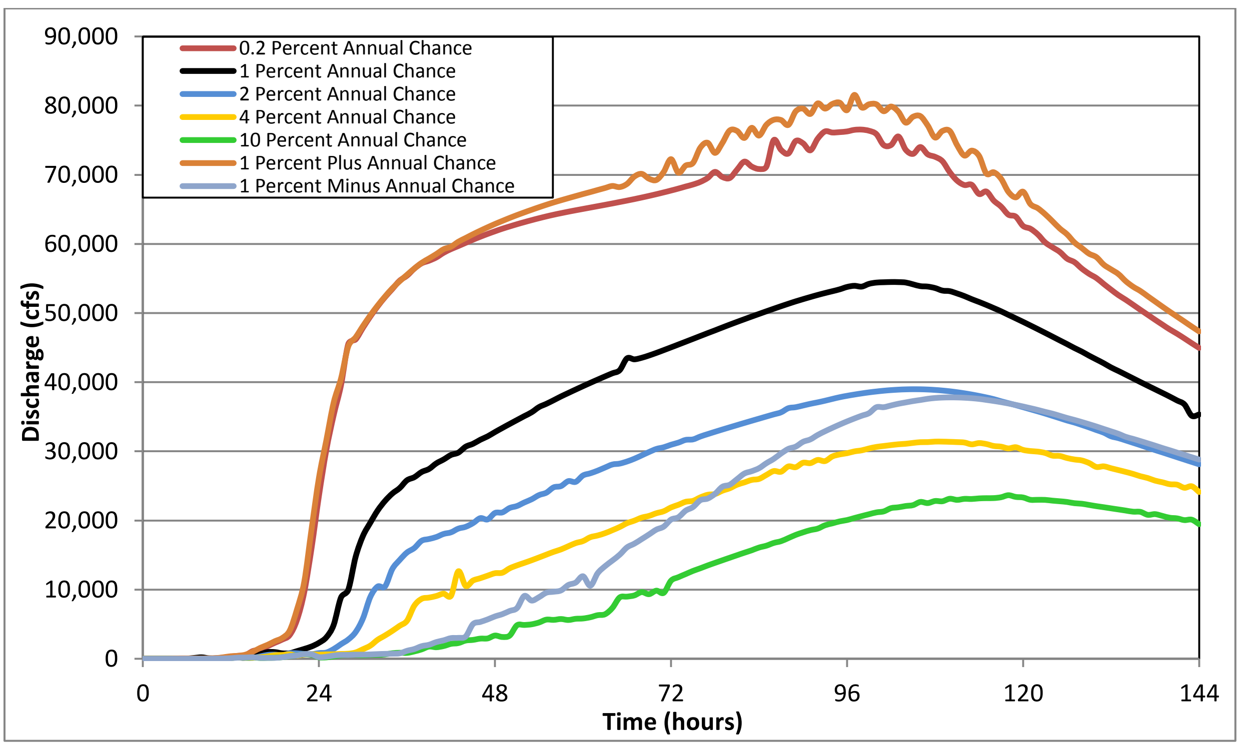

Figure 11: Inflow Hydrograph for Middle Brazos-Palo Pinto 2 from Middle Brazos-Palo Pinto 1

The inflow hydrograph from MBPP2, applied as a flow hydrogrpah in MBPP4, is shown in Figure 12

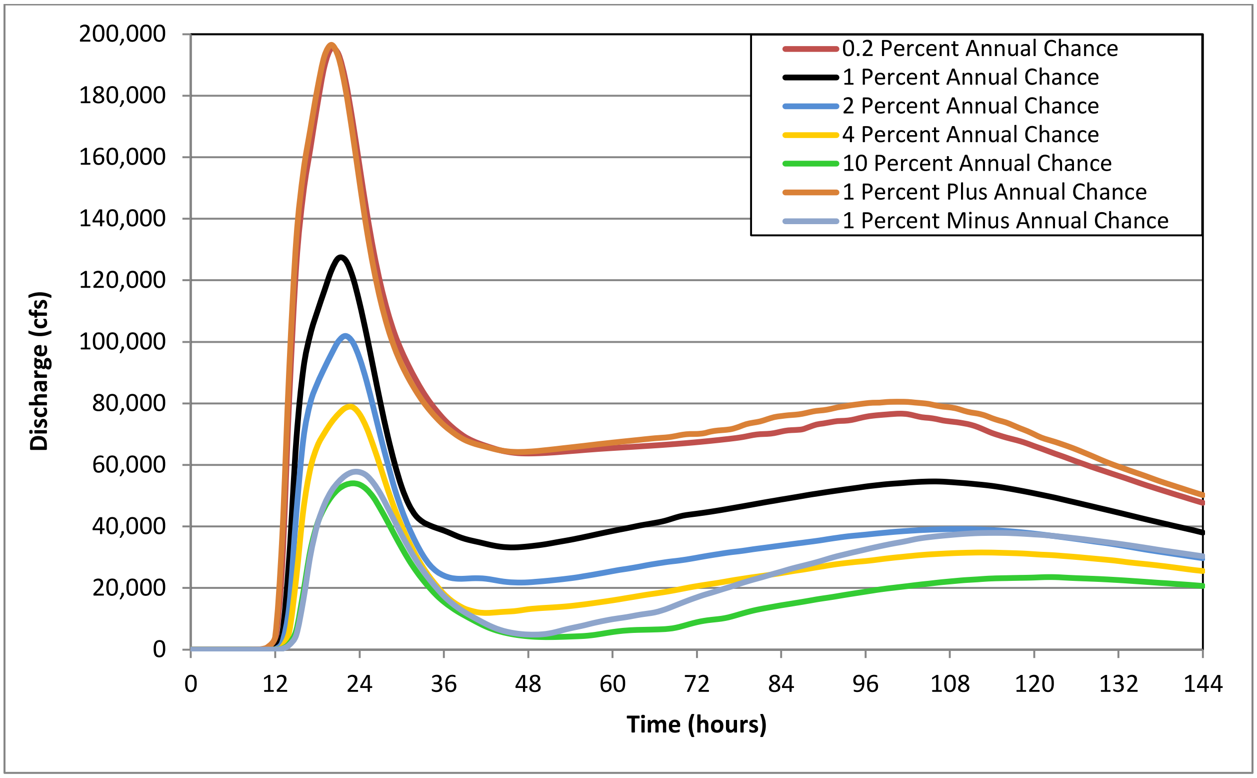

Figure 12: Inflow Hydrograph for Middle Brazos-Palo Pinto 4 from Middle Brazos-Palo Pinto 2

The inflow hydrograph from MBPP3, applied as a stage hydrograph in MBPP4, is shown in Figure 13.

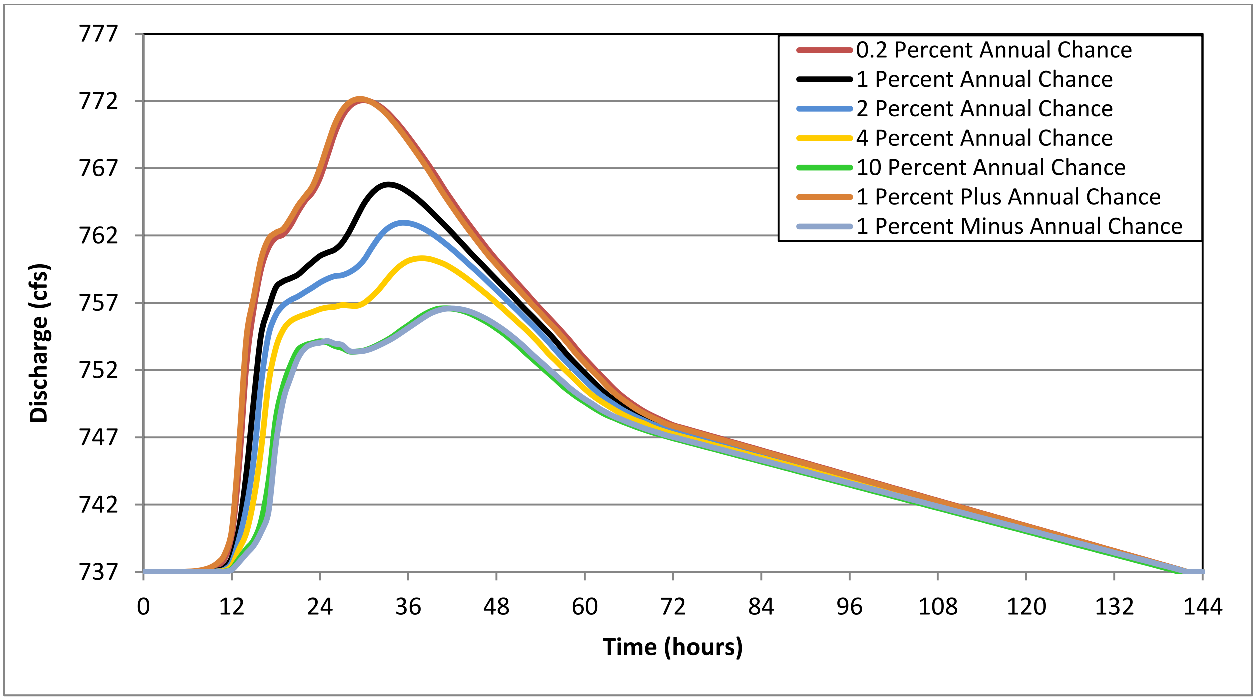

Figure 13: Inflow Hydrograph for Middle Brazos-Palo Pinto 4 from Middle Brazos-Palo Pinto 3

As showin in Figure 13 above, MBPP3 inflow data was interpolated using the inperpolate missing values tool, in order to allow for the extended simulation time for the MBPP4 model runs. Enginnering judgement was used to make the assumption that the hydrograph would follow a path to end at the starting simulation stage height of 736.84 feet.

The inflow hydrograph from MBPP4, applied as a flow hydogrph in MBPP5, is shown in Figure 14.

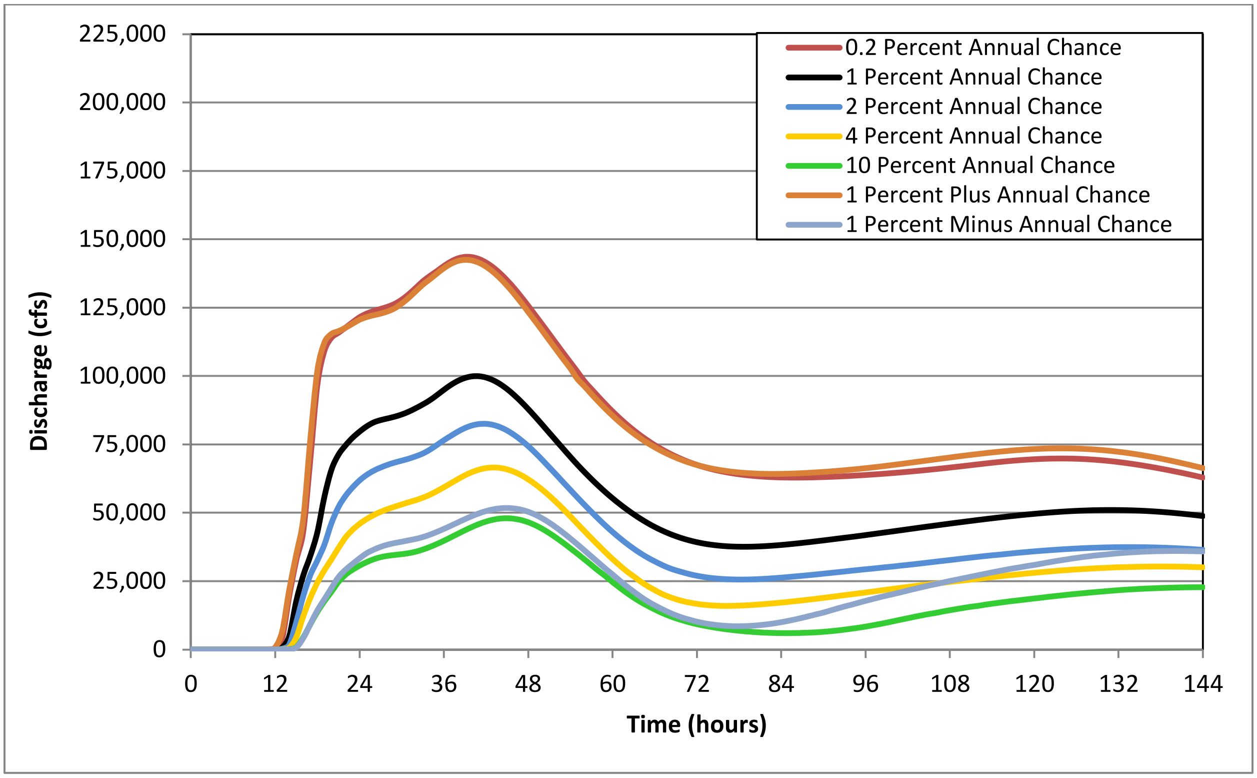

Figure 14: Inflow Hydrograph for Middle Brazos-Palo Pinto 5 from Middle Brazos-Palo Pinto 4

In order to achieve a seamless flood hazard result at a transition location (locations where flow is exchanged between 2D model areas), the water surface elevation (WSE) and inundation tie-ins between models must be made as close as possible. A 1,000 feet buffer was applied to each model work area for the mesh boundary. This is done so that the inflow boundary condition of the downstream model and the normal depth outlet boundary condition of the upstream model are far enough away from the work area transition location that they do not impact the WSE tie-ins between models in an undesired way. To make this overlap work without double accounting for rainfall, an internal 2D connection is placed in the upstream model to extract a hydrograph at the exact same location as the inflow boundary condition tofor the downstream model location. This internal 2D connection is placed well upstream of the normal depth outlet boundary condition to ensure the flow hydrograph being passed to the downstream model is not affected by normal depth assumptions. Approximately halfway between the model overlap is the actual model area boundaries where the mapped floodplain products switch from the upstream model results to the downstream model results. This transition location is the targeted area to have the water surface elevation and inundation tie-in as closely as possible.

2.2.4 Hydraulics

This section describes the remaining hydraulic modeling considerations, including implementation of Manning's roughness, breaklines, refinement regions, and hydraulic structures within the 2D computational mesh..

2.2.4.1 Roughness Coefficients

Manning's n roughness coverage was developed for the 2D computational mesh using typical roughness values for given NLCD land classifications. Two different sets of Manning's n values were used for areas within the channel and all other areas outside of the channels of the stream network. The channel layers were created using a 100 foot buffer. This allows for the model to accurately represent deep, swift flow within the channel and shallow overland flow outside of the channel areas. The table below shows a typical landuse-roughness matrix used in defining the roughness coverage for the study area for areas both inside and outside of the channel. . In the HEC-RAS model Channel n values are listed as land classification – Channel, and Overbank bank n values are listed as land classification – Base.

Table 8: NLCD 2019 Manning's n Roughness Matrix

NLCD Classification	Channel		Overbank	
	N Value	Source	N Value	Source
Open Water	0.03	Chow, 1959	0.03	Chow 1959
Developed, Open Space	0.035	Chow, 1959	0.04	NRCS KS Dam Breach, 2016
Developed, Low Intensity	0.035	Chow, 1959	0.08	NRCS KS Dam Breach, 2016
Developed, Medium Intensity	0.035	Chow, 1959	0.1	NRCS KS Dam Breach, 2016
Developed, High Intensity	0.035	Chow, 1959	0.15	NRCS KS Dam Breach, 2016
Barren Land	0.03	Chow, 1959	0.03	NRCS KS Dam Breach, 2016
Deciduous Forest	0.05	Chow, 1959	0.16	NRCS KS Dam Breach, 2016
Evergreen Forest	0.05	Chow, 1959	0.16	NRCS KS Dam Breach, 2016
Mixed Forest	0.05	Chow, 1959	0.15	NRCS KS Dam Breach, 2016
Scrub/Shrub	0.04	Chow, 1959	0.1	NRCS KS Dam Breach, 2016
Grassland/Herbaceous	0.04	Chow, 1959	0.15	HCFCD modeling Guidelines, 2018
Pasture/Hay	0.04	Chow, 1959	0.15	HCFCD modeling Guidelines, 2018
Cultivated Crops	0.04	Chow, 1959	0.1	HCFCD modeling Guidelines, 2018
Woody Wetlands	0.04	Chow, 1959	0.12	NRCS KS Dam Breach, 2016
Emergent Herbaceous Wetland	0.04	Chow, 1959	0.07	NRCS KS Dam Breach, 2016

2.2.4.2 Breaklines

Breaklines align grid cell faces and were used within the 2D mesh area to define prominent features including road embankments and hydraulic structures. Road embankment features were delineated in GIS and imported into RAS6 as breaklines to contain water where appropriate. Similarly, significant bridge/culvert crossings that were not processed out of the terrain data were modeled by v-notch breaklines adjacent to the road embankment to align grid cells around the embankment and allow water to be routed through the embankment without creating artificial backwater. An example of the v-notch breakline approach is shown in Figure 15.

County, interstate, common name, state recognized, and U.S. roads were incorporated for road breaklines from the U.S. Census Bureau TIGER/Line road layer.

There were ten dams located within the HUC-8 modeling area. Six out of these ten were not registered as “large” dams and were modeled with breaklines to show that they held back water based on terrain. These six dams are: Lake Eddleman Dam, Lake Mineral Wells Dam, Lake Tucker Dam, Ruckers Creek WS SCS Site 1 Dam, Star Hollow Lake Dam, and Waddell Ranch Dam No 3. The remaining four dams were registered as “large” dams and considered too large to use only breaklines. Therefore, a 2D connection was used to model these dams. The four large dams are:Lake Palo Pinto Dam, Graham Dam, Morris Sheppard Dam, and De Cordova Bend Dam. To best represent these four dams, data was gathered from the Texas Water Development Board and Texas Commission on Environmental Quality (TCEQ) Dam Inventory database. Additionally, data was obtained from the Brazos River Authority for the De Cordova Bend Dam and Morris Sheppard Dam. A stage-discharge rating curve was hand calculated and incorporated into the Lake Palo Pinto Dam 2D connection using the emergency spillway data obtained from TWDB. Because Graham Dam is an earthfill dam, the 2D connection was placed based on terrain data in addition to data gathered from TWDB. Model runs helped to determine the length of the connection that would cover all spillways at the structure. All sixteen tainter gates in the De Cordova Bend Dam and the nine roof-weir gates in the Morris Sheppard Dam were included in their respective 2D connections, as well as the ogee weirs. It was determined that the “roof-weir” gates in the Morris Sheppard Dam would best be modeled as sluice-type gates to convey an accurate representation of flow at the structure. Engineering judgement was used to approximate the rate and WSEL at which the gates would open and close for the Morris Sheppard Dam. Gates for De Cordova Bend Dam were left fully open for the duration of simulation, in order to overcome overtopping issue at the Dam in the model. Private dams were not modeled as showing protection. This is to lessen the burden on private dam owners to maintain their dams in order to sustain the regulatory products that could be created in the future as a result of this study. The study area does not include any FEMA accredited levees.

Breaklines were also used along all the stream centerlines of streams draining greater than one square mile of drainage area, and 0.5 square miles of drainage area within densely populated areas. Each streamline was topo-derived and the stream centerline was enforced with 100 feet cell spacing in order to align cells along the stream line and capture more detail along the one square mile stream network. Streamline alignment was also hand checked with the terrain by the modeler to ensure accuracy. Stream names were referenced from other sources such as NFHL and NHD datasets. In the HEC-RAS model, streams that passed through densely populated regions were enforced as breaklines using 50ft cell spacing.

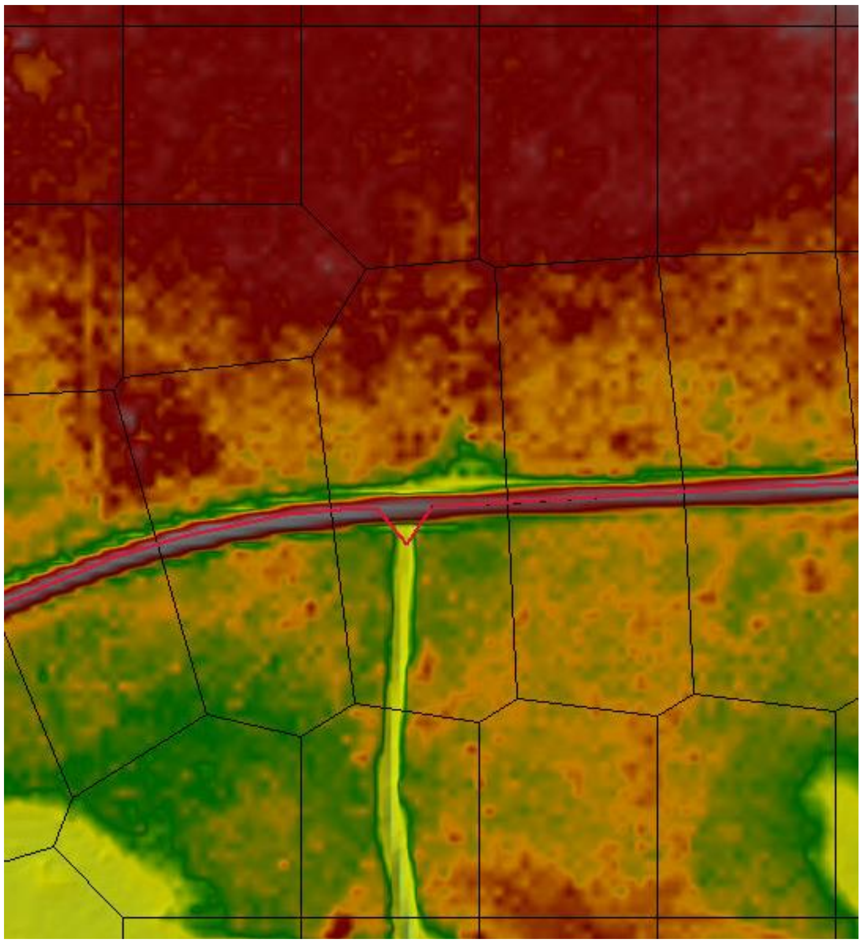

Figure 15: V-notch Breakline Approach at Bridge Crossing

2.2.4.3 Refinement Regions

Refinement regions were created for each community within the model. The political boundary was used to determine the shape of the refinement region. The regions were assigned a cell spacing of 50 feet by 50 feet. This finer cell spacing allows for more hydraulic calculations and mapping detail near areas where there are likely to be more structures. Table 9 shows the communities contained within MBPP watershed that were modeled with refinement regions as well as the square mileage of the refinement region.

Table 9: Communities with 2D Mesh Refinement

Community Name	Area (mi^2)
Olney City	2.03
Graham City	5.62
Graford City	0.72
Bryson City	1.42
Palo Pinto CDP	0.87
Perrin CDP	1.60
Strawn City	0.78
Mingus City	1.55
Gordon City	0.97
Ranger City	7.13
Millsap Town	1.47
Cool City	1.65
Mineral Wells City	21.2
Lipan City	1.06
Horeshoe Bend CDP	0.003
Cresson City	5.92
Weatherford City	5.46
Granbury City	13.6
DeCordova City	1.62
Brazos Bend City	0.95
Pecan Plantation CDP	7.64
Horseshoe Bend CDP	1.72
Western Lake CDP	3.51
Oak Trail Shores CDP	2.54
Canyon Creek CDP	2.56

2.2.5 Quality Control

The 2D BLE results were independently assured to meet quality standards of the project. Standard checklists complying with FEMA standards were used to review hydrology and hydraulics results, the resulting flood hazard area delineations and CNMS dataset. Quality assurance during the data development process includes, but is not limited to the following QC checks:

- Hydrological QC – included checks for curve number calculation, input precipitation, flood events, areal reduction factor and human error.
- Hydraulic QC – included checks for RAS geometry, breakline placement, v-notch placement to ensure water conveyance at crossings, refinement regions, roughness coefficients, boundary/initial conditions, timestep and mapping outputs
- Mapping – included checks for spot checking flood inundation accuracies based on floodplain mapping criteria described in section 4.1.2, ensuring flood extents from higher frequency events did not exceed lower frequency extents due to GIS smoothing algorithms, and topological overlap and cluster tolerance errors were resolved

- CNMS - Included review of the A1-A5 analysis for all effective approximate reaches in the HUC, geometry updates to newly studied reaches added as Zone X, and removal of scoped areas which lie outside of the final BLE footprint.

3. Results

The 2D BLE results for the study produced flood hazard area that compared reasonably well with effective SFHA in most cases, and provides additional estimated flood hazard risk area where not previously mapped. The HEC-RAS peak (max) results were exported for mapping and the HEC-RAS model was run with a hydrograph output interval of 1 hour, mapping output interval of 1 hour and the detailed output interval of 1 hour. The MBPP watershed is sufficient to facilitate FEMA regulatory processes while also providing the best available information for planning purposes. To further check the model's accuracy additional profile lines were added to the model areas and compared to Base Flood WSEs that were available in the Hood County Flood Insurance Study (FIS) dated April 5, 2019, Palo Pinto County FIS effective April 5, 2019,and Parker County FIS effective April 5, 2019. The comparison is shown below in Table 10. The 2D BLE results should be verified through community work map meetings as part of the regulatory workflow.

Table 10: Effective and Model Base Flood Elevation(BFE) Comparison after calibration

Location Description	Effective BFE (feet)	Model BFE (feet)	Difference (feet)
Crystal Creek Above Crystal Creek Tributary 3	863	864.5	1.5
Brazos River Downstream of Bridge on IH20	761	754.4	6.6
Pollard Creek at Private dam Approximately 1600' upstream of U.S. Highway 281	963.5	959.7	3.8
Rock Creek Tributary 2 Approximately 2000' upstream of FM1195	848.5	852.4	3.9
Brazos River at DeCordova Bend Dam	694.5	694.7	0.2
Lambert Branch at Houston St	703.5	710.4	6.9
Brazos River at Hood-Somervell County Line	622.5	627.6	5.1
Brazos River at Hood-Parker County Line	710.5	714.6	4.1

3.1 Calibration

Five USGS gages within the model area with more than 10-years of flow record were used as the first priority for calibration of the 1-percent annual chance event. Discharges at gages were compared to discharges in the 2D models at the exact same locations. If a published rating curve was available, WSE from the model was compared to the calculated 1-percent WSE from the gage analysis.

Effective data was the second priority for calibration. Modeled flows were compared to flows from the summary of discharges tables from the Hood County FIS (Effective April 2019), Palo Pinto County FIS (Effective April 2019), and Parker County FIS (Effective April 2019). Known water surface elevations were used for validation, not calibration. Upper and lower limits for the effective flows were calculated by hand and were not taken from the FIS report. They were calculated by:

Upper Limit= 0.501 * 1%Q

Lower Limit=1.995 * 1%Q

Regression analysis was used to provide tertiary calibration points. Adjustments to the CN and to hydraulic features within the model were made until the flows in the model matched closely with the peak flows determined from gage, effective data, and/or regression data. CN's for MBPP2 and MBPP4 were increased to 82. CN for MBPP5 was increased to 85. A calibration region in MBPP4 was used to lower the open water channel Mannings around gage 08089000 from 0.03 to 0.01, in order to increase the flow. Final results following model calibration at the calibration locations are presented in Table 11. The discharge from HEC-RAS model were calibrated with five USGS stream gages, however due to the limitations and scope of this BLE study, extensive efforts were not feasibile.Therefore, model flows were acceptable if they were within gage, effective, and regression data limits.

Table 11: Calibration Results

Calibration Location	Source	Method Used in Original Study	Reference			HEC-RAS 6.1 (2D) (cfs)
			Lower Limit (cfs)	1-percent (cfs)	Upper Limit (cfs)	
Gage 08088000	Brazos Rv nr South Bend, TX	USGS	49,140	64,480	98,070	84,342*
Gage 08088100	Salt Ck at Olney, TX	USGS	4,148	6,709	14,040	6,048*
Gage 08088300	Brian Ck nr Graham, TX	USGS	5,314	7,576	12,600	11,316
Gage 08089000	Brazos Rv nr Palo Pinto, TX	USGS	78,160	93,540	117,600	80,094
Gage 08090800	Brazos Rv nr Dennis, TX	USGS	99,950	127,200	174,900	104,473
West Salt Creek	Regression Analysis	USGS-SIR 2009-5087	8,339	16,638	33,198	10,370
Upper East Fork Keechi Creek	Regression Analysis	USGS-SIR 2009-5087	3,897	7,776	15,514	11,549
Cottonwood Creek- Palo Pinto Creek	Regression Analysis	USGS-SIR 2009-5087	6,652	13,272	26,481	14,837
Upper Barton Creek	Regression Analysis	USGS-SIR 2009-5087	8,223	16,408	32,738	24,323

*All gage flows were taken with SA/2D Connection, with exception of gage 08088000 and 08088100. Flows for both of these gages were taken with a profile line to capture full extent of floodplain.

Table 11, continued: Calibration Results

Calibration Location	Source	Method Used in Original Study	Reference			HEC-RAS 6.1 (2D) (cfs)
			Lower Limit (cfs)	1-percent (cfs)	Upper Limit (cfs)	
Little Sunday Creek	Regression Analysis	USGS-SIR 2009-5087	4,309	8,597	17,154	9,006
Russell Creek	Regression Analysis	USGS-SIR 2009-5087	4,465	8,909	17,775	12,637
Rush Creek	Regression Analysis	USGS-SIR 2009-5087	5,918	11,808	23,561	17,215
Crystal Creek Above Crystal Creek Tributary 3	Palo Pinto FIS	HEC-RAS 4.1.0	513	1,024	2,043	1,116
Brazos River Downstream of Bridge on IH20	Parker FIS	USGS Regional Regression Equations	86,172	172,000	313,140	100,814
Whatley Creek at Withers Road	Palo Pinto FIS	HEC-RAS 4.1.0	354	707	1,411	786
Pollard Creek at Private dam Approximately 1600 feet upstream of U.S. Highway 281	Palo Pinto FIS	HEC-RAS 4.1.0	531	1,060	2,114	607
Rock Creek Tributary 2 Approximately 2000 feet upstream of FM1195	Palo Pinto FIS	HEC-RAS 4.1.0	470	939	1,873	1217
DeCordova Bend Dam	Hood FIS	USGS Regional Regression Equations	59,218	118,200	235,809	80,746
Rough Creek at State Route 144	Hood FIS	USGS Regional Regression Equations	5,701	11,380	22,703	7558
Lambert Branch at Houston St	Hood FIS	USGS Regional Regression Equations	3,412	6,810	13,586	3475

Table 11, continued: Calibration Results

Calibration Location	Source	Method Used in Original Study	Reference			HEC-RAS 6.1 (2D) (cfs)
			Lower Limit (cfs)	1-percent (cfs)	Upper Limit (cfs)	
Hood-Somervell County Line	Hood FIS	USGS Regional Regression Equations	61,974	123,700	246,782	81,674
Hood-Parker County Line	Hood FIS	USGS Regional Regression Equations	61,773	123,300	245,984	91,460

Figure 16 shows the final results of the calibration locations compared to modeled flows throughout the MBPP watershed along with error bars created using the differrence between 1-percent and 1-percent plus discharges and 1-percent and 1-percent minus discharge as minimum and maximum values. Twenty two comparisons were made with varying drainage areas to ensure the calibration of excess precipitation for different points over the entire watershed area. This large collection of calibration points provides confidence in results throughout the entire watershed.

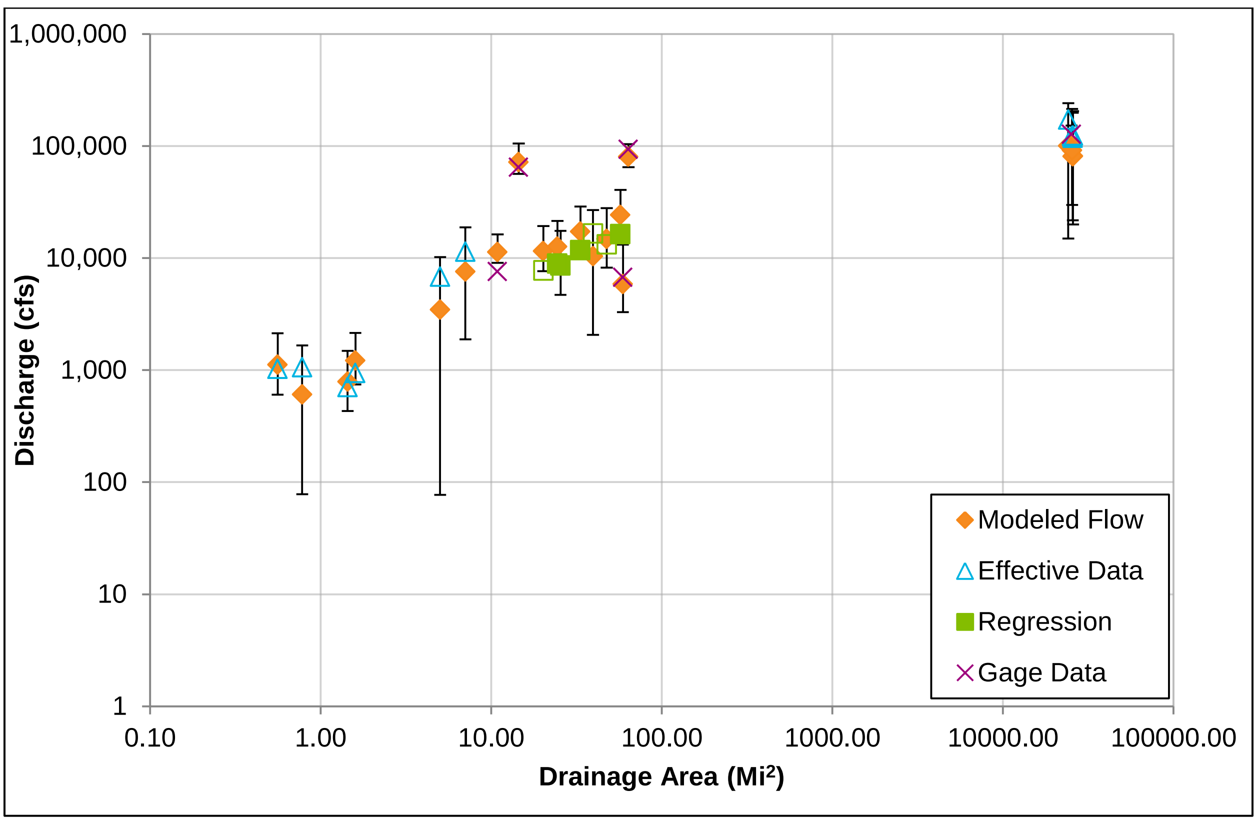

Figure 16: Calibration Comparison

The WSEL from the HEC-RAS model was validated using two USGS stream gages, gage 08088000 and gage 08090800. Based on the published rating curve available, WSE from the model was compared to the calculated 1-Percent WSEL from the gage analysis, as shown in Table 12.

Table 12: 1-Percent Gage WSEL and RAS WSEL Comparison

USGS Gage ID	Lower Bound (feet)	Gage WSEL 1-percent (feet)	Upper Bound (feet)	HEC-RAS 6.1 WSEL (feet)
08088000	1,041.19	1,046.48	1,056.14	1,043.9
08089000	861.32	865.06	870.45	851.38
08090800	737.18	742.26	750.02	732.14

It was observed that MBPP1 WSE was calibrated much better than MBPP2 model. WSE at the gage locations (Gage 08089000) in MBPP2 model does not fall within the estimated range. The MBPP2 model is located downstream of the outlet of Morris Sheppard Dam, modeled in the upstream MBPP1 model, it is likely that the WSE of MBPP2 is affected by the presence of Morris Sheppard Dam in MBPP1, as MBPP2 is modeled to receive the outflow from the dam. It is also observed that model WSEs fall short of the lower bound range for gage 08090800. This can be explained as being a by-product of the upstream inflow from MBPP3 being applied as a Stage Hydrograph at the MBPP4 inlet boundary. WSE data for Gages 08088100 and 08088300 were not available for use in this study, and not included in table. At all of the gage locations, flows calculated by the 2D BLE model and the gage analysis estimates compared favorably. Due to the limited engineering efforts put in the Base Level Engineering, calibration/validation to the 1-percent discharge was given priority for the study.

3.2 Challenges

A considerable challenge for the MBPP watershed was the size of the HUC-8 basin. In order to create this model without creating runtime or cell number issues, it was decided that the watershed would be split into five working models.

The most upstream model MBPP1 receives inflow from Brazos river. As modeling this inflow was outside the scope of the HUC-8, an inflow hydrograph was developed using the peak flow data from a downstream gage 08088000. Rock creek headwater stream was split between modeling areas MBPP1 and MBPP2. As a result an inflow hydrograph was needed to model the stream, and placed at the split location as an inflow to MBPP1. Upon compilation of final modeling and mapping, it was apparent that the entirety of Rock Creek could have been included in MBPP1 model as part of its model footprint, rather than using the inflow hydrograph; this option for redelineating the model areas of MBPP1 and MBPP2 could be considered for future BLE updates and/or more detailed study. The Rock Creek inflow hydrograph was implemented as an inflow boundary condition using the stage hydrograph option.

There were also a number of large dam structures in each modeling area that required 2D connections, and use of the weir equation option in order to model flow through. In MBPP1, Morris Sheppard Dam containing Possum Kingdom Lake has regulated flow. Due to the presence of gates that regulate flow through this dam, the decision was made to implement these gates into the dam structure in the model. Gate data was taken from TCEQ Dam inventory data, and Brazos River Authority website. An engineering assumption was made on the elevation at which the gates open and close. It was assumed that the gates would begin to open at an elevation, a few feet above the gate invert elevation. It was also assumed that the gates would begin to close a few feet below the gate opening elevation, but above the invert elevation.

The other dam present in MBPP1 is Graham Dam, at the outlet of Lake Graham. This dam is an earthfill dam, and was implemented as a 2D connection with the weir equation option in the MBPP1 model. Weir data was taken from TCEQ dam invertory data, as well as terrain data via LIDAR at the dam location.

The MBPP2 model contained no dam structures large enough to be considered in modeling efforts. The MBPP3 model contains Lake Palo Pinto dam at the outlet of Lake Palo Pinto. Lake Palo Pinto Dam was implemented using a 2D connection with the weir option. Weir coeffiencent was assumed to be 3.1 and weir width was measured using the terrain LIDAR dem data. A rating curve was developed using TCEQ dam inventory data, to help model flow through the dam's spillways.

The MBPP4 model area contained no sizable dam's to warrant dam implementation. The MBPP5 model area contains one large dam, with regulated flow. Similar to Morris Sheppard Dam, De Cordova Dam contains regulated flow. Gate dimensions were obtained from TCEQ dam inventory data. Through initial iterations of model flow, it was observed that flow was ovetopping the top of the dam. In order, to alleviate this issue the decision was made to leave the gates open at 35 feet throughout the entirety of the model simulation period. Due to scope of the study, this was determined to be an acceptable solution.

MBPP1 contains two tie in locations. One tie in is at Morris Sheppard Dam, and another at a bridge crossing Rock Creek. Due to the difficult nature of achieving tie in at both locations, the following mapping decision was made: At the Morris Sheppard Dam location (MBPP1 to MBPP2), we used MBPP1 mapping upstream of the dam and MBPP2 downstream of the dam. At the Rock Creek bridge location (MBPP2 to MBPP1), we used MBPP2 mapping upstream of the bridge and MBPP1 mapping downstream of the bridge.

Tie in between MBPP3 and 4 required a stage hydrograph to facilitate a reasonable mapping tie in between the two models. A calibration region, lowering open water channel mannings N from 0.03 to 0.01, at the inlet of MBPP4 was required to achieve tie in between MBPP2 and MBPP4.

Gage 08088610 in MBPP2 is just downstream of Morris Sheppard Dam. Due to the nature of this dam, it was determined that it would be too difficult to calibrate the flow in MBPP2 to this 08088610 peak gage data. As a result, two other points of calibration were developed through regression analysis.

The large amount of breaklines and refinement regions throughout the entire HUC8 modeling area increased the total number of cells and resulted in increased model run times. In MBPP5, the Weatherford City refinement region contained a long narrow area that was included with the outlined city polygon. Review of aerial imagery showed that this was most likely a road that was owned by the city. To prevent cell error, this narrow area was not enforced with the Weatherford City refinement region. However, streamlines that were previously extended to the 0.5sqmi extent due to intersecting with the refinement region polygon were left extended.

Within the watershed, there are several populated areas and agricultural fields that appear to be trapping water which prevents runoff from reaching the channel in the model.Various v-notches were applied to represent cross culverts and improve conveyance. Further detail and study of the flow patterns and likely runoff conveyance would be recommended as part of a future study if more detailed flood risk information was needed in these areas.

MBPP3 was ran for 72 hours, as it was a headwater tributary area feeding into Brazos River main stem of MBPP4. MBPP4 simulation time was set for 144 hours to capture the two inflow peaks coming from MBPP2 inflow data. Rather than extending the MBPP3 model duration and run time from 72 hours to 144 hours, the MBPP3 inflow data was interpolated using the interpolate missing values tool in HEC-RAS. The assumption was made, based on engineering judgement, that the stage hydrograph would end at the same elevation as at the start of the simulation, a stage height of 736.84 feet.

Due to various large dams in the models, a few velocity hotspots were observed. Due to the nature of the study, the HEC-RAS models were run using Diffusion wave equations that do not include the local acceleration (changes in velocity with respect to time) and convective accelration (changes in velocity with respect to distance) terms.

3.3 Recommendations

This study provides significant information useful for flood identification and communication among those affected. The study is highly scalable, and stakeholder input and further analysis would enhance the product and inform implementation of regulatory flood hazard areas. In addition, the validity of the 2D BLE results should be verified through community work map meetings before being applied as a regulatory product.

Point source Atlas 14 rainfall was used in the analysis, and due to the large size of the modeled area (the entire HUC-8 watershed), the point rainfall used has a tendency to vary more widely from the actual point rainfall data at any specific location within the watershed. For detailed modeling and further improvements, smaller-sized modeled areas are recommended, which will result in smaller rainfall and curve number variability. In addition, future versions of HEC-RAS are anticipated to include the capability to utilize spatially varying rainfall, which may result in additional improvements. The hydraulic model can further be improved by using a smaller cell size than 200 foot along with adding structural and survey data for each crossing.

Additional detailed study in the future could consider use of full momentum equation to better simulate rapidly changing flood wave.

4. Floodplain Mapping and Effective Zone A Validation

The following sections provide a synopsis of how raw modeled depths were translated into SFHA. In addition to developing a new SFHA, the BLE model data was leveraged to validate the effective Zone A studies within the project footprint.

4.1 Special Flood Hazard Area

4.1.1 Model Outputs

The HEC acknowledged RAS Mapper may not render water surface elevation values and/or delineate inundation extent appropriately for direct use in FEMA regulatory mapping products. With guidance from TWDB, AECOM created a workflow to export model water surface elevation values for each 2D mesh cell to develop regulatory-ready water surface elevation grids and subsequent flood hazard area mapping features.

4.1.2 Methodology

The sloping render mode plots water surface elevation (WSE) by interpolating the WSE between the 2D cell faces, producing a more continuous flood inundation extent. Depth rasters from the sloping render mode were exported for the 10-percent, 1-percent, and 0.2-percent flood events with a tolerance of 0.001 feet. To reduce the extent of disconnected flood areas, raster grid processing is used to filter and remove disconnected, small, or shallow areas of flooding by processing through the 'Mapping Threshold Matrix' shown in Table 13.

Table 13: Mapping Threshold Matrix

Area (acres)	Average Depth (feet)
< 0.33	-
0.33 – 0.5	< 0.5
0.5 – 1.0	< 0.33
1.0 – 2.0	<0.1

Polygon outputs from the 'Mapping Threshold Matrix' also fill in minor areas of high ground (islands) that are less than 0.33 acre. The outputs are then modified through a Simplication and Smoothing process to reduce unnecessary/erroneous vertices, remove rough edges and reduce the size and complexity of the raw floodplain polygons for the 1-percent, and 0.2-percent flood events. For the MBPP watershed, the polygon outputs were simplified by retaining critical points at a 5 foot tolerance. The simplified polygon outputs were then smoothed utilizing the PAEK algorithm and the tolerance was set to 25 feet. The 10-percent flood event polygons are not modified through the simplification and smoothing process and are delivered in the rasterized polygon shape.

Due to topographic differences within a lake footprint, these areas sometimes appear partially mapped in the flood extents from the model results. Lakes and reservoirs larger than 40 acres are reviewed to ensure full inundation on the 1-percent, and 0.2-percent polygon extents. If necessary, lake boundaries were copied into the flood event polygons to make sure they are fully mapped.

Once the final polygon flood extents are complete, it is necessary to merge the 10-percent boundaries into the 1-percent and the 1-percent extents into the 0.2-percent extents. This step ensures that the extents of the 10-percent floodplain is smaller than the 1-percent floodplain, and the 1-percent is smaller than the extents of the 0.2-percent floodplain.

4.1.3 BLE Flood Hazard Layer

BLE database format FLD_HAZ_AR feature classes were developed and attributed with Zone A and Shaded Zone X features. The BLE FLD_HAZ_AR feature class was tested for topological errors described in the FIRM Database Technical Reference and all errors were fixed for data integrity and schema agreement. The 10-percent boundaries have been included in the BLE TENPCT_FP feature class.

4.1.4 Additional 1-Percent Features

The BLE results for this study produced a SFHA that compares favorably with the effective SFHA. These boundaries provide an estimated SFHA in areas that have not been previously studied and therefore do not currently have an SFHA mapped. These results provide context for flood risk communication as part of the Discovery process, and should be verified through community work map meetings before being applied to a regulatory product.

A map showing the BLE results is included as Appendix A BLE Map..

4.2 Validation of Effective Zone A SFHA

The inventory of Zone A studies (2,779.6 miles) in the Middle Brazos-Palo Pinto Watershed were classified in CNMS with validation status of "UNVERIFIED" (879.5 miles) or "VALID" (1,900.1 miles), and with status type of "BEING STUDIED." The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A3 were evaluated for the CNMS inventory of Zone A studies.

4.2.1 Intial Assessment A1 – Significant Topography Update Check

This check involves determining whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. The effective studies in this watershed are either older studies (completed before the year 2000) or fairly ne studies (completed in 2015 or later). For the older effective studies, the LiDAR sources used in this BLE study are considered significant improvements from the effective zone A LiDAR source and, therefore, these reaches fail this check. The newer effective studies utilized LiDAR sources already, so those reaches pass this check.

4.2.2 Initial Assessment A2 – Check for Significant Hydrology Changes

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

For Zone A streams within the MBPP watershed studied as a part of MIP case #12-06-0897S, 2009 regression equations (SIR 2009-5087) were utilized. No new equations that create a significant change in BFE have been published since 2009, resulting in A2 passing for these streams. For all other Zone A streams within the MBPP watershed, regression equations were not known to be used for any effective studies and, therefore, pass this assessment check as well.

4.2.3 Initial Assessment A3 – Check for Significant Development

This check involves using the National Urban Change Indicator (NUCI) dataset to assess increased urbanization in the watershed of the Zone A study. If the percentage of urban area within the HUC-12 watershed containing the effective Zone A study is 15% or more, and has increased by 50% or more since the effective analysis, the study would fail this check. Although the NUCI data provide year-to-year changes in urbanization, the NLCD also is needed to establish a baseline of urban land cover for this analysis. The check for significant development in this watershed was completed by evaluating percentage of urban change at the HUC-12 level. All effective studies within the MBPP HUC-8 are in rural watersheds and, therefore, pass this check.

All of the initial assessment results are shown in Table 14.

Table 14: Zone A Initial Assessment Results

Assessment Check	Pass / Fail	Notes
A1 – Topography	Pass/Fail	LiDAR sources available are a significant improvement from effective topography/ Effective Study did not utilize LiDAR source and LiDAR is now available
A2 – Hydrology	Pass	Regression equations not used in effective study OR New equations have not been published since those used in effective study
A3 – Development	Pass	Watershed does not meet urban threshold

4.2.4 Validation Check A4 – Check of Studies Backed by Technical Data

Zone A studies that pass all initial assessment checks described above may be categorized as "Valid" in the CNMS Inventory only if the effective Zone A study is supported by modeling or sound engineering judgment and all regulatory products are in agreement. If the effective Zone A study passes all initial assessment checks, but is not supported by modeling, or if the original engineering method used is unsupported or undocumented, a comparison of the BLE results and effective Zone A's is performed. As previously mentioned in the discussion on A1, effective studies fall into an "older" and "newer" set of effective studies. The older studies are not supported by technical data and fail this check. The newer set of effective studies are model-backed and pass this check.

4.2.5 Validation Check A5 – Comparison of BLE and Effective Zone A

The BLE /effective Zone A comparison method leverages the existing Floodplain Boundary Standard (FBS) certification procedures described in FEMA SID 113, but with a slight modification. This modified FBS comparison approach uses the 1-percent plus and 1-percent minus flood profiles and horizontal and vertical tolerances described in FEMA's Automated Engineering guidance document dated May 2016. For the comparison of BLE and effective Zone A in the Texas study area, the following vertical and horizontal tolerances were used to conduct the modified FBS procedure. One point was placed every 200 feet along the floodplain boundaries for comparison.

- Vertical Tolerance: +/- 5 feet (one-half contour interval of effective topographic source).
- Horizontal Tolerance: +/- 75 feet (standard horizontal tolerance for BLE comparison testing).

Comparison results for thse streams were grouped at the HUC-12 level and are summarized in Table 15 to better understand the general health of the HUC-12 watershed, but the validation check was performed at the stream level. Streams where the percentage of passing FBS sample points is greater than or equal to 85% are marked as "Pass", otherwise marked as "Fail".

Table 15: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Middle Brazos Palo Pinto Watershed	All Streams	163,321	20,746	142,575	87%	Pass	
Baker Creek-Brazos River	120602011003	2,306	82	2,224	96%	Pass	2.8
Bear Creek-South Fork Palo Pinto Creek	120602010805	4,474	126	4,348	97%	Pass	2.3
Bee Creek-Brazos River	120602011207	540	324	216	40%	Fail	50.9
Board Timber Creek-Rock Creek	120602010202	1,267	110	1,157	91%	Pass	4.3
Brier Branch	120602010104	1,746	103	1,643	94%	Pass	2.9
Buck Hollow-Dry Creek	120602010106	1,815	255	1,560	86%	Pass	7.5

Table 15, continued: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Cidwell Branch-Spring Creek	120602011202	2,275	918	1,357	60%	Fail	34.3
Connor Creek-Brazos River	120602010503	2,028	283	1,745	86%	Pass	12.4
Cottonwood Creek-Dry Creek	120602011102	2,236	89	2,147	96%	Pass	5.0
Cottonwood Creek-Kickapoo Creek	120602011109	1,494	394	1,100	74%	Fail	21.1
Cottonwood Creek-Palo Pinto Creek	120602010801	2,764	214	2,550	92%	Pass	6.2
Cove Creek-Brazos River	120602010502	2,628	336	2,292	87%	Pass	9.0
Crockery Creek-Kickapoo Creek	120602011107	1,512	254	1,258	83%	Fail	13.4
Dark Valley Creek-Brazos River	120602010705	1,581	411	1,170	74%	Fail	20.8
Dobbs Valley-Brazos River	120602011106	1,298	109	1,189	92%	Pass	6.7
Dry Creek-Salt Creek	120602010101	1,976	98	1,878	95%	Pass	2.5
Eagle Creek	120602010703	2,566	236	2,330	91%	Pass	7.4
Fall Creek	120602011301	2,256	1,011	1,245	55%	Fail	33.6
Flint Creek	120602010105	2,669	178	2,491	93%	Pass	3.3
Georges Creek-Brazos River	120602011303	1,725	935	790	46%	Fail	27.6
Gibson Creek-Palo Pinto Creek	120602010809	5,211	212	4,999	96%	Pass	3.3
Grindstone Creek	120602011105	2,312	306	2,006	87%	Pass	10.4
Hill Creek-Brazos River	120602011110	1,078	104	974	90%	Pass	8.9
Hogpen Hollow-Brazos River	120602011004	1,719	92	1,627	95%	Pass	4.3
Jowell Creek-Possom Kingdom Lake	120602010506	1,959	96	1,863	95%	Pass	3.9
Lake Creek-Palo Pinto Lake	120602010901	2,992	77	2,915	97%	Pass	2.1
Lake Graham-Salt Creek	120602010107	3,599	644	2,955	82%	Fail	9.1
Little Caddo Creek	120602010402	786	173	613	78%	Fail	17.6
Little Cedar Creek	120602010301	1,559	163	1,396	90%	Pass	8.4
Little Keechi Creek-Brazos River	120602010706	2,356	214	2,142	91%	Pass	7.3
Little Salt Creek	120602010102	1,850	93	1,757	95%	Pass	2.5
Little Sunday Creek	120602010902	2,273	62	2,211	97%	Pass	2.2
Long Creek	120602011203	788	410	378	48%	Fail	41.9
Lost Creek-Big Sunday Creek	120602010903	4,425	133	4,292	97%	Pass	2.4
Loving Creek-Brazos River	120602010704	1,899	573	1,326	70%	Fail	23.9
Lower Barton Creek	120602010808	1,671	26	1,645	98%	Pass	1.2
Lower Caddo Creek	120602010404	1,052	75	977	93%	Pass	5.7
Lower Cedar Creek	120602010304	1,580	428	1,152	73%	Fail	21.7
Lower East Fork Keechi Creek	120602010607	3,154	113	3,041	96%	Pass	2.5
Lower Ioni Creek	120602010702	957	239	718	75%	Fail	20.0
Lower Rock Creek	120602011104	2,039	97	1,942	95%	Pass	4.0
Middle Caddo Creek	120602010403	1,906	477	1,429	75%	Fail	20.0
Middle Cedar Creek	120602010303	1,133	284	849	75%	Fail	20.1
Middle Rock Creek	120602011103	1,408	30	1,378	98%	Pass	1.6
Palo Pinto Lake-Palo Pinto Creek	120602010905	2,743	195	2,548	93%	Pass	5.7

Table 15, continued: BLE Comparison Results

HUC-12 Watershed		Total FBS points	Fail	Pass	%Pass	BLE Comparison Pass? (>85%)	Priority Score
Watershed Name	Watershed Number						
Patrick Creek	120602011108	1,045	133	912	87%	Pass	10.3
Pecan Branch-Keechi Creek	120602010608	2,347	109	2,238	95%	Pass	3.7
Pinnington Creek-Rock Creek	120602010203	733	130	603	82%	Fail	11.1
Pollard Creek-Brazos River	120602011002	2,930	150	2,780	95%	Pass	4.2
Ramsey Creek-Possom Kingdom Lake	120602010505	1,367	73	1,294	95%	Pass	4.8
Robinson Creek	120602011204	1,238	571	667	54%	Fail	36.9
Rocky Bluff Creek-Buck Creek	120602010906	2,980	55	2,925	98%	Pass	1.5
Rucker Creek	120602011206	817	337	480	59%	Fail	33.1
Rush Creek	120602010803	3,556	100	3,456	97%	Pass	2.2
Russell Creek	120602010802	1,495	93	1,402	94%	Pass	4.2
Saline Creek-Big Sunday Creek	120602010904	1,283	62	1,221	95%	Pass	3.9
Salt Creek	120602010602	1,353	48	1,305	96%	Pass	1.8
Sanchez Creek	120602011201	4,724	2,266	2,458	52%	Fail	41.2
Springdale Branch-West Fork Keechi Creek	120602010603	1,162	49	1,113	96%	Pass	2.1
Strouds Creek	120602011205	1,347	528	819	61%	Fail	30.6
Tonk Branch-Brazos River	120602010501	2,863	497	2,366	83%	Fail	13.0
Turkey Creek	120602011001	1,781	214	1,567	88%	Pass	9.6
Two Bush Branch	120602010605	2,564	229	2,335	91%	Pass	4.8
Upper Barton Creek	120602010807	5,825	183	5,642	97%	Pass	2.5
Upper Caddo Creek	120602010401	796	133	663	83%	Fail	13.4
Upper Cedar Creek	120602010302	1,739	281	1,458	84%	Fail	12.9
Upper East Fork Keechi Creek	120602010606	1,212	86	1,126	93%	Pass	3.5
Upper Ioni Creek	120602010701	1,579	434	1,145	73%	Fail	22.0
Upper Rock Creek	120602011101	3,004	70	2,934	98%	Pass	1.9
Vaughn Branch-West Fork Keechi Creek	120602010604	1,575	128	1,447	92%	Pass	5.9
Veale Creek-Possom Kingdom Lake	120602010504	1,563	160	1,403	90%	Pass	10.2
Walnut Creek-Brazos River	120602011208	1,755	638	1,117	64%	Fail	28.8
Walnut Creek-Palo Pinto Creek	120602010806	4,152	122	4,030	97%	Pass	2.4
West Fork Palo Pinto Creek-South Fork Palo Pinto Creek	120602010804	4,435	170	4,265	96%	Pass	3.1
West Rock Creek-Rock Creek	120602010201	2,303	153	2,150	93%	Pass	3.3
West Salt Creek	120602010601	198	99	99	50%	Fail	25.0
White Water Creek-Salt Creek	120602010103	1,303	45	1,258	97%	Pass	1.7
Wilson Creek-Brazos River	120602011302	1,108	565	543	49%	Fail	30.4
Worser Creek-Palo Pinto Creek	120602010907	1,584	53	1,531	97%	Pass	2.7
Salt Creek	120602010602	1,353	48	1,305	96%	Pass	1.8

4.2.6 Validation Results

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the MBPP watershed has been updated as summarized in Table 16 and illustrated in Figure 17.

Table 16: Zone A Validation Results

Validation Status	Status Type	Total Miles
VALID	BEING STUDIED	1,900.1
UNVERIFIED	BEING STUDIED	879.5

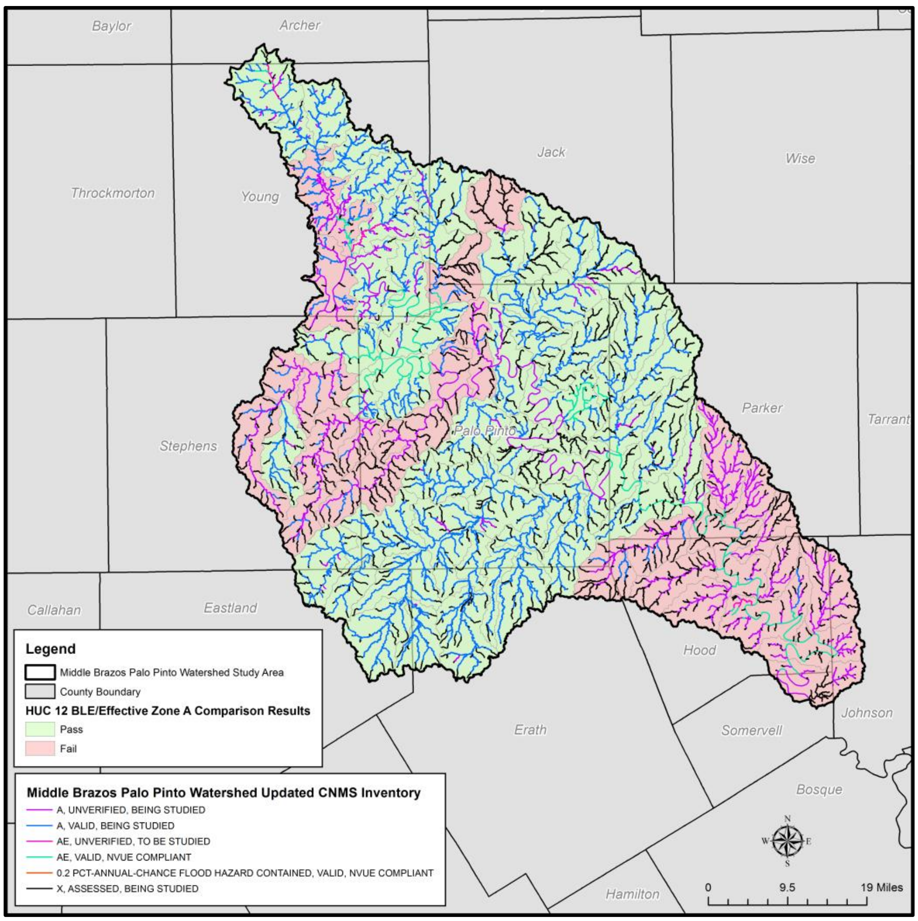

Figure 17: Middle Brazos-Palo Pinto Watershed CNMS Validation Results

An overall risk for each HUC-12 watershed was calculated using the National Flood Risk Percentages Dataset and its proportional area. The weighted risk was multiplied by the percentage of points in the watershed that failed the CNMS comparison to effective to determine the priority score. Figure 18 below shows the range of the HUC-12 priority scores which can be used to initiate discussions during the Discovery phase.

Bee Creek-Brazos River HUC-12 was determined to have the highest priority score and the most need while Lower Barton Creek HUC-12 had the lowest score.

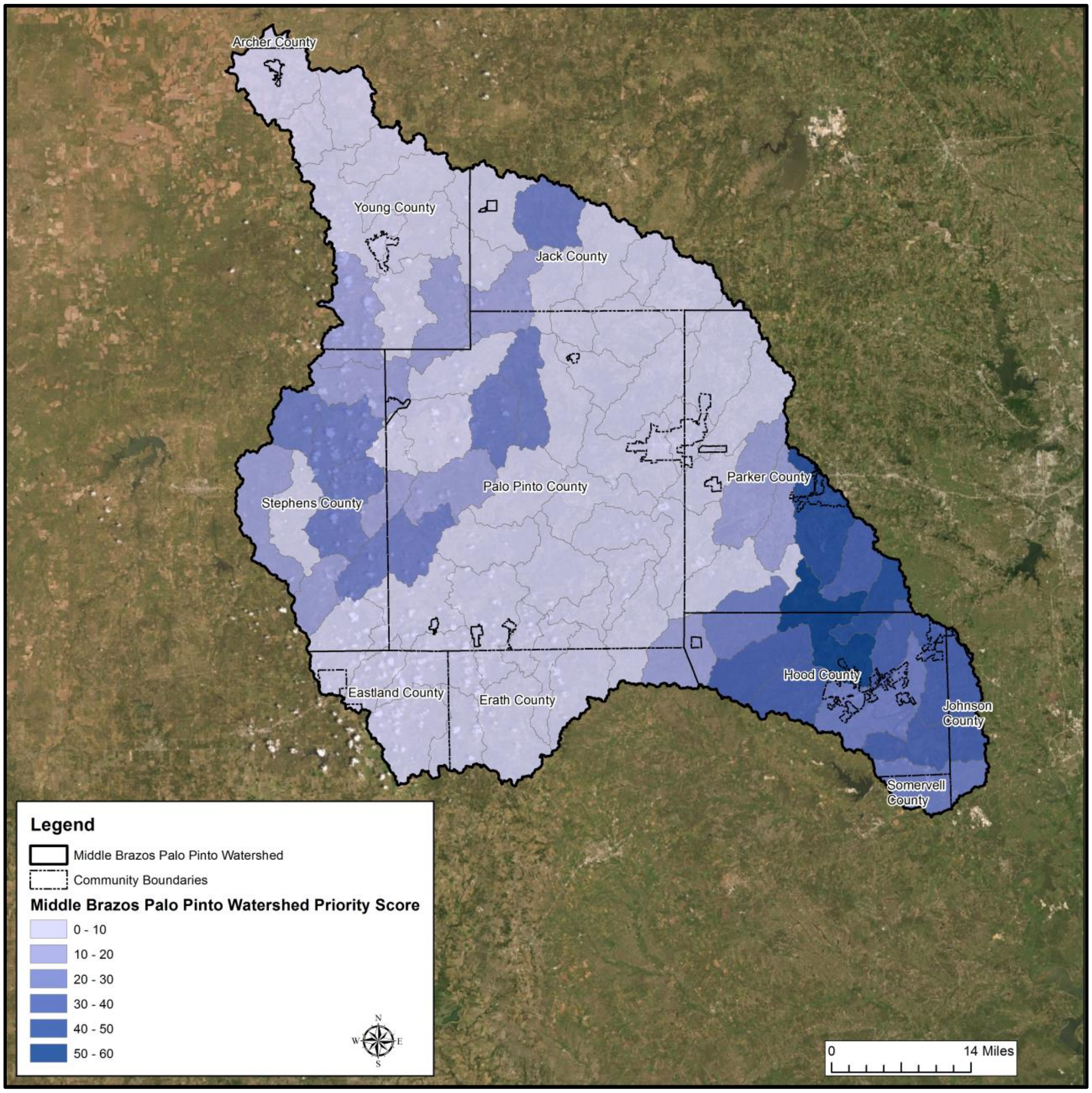

Figure 18: Ranking of Middle Brazos-Palo Pinto Watershed HUC-12s

4.3 Flood Risk Analysis

A flood risk analysis was performed for this project. The updated 1-percent annual chance depth grid was used to calculate the potential flood losses. The loss results are stored in the S_FRAC_AR spatial file within the FRD geodatabase. All results are reported in whole dollar values.

Hazus version 5.1 was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 5.1 uses dasymetric census blocks. Dasymetric mapping removes undeveloped areas (such as areas covered by other bodies of water, wetlands, or forests) from the census blocks, changing their shape and reducing their size in these areas. For more information on dasymetric data visit FEMA's Media Library for the Hazus-MH Data Inventories: Dasymetric vs. Homogenous, or Hazus 3.0 Dasymetric Data Overview.

Hazus analysis was performed by watershed extents for each return period to ensure proper model processing. A summary of results for counties within the watershed for the 1-percent annual chance scenarios are shown Table 17. Totals only reflect data for thos census tracts/blocks included in the user's study region and will reflect the entire county only if all of the census blocks for that county/state were selected at the tie of study region creation.

Table 17: Hazus 5.1 Results for 1-Percent-Annual-Chance (100 year) Scenario

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Archer	$11,194,000	$5,598,000	$251,000
Eastland	$305,616,000	$198,610,000	$39,711,000
Erath	$145,306,000	$86,215,000	$7,352,000
Hood	$5,424,143,000	$3,260,880,000	$1,179,597,000
Jack	$216,071,000	$115,419,000	$15,943,000
Johnson	$134,903,000	$83,638,000	$9,682,000
PaloPinto	$2,996,617,000	$1,901,422,000	$539,166,000
Parker	$2,531,749,000	$1,542,564,000	$277,112,000
Somervell	$87,751,000	$49,959,000	$6,800,000
Stephens	$96,217,000	$56,087,000	$11,167,000
Young	$1,735,132,000	$1,164,146,000	$267,463,000
Total	**$13,684,699,000**	**$8,464,538,000**	**$2,354,244,000**

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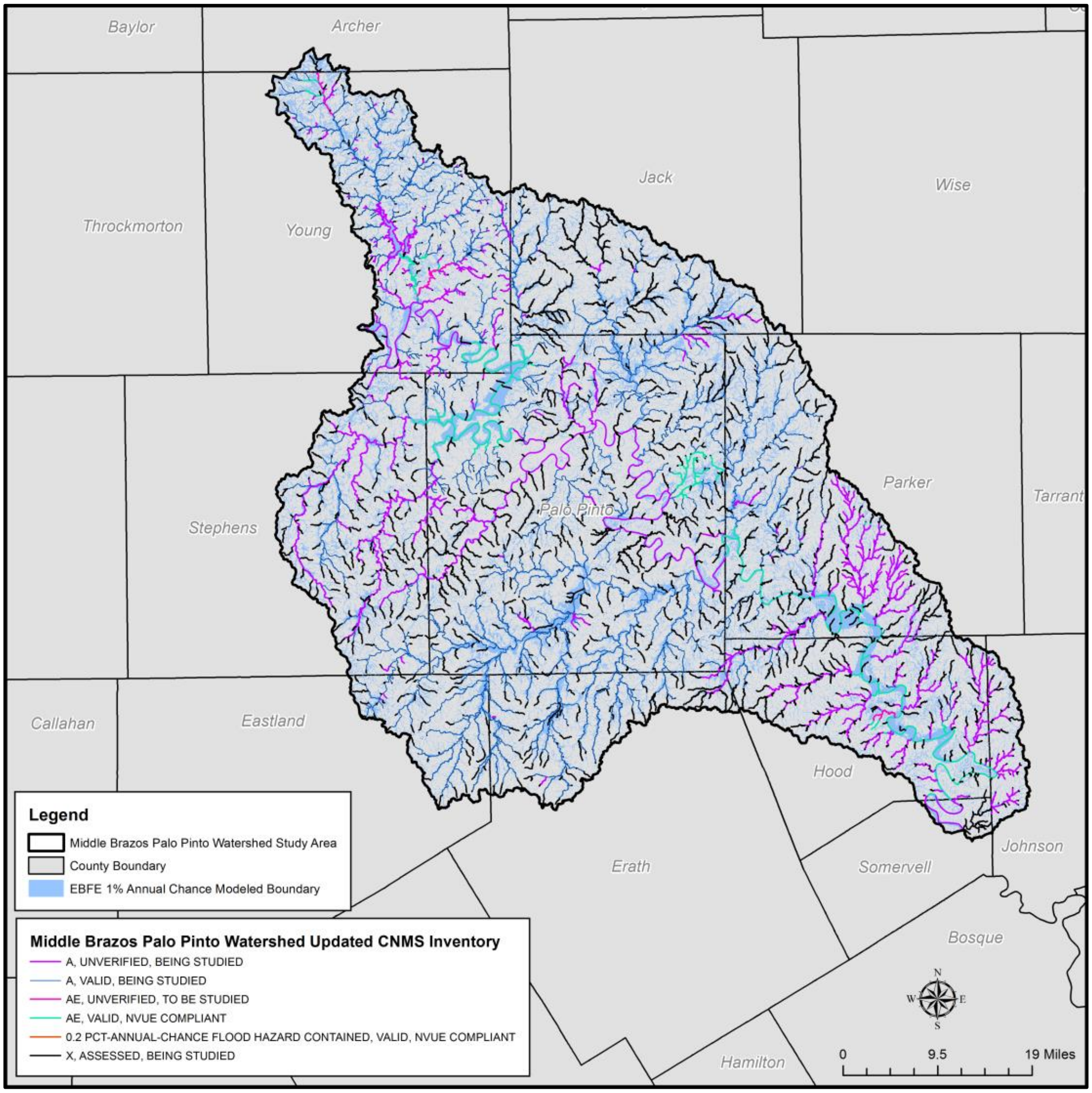
Appendix A BLE Map



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