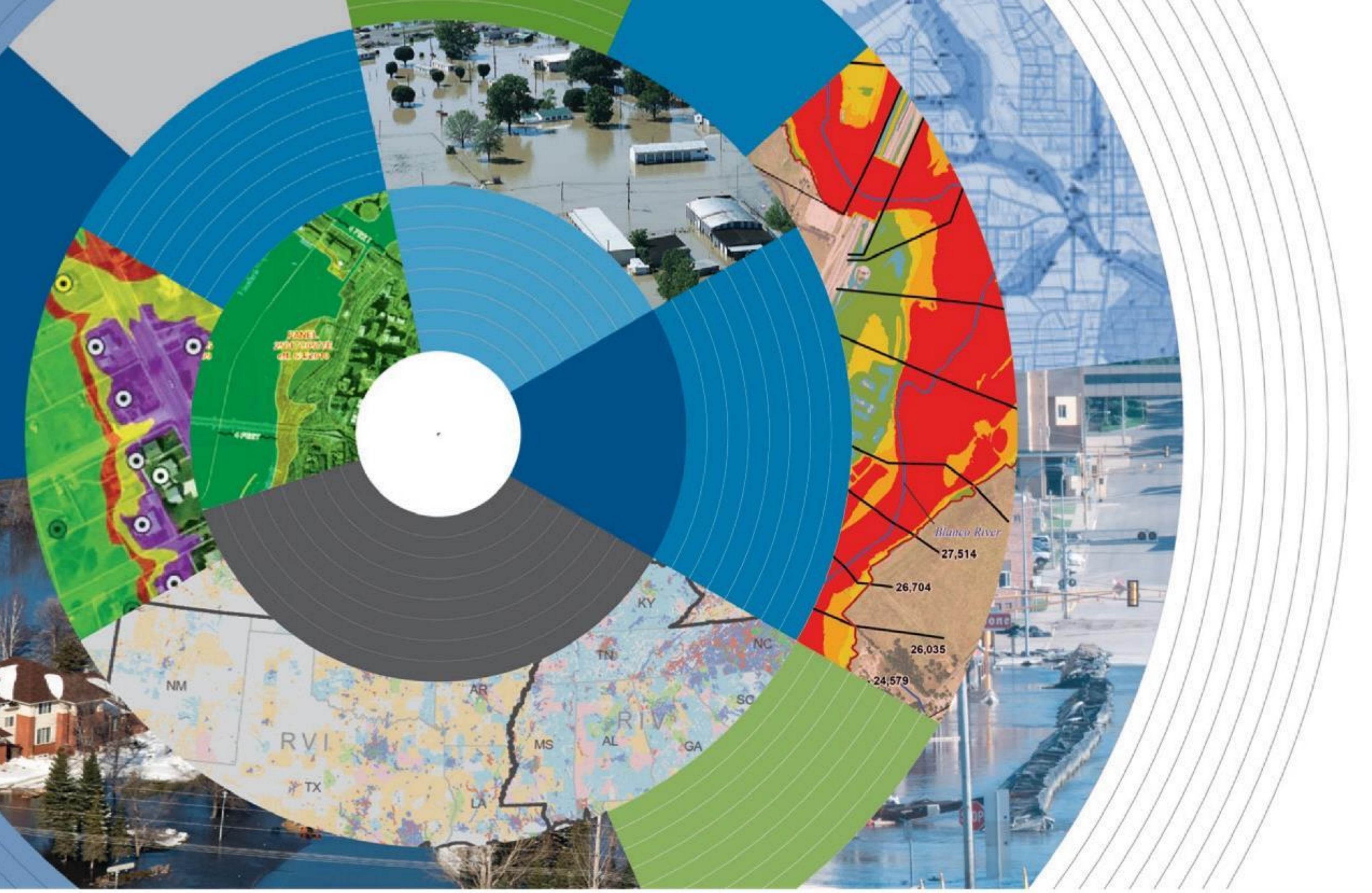

Base Level Engineering Report

Palo Duro (HUC8 11120102)

Texas Water Development Board

April 2024

Version 4.0

Report Prepared for:

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1.0	June 6, 2023	First draft to TWDB for review	OlssonFTN/FNI
2.0	July 21, 2023	Revised for backcheck submittal	OlssonFTN/FNI
3.0	August 11, 2023	Revised for backcheck submittal	OlssonFTN/FNI
4.0	April 3, 2024	Sections 5.1 and 5.2 added.	OlssonFTN/FNI

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Executive Summary

The Texas Water Development Board (TWDB) contracted with the Freese and Nichols, Inc. (FNI) team in September 2021 to develop Base Level Engineering for multiple HUC8 Watersheds within the State. OlssonFTN, as a subcontractor and member of the FNI Team, will complete a Base Level Engineering (BLE) analysis for the Palo Duro HUC-8 in Northwest Texas, to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHAs). This BLE study will provide significant data for several Texas counties previously lacking modernized flood models.

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-percent annual chance event as well as estimates of flood hazard boundaries for multiple recurrence intervals.

The source digital terrain data used for surface model development in support of hydrologic and hydraulic analysis as well as mapping activities were leveraged from various local, State, and Federal partners.

Flood discharges and water surface elevations for this study were calculated by utilizing the rain-on-grid two-dimensional (2-D) modeling capabilities of the Hydrologic Engineering Center's River Analysis System (HEC-RAS), which translates rainfall into runoff based on an underlying terrain and various other physically based parameters. 2D HEC-RAS models were developed in accordance with the 2019 FEMA Region 6 Base Level Engineering Submittal Guidance, which relies heavily on *HEC-RAS River Analysis System, 2D Modeling Users' Manual 5.0* (Bruner, 2016). All models were developed in the HEC-RAS program version 6.3.0.

The stream mile network that was validated for these watersheds was compiled using FEMA's Community Needs Management Strategy (CNMS) inventory. CNMS is an inventory of flood hazard studies and flood hazard mapping needs for areas where a study is needed. This data is helpful for community officials in analyzing and depicting flood hazards to enhance the understanding of flood risks. Communities may use this information to make informed decisions on their planning and flood mitigation efforts. Stream miles from FEMA's Community Needs Management Strategy (CNMS) inventory were not reviewed as part of this submittal and will be validated for these watersheds at a later date.

1.0 Introduction

Recent innovations and efficiencies in floodplain mapping have allowed the U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) to develop a process called Base Level Engineering (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-percent 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 five years, FEMA must evaluate whether the information on 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 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.

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 Standard SID #29 requires that during Discovery, 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, an analysis is required that estimates the likely changes. This data and any associated analyses should be shared, and 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 can not 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 MAP program may also be valuable to external stakeholders.

TWDB contracted the Freese and Nichols team to complete a BLE analysis for the Palo Duro Watershed in Northwest Texas to support FEMA's Discovery process and validation of effective Zone A Special Flood Hazard Areas (SFHA). The study extents include portions of Curry, Deaf Smith, Oldham, Potter, Quay, and Randall Counties, and include the following communities: the City of Canyon and the Town of Vega. The study area consists of three HUC-10 basins: Upper Palo Duro Creek, North Palo Duro Creek, and Lower Palo Duro Creek. **Figure 1** shows the location of the Palo Duro HUC-10 basins with respect to the counties and communities mentioned above.

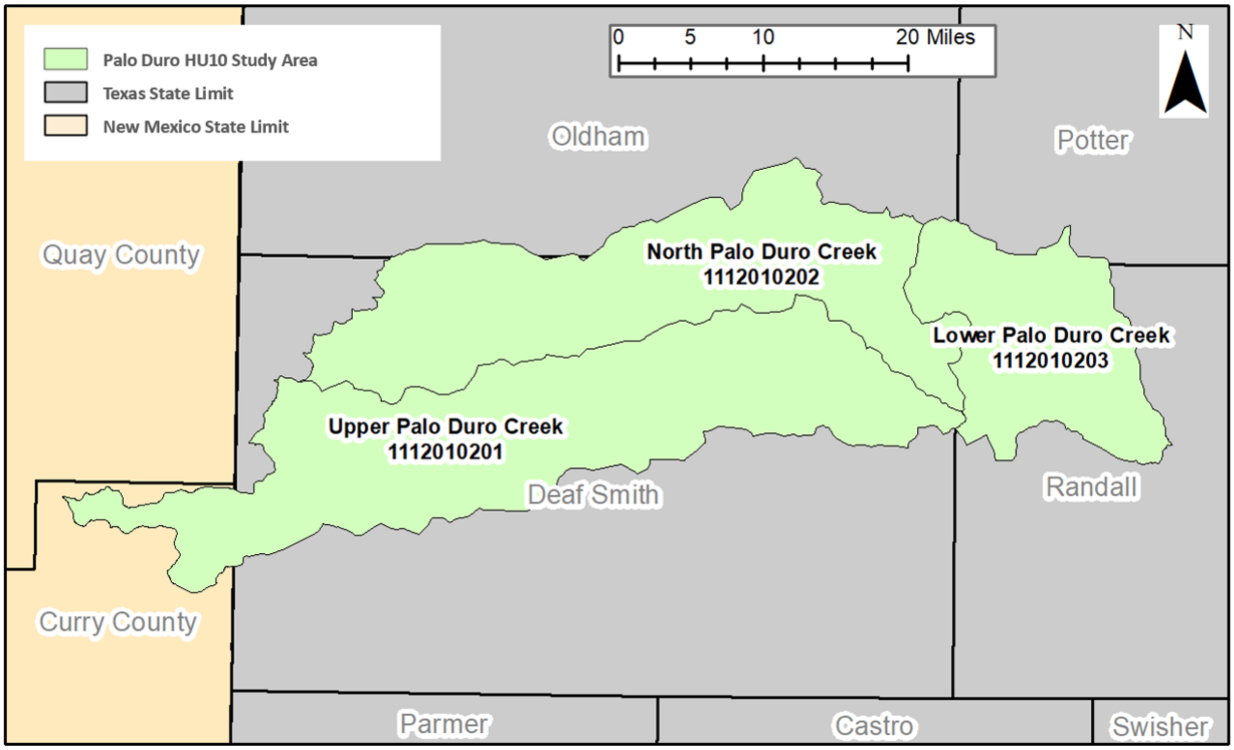

Figure 1: Palo Duro Watershed HUC-10 Basins

The Base Level Engineering assessment prepared cursory engineering analysis for approximately 257 miles of stream reaches within the Palo Duro Watershed with a minimum drainage area tolerance of 0.1 square mile. The Palo Duro Watershed contains distinct topography for its watershed. The distinct topography correlates to unique flood infrastructure for each of the subregions. The watershed is made up of a combination of playas and riverine characteristics (e.g., comprised primarily of rivers and streams). Due to the varied natural infrastructure, stream reach delineations were only extended through the riverine subregions. The playa lakes are generally hydraulically disconnected, and therefore, stream reaches were not created for these features. These regions of the watershed are colloquially referred to as “on the caprock” to describe the geographical transition. The BLE analysis was completed using a 2D grid to represent the watershed and therefore the entire watershed was included in hydrologic and hydraulic modeling. The following sections will summarize the BLE process and will discuss the results along with their recommended use.

2.0 2D BLE Modeling Inputs and Controls

Section 2.0 discusses the fundamental components required to execute a 2D BLE analysis for the Palo Duro (HUC 11120102) Watershed. Inputs including elevation data, hydrology from rain-on-grid and inflow hydrographs, and hydraulic analyses and variables are defined in the following sections. The HEC-RAS 6.3.0 rain-on-grid utility was applied in the production of these Texas 2D BLE products.

2.1 Topographic Data

A high-resolution Digital Elevation Model (DEM) derived from Light Detection and Ranging (LiDAR) provides a detailed representation of the Earth's surface. DEMs are one of the fundamental components for 2D engineering analyses and are used to direct the hydrology through the model area. The seamless DEMs developed to support the 2D BLE modeling and analysis, within the Palo Duro watershed, were executed using the following steps:

- Available 1-meter DEMs within each watershed were gathered from the Science Base Catalog and USGS National Map;
- DEMs were reprojected into NAD 1983 State Plane Texas North (EPSG 2275), re-sampled to 10-foot resolution, and mosaicked with GDAL, GRASS, and ArcGIS geoprocessing tools; and,
- Quality Assurance (QA) and Quality Control (QC) measures were implemented to ensure topographic data meets quality standards of the project.

Additional documentation regarding DEMs including coverage, accuracy, acquisition dates, and source contact/agency are presented in the figures, tables, and text in the sections below.

2.1.1 Inventory

DEMs were inventoried for the Palo Duro Watershed, including buffer of at least 1000-foot around the watershed boundary. **Figure 1** depicts the datasets identified and leveraged for the watershed. Data from FEMA and USGS were queried to build the inventory with the most current and available data resources.

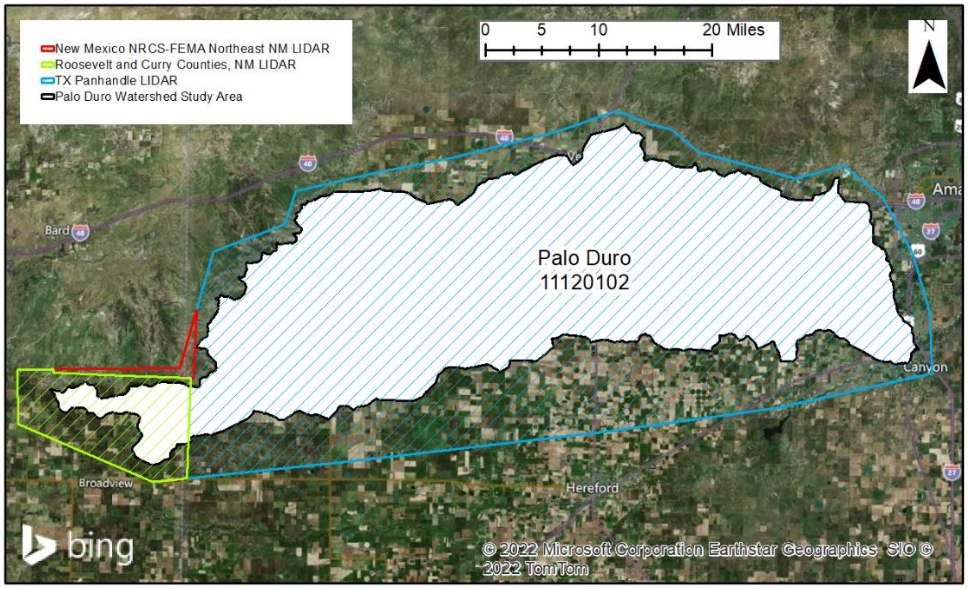

Figure 2: Palo Duro Watershed BLE Source Terrain Data

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 as defined in the FEMA 2020 BLE Region 6 Submittal Guidance document. **Table 1** presents the complete list of source elevation data and attributes leveraged for the Palo Duro watershed.

Table 1: Source Topographic Data (DEMs) Leveraged for Palo Duro Watershed

Counties	Year	Description	Data Type	3DEP Quality Level	Vertical Accuracy (RMSE)	Source/Owner	Approximate Footprint (Sq. Mi.)
Curry	2016	Roosevelt and Curry Counties, NM LIDAR	Airborne LiDAR	2	11.9 cm	USGS	291
Quay	2017	NRCS-FEMA Northeast NM LIDAR	Airborne LiDAR	2	9.8 cm	USGS	28
Deaf Smith, Oldham, Potter, and Randall	2018	TX Panhandle LiDAR	Airborne LiDAR	2	7.2 cm	USGS	1491

2.1.2.1 Watershed Source Terrain Data

The source elevation data for the Palo Duro watershed were 1-meter DEMs derived from the 2018 FEMA Texas Panhandle LiDAR data, 2017 NRCS Northeast New Mexico LiDAR, and 2016 Roosevelt & Curry Counties, NM LiDAR. **Figure 2** depicts the extent of the data defined in **Table 1.**

2018 Texas Panhandle LiDAR

The 2018 FEMA Texas Panhandle LiDAR was acquired between February 9, 2018, to September 3, 2019. The vertical accuracy for the dataset is reported to be 7.2 cm RMSEz at a 95% confidence level, which meets project accuracy specifications of the National Standard for Spatial Data Accuracy (NSSDA). These accuracies meet FEMA standards for floodplain reevaluation studies and map modernization programs designed to update the Flood Insurance Rate Maps (FIRM).

2017 NRCS-FEMA Northeast NM LiDAR

The 2017 New Mexico NRCS-FEMA Northeast NM LiDAR was acquired between November 20, 2017, and February 11, 2018. The vertical accuracy for the dataset is reported to be 9.8 cm RMSEz at a 95% confidence level, which meets project accuracy specifications of the National Standard for Spatial Data Accuracy (NSSDA). These accuracies meet FEMA standards for floodplain reevaluation studies and map modernization programs designed to update the Flood Insurance Rate Maps (FIRM).

2016 Roosevelt & Curry Counties, NM LiDAR

The 2015 Roosevelt & Curry Counties, NM LiDAR was acquired between September 30, 2015, and March 25, 2016. The vertical accuracy for the dataset is reported to be 11.9 cm RMSEz at a 95% confidence level, which meets project accuracy specifications of the National Standard for Spatial Data Accuracy (NSSDA). These accuracies meet FEMA standards for floodplain reevaluation studies and map modernization programs designed to update the Flood Insurance Rate Maps (FIRM).

2.1.3 Data Development Methodology

DEMs were combined into a single mosaic file for each collection that represented the footprint of each data source within the project area. Tools within ArcGIS were used to apply horizontal projection transformations and vertical datum shifts. The DEMs were projected horizontally to North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS) Texas North (4201) in feet. Additionally, all DEMs were adjusted vertically to NAVD88 in feet.

2.1.4 DEM QA/QC

2.1.4.1 DEM Quality Assurance

Seamless DEMs used in the BLE analyses were developed and independently assured to meet quality assurance (QA) standards of the project. Quality assurance during the data development process included, but was not limited to:

- Horizontal Projection Check (NAD83 SPCS 4202 FT)
- Vertical Datum Check (NAVD88 FT)
- Resolution Check (1-meter to 10-foot resolution)
- Seamless Data Check to ensure the DEM files are consistent and seamless along source data edges

2.1.4.2 DEM Quality Control

Quality control (QC) measures were implemented following the development process of the seamless DEMs and included visual observations using hillshade, color rendering, and/or other visual aids to review and identify potential impactful anomalies within the DEM surfaces. This QC step included, but was not limited to:

- 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.

Following these QA/QC steps, the final DEM data developed for the Palo Duro Watershed are assured to meet FEMA standards and present a representative surface developed from leveraged elevation data for the purposes of this BLE project.

Stream centerlines were delineated to 0.1 square mile within each watershed and were cutoff at the caprock and/or first playa. Stream centerlines were smoothed and generalized.

2.2 2D BLE Methods

The following sections describe the methodology used in the 2D BLE analysis of the Palo Duro Watershed. This section includes discussion regarding the overall approach along with hydrologic and hydraulic methodologies and results.

2.2.1 Model Areas

The Palo Duro Watershed covers a total area of approximately 999 square miles. While possible to model the entire HUC8 in a single 2D HEC-RAS model, the large area would lead to excessively long model run times and inhibit the model's usability for future users. To combat this issue and simplify model development, the study team divided the Palo Duro HUC8 into several smaller models, consisting of a single HUC10 or group of HUC10s within the larger HUC8. It was decided to combine the two upstream HUC10 watersheds (1112010201 and 1112010202) due to water artificially building up at the boundary between the two models. Since the two HUC10 watershed run parallel to each other, external boundary conditions couldn't be placed between the two. The combined model was then split into an upstream and downstream model to reduce run times. **Table 2** and **Figure 3** present the grouping of HUC10s for each 2D model. As described in **Section 2.2.2 Model and Boundary Condition Setup**, these models remain interconnected via external boundary conditions, so no runoff volume is lost through the subdivision of the HUC8.

Table 2: Palo Duro Model Areas

Model	HUC10(s)	HUC10 Name(s)	Area (Sq. Mi.)
PaloDuro_01_02_UP	1112010201,1112010202	North Palo Duro Creek, Upper Palo Duro Creek	496
PaloDuro_01_02_DOWN	1112010201,1112010202	North Palo Duro Creek, Upper Palo Duro Creek	320
PaloDuro_203	1112010203	Lower Palo Duro Creek	185

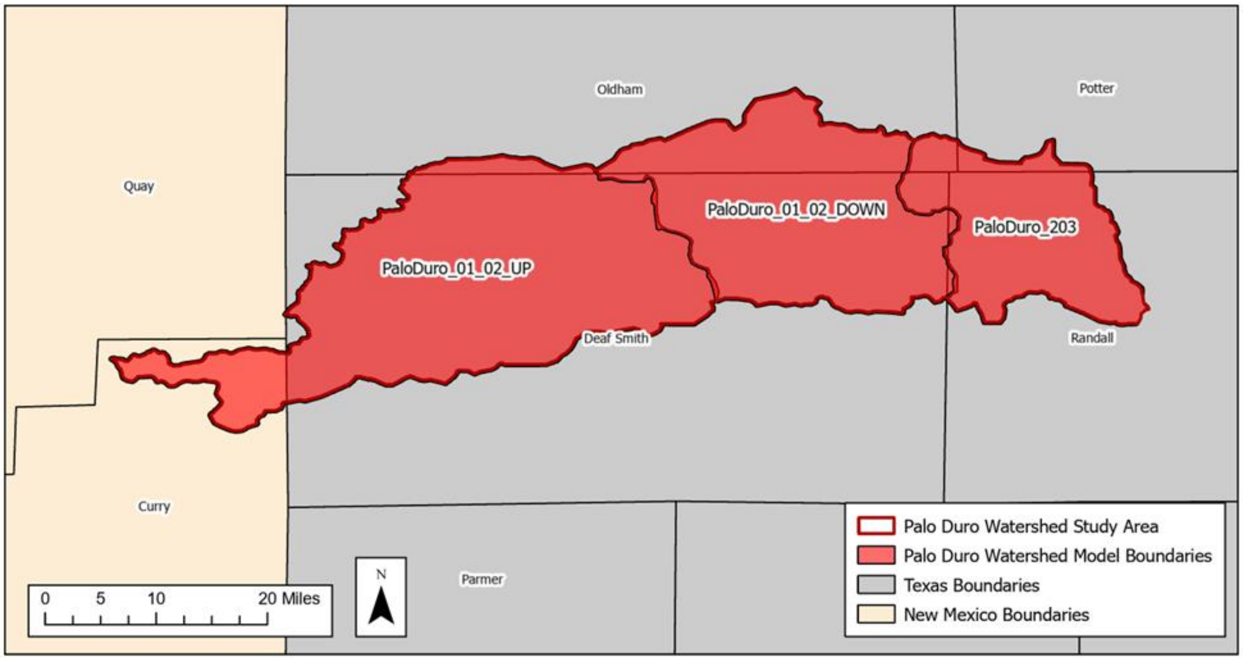

Figure 3: Palo Duro Model Domain

2.2.2 Model and Boundary Condition Setup

HEC-RAS 2D rain-on-grid modeling requires two main components, a 2D computational mesh and inflow hydrology. The 2D computational mesh boundaries were established within the Palo Duro HUC8 watershed according to the groupings presented in **Table 2**. Inflow hydrology can be applied through various methods in HEC-RAS 2D modeling, but hydrology methods are limited to two categories for the Palo Duro HUC8. These are flow hydrographs and precipitation time-series. **Section 2.2.4.1 Precipitation for HEC-RAS 2D** describes the development the precipitation data applied to each model. Precipitation, rather than excess precipitation, was applied directly to the 2D mesh because simplistic hydrologic losses can be accounted for entirely within HEC-RAS version 6.3.0.

A normal depth boundary condition was utilized along all basin outflows that uses an approximate energy grade-line slope estimated from the LiDAR terrain data but were adjusted as necessary to ensure a tie-in within 0.5 ft of the surrounding models.

External boundary conditions were applied along each model area's boundary where a transfer of flow (inflow or outflow) may occur. The upstream area of each model, where applicable, has an inflow hydrograph applied that accounts for outflow from the upstream model area. For example, the PaloDuro_01_02_Down model has an inflow hydrograph at its upstream end that applies the outflow from the PaloDuro_01_02_Up model. **Figure 4 – 6** show the major inflows (Palo Duro Creek and North Palo Duro Creek) applied within the models.

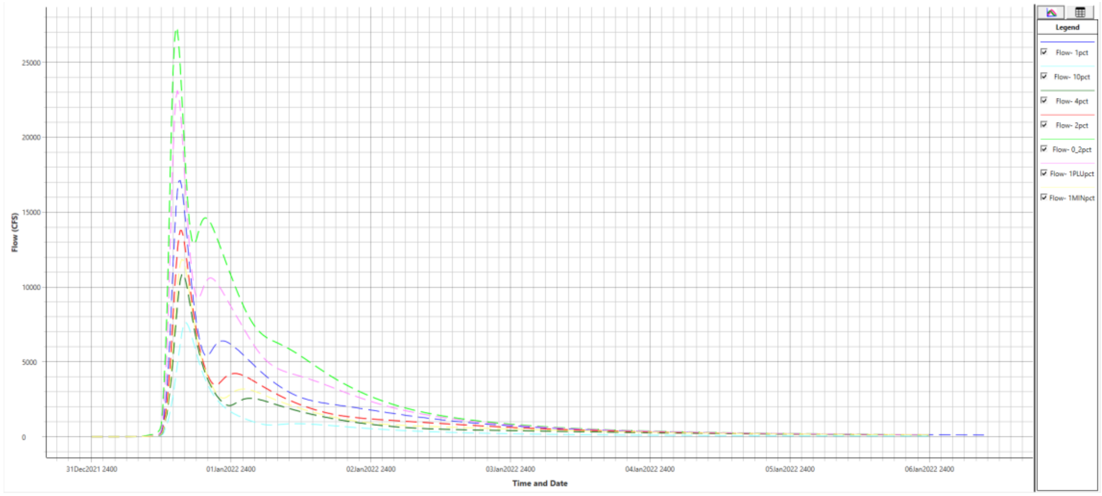

Figure 4: Palo Duro Creek Inflow to PaloDuro_01_02_Down Model

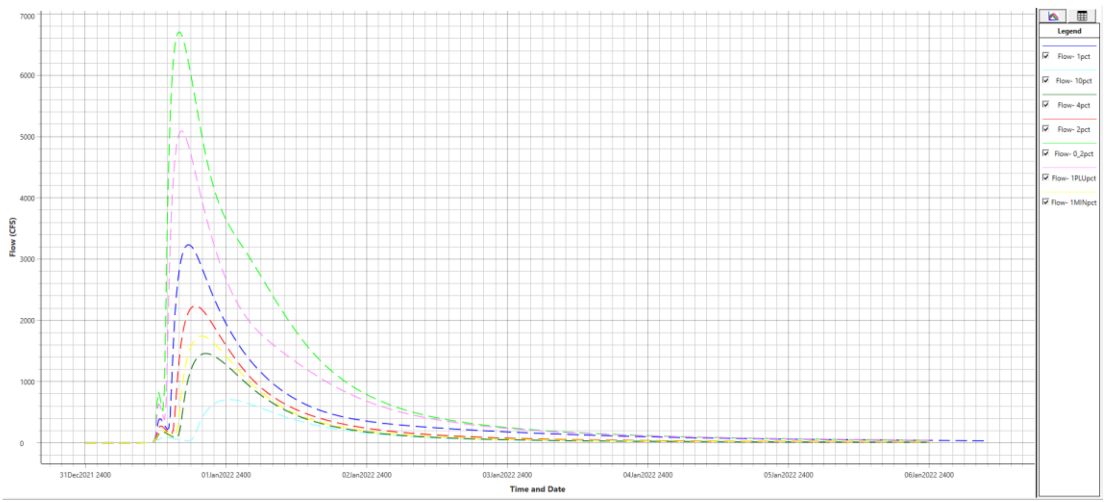

Figure 5: North Palo Duro Creek Inflow to PaloDuro_01_02_Down Model

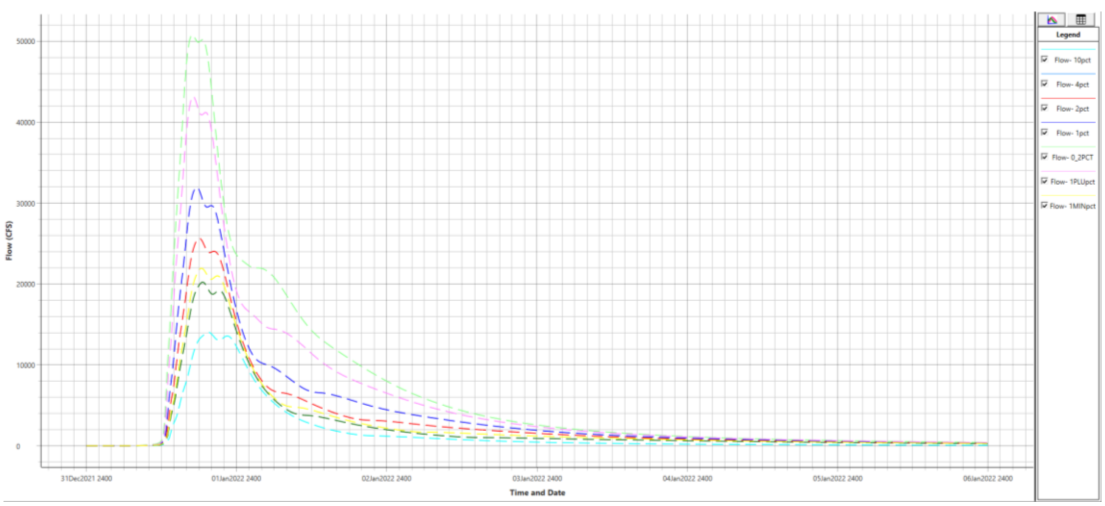

Figure 6: Palo Duro Creek Inflow to PaloDuro_03 Model

2.2.3 2D Computational Mesh and Settings

The HEC-RAS 2D computational mesh defines both the extent and level of detail of 2D hydraulic results. The density and detail of the 2D mesh is the primary component that defines the resolution of hydraulic results (e.g., more detail-finer results, less detail-coarser results). A more detailed mesh may provide finely resolved and accurate results, but it can lead to excessively long computation times which are prohibitive to future use of BLE models. To provide a balance between mesh detail and model performance, the base mesh for each model was developed using 200’x200’ cells. The mesh was refined through the addition of breaklines along roadways, reservoirs, stream centerlines, and other topographically significant features. The mesh for each model area was developed in a manner that allows for automatic regeneration of the mesh by future users, without the need for manual cell edits.

Hydraulic results are also influenced by the many computational settings used in each HEC-RAS simulation. Of the available settings, the two most influential to results are the computational timestep and the equation set. Models use the “Adjust Time Step Based on Time Series of Divisors” function. The simulation begins with a timestep of 60 seconds and is lowered to 15 seconds when rainfall begins to rise. Each model applies the Diffusion Wave equation set. All other computational settings were kept at their default values as sensitivity analyses were conducted early in the modeling process and showed little to no impact on model results.

2.2.4 Hydrology

Hydrologic data for the Palo Duro Watershed was derived from NOAA Atlas 14, Volume 11 Version 2.0 precipitation data, which was obtained from NOAA’s Precipitation Frequency Data Server. Spatial variation of precipitation depths was accounted for by developing area-weighted average depths for each model area presented in **Table 2**. For contributing basins outside of the study area, inflows were applied through an external boundary condition at the upstream boundary Palo Duro watershed. The flow hydrograph for the contributing basin was obtained from the 2D BLE model of the respective watershed. The 10%, 4%, 2%, 1%-minus, 1%, 1%-plus, and 0.2% annual exceedance probability events were simulated in the Palo Duro Watershed.

2.2.4.1 Precipitation for HEC-RAS 2D

The average NOAA Atlas 14 precipitation-frequency depths for each model area in **Table 2** were converted to a precipitation time-series dataset within a simplified HEC-HMS v4.8 model. Default parameters were assigned to a single basin to extract the precipitation time-series data (infiltration was not accounted for in the rainfall data because it will be calculated within the hydraulic models). A frequency storm was created within HEC-HMS for each event listed in **Section 2.2.4 Hydrology**. Each frequency storm utilized the parameters listed in **Table 3**. The precipitation-frequency depths for each model area and simulation event are summarized in

Table 4 **-6**. A precipitation time-series was then extracted from the HEC-HMS models and utilized in the HEC-RAS 2D simulations.

Areal reduction was not utilized within this study. Although using rainfall reduction may be appropriate when computing flows at the outlet of a HUC-8 or the total contributing drainage area to a gage, reducing the rainfall applied over the model meshes would lead to an underestimation of the flood risk in the upland portions of the models.

In addition to the recurrence interval precipitation depths, NOAA Atlas 14 also provides 90% confidence limits for each reported precipitation depth. The 90% confidence intervals correspond to +/- 1.645 standard deviations, which was determined using the probability table for the standard normal distribution. The 1%-minus and 1%-plus event depths utilize the following equation:

$$1\%\ precip \mp \frac{Upper\ Limit - Lower\ Limit}{3.29}$$

Table 3: HEC-HMS Frequency Storm Parameters

Parameter	Value
Annual-Partial Conversion	None
Storm Duration	1-day
Intensity Duration	5-minute
Intensity Position	50%
Area Reduction	None
Storm Area	-

Table 4: PaloDuro_01_02_UP– Precipitation-Frequency Depths

Duration (min)	Percent Annual Chance Precipitation Depth (in)						
	10%	4%	2%	1%-	1%	1%+	0.2%
5	0.60	0.74	0.84	0.74	0.95	1.16	1.23
15	1.19	1.45	1.65	1.45	1.87	2.28	2.42
60	1.99	2.43	2.77	2.44	3.13	3.83	4.08
120	2.34	2.87	3.30	2.95	3.75	4.56	4.93
180	2.52	3.12	3.60	3.25	4.12	4.99	5.44
360	2.87	3.55	4.11	3.76	4.72	5.68	6.29
720	3.23	3.98	4.58	4.21	5.24	6.27	7.05
1440	3.65	4.47	5.12	4.72	5.83	6.93	7.86

Table 5: PaloDuro_01_02_DOWN – Precipitation-Frequency Depths

Duration (min)	Percent Annual Chance Precipitation Depth (in)						
	10%	4%	2%	1%-	1%	1%+	0.2%
5	0.62	0.74	0.84	0.73	0.94	1.16	1.21
15	1.21	1.47	1.66	1.44	1.86	2.27	2.38
60	2.05	2.48	2.80	2.44	3.14	3.85	4.05
120	2.42	2.96	3.38	3.00	3.83	4.66	4.99
180	2.63	3.24	3.73	3.34	4.24	5.15	5.57
360	3.00	3.71	4.29	3.89	4.91	5.92	6.49
720	3.38	4.16	4.79	4.38	5.47	6.56	7.26
1440	3.81	4.66	5.34	4.90	6.06	7.23	8.05

Table 6: PaloDuro_03– Precipitation-Frequency Depths

Duration (min)	Percent Annual Chance Precipitation Depth (in)						
	10%	4%	2%	1%-	1%	1%+	0.2%
5	0.61	0.74	0.85	0.74	0.95	1.16	1.22
15	1.22	1.47	1.67	1.45	1.87	2.29	2.40
60	2.09	2.53	2.87	2.50	3.22	3.94	4.15
120	2.49	3.03	3.46	3.07	3.92	4.77	5.11
180	2.71	3.33	3.81	3.41	4.33	5.25	5.68
360	3.11	3.83	4.40	3.98	5.01	6.04	6.61
720	3.52	4.31	4.95	4.50	5.62	6.74	7.40
1440	3.97	4.84	5.53	5.06	6.26	7.46	8.19

2.2.4.2 Hydrologic Losses

Hydrologic losses were calculated within HEC-RAS according to the SCS Curve Number method. Curve numbers were calculated by intersecting the National Land Cover Dataset (NLCD) 2019 with soils data obtained from the USDA Soil Survey Geographic Database (SSURGO). A curve number was then assigned to each resultant value of the intersected land cover classification and hydrologic soil group, as presented in **Table 7**. These parameters represent the Curve Numbers (CN) applied to the HEC-RAS 2D models, which correspond to ARC II, or average antecedent moisture conditions. The values presented in **Table 7** represent adjusted CN values that were utilized in the 10%, 4%, 2%, 1%, 1% -, 1%+, and 0.2% events. CN values were originally selected using results from a previous study in a nearby watershed (Running Water Draw). These values were determined by Soil Conservation Service's (SCS) Technical Release 55 (TR-55). Since no gages were present in the watershed, OlssonFTN coordinated with FNI to calibrate the models by adjusting CN values as necessary, so that gages in the downstream watershed could be matched. The initial abstraction ratio for the default CN layer was set to 0.20. The minimum infiltration rate was set to 0 in/hr.

Table 7: Land Use-Soils-CN Matrix

Land Use Grid Code	NLCD Land Use Description	Hydrologic Soil Group				TR 55 Cover Type and Hydrologic Condition
		A	B	C	D	
11	Open Water	99	99	99	99	N/A
21	Developed Open Space	39	61	74	80	Open Space (Good)
22	Developed Low Intensity	46	65	77	82	Residential (2 acres)
23	Developed Medium Intensity	61	75	83	87	Residential (1/4 acre)
24	Developed High Intensity	89	92	94	95	Commercial
31	Barren Land	77	86	91	94	Urban (Newly graded)
41	Deciduous Forest	30	55	70	77	Woods (Good)
42	Evergreen Forest	45	66	77	83	Woods (Poor)
43	Mixed Forest	36	60	73	79	Woods (Fair)
52	Shrub Scrub	30	48	65	73	Brush (Good)
71	Herbaceous[1]	49	62	74	85	Herbaceous (Good)
81	Hay Pasture	39	61	74	80	Pasture (Good)
82	Cultivated Crops	64	75	82	85	Row Crop (SR + CR - Good)
90	Woody Wetlands	30	55	70	77	Woods (Good)
95	Emergent Herbaceous Wetlands	30	58	71	78	Meadow

[1]TR 55 did not include a value for soil group A. Desert shrub (good) was used for that group instead.

2.2.4.3 Reservoirs

There are no USACE regulated reservoirs in this watershed. The City of Canyon FIS report included an Elevation-Storage-Discharge table for Bivins Lake, which can be found in the most downstream HUC10 (1112010203). It was noted that the emergency spillway had been updated since the effective date of the FIS Report, so the rating curve was not included in the 2D/SA connection. The dimensions of the spillway were confirmed by comparing data found on the TCEQ Central Registry and the terrain. The Spillway includes a 200 ft wide earth cut channel, with a 450 ft and 7 ft tall fuse plug. No details were provided on the central outlet of the dam. While there is no information indicating that the central outlet functions during routine events (FIS text indicates no discharge until the emergency spillway elevation), the small culvert invert has been altered to drain the standing water left after the hot start run in an attempt to start event modeling with no water behind the dam.

All other reservoirs were determined to be not hydrologically significant. Breaklines were placed on top of the dams and terrain modifications were added as necessary.

2.2.5 Hydraulics

Hydraulic analysis of the Palo Duro Watershed was conducted in HEC-RAS v6.3.0 using a rain-on-grid modeling approach. This section describes the development of hydraulic input data and its implementation in the 2D model.

2.2.5.1 Roughness Coefficients

A manning's roughness layer was developed for the 2D mesh by applying typical values associated with NLCD land cover classifications. In addition to the base manning's roughness layer from the NLCD data, manning's roughness values were refined along stream centerlines to override excessively high channel roughness values resulting from the NLCD layer. A calibration area was added to the model to incorporate Channel Manning's Values. An initial buffer of 25 feet was found to be appropriate for most streams but was adjusted as necessary. Channel roughness values were assigned according to a review of aerial imagery and generally range from 0.03 – 0.04. documents the typical roughness values assigned to each NLCD land cover classification, which correspond with the 2019 FEMA Region 6 Base Level Engineering Submittal Guidance document. **Table 8** documents the typical roughness values assigned to each NLCD land cover classification, which correspond with the 2019 FEMA Region 6 Base Level Engineering Submittal Guidance document.

Table 8: NLCD 2019 Manning's Roughness

Land Use Grid Code	NLCD Land Use Description	Minimum Manning's N	Maximum Manning's N	Selected Manning's N
11	Open Water	0.025	0.05	0.03
21	Developed Open Space	0.04	0.05	0.04
22	Developed Low Intensity	0.06	0.12	0.06
23	Developed Medium Intensity	0.08	0.16	0.08
24	Developed High Intensity	0.12	0.2	0.12
31	Barren Land	0.3	0.03	0.03
41	Deciduous Forest	0.1	0.20	0.1
42	Evergreen Forest	0.1	0.16	0.1
43	Mixed Forest	0.1	0.20	0.1
52	Shrub Scrub	0.07	0.16	0.07
71	Herbaceous	0.035	0.05	0.035
81	Hay Pasture	0.045	0.05	0.045
82	Cultivated Crops	0.045	0.05	0.045
90	Woody Wetlands	0.1	0.15	0.10
95	Emergent Herbaceous Wetlands	0.07	0.085	0.07

2.2.5.2 Breaklines and Hydraulic Structures

Breaklines were used within the 2D mesh to align cell faces along stream centerlines, roadway and railroad embankments, and other hydraulically significant features. Roadway centerlines were initially identified within ArcGIS and then imported into HEC-RAS as breaklines, see **Figure 7** for locations of the breaklines.

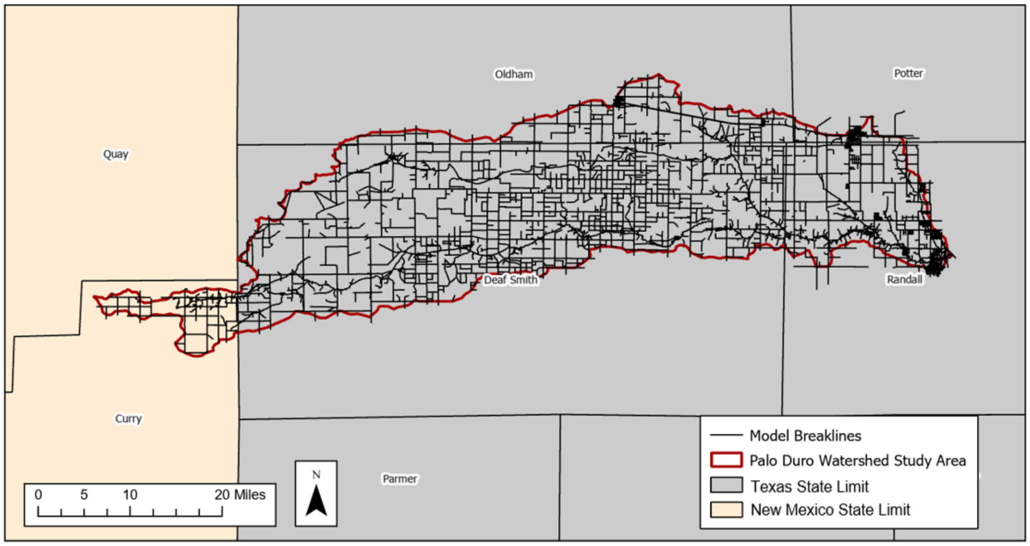

Figure 7: Palo Duro Watershed Breaklines

2.2.5.3 Initial Conditions

Initial conditions in the Palo Duro Watershed are influenced by the dominance of playa lakes in overland areas along the caprock. The applicability of an initial water surface elevation within the playas was investigated during a sensitivity analysis. The study team referenced City of Lubbock criteria and *Playa Lakes in the Southern High Plains: Runoff, Infiltration, and Recharge* (Weinberg et.al, 2021) when determining an appropriate initial condition for the playa lakes. The study team created an initial condition run that applies 2" of rainfall that is then allowed to infiltrate and flow completely out of each model area. A restart file was generated at the end of this simulation, which was then applied as the initial conditions of each frequency event simulation.

2.2.5.4 Terrain Modifications

Hydraulically significant culvert crossings at roadways were identified based on embankment height, volume behind the embankment, and contributing area. For hydraulically significant features, terrain modifications were used to burn a channel into the terrain within HEC-RAS, shown in **Figure 8**. Terrain modification parameters were estimated using aerial imagery.

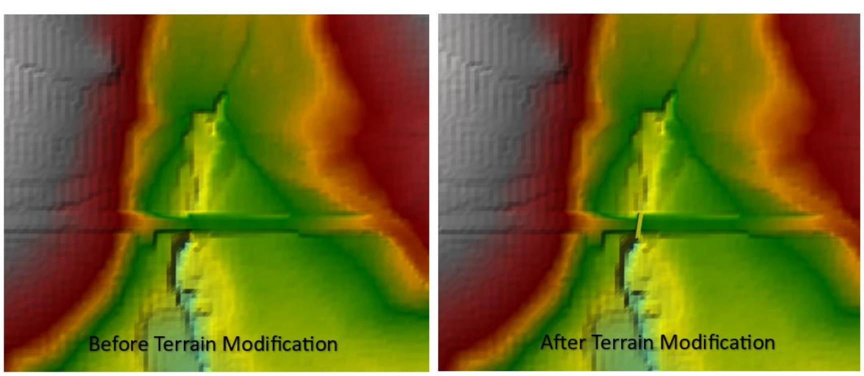

Figure 8: Terrain Modification Example

3.0 Model Results

The results of this study produced an SFHA that provides additional and/or new mapping across most of the Palo Duro HUC8. The estimated SFHA boundaries can serve as an estimate for flood risk in the area, which has not been previously studied. The discharge rates measured at key locations in the watershed compare reasonably well with the stream gage analysis. These results provide context for flood risk within the watershed and should be verified through community meetings before being applied to a regulatory product.

3.1 Gage Analysis

There were no known gages located within the Palo Duro Watershed, but there are gages present in the downstream HUC08 watershed (Tierra Blanca). OlssonFTN coordinated with FNI during the calibration process to ensure discharges in Terra Blanca matched USGS gages.

3.2 Regression Analysis

To generate a point of comparison, the study team completed a regression analysis according to equations created by USGS listed in **Table 9**. The equations were derived from "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). Reference lines (shown in **Figure 9**) were created in ArcGIS for comparison with results from model runs. Locations of reference lines were determined by terrain data on primarily the mainstream line.

The flows calculated from the regression equations can be found in **Table 10** and the modeled results can be found in **Table 11**. No changes were made according to regression results because downstream gages took precedence over regression equations. **Figure 10** shows the comparison between Regression equations and model results for the 1% event. The error bars represent the HEC-RAS 1% Plus and 1% Minus events. It was noted that results for reference lines found upstream in areas dominated by playas had large percent errors and results for reference lines found downstream in areas with riverine characteristics results were very similar to calculated flows (less than a 10% difference). It is likely most of the data used to determine the regression equations was not collected from areas with playas, and therefore is not a good estimate for that type of terrain. Additionally, the terrain type makes it difficult to determine the drainage area, which is one of the parameters in the equation.

Table 9: Regression Equations

Regression Equation	RSE	Adj. R-squared	AIC statistic	PRESS statistic
$Q_{10} = P^{1.203}S^{0.403} \times 10^{[0.918\Omega+13.62-11.97A^{-0.0289}]}$	0.25	0.89	86.5	46.6
$Q_{25} = P^{1.140}S^{0.446} \times 10^{[0.945\Omega+11.79-9.819A^{-0.0374}]}$	0.26	0.89	140	49.5
$Q_{50} = P^{1.105}S^{0.476} \times 10^{[0.961\Omega+11.17-8.997A^{-0.0424}]}$	0.28	0.87	220	55.6
$Q_{100} = P^{1.071}S^{0.507} \times 10^{[0.969\Omega+10.82-8.448A^{-0.0467}]}$	0.30	0.86	320	64.8
$Q_{500} = P^{0.988}S^{0.569} \times 10^{[0.976\Omega+10.40-7.605A^{-0.0554}]}$	0.37	0.81	591	98.7

RSE, residual standard error in log10-units of cubic feet per second; Adj., adjusted; AIC , Akaike Information Criterion; PRESS , Prediction Error Sum of Squares; Q_T, peak streamflow for T -year recurrence interval in cubic feet per second; P, mean annual precipitation in inches; S, dimensionless main-channel slope; Ω ,OmegaEM parameter that represents a generalized terrain and climate index that conveys relative differences in peak-streamflow potential across the study area; and A, drainage area in square miles (Asquith and Roussel, 2009).

Table 10: Regression Equations – Calculated Results

Reference Line	Latitude	Longitude	Drainage Area (Sq. Mi.)	10% (cfs)	4% (cfs)	2% (cfs)	1% (cfs)	0.2% (cfs)
HUC01 _Reference Line 1	34.9604	-102.908	106.8	5,413	8,965	12,417	16,962	32,225
HUC01 _Reference Line 2	35.0059	-102.742	181.5	7,056	11,546	15,869	21,490	40,067
HUC02 _Reference Line 1	35.134	-102.842	7.0	512	752	958	1,204	1,937
HUC02 _Reference Line 4	35.0857	-102.22	285.0	5,544	8,527	11,225	14,522	24,673
HUC03 _Reference Line 1	35.0297	-102.132	485.2	10,157	16,256	22,026	29,387	53,134
HUC03 _Reference Line 2	35.0601	-102.053	53.1	3,712	6,024	8,225	11,068	20,376
HUC03 _Reference Line 3	35.0165	-101.983	548.4	11,356	18,050	24,356	32,362	57,968
HUC03 _Reference Line 4	35.0021	-101.912	625.4	11,625	18,459	24,891	33,044	59,107

Table 11: Regression Equations – Model Results

Reference Line	Latitude	Longitude	Drainage Area (Sq. Mi.)	10% (cfs)	4% (cfs)	2% (cfs)	1% (cfs)	0.2% (cfs)
HUC01 _Reference Line 1	34.9604	-102.908	106.8	2,256	3,766	5,063	6,566	11,006
HUC01 _Reference Line 2	35.0059	-102.742	181.5	1,164	2,136	3,127	4,360	8,564
HUC02 _Reference Line 1	35.134	-102.842	7.0	2,635	3,821	5,133	6,483	10,422
HUC02 _Reference Line 4	35.0857	-102.22	285.0	10,152	14,586	18,480	22,867	35,575
HUC03 _Reference Line 1	35.0297	-102.132	485.2	14,119	20,331	25,764	32,088	50,988
HUC03 _Reference Line 2	35.0601	-102.053	53.1	2,144	3,842	5,530	7,543	13,022
HUC03 _Reference Line 3	35.0165	-101.983	548.4	13,395	20,320	26,106	33,151	55,690
HUC03 _Reference Line 4	35.0021	-101.912	625.4	12,858	20,963	27,087	34,160	57,885

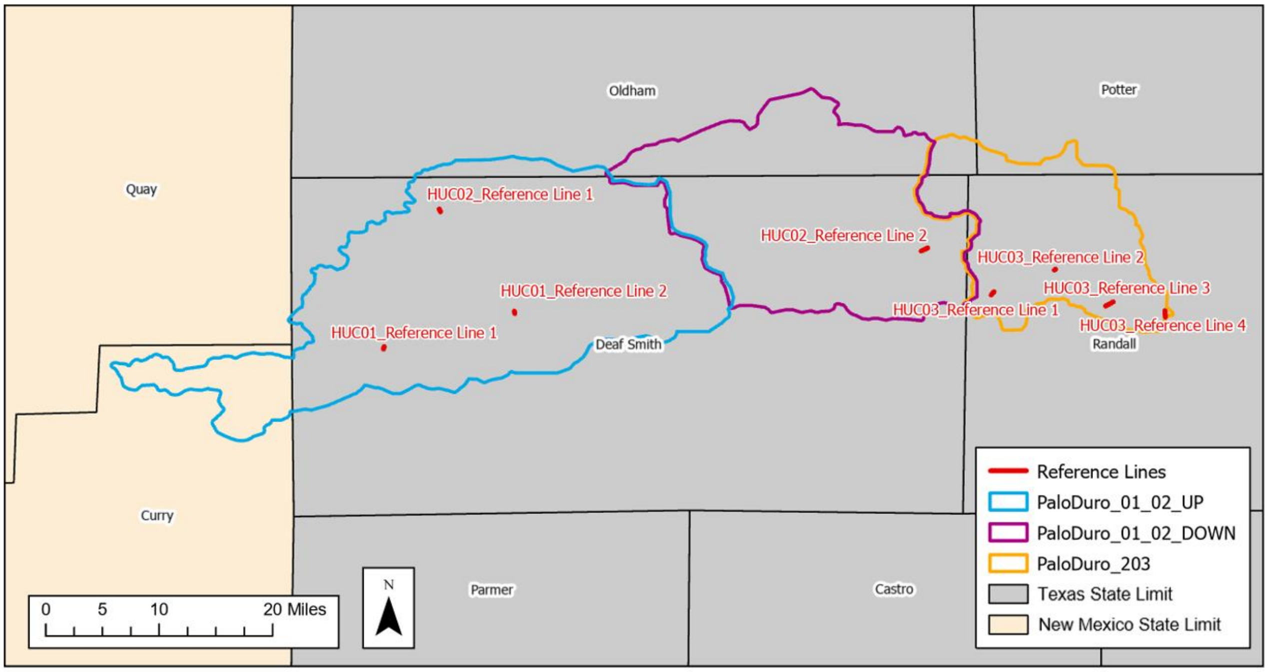

Figure 9: Regression Reference Lines in Palo Duro Watershed

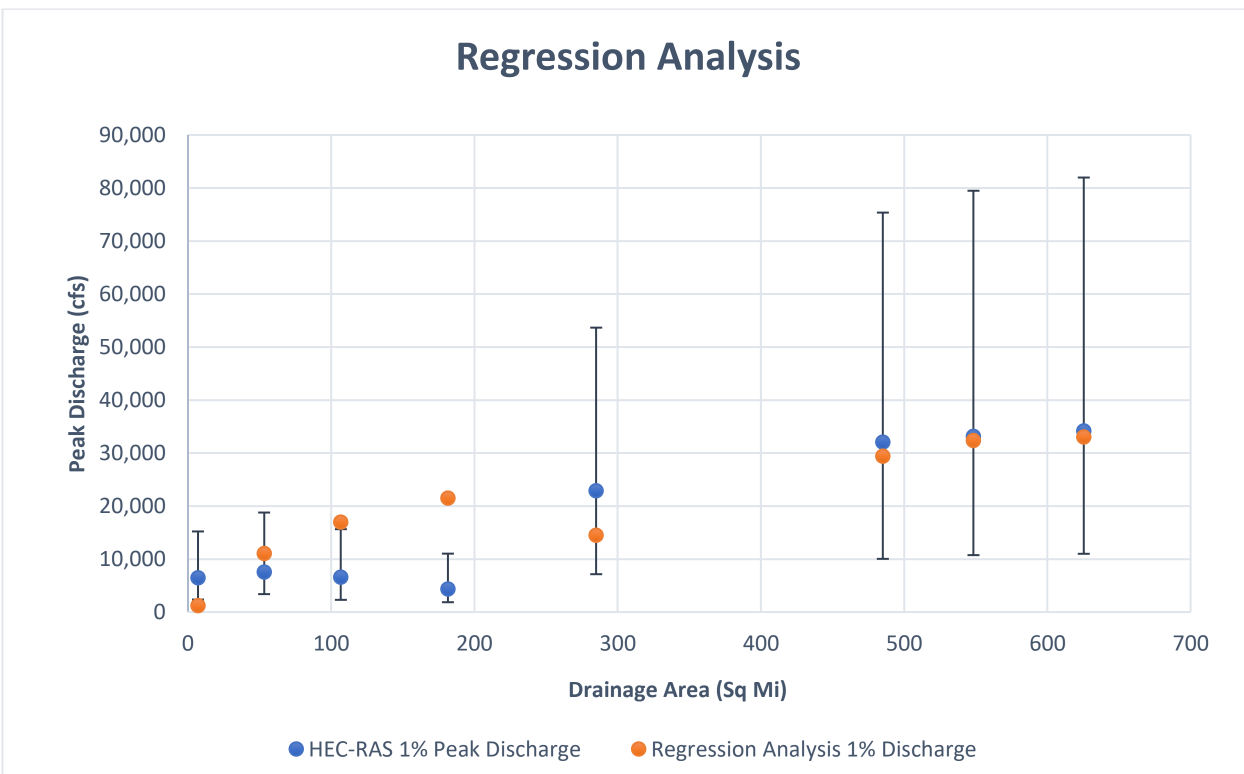

Figure 10: Comparison at Regression Locations

3.3 Sensitivity Analysis

To evaluate which model parameters significantly impact results, multiple sensitivity analyses were run. These sensitivities included variation of model equations (e.g., Diffusion Wave vs. Full Momentum), variation of Minimum Infiltration Rates, and varying CN values. While many of the analyses yielded minimal changes in the model results, it was noted that changing from the default Curve Numbers made large changes in model results.

3.4 Frequency **Event Results**

Peak outflows from each HUC10 watershed were extracted from the model using reference lines (see **Figure 9**) and are summarized for each simulated frequency event in **Table 12.** Palo Duro Watershed is made up of three HUC10 watersheds. Upper Palo Duro Creek and North Palo Duro Creek both drain into Lower Palo Duro Creek. **Figure 11** shows the relationship between Drainage Area and Discharges within the watershed. The relationship appears to be mostly linear, with a slight jump representing the Upper Palo Duro Creek Watershed. The west part of the HUC-10 watershed is made up of primarily playas. Rather than flowing downstream, water gets caught within the playa and infiltrated into the soil, therefore it is not contributing to the discharges seen at the outlet of the HUC-10 watershed.

There was one detailed study area present, which is in Canyon, Texas. A comparison was made between the lettered cross sections and the BLE model results, which can be found in **Table 13**. Some differences should be expected due to the changes in methodology and updates in modeling technology. The effective models are 1D steady flow models, meaning one discharge is applied to the model for the duration of the simulation. The BLE study utilizes 2D unsteady-flow models. Additionally, the BLE analysis does not include detailed structure data. Differences between the effective data and BLE data may indicate a need for an updated Detailed Zone AE study.

Table 12: Frequency Event Peak Discharge Summary (cfs)

Name	HUC-10 Area (sq. mi.)	Drainage Area (sq. mi.)	10%	4%	2%	1%-	1%	1%+	0.2%
North Palo Duro Creek Flow Check	166	166	707	1,460	2,238	1,744	3,233	5,093	6,709
Upper Palo Duro Creek Flow Check	331	331	7,620	10,871	13,779	11,850	17,122	23,116	27,321
Upper Palo Duro Creek Outlet	357	357	9,093	12,709	15,783	13,830	19,477	26,127	31,182
North Palo Duro Creek Outlet	457	457	10,341	14,777	18,686	15,936	23,057	30,922	35,729
Lower Palo Duro Creek Outlet	185	999	13,611	20,918	27,047	23,114	34,107	47,734	57,835

Table 13: Detail Study Area – Model Comparison

Stream Name	Lettered Cross Section	Effective 1% Annual-Chance WSEL (ft)	Modeled 1% Annual-Chance WSEL (ft)	Difference Effective – Modeled (ft)
Spring Draw	A	3496.5	3495.2	1.3
Spring Draw	B	3505	3503	2.0
Spring Draw	C	3512.7	3511	1.7
Spring Draw	D	3512.9	3514	-1.1
Spring Draw	E	3526.7	3523	3.7
Spring Draw	F	3552	3546.2	5.8
Palo Duro Creek	A	3484.4	2488.2	-3.8
Palo Duro Creek	B	3484.7	2488.2	-3.5
Palo Duro Creek	C	3496.4	3495.1	1.3
Palo Duro Creek	D	3496.4	3495.2	1.2
Palo Duro Creek	E	3497	3498.5	-1.5
Palo Duro Creek	F	3497.2	3499.2	-2.0
Palo Duro Creek	G	3501.52	3503.5	-2.0
Palo Duro Creek	H	3508.39	3509.1	-0.7
Palo Duro Creek	I	3512.66	3513.8	-1.1
Palo Duro Creek	J	3515.26	3516.1	-0.8
Palo Duro Creek	K	3526.14	3526.5	-0.4
Palo Duro Creek	L	3531.7	3535.5	-3.8
Palo Duro Creek	M	3539.8	3543.3	-3.5
Palo Duro Creek	N	3546.8	3549.4	-2.6
Palo Duro Creek	O	3550	3552.6	-2.6
Palo Duro Creek	P	3552.4	3555.7	-3.3
Palo Duro Creek	Q	3557	3560.9	-3.9
Palo Duro Creek	R	3562.3	3565	-2.7

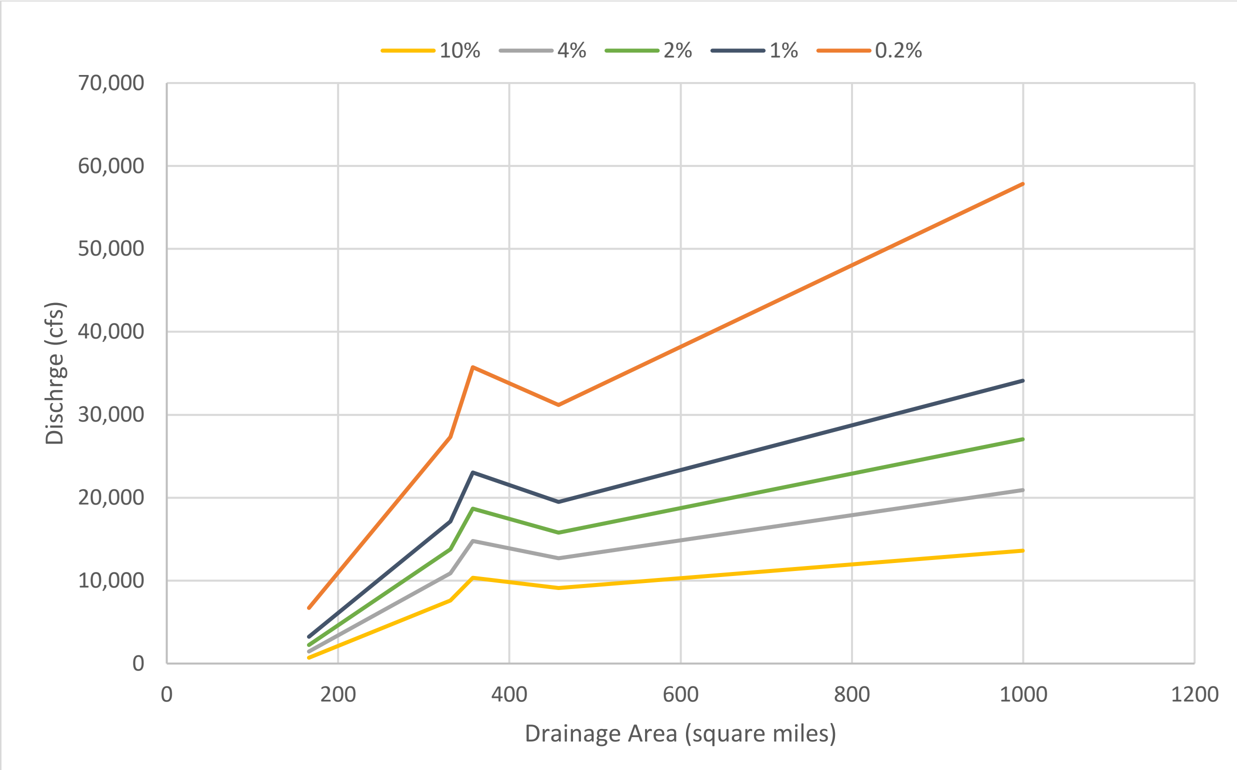

Figure 11: Drainage Areas vs. Discharges

3.5 Challenges

BLE studies are high level and low detail. Structure data was not provided in most of the watershed, so assumptions had to be made about culvert/bridge parameters. Structure data for Bivins lake with included but was outdated. These factors can affect the validity of the model. For future studies, structure survey data should be incorporated to refine results and more accurately estimate discharge out of the bridge/structure.

The dominance of playa lakes throughout the watershed and lack of stream gages present challenges for the 2D BLE analysis. The precise initial conditions of playa lakes are difficult to simulate within a HEC-RAS 2D model and their natural seasonal variability adds a level of uncertainty to model results.

The lack of stream gage records within the Palo Duro watershed reduces comparison points for the analysis and limits the ability to simulate historical events which could verify the 2D BLE results and approach. OlssonFTN coordinated with FNI to calibrate discharges to gages in the downstream watershed (Terra Blanca Watershed) and compared results within the watershed to regional regression equations.

Additionally, the watershed's terrain is very flat and does not contain one outlet. Water spills into surrounding watersheds in many different areas. To ensure water was not artificially built-up along the watershed edges, boundary conditions had to be added around the entirety of the watershed.

3.6 Recommendations

This study provides useful information for flood risk identification and communication among stakeholders within the watershed. This study is scalable, and additional analysis will enhance the product and further inform the implementation of regulatory flood hazard areas. The validity of the 2D BLE analysis should be verified through community meetings prior to being applied as a regulatory product.

4.0 Quality Control

Throughout the BLE analysis, multiple quality checks were performed. These included checks to review the terrain data processing prior to hydraulic model development; hydrologic discharge and model parameter checks; hydraulic checks for complete model coverage, addition of terrain modification locations to allow for hydraulic connectivity through structures, revisions to dam spillways and top of dams, and revisions to Manning's "n" values; floodplain mapping cleanup; database quality checks and review; and final submittal reviews. Significant efforts were made to reasonably resolve all items noted prior to submittal. Please see the information included in the Reporting and Documentation > Internal Reviews folder for additional details on the hydraulic review documentation.

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

Following the HEC-RAS analysis, the model results were then imported into the HEC-RAS 6.3 RAS Mapper tool to map floodplain boundaries for the model extent. This tool uses a routine that develops water surface elevation grids based on the 10-foot cell size DEM. The sloping rendering mode was used with the "Depth-Weighted Faces" mapping option selected to reduce the effect of cupping and skewed results. For this BLE analysis, mapping results were developed for three (3) events. These events were the 10-, 1-, and 0.2-percent-events. The results of these analyses were used to perform an updated Flood Loss Analysis using the HAZUS program.

The 10-, 1-, and 0.2-percent-event mapping was refined by removing a depth of 1/3 feet or less. Mapping pieces smaller than 1/3 acre were removed. The resulting floodplain spatial data was generalized using a 5-foot tolerance, then smoothed with smoothing tolerance 2.5x input raster cell size. To avoid topology errors, the floodplain spatial data was generalized once again with a 0.3-foot tolerance. After the initial boundary edits, the resulting floodplain boundaries were merged into a single watershed map boundary. For the 10-percent-event, minor areas of high ground (islands) less than 0.5 acres were filled in. For the 1-, 0.2-percent-event, islands less than 2 acres were filled in.

Once the map boundaries were cleaned, the resulting rasters (Water Surface Elevation, Depth, etc.) were developed with the raster set to correspond in extent to the cleaned polygon boundary. This ensures that the water surface raster and the floodplain boundary are consistent with each other. The backwater WSE at HUC10 watershed boundaries was extended upstream to produce clean tie-ins, with no drawdowns. The depth raster product was created at the end of the process by performing a raster subtraction with the water surface elevation raster and the ground DEM. Depth rasters were populated with the value 0.1 feet for areas where holes were filled.

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

A large portion of the Zone A studies (111 miles) in the Palo Duro Watershed were classified in CNMS with a validation status of "UNVERIFIED" and status type of "TO BE STUDIED." Another 4.6 miles of Zone A studies were classified in CNMS with a validation status of "VALID" and status type of "NVUE COMPLIANT." The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A3 were evaluated for the CNMS inventory of Zone A studies.

5.1.1 Initial Assessment A1 – Significant Topography Update Check

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

The significant topography update check determines whether a topographic data source is available that is significantly better than what was used for the effective Zone A modeling and mapping. This check will FAIL if the effective study topographic source does not meet the FEMA SID 43 vertical accuracy requirements, and a new LiDAR source is available (complete or in progress) for the study area that does meet or exceed SID 43. If the effective topographic data source was LiDAR that meets SID 43 this check will automatically PASS, even if a newer LiDAR source is available that meets or exceeds SID 43. If the topographic data source was not provided, then studies with effective dates prior to 2000 were assumed to be non-LiDAR based studies and failed the check while studies completed after 2000 were assumed to have used LiDAR (unless otherwise attributed) and passed the check.

5.1.2 Initial Assessment A2 – Check for Significant Hydrology Changes

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

New regression equations were made available for Texas in 2009. Thus, effective studies using regression equations that were completed prior to 2009 are assumed to FAIL the A2 assessment. Studies using regression equations that were completed after 2009 or studies using methods other than regression equations are assumed to PASS the A2 assessment.

5.1.3 Initial Assessment A3 – Check for Significant Development

This check involves using the National Land Cover Database (NLCD) dataset to assess increased urbanization in the watershed of the Zone A study. The ESRI USA NLCD Impervious Surface Time Series was used to create a raster showing the difference in imperviousness from 2001 to 2016.

If significant landuse change was identified in the effective study area or areas adjacent to the effective study, A3 was set to FAIL. Otherwise, effective studies were assumed to PASS the A3 assessment.

Table 14: Zone A Initial Assessment Results

Assessment Check	Pass/Fail	Comments/Notes
A1 - Topography	Fail	LiDAR significantly better than effective USGS topo source/Effective mapping leveraged LiDAR data.
A2 - Hydrology	Fail	Hydrology was completed before 2009 for all studies within the watershed.
A3 - Development	Pass	The only areas with significant landuse change occur in Zone AE studies, which are not included in the A checks.

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

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

If the effective study was model backed, then A4 is set to PASS. If the effective study was not model backed, then A4 is set to FAIL. If it was unknown if the study was model backed or not, then it was assumed it was not model backed and the A4 assessment was set to FAIL.

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

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

Vertical Tolerance: +/- 5 feet (one-half contour interval of assumed effective topographic source).

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

The effective Zone A comparison was performed at the full extent of the Lower West Fork Trinity Watershed. The validation of the effective Zone A boundaries using 2D flood hazard products differ from the standard 1D methods due to the lack of cross sections and their use with standard FBS methodology. For this 2D study, the effective Zone A boundaries were compiled using the National Flood Hazard Layer. These data were dissolved into one continuous Zone A layer, which then had test points placed along its perimeter every 500 feet.

For each test point, a vertical test and horizontal test were performed. These tests compare the 1% plus and 1% minus against the DEM at the test point locations. These 1% plus and 1% minus values are products of the new 2D BLE study. If the point fails either the vertical test or horizontal test, then the point fails and is assigned a value of "F". If the point passes both the vertical and horizontal test, then the point passes and is assigned a value of "P".

For the vertical test the following must be true. (1-percent-minus WSEL – vertical tolerance) is less than or equal to the topographic elevation at study point and the topographic elevation at study point is less than or equal to the (1-percent-plus WSEL + vertical tolerance). The vertical tolerance is defined by half the contour interval of the USGS 24K Quad for the study area. For this study we used a vertical tolerance of 5ft since the contour interval was 10ft.

For the horizontal test the following must be true. 1-percent-plus WSEL is greater than or equal to the minimum topographic elevation within a 75-foot radius of the validation point AND 1-percent-minus WSEL is less than or equal to the maximum topographic elevation within a 75-foot radius of the validation point.

Points were then grouped by HUC-12 watersheds. A pass percentage was calculated for each HUC based on the number of passing points divided by total number of points within that watershed. The Passing threshold used to determine if the HUC-12 watershed passed or failed the check was based on the risk class. Palo Duro Watershed had 3 risk classes: A, B, and C. Since multiple risk classes were present the most conservative passing threshold of 95%was used. If the watershed had 95% or higher passing points than all the effective Zone A reaches within that HUC passed. If the watershed had less than 95% passing points, then all the reaches within that watershed failed.

5.1.6 CNMS Validation Results

Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Palo Duro Watershed study area has been updated, total miles in each of these categories are summarized in **Table 15** and illustrated in **Figure 12** below.

Table 15: Zone A Validation Results

Flood Zone	Validation Status	Status Type	Total Miles
A	UNVERIFIED	BEING STUDIED	105.0
AE	UNVERIFIED	TO BE STUDIED	6.1
AE	VALID	NVUE COMPLIANT	4.6
X	ASSESSED	BEING STUDIED	675.4

Table 16: BLE Comparison Results

HUC-12 Watershed		Total FBS Points	Fail	Pass	% Pass	BLE Comparison Pass?
Watershed Name	HUC12 ID					
Buffalo Lake	111201020101	356	106	250		Fail
Headwaters Palo Duro Creek	111201020102	N/A	N/A	N/A	N/A	N/A
Town of Simms-Palo Duro Creek	111201020103	N/A	N/A	N/A	N/A	N/A
Overstreet Lake-Palo Duro Creek	111201020104	N/A	N/A	N/A	N/A	N/A
Conkwright Ranch-Palo Duro Creek	111201020105	N/A	N/A	N/A	N/A	N/A
Palo Duro Creek	111201020106	16	13	3		Fail
Red Windmill Lake	111201020201	N/A	N/A	N/A	N/A	N/A
Hay Lake	111201020202	N/A	N/A	N/A	N/A	N/A
111201020203	111201020203	N/A	N/A	N/A	N/A	N/A
Dodson Lake	111201020204	N/A	N/A	N/A	N/A	N/A
Memorial Park-Town of Vega	111201020205	N/A	N/A	N/A	N/A	N/A
Upper North Palo Duro Creek	111201020206	N/A	N/A	N/A	N/A	N/A
Lower North Palo Duro Creek	111201020207	39	39	0	0.0%	Fail
Negro Arroyo	111201020301	333	234	99	34.4%	Fail
Bivins Lake-Palo Duro Creek	111201020302	277	236	41	14.4%	Fail
Spring Draw	111201020303	515	381	134	25.9%	Fail
City of Canyon-Palo Duro Creek	111201020304	563	432	131	25.0%	Fail

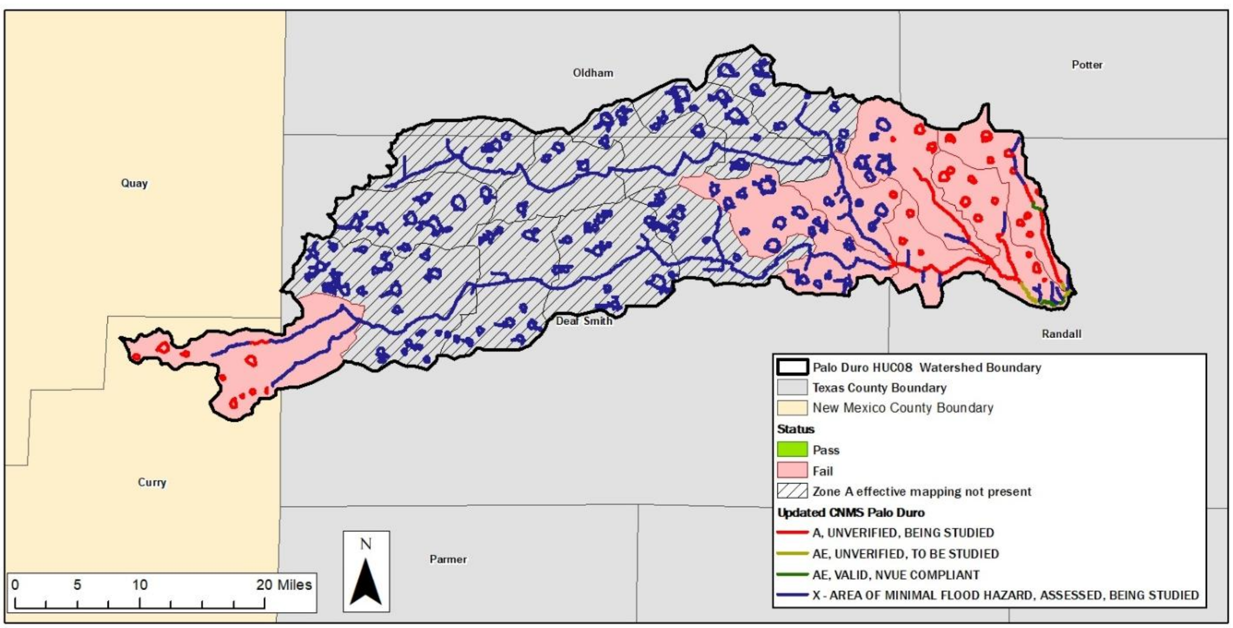

Figure 12: CNMS Validation Results

5.2 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 6.0 was used for the basic and refined loss analysis.

The losses are reported via census blocks. It is important to note that Hazus version 6.0 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.

The Hazus analysis was performed within the project watershed extends for the 100-return period. A summary of results per County for the 1-percent annual chance scenarios are shown in **Table 17**.

Table 17: HAZUS Results for 1% Annual Chance Scenario

County	Full Replacement – Total Loss	Dollar Exposure (Replacement Value) - Buildings	Dollar Exposure (Replacement Value) - Contents
Curry	$130,000.00	$18,114,000.00	$16,211,000.00
Deaf Smith	$17,425,000.00	$741,198,000.00	$571,651,000.00
Oldham	$37,852,000.00	$330,457,000.00	$276,411,000.00
Potter	$28,536,000.00	$441,304,000.00	$319,236,000.00
Randall	$104,946,000.00	$2,007334,000.00	$1,299,050,000.00
Total	**$188,889,000.00**	**$3,538,407,000.00**	**$2,482,559,000.00**

6.0 References

Bibliography list of references used and referred to throughout document.

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