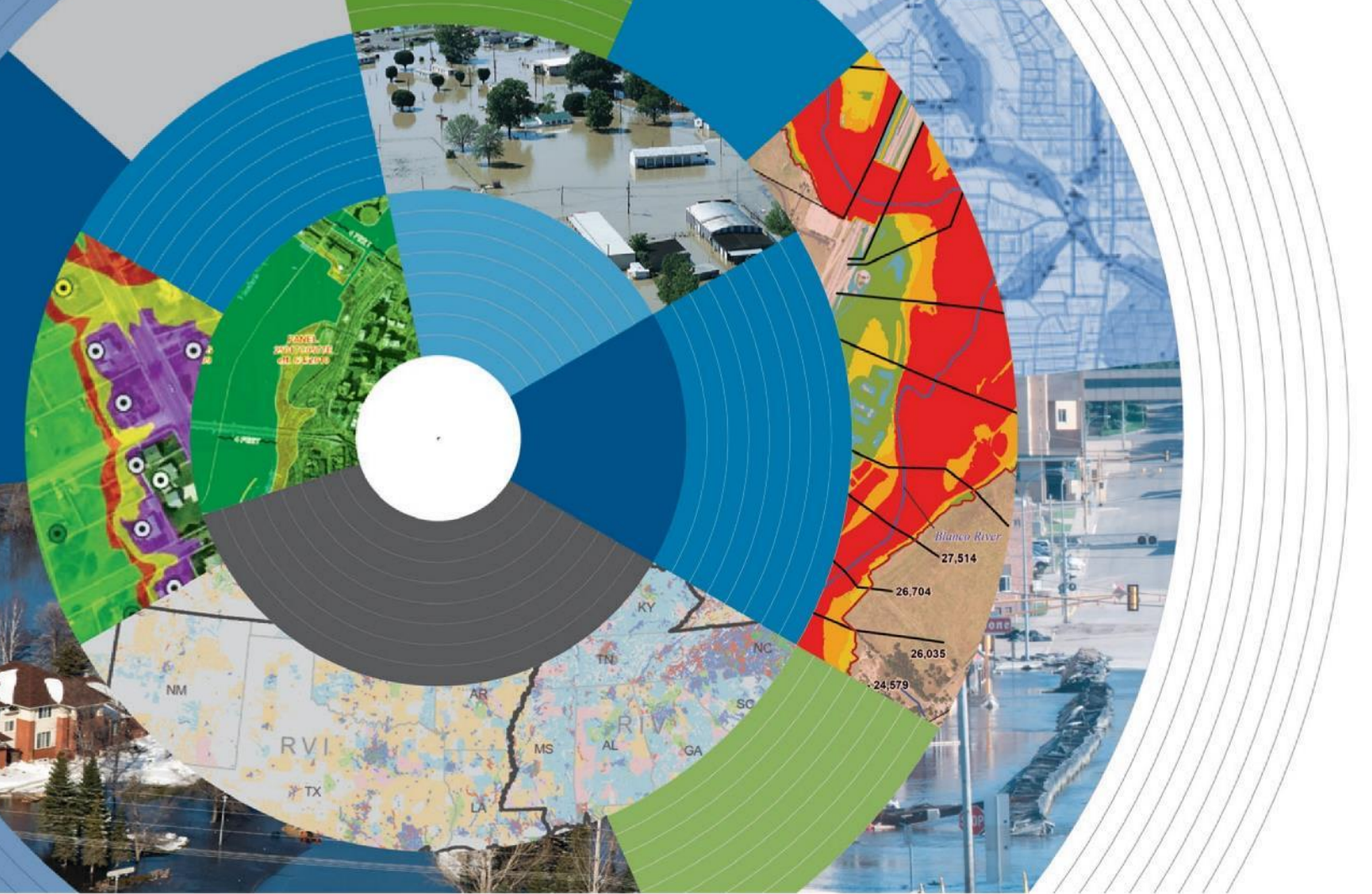




Base Level Engineering Report

Upper Prairie Dog Town Fork Red (HUC-8 11120103)

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Executive Summary

The Texas Water Development Board (TWDB) contracted with Freese and Nichols, Inc. in September 2021 to complete a Base Level Engineering (BLE) analysis for the Upper Prairie Dog Town Fork Red (UPDT) 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.

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. 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.

Economic losses due to flood risk were calculated on a census block level for the 1% AEP and 0.2% AEP storm events and aggregated to a HUC-8 level using FEMA's Hazus software. The Hazus results are presented below in **Table 1** & **Table 2**.

Table 1: Hazus 1% Loss Estimation

County Name	Building Loss	Contents Loss	Total Loss
Armstrong	\$2,592,000.00	\$1,659,000.00	\$82,709,000.00
Briscoe	\$58,000.00	\$32,000.00	\$337,000.00
Carson	\$112,000.00	\$63,000.00	\$1,973,000.00
Donley	\$11,000.00	\$5,000.00	\$281,000.00
Hall	\$8,000.00	\$9,000.00	\$85,008.00
Potter	\$66,260,000.00	\$126,216,000.00	\$1,713,656,000.00
Randall	\$173,932,000.00	\$157,065,000.00	\$2,262,696,000.00
Swisher	\$530,000.00	\$367,000.00	\$37,532,000.00
Total	\$243,503,000.00	\$285,416,000.00	\$4,099,269,008.00

Table 2: Hazus 0.2% Loss Estimation

County Name	Building Loss	Contents Loss	Total Loss
Armstrong	\$4,808,000.00	\$3,359,000.00	\$110,305,000.00
Briscoe	\$98,000.00	\$53,000.00	\$493,000.00
Carson	\$180,000.00	\$101,000.00	\$2,649,000.00
Donley	\$56,000.00	\$30,000.00	\$486,000.00
Hall	\$51,000.00	\$78,000.00	\$351,000.00
Potter	\$93,749,000.00	\$184,785,000.00	\$2,030,270,000.00
Randall	\$239,333,000.00	\$219,909,000.00	\$2,732,441,000.00
Swisher	\$853,000.00	\$692,000.00	\$48,587,000.00
Total	\$339,128,000.00	\$409,007,000.00	\$4,925,582,000.00

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 Freese and Nichols, Inc. to complete a BLE analysis for the Upper Prairie Dog Town Fork Red Watershed, shown in **Figure 1**, 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 Armstrong, Briscoe, Carson, Donley, Hall, Potter, Randall, and Swisher Counties, and include the following communities: the Cities of Amarillo, Canyon, Claude, Happy, Lake Tanglewood, Palisades, and Timbercreek Canyon. The study area consists of six HUC-10 basins: Headwaters Prairie Dog, Happy Draw, Gip Creek, Battle Creek, Headwaters Mulberry, and Mulberry Creek.

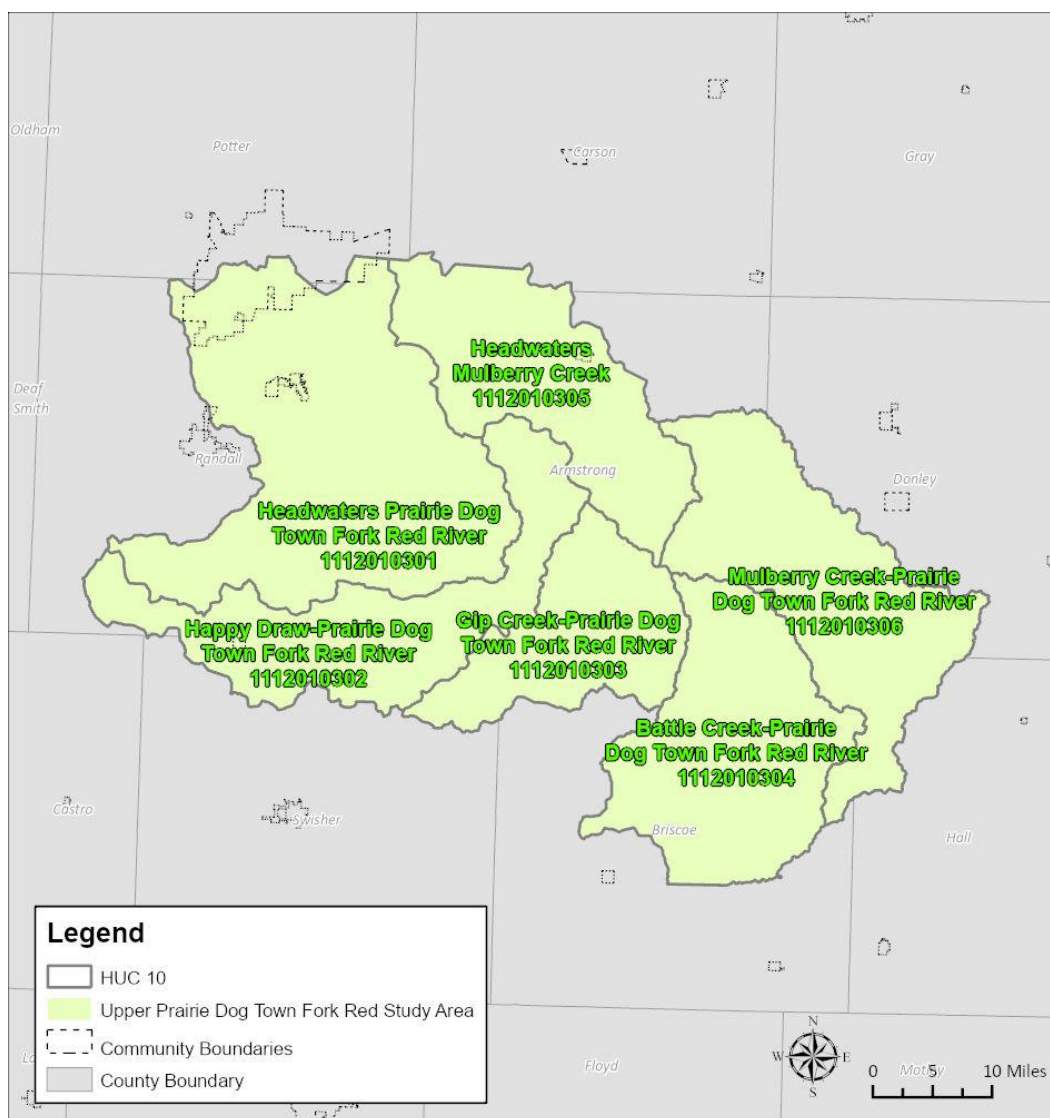


Figure 1: Upper Prairie Dog Town Fork Red HUC-10 Basins

The Base Level Engineering assessment prepared cursory engineering analysis for approximately 4,340 miles of stream reaches within the Upper Prairie Dog Town Fork Red Watershed with a minimum drainage area tolerance of one square mile. The watershed is divided into two subregions with distinct topography for each subregion. The distinct topographies correlate to unique flood infrastructure for each of the two subregions. The upper region of the basin is dominated by the Playa Lake system while the lower region of the basin is comprised primarily of rivers, streams, and lakes. Due to the varied natural infrastructure, stream reach delineations were only extended through the lower regions of rivers and streams. The playa lakes are generally hydraulically disconnected and therefore stream reaches were not created for these features. 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 Upper Prairie Dog Town Fork Red 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 Upper Prairie Dog Town Fork Red watersheds, were executed using the following steps:

- Available 1-meter DEMs within each watershed were inventoried and sourced from FEMA, NOAA, and USGS;
- Seamless DEMs were produced using GIS spatial analyst and 3D analyst tools and resampled to 10-foot resolution; 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 each HUC8 watershed, including a 1-mile buffer around each watershed boundary. Data from USGS was queried to build the inventory with the most current and available data sources.

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 3** depicts the complete list of source elevation data and attributes leveraged for the Upper Prairie Dog Town Fork Red watershed.

Table 3: Source Topographic Data (DEMs) Leveraged for Upper Prairie Dog Town Fork Red Watershed

Watershed	Counties	Year	Description	Data Type	3DEP Quality Level	Vertical Accuracy (RMSE)	Source/ Owner	Approx. Footprint (Sq. Mi.)
Upper Prairie Dog Town Fork Red (HUC 11120103)	Armstrong, Briscoe, Carson, Donley, Hall, Potter, Randall, Swisher	2018	USGS Texas Panhandle LiDAR	Airborne LiDAR	2	4.3 cm	USGS	2,152

2.1.2.1 Watershed Source Terrain Data

The source elevation data for the Upper Prairie Dog Town Fork Red watershed was 1-meter DEMs derived from the 2018 USGS Texas Panhandle LIDAR data. **Figure 2** depicts the extent of the data defined in **Table 3**.

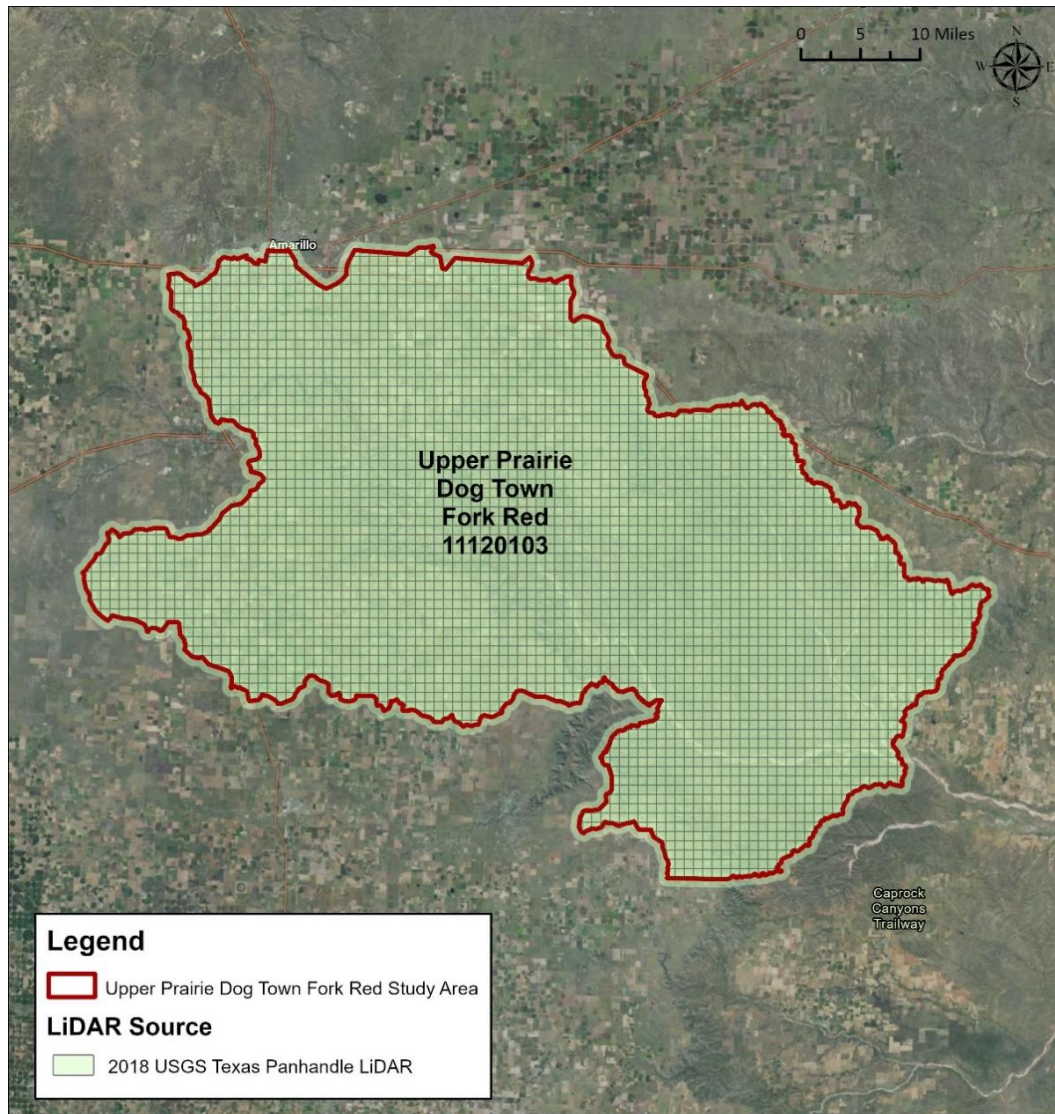


Figure 2: Upper Prairie Dog Town Fork Red Watershed BLE Source Terrain Data

USGS 2018 FEMA Texas Panhandle LiDAR

The 2018 FEMA Texas Panhandle LiDAR was acquired between February 9, 2018, to September 9, 2019. The vertical accuracy for the dataset is reported to be 4.3 cm RMSE at a 95% confidence level which meets project accuracy specifications of the 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 processed for the Upper Prairie Dog Town Fork Red watershed for the BLE modeling efforts. 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 Central (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 developed for use in the Upper Prairie Dog Town Fork Red watershed. BLE analyses were developed and independently assured to meet QA standards of the project. QA standards during the data development process included, but were not limited to the following:

- Horizontal Projection Check (NAD83 SPCS 4201 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

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 the following:

- 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 Tule and Upper Prairie Dog Town Fork Red watersheds are 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

The following sections describe the methodology used in the 2D BLE analysis of the Upper Prairie Dog Town Fork Red Watershed. This section includes discussion regarding the overall approach along with hydrologic and hydraulic methodologies and results.

2.2.1 Model Areas

The Upper Prairie Dog Town Fork Red Watershed covers a total area of 2,152 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 Upper Prairie Dog Town Fork Red HUC8 into six models, one for each HUC10 area. **Table 4** presents each 2D model and **Figure 3** provides a visual of the model boundaries. As described in **Section 2.2.2 Model and Boundary Condition Setup**, these

models remain interconnected via internal boundary conditions, so no runoff volume is lost through the subdivision of the HUC8.

Table 4: Upper Prairie Dog Town Fork Red Model Areas

Model	HUC10	HUC10 Name	Area (Sq. Mi.)
1112010301	1112010301	Headwaters Prairie Dog	601
1112010302	1112010302	Happy Draw	319
1112010303	1112010303	Gip Creek	218
1112010304	1112010304	Battle Creek	350
1112010305	1112010305	Headwaters Mulberry	299
1112010306	1112010306	Mulberry Creek	365

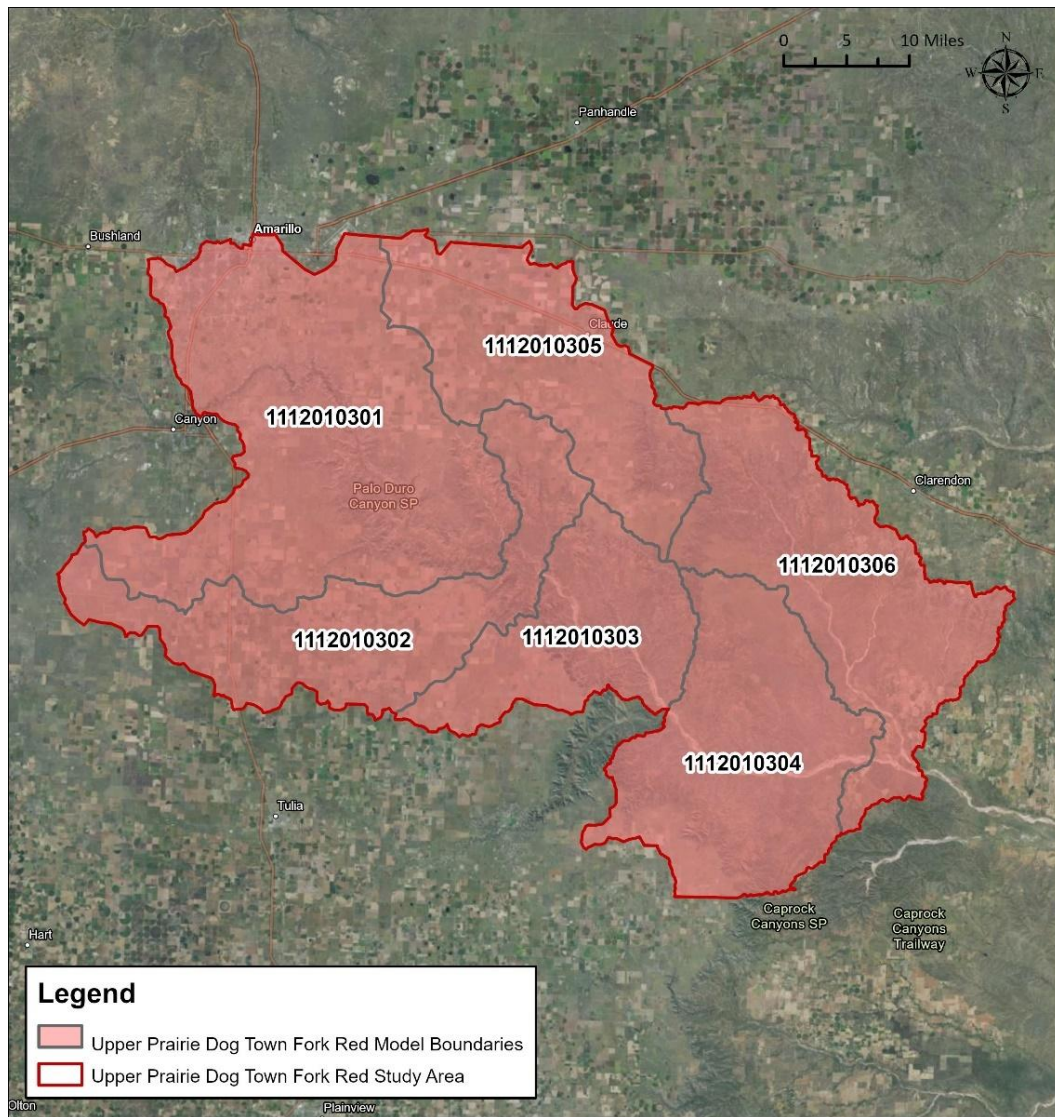


Figure 3: Upper Prairie Dog Town Fork Red HUC-10 Model Boundaries

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. HUC10 boundaries with a 1000' buffer applied were used to establish the 2D model domain boundaries within the Upper Prairie Dog Town Fork Red HUC8. Inflow hydrology can be applied through various methods in HEC-RAS 2D modeling, but hydrology methods are limited to two categories for the Upper Prairie Dog Town Fork Red HUC8. These are flow hydrographs and precipitation time-series.

Section 2.2.3.1 Precipitation for HEC-RAS 2D describes the development of the precipitation data applied to each model. Precipitation, rather than excess precipitation, was applied directly to the 2D mesh because hydrologic losses can be accounted for entirely within HEC-RAS version 6.3.0.

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 1112010302 (Happy Draw) model has an inflow hydrograph at its upstream end that applies the outflow from the 1112010301 (Headwaters Upper Prairie Dog Town) model.

Inflow hydrographs from external HUC-8 watersheds Palo Duro, Tierra Blanca, and Tule were applied as boundary conditions at the appropriate confluence locations. These HUC-8 watersheds are being studied under the same task order contract as this HUC-8 and the 2D Base Level Engineering computed flows were used as inflow hydrographs. The inflow hydrographs from external HUC-8 watersheds are shown in **Figure 4 - Figure 6**. To properly account for the backwater effects of Palo Duro on Tierra Blanca, the inflow location to Upper Prairie Dog was adjusted after completing the Tierra Blanca models. To prevent double counting of storage, a profile line was placed at the appropriate confluence. This approach has some limitations compared to the typical reference line method. The primary limitation is that the mapping output interval, which sets the hydrograph interval for a profile line, is 1-hr as opposed to the 15-min interval used in other model domains. It was confirmed that the hydrograph captures the peak flow for the mapped storm events.

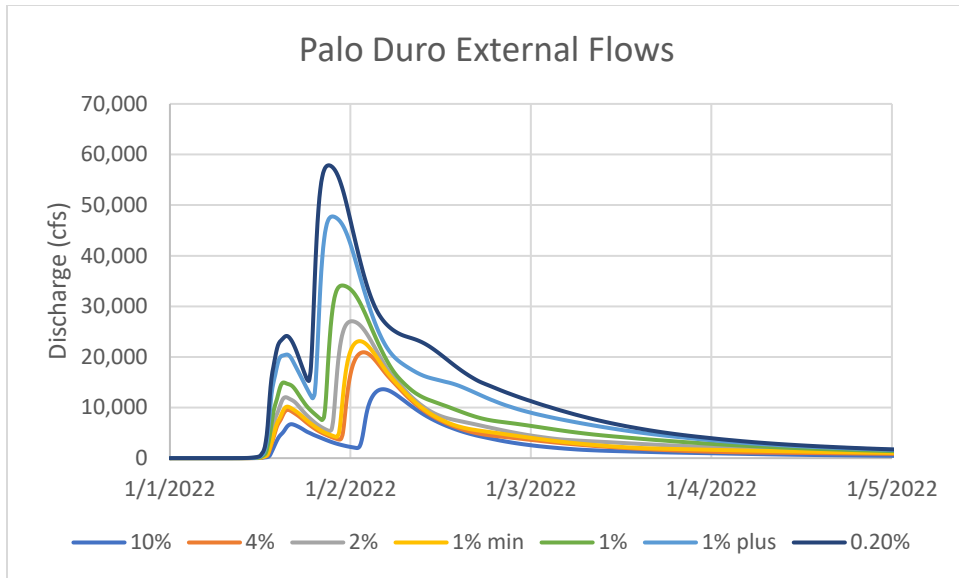


Figure 4: Palo Duro HUC8 Inflow Hydrograph

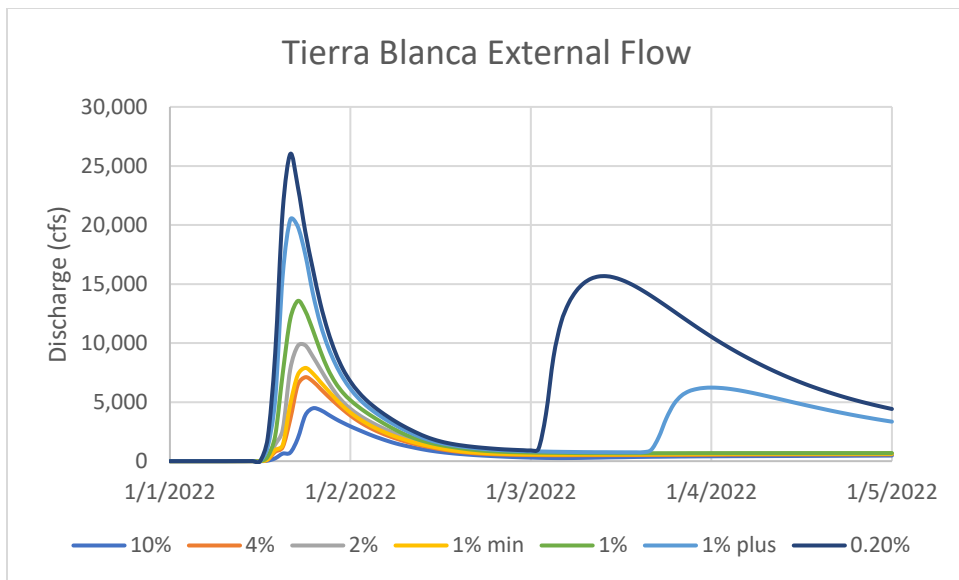


Figure 5: Tierra Blanca HUC8 Inflow Hydrograph

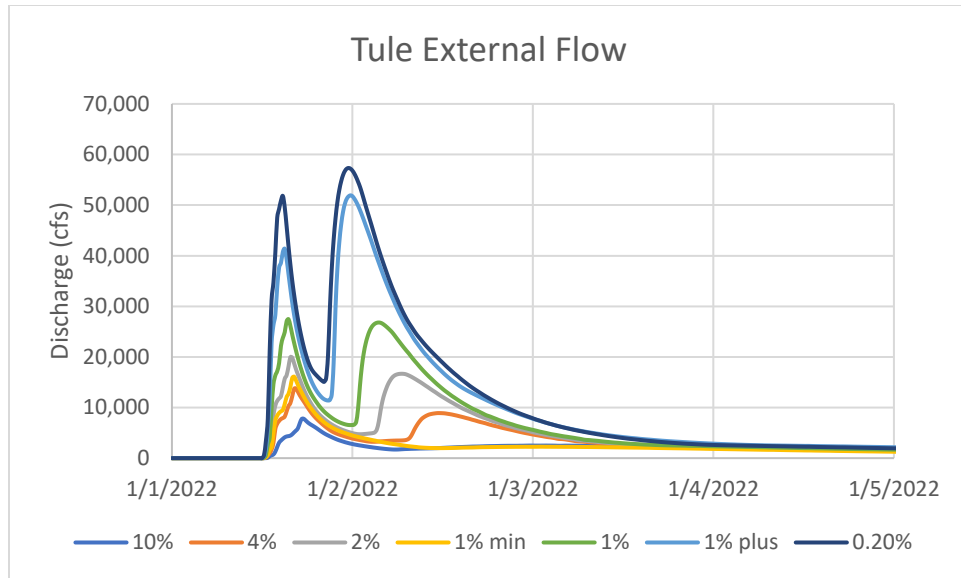


Figure 6: Tule HUC8 Inflow Hydrograph

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. There were also normal depth boundaries applied along all other sections of the model perimeter to prevent ponding. These normal depth boundaries were split up by topography (i.e. riverine, caprock) to estimate the energy grade-line.

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. To add detail to dense urban areas, refinement regions that enforced 100'x100' cells were added in over urban areas in TxDOT's municipalities layer. The mesh was further 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. The models in the Upper Prairie Dog Town Fork Red Watershed, with the exception of 1112010302, use a 30 second timestep with the Diffusion Wave equation set. The 1112010302 (Happy Draw) HUC10 contains many steep drops in terrain that resulted in model instabilities. In response to these instabilities, the Happy Draw HUC10 uses a courant varied timestep. The varied timestep allows the model to determine the appropriate timestep to keep the 2D courant residence time in the ideal range between 0.5 and 2. All other computational settings were kept at their

default values. As described in **Section 2.3.2**, the sensitivity of results to additional computational settings was preliminarily evaluated, but the initial settings listed in this section were maintained following the sensitivity analysis. The location of USGS gages in relation to each HEC-RAS model's 2D computational mesh can be seen in **Figure 7** below.

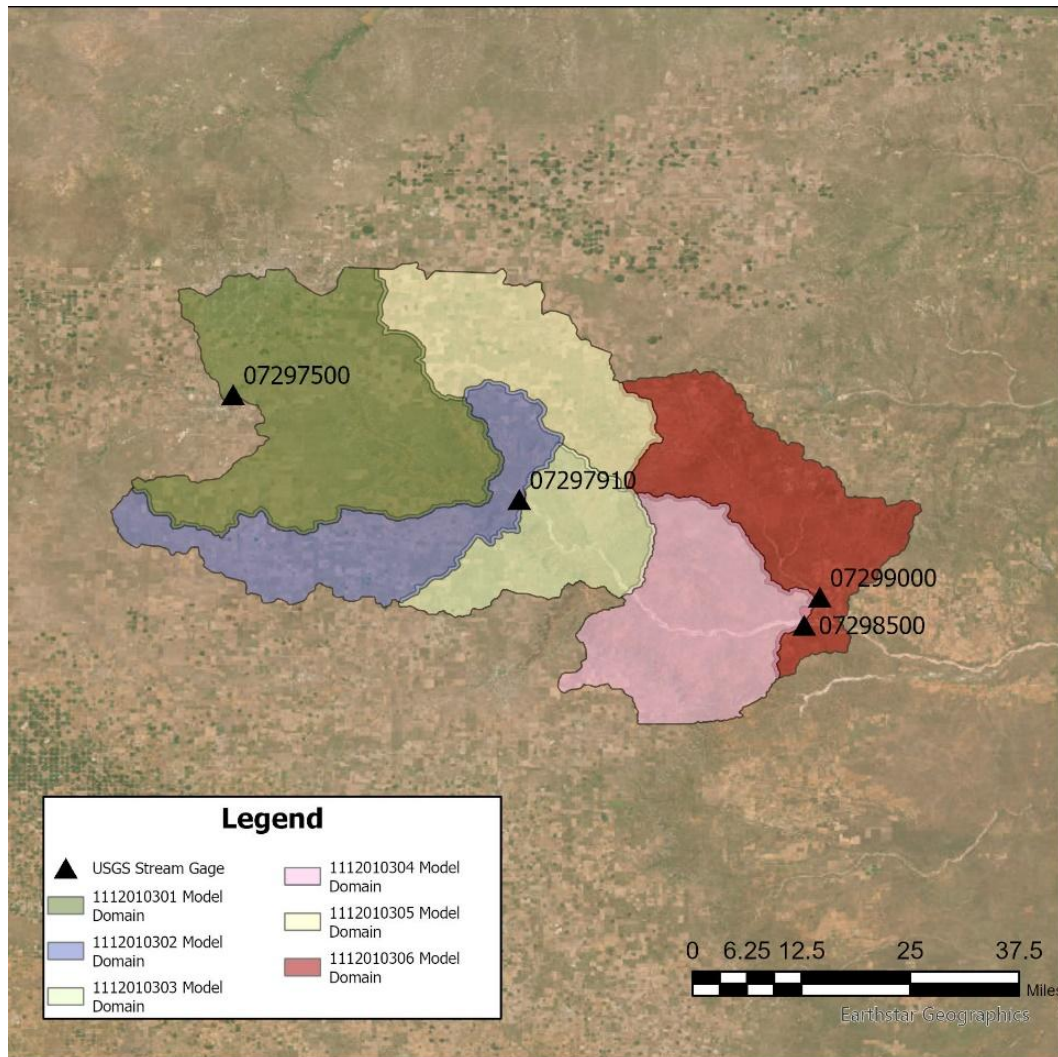


Figure 7: HEC-RAS 2D Computational Mesh Extents and USGS Gages

2.2.3 Hydrology

Hydrologic data for the Upper Prairie Dog Town Fork Red 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 in ArcGIS with NOAA Atlas 14 precipitation raster files for each model area presented in **Table 6-Table 11**. The 10%, 4%, 2%, 1%-minus, 1%, 1%-plus, and 0.2% annual exceedance probability events were simulated in the Upper Prairie Dog Town Fork Red Watershed.

2.2.3.1 Precipitation for HEC-RAS 2D

The average NOAA Atlas 14 precipitation-frequency depths for each model area in **Table 6-Table 11** were converted to a precipitation time-series dataset within a dummy HEC-HMS v4.9 model. A frequency storm was created within HEC-HMS for each event listed in **Section 2.2.3 Hydrology**. Each frequency storm utilized the parameters listed in **Table 5**. A precipitation time-series was then extracted from the HEC-HMS models and utilized in the HEC-RAS 2D simulations.

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. The 1%-minus and 1%-plus events utilize the 1% precipitation depths +/- 1.645 standard deviations. See **Equation 1: 1% Plus and Minus Precipitation** for the equation used to calculate the precipitation for the 1% plus and minus events.

Equation 1: 1% Plus and Minus Precipitation

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

Table 5: 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 6: 1112010301 – Precipitation-Frequency Depths

Duration (min)	Percent Annual Chance Precipitation Depth (in)						
	10%	4%	2%	1%-	1%	1%+	0.2%
5	0.61	0.74	0.86	0.76	0.97	1.19	1.26
15	1.20	1.47	1.69	1.50	1.93	2.36	2.49
60	2.07	2.53	2.92	2.58	3.32	4.07	4.27
120	2.47	3.02	3.48	3.10	3.96	4.82	5.12
180	2.70	3.30	3.80	3.41	4.33	5.25	5.61
360	3.11	3.80	4.37	3.95	4.97	6.00	6.47
720	3.54	4.33	4.97	4.52	5.65	6.77	7.39
1440	4.02	4.91	5.62	5.15	6.37	7.59	8.32

Table 7: 1112010302 – Precipitation-Frequency Depths

Duration (min)	Percent Annual Chance Precipitation Depth (in)						
	10%	4%	2%	1%-	1%	1%+	0.2%
5	0.60	0.73	0.85	0.76	0.98	1.20	1.26
15	1.18	1.45	1.69	1.50	1.94	2.38	2.50
60	2.02	2.48	2.89	2.57	3.32	4.07	4.27
120	2.42	2.97	3.44	3.07	3.94	4.80	5.08
180	2.66	3.25	3.76	3.36	4.29	5.21	5.55
360	3.07	3.76	4.33	3.89	4.93	5.96	6.41
720	3.51	4.31	4.96	4.50	5.65	6.80	7.44
1440	4.01	4.92	5.66	5.17	6.44	7.71	8.51

Table 8: 1112010303 – Precipitation-Frequency Depths

Duration (min)	Percent Annual Chance Precipitation Depth (in)						
	10%	4%	2%	1%-	1%	1%+	0.2%
5	0.61	0.76	0.88	0.78	1.01	1.24	1.32
15	1.22	1.50	1.74	1.55	2.00	2.45	2.60
60	2.09	2.57	2.99	2.66	3.44	4.21	4.47
120	2.52	3.10	3.60	3.22	4.12	5.03	5.40
180	2.77	3.41	3.95	3.54	4.52	5.50	5.95
360	3.21	3.96	4.58	4.14	5.24	6.34	6.93
720	3.67	4.55	5.27	4.82	6.05	7.28	8.05
1440	4.17	5.18	6.00	5.53	6.89	8.24	9.15

Table 9: 1112010304 – Precipitation-Frequency Depths

Duration (min)	Percent Annual Chance Precipitation Depth (in)						
	10%	4%	2%	1%-	1%	1%+	0.2%
5	0.63	0.77	0.88	0.76	0.99	1.21	1.28
15	1.25	1.52	1.74	1.52	1.96	2.41	2.53
60	2.16	2.63	2.99	2.60	3.36	4.13	4.36
120	2.60	3.17	3.62	3.19	4.09	5.00	5.36
180	2.85	3.50	4.00	3.55	4.53	5.52	5.97
360	3.30	4.07	4.68	4.20	5.32	6.45	7.06
720	3.76	4.67	5.42	4.94	6.22	7.49	8.28
1440	4.27	5.32	6.19	5.70	7.12	8.54	9.47

Table 10: 1112010305 – Precipitation-Frequency Depths

Duration (min)	Percent Annual Chance Precipitation Depth (in)						
	10%	4%	2%	1%-	1%	1%+	0.2%
5	0.63	0.77	0.88	0.78	1.01	1.23	1.32
15	1.24	1.52	1.75	1.56	2.00	2.43	2.61
60	2.14	2.62	3.01	2.68	3.43	4.19	4.48
120	2.55	3.12	3.59	3.22	4.09	4.96	5.34
180	2.79	3.41	3.92	3.53	4.46	5.39	5.82
360	3.20	3.93	4.51	4.09	5.12	6.15	6.69
720	3.64	4.46	5.13	4.70	5.83	6.96	7.65
1440	4.12	5.05	5.79	5.36	6.58	7.80	8.62

Table 11: 1112010306 – Precipitation-Frequency Depths

Duration (min)	Percent Annual Chance Precipitation Depth (in)						
	10%	4%	2%	1%-	1%	1%+	0.2%
5	0.63	0.77	0.87	0.76	0.98	1.20	1.27
15	1.26	1.52	1.74	1.52	1.96	2.40	2.52
60	2.20	2.66	3.02	2.64	3.40	4.16	4.40
120	2.65	3.23	3.68	3.25	4.16	5.06	5.42
180	2.92	3.56	4.07	3.63	4.61	5.60	6.04
360	3.40	4.16	4.78	4.30	5.43	6.55	7.16
720	3.89	4.80	5.54	5.06	6.33	7.60	8.44
1440	4.43	5.47	6.32	5.84	7.24	8.64	9.68

2.2.3.2 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 Gridded Soil Survey Geographic Database (gSSURGO). A curve number was then assigned to each resultant value of the intersected land cover classification and hydrologic soil group. Based on results from the sensitivity analyses and stream gage analysis, and adjustment of minus 15 was applied to the Antecedent Runoff Condition II (ARC II), or average antecedent moisture conditions, as presented in **Table 12**. A minimum curve number of 30 was utilized in all scenarios. These parameters represent the default Curve Numbers applied to the HEC-RAS 2D models. The values presented in **Table 12** were utilized in all studied events. The initial abstraction ratio for the default CN layer was set to 0.20.

Table 12: Land Use-Soils-CN Matrix

Land Use Grid Code	NLCD Land Use Description	Hydrologic Soil Group			
		A	B	C	D
11	Open Water	84	84	84	84
21	Developed Open Space	34	54	64	69
22	Developed Low Intensity	46	60	68	72
23	Developed Medium Intensity	66	73	76	78
24	Developed High Intensity	74	77	79	80
31	Barren Land	30	46	59	65
41	Deciduous Forest	30	40	55	62
42	Evergreen Forest	30	40	55	62
43	Mixed Forest	30	40	55	62
52	Shrub Scrub	30	33	50	58
71	Herbaceous	34	47	59	70
81	Hay Pasture	30	46	59	69
82	Cultivated Crops	36	52	61	65
90	Woody Wetlands	57	65	72	78
95	Emergent Herbaceous Wetlands	57	65	72	78

2.2.4 Hydraulics

Hydraulic analysis of the Upper Prairie Dog Town Fork Red 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.

2.2.4.1 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. Refinements along the stream centerlines extend to approximately 200 ft on either side of the centerline in order to capture one cell on either side of the stream in the channel's n-value region. Channel roughness values were assigned according to a review of aerial imagery and generally range from 0.035 – 0.06. **Table 13** documents the typical roughness values assigned to each NLCD land cover classification.

Table 13-NLCD 2019 Manning's Roughness Values

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	0.03	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	0.023	0.03	0.03
41	Deciduous Forest	0.10	0.20	0.10
42	Evergreen Forest	0.08	0.16	0.10
43	Mixed Forest	0.08	0.20	0.10
52	Shrub Scrub	0.07	0.16	0.07
71	Herbaceous	0.025	0.05	0.035
81	Hay Pasture	0.025	0.05	0.045
82	Cultivated Crops	0.02	0.05	0.045
90	Woody Wetlands	0.045	0.15	0.10
95	Emergent Herbaceous Wetlands	0.05	0.085	0.07

2.2.4.2 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. Stream centerlines generated from the terrain data were enforced to align cell faces perpendicular to flow. These breaklines were delineated to 0.1 square mile by automated process and manually cleaned to meet modeling needs. With the unique topography of West Texas, stream centerlines were ended when the flow regime changed from riverine to a network of playas and overflows.

Roadway centerlines were initially identified within ArcGIS and then imported into HEC-RAS as breaklines. Culvert crossings at roadways with an embankment height greater than 2m, a volume behind the embankment greater than 5 ac-ft, and a contributing drainage area greater than 1 sq. mi. were identified as hydraulically significant. For hydraulically significant features, v-notches were added at the culvert crossing to approximate the capacity of the culvert. Adding v-notches to the significant roadway embankments aids in appropriately accounting for storage within the watershed. **Figure 6** shows an example of a v-notch breakline. For crossings through multi-lane highways that span more than the length of a cell, the v-notch approach is insufficient, and thus a channel terrain modification was applied. Additionally, a reference line was added to every dam in the TCEQ inventory within the model boundaries to improve model usability for future users.

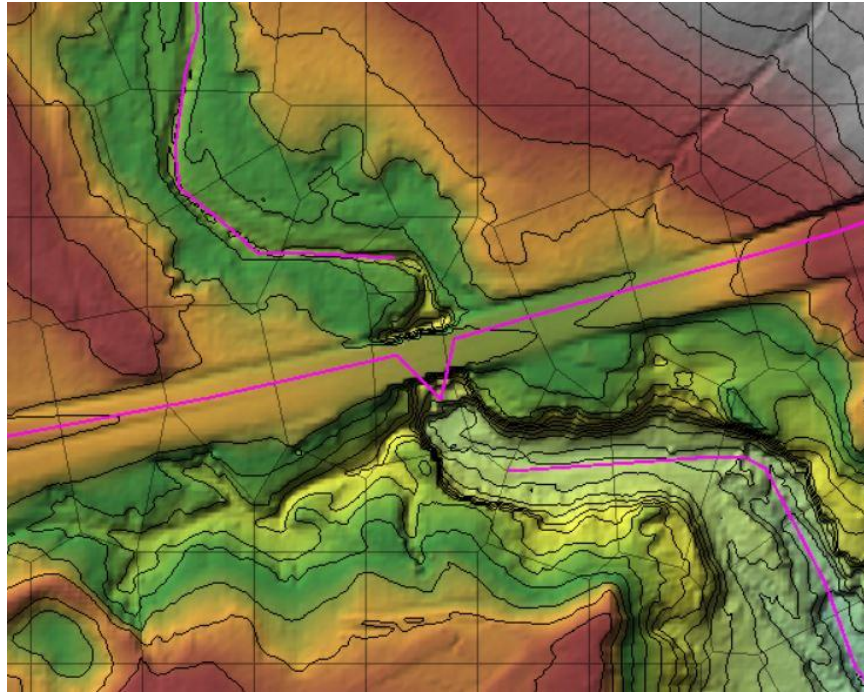


Figure 8: V-Notch Breakline Example

Lake Tanglewood Dam is in the Upper Prairie Dog Town Fork Red HUC-8, within the Headwaters Prairie Dog Town Fork Red River (1112010301) HUC-10. The embankment for this reservoir was accounted for by adding a SA/2D connection along the dam crest utilizing LiDAR elevations. No elevation data, control points, or rating curves were taken from external sources, and the SA/2D connection was utilized to alleviate instabilities downstream of Lake Tanglewood Dam. Discharge overtopping the dam was quantified using the weir flow equation.

2.2.4.3 Initial Conditions

Initial conditions in the Upper Prairie Dog Town Fork Red 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 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 did not apply an initial condition run to the Upper Prairie Dog Town Fork Red Watershed. The Tule watershed directly upstream did utilize an initial conditions run in their modeling efforts. The study team for the Tule watershed 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.

As documented in Section 2.3.2 Sensitivity Analysis, additional investigation is recommended to determine appropriate playa initial conditions. The 2D BLE analysis relies on the LiDAR terrain to account for storage. Additional investigation into the playa conditions at the time of the LiDAR flight would be necessary to determine precise dry volume for each playa. The final BLE frequency event simulations discussed below utilize the conditions captured by the LiDAR as initial conditions, rather than the restart

file mentioned in this section due to the approximate nature of BLE modeling and the model validation process discussed further below.

2.3 Model Results

The results of this study produced a SFHA boundary that can serve as an estimate for flood risk in areas which have 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.

2.3.1 Stream Gage Analysis

There is a total of four USGS stream gages within the Upper Prairie Dog Town Fork Red watershed. Of the four, only two USGS gages within the Upper Prairie Dog Town Fork Red Watershed had valid statistical peak flow data available for an adequate length of record. The statistical peak flow data from the 1% AEP storm at USGS Stream Gages 07298500 and 07297910 were determined to be the most relevant values on which to focus model validation efforts. Details about the relevant Upper Prairie Dog Town Fork Red gages and their locations can be seen in **Table 14** and **Figure 9**. The statistical peak flows for the USGS Stream Gages were produced using HEC-SSP 17B and can be found in **Table 15**.

Table 14: USGS Stream Gages in UPDT HUC8

ID	Gage Name	Notes	Years	Valid Years	Used?
7297500	Pr Dog Twn Fk Red Rv nr Canyon	Misc. years available in 1920s and 1940s – Not Valid	13	0	No
7297910	Pr Dog Twn Fk Red Rv nr Wayside	Current Buffalo Lake control structure completed 1992	55	30	Yes
7299000	Mulberry Ck nr Brice	Not enough data	2	2	No
7298500	Pr Dog Twn Fk Red Rv nr Brice	Valid Years: 2003 -2022	32	19	Yes

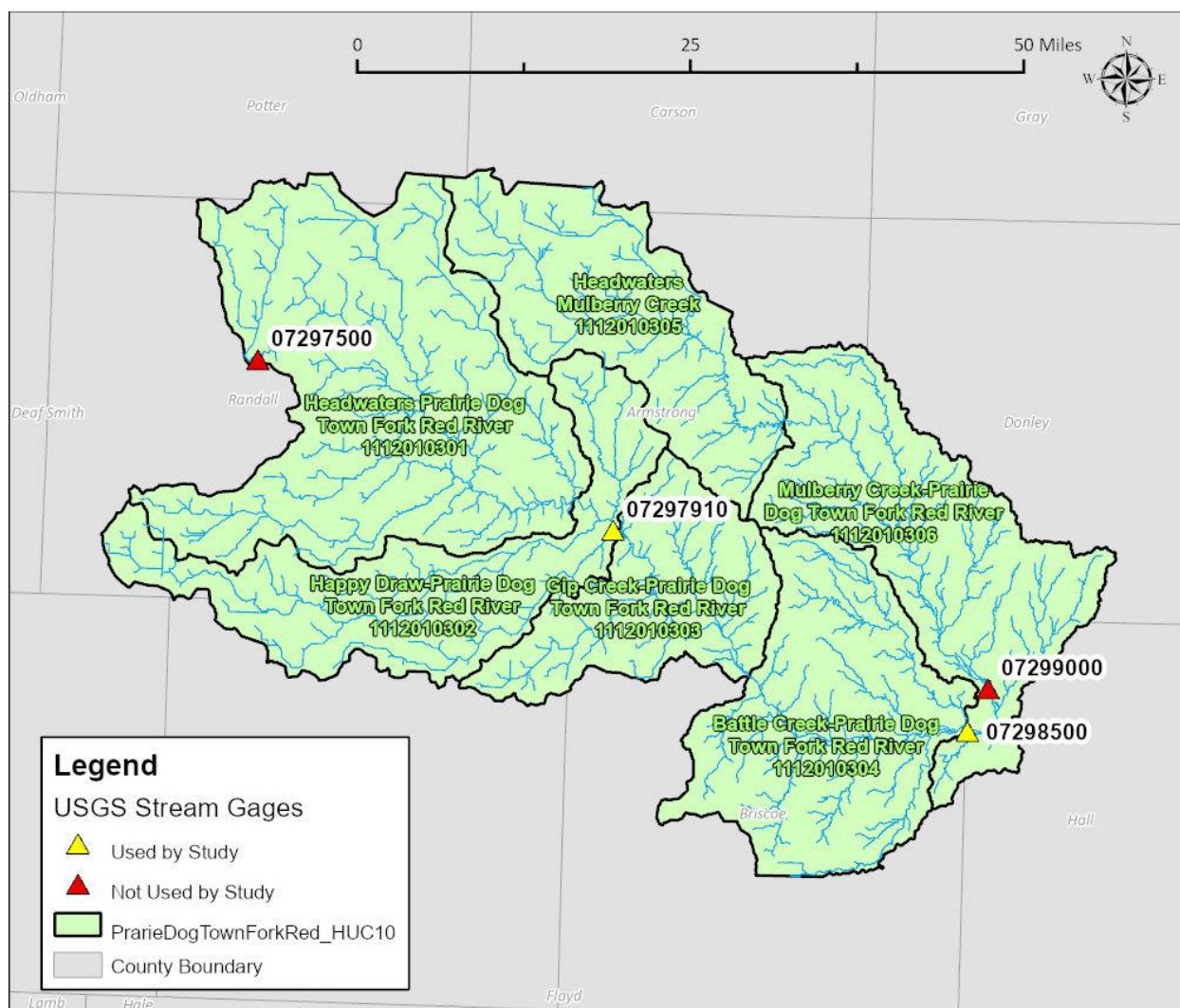


Figure 9: USGS Gages within UPDT HUC8

Table 15: USGS Gage Statistical Peak Streamflows

Location	1% AEP Peak Flow (cfs)
07297910 – Pr Dog Twn Fk Red Rv nr Wayside, TX	41,605
07298500 – Pr Dog Twn Fk Red Rv nr Brice, TX	75,683

2.3.2 Sensitivity Analysis

To evaluate which model parameters significantly impact results, multiple sensitivity analyses were run with varied parameters. **Table 16** presents the parameters varied for each sensitivity run. All sensitivity analyses were computed for the 1% frequency event. These runs were used to inform the final frequency event model configuration. No individual sensitivity run was used for the final model.

Table 16: Sensitivity Analysis Parameters

Sensitivity Run	Category	Infiltration Layer	Manning's Roughness	Equation Set	Computational Timestep	Initial Conditions
Base Model	-	CN	Base	Diffusion Wave	Varied	Dry
Full Momentum	Numerical Sensitivity	CN	Base	Full Momentum	Varied	Dry
Reduced Timestep (1/3 Base)	Timestep Sensitivity	CN	Base	Diffusion Wave	Varied	Dry
CN1.5	Physical Parameter Sensitivity	CN1.5	Base	Diffusion Wave	Varied	Dry
CNIII	Physical Parameter Sensitivity	CNIII	Base	Diffusion Wave	Varied	Dry
Manning's n - 50%	Physical Parameter Sensitivity	CN	N*50%	Diffusion Wave	Varied	Dry
Manning's n + 50%	Physical Parameter Sensitivity	CN	N*150%	Diffusion Wave	Varied	Dry

The results of the sensitivity analyses at selected USGS gage locations are summarized within the watershed in **Table 17** through **Table 19**.

Table 17: Sensitivity Analysis Results – Peak Flow Results (cfs)

Location	Base Model	Full Momentum	Reduced Timestep (1/3 Base)	CN1.5	CNIII	Manning's n – 50%	Manning's n + 50%
07297910 – Happy Draw	54,906	55,457	54,652	45,113	103,450	73,921	52,169
07298500 – Mulb Ck	120,512	111,347	111,610	70,228	179,026	123,658	109,272

Table 18: Sensitivity Analysis Results – Time of Peak (hr)

Location	Base Model	Full Momentum	Reduced Timestep (1/3 Base)	CN1.5	CNIII	Manning's n – 50%	Manning's n + 50%
07297910 – Happy Draw	19.00	19.00	19.00	31.00	17.00	17.00	31.00
07298500 – Mulb Ck	18.00	19.00	19.00	21.00	18.00	18.00	19.00

Table 19: Sensitivity Analysis Results - Peak Water Surface Elevation (ft)

Location	Base Model	Full Momentum	Reduced Timestep (1/3 Base)	CN1.5	CNIII	Manning's n – 50%	Manning's n + 50%
07297910 – Happy Draw	2481.6	2481.9	2481.6	2481.0	2481.1	2480.7	2482.1
07298500 – Mulb Ck	2067.1	2067.3	2067.1	2065.6	2069.0	2066.1	2067.8

The sensitivity analysis revealed the base model assumptions for equations selection and time step did not significantly impact model results and therefore no changes were made to the selected computational settings. The sensitivity analysis demonstrated the potential impacts to the flooding results based on curve number and manning's n values. These parameters were considered in the model refinement when validating to available data.

2.3.3 Frequency Event Results

The results of the analysis at selected USGS gage locations are summarized in **Table 20** for each simulated frequency event and are compared against the USGS gage values for the 1% event in **Table 21**. There is significant variability between the observed data and the computed curve for the Wayside gage in Happy Draw. For this reason, gage comparison the Brice gage in Mulberry Creek was prioritized for model validation. A comparison of drainage area of each model to peak flows for storm event is shown in **Figure 10**. This figure also contains the 1% AEP statistical flow with 90% confidence bounds for the USGS gages used in this study. This figure does not include any other comparison points as:

- There are no FEMA effective detailed studies in this watershed
- Regression equations do not provide meaningful drainage area to flow relationships for the caprock topography

Table 20: Frequency Event Peak Discharge Summary at Selected USGS Gages (cfs)

Location	10%	4%	2%	1%-	1%	1%+	0.2%
07297910 – Happy Draw	15,181	24,374	34,309	27,259	43,818	61,803	76,460
07298500 – Mulb Ck	17,481	32,082	45,322	35,066	67,465	110,248	143,215

Table 21: Difference in 1% Event Discharges at Selected USGS Gages

Location	Statistical Peak Flow (cfs)	Model Peak Flow (cfs)	Percent Difference (%)
07297910 – Happy Draw	41,605	43,818	5
07298500 – Mulb Ck	75,683	67,465	11

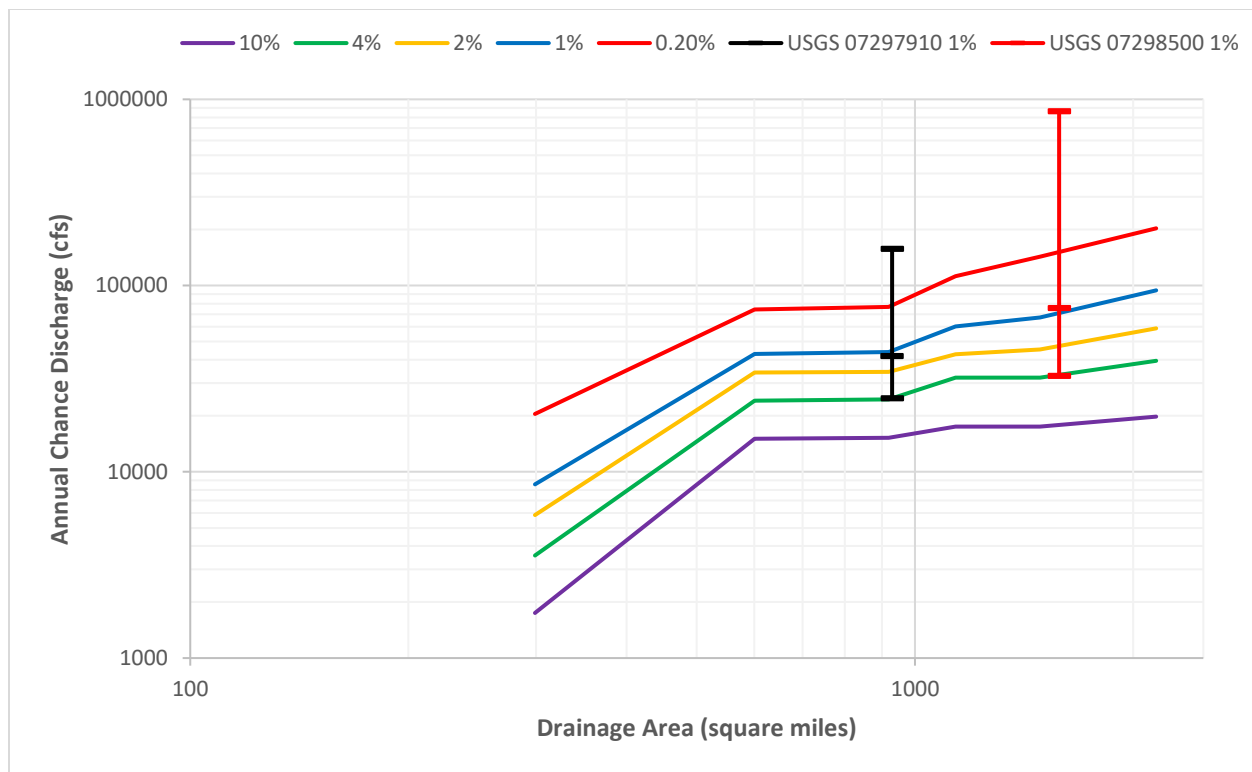


Figure 10: Drainage Area vs. Peak Flow

2.3.4 Challenges

The lack of stream gages present challenges for the 2D BLE analysis. The scarcity of recent stream gage records within the Upper Prairie Dog Town Fork Red and surrounding watersheds reduces comparison points for the analysis and limits the ability to simulate historical events which could verify the 2D BLE results and approach. Without many statistically significant gages in the upstream HUC 8s, there is very little way to validate the inflows into the UPDT watershed. This is further complicated by the presence of reservoirs in the Tule and Tierra Blanca HUC 8s that could significantly impact the Upper Prairie Dog Town Fork Red flows. There were no HEC-RAS bugs or issues associated with these models.

2.3.5 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.

3.0 Quality Control

In addition to internal QA/QC conducted by the FNI Team, an independent QA/QC was performed by a TWDB designated team that is independent of the production team. The production team coordinated the reviews and respond/resolve the review comments. Documentation of both internal QA/QC and the independent QA/QC can be found in the Task Documentation folder.

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

To develop the floodplain polygons and depth rasters, the model results were exported from HEC-RAS version 6.3.0 using the sloping render method. Depth grid and water surface elevation rasters were exported for the 10%, 1%, and 0.2% annual chance events. All tie-ins were within 0.5 ft at the main channel connections between models. Zone A floodplains produced in this study are compared to FEMA effective Zone A and Zone AE floodplains in **Figure 11**, **Figure 12**, and **Figure 13**. FEMA effective Zone AE floodplains are represented in the DTL_STUD_AR and DTL_STUD_LN features in the provided flood risk database. The Zone A floodplains produced in this study have a greater extent than the effective floodplains in both the playa region and along Headwaters Prairie Dog Town Fork Red River due to differences in the TWDB BLE approved mapping process.

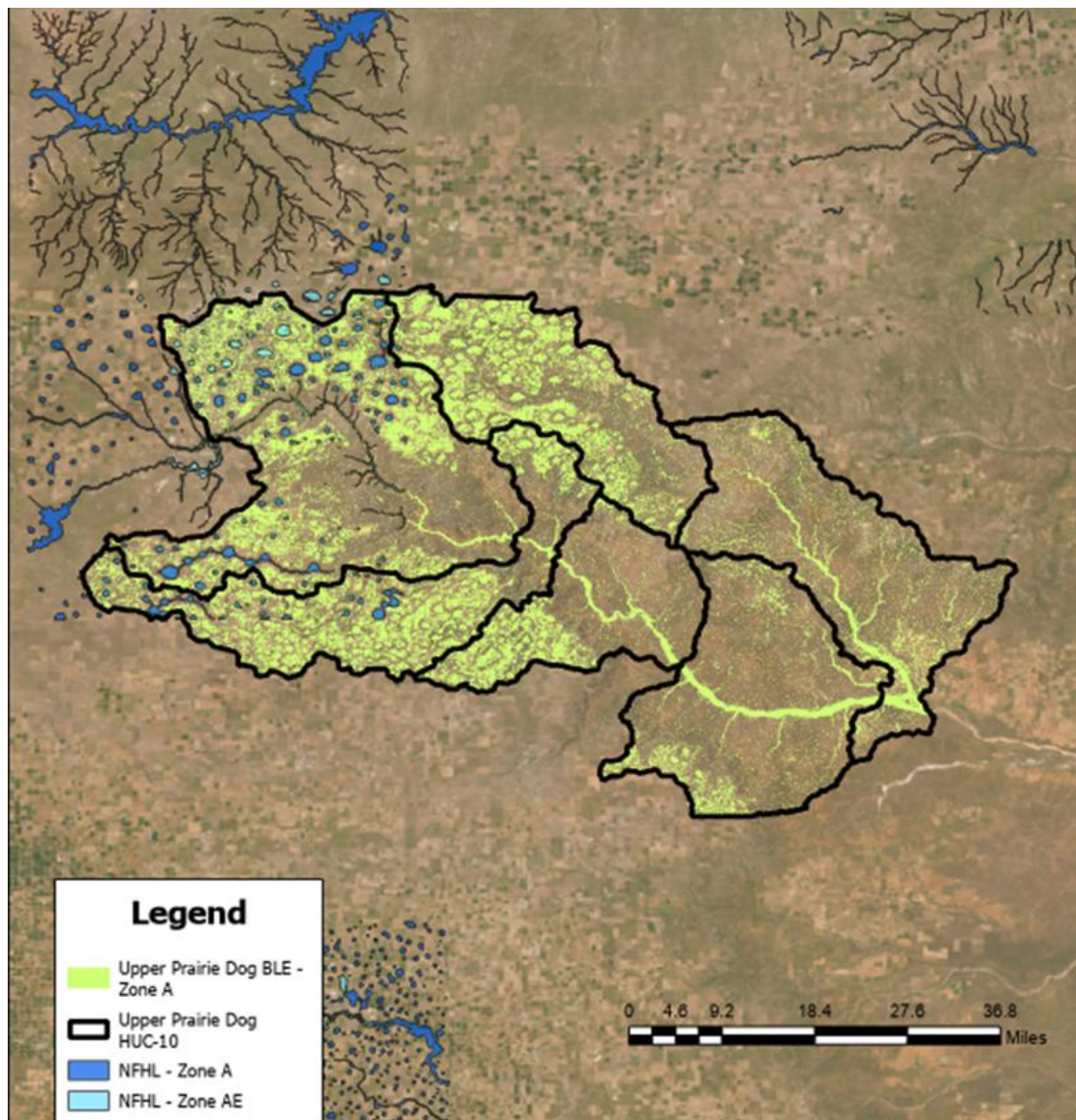


Figure 11: Effective Mapping Comparison 1

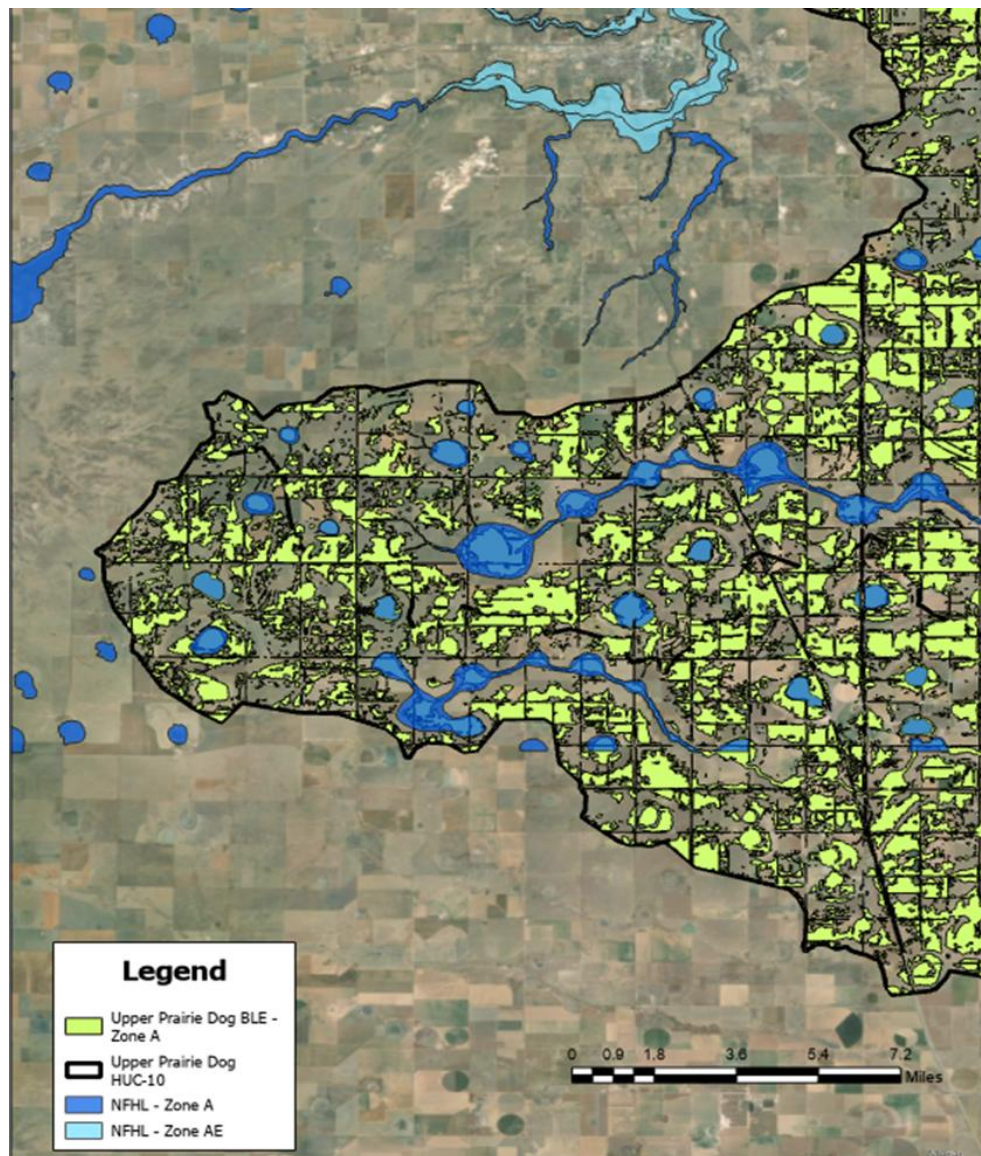


Figure 12: Effective Mapping Comparison 2

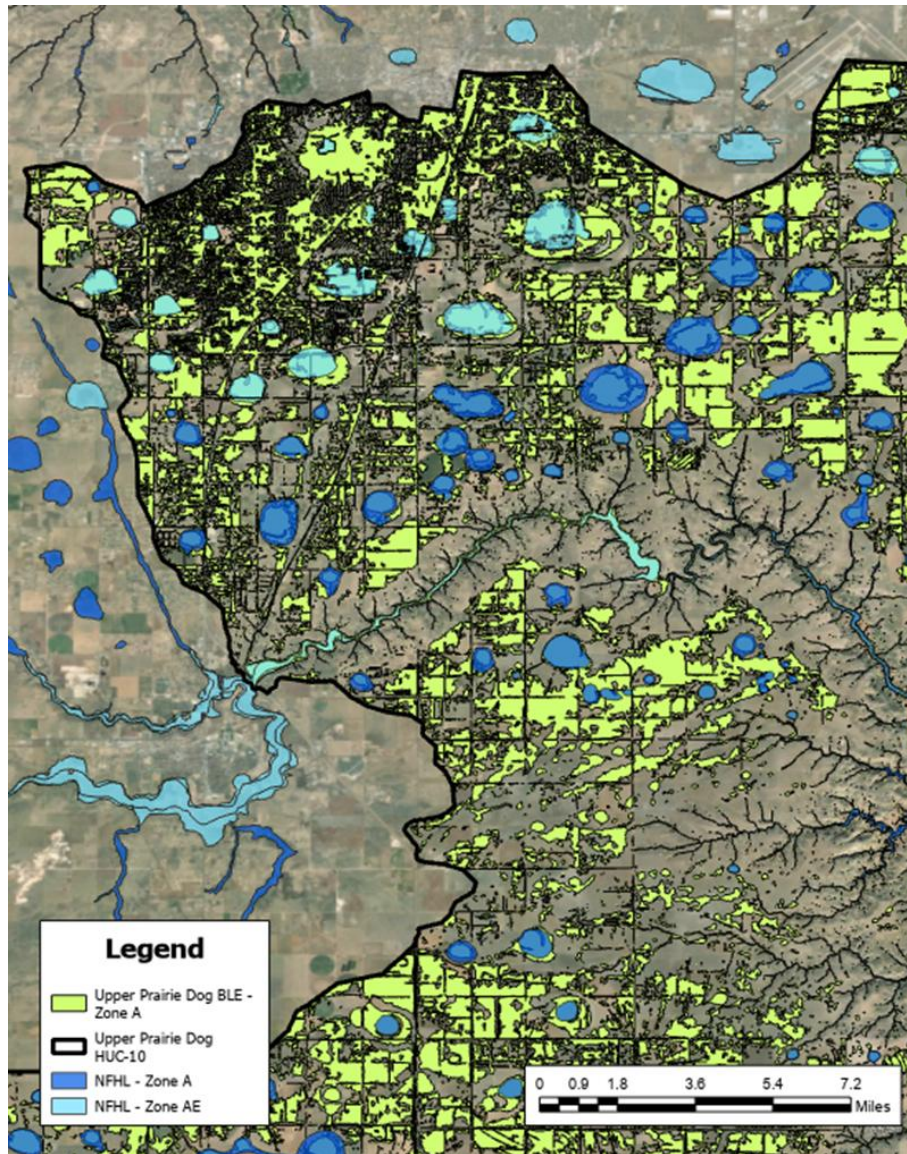


Figure 13: Effective Mapping Comparison 3

The output was combined to form a continuous WSE and depth raster for the entire HUC-8. To produce a clean mapping product, floodplains less than 0.33 ac and an average depth less than 0.33' were removed from the raw modeling results for all AEPs. The filtered raster was then converted into a polygon shapefile and holes in the floodplain were filled. Holes up to 0.5 ac were filled in the 10% event, while holes up to 2 ac were filled in the 1% and 0.2% events. The floodplain polygons were simplified (5' tolerance), smoothed (25' tolerance), and simplified once more (0.3' tolerance) for the 1% and 0.2% AEP events. Additionally, relevant water bodies and a 5-foot channel buffer were merged into all floodplains and high-frequency storm floodplain extents were merged into lower frequency events (i.e. the 10% AEP floodplains were merged into the 1% and 0.2% floodplains). These additions help to ensure that all stream centerlines are contained and areas of significant conveyance or storage are shown in the flood risk products even if their flow depths remain shallow. A flood risk database was created according to

the Texas Two-Dimensional Base Level Engineering Guidelines and populated with the following mapping products:

Feature Dataset:

- Base Dataset (Boundaries & Political Areas)
- CNMS Dataset
- EBFE Dataset (Floodplains, BFEs, Water Features, FEMA Data)
- Mit_Haz Dataset
- Rasters:
 - Base Flood Elevation 500-year Depth Grid
 - Base Flood Elevation 100-year Depth Grid
 - Base Flood Elevation 500-year Water Surface Elevation Grid
 - Base Flood Elevation 100-year Water Surface Elevation Grid
- Tables:
 - Source Citation Table

4.1 Challenges

The widespread, shallow floodplains in the playa dominated areas (caprock) were a challenge to filter and clean. In this HUC, TWDB and the TWDB's BLE program manager directed that all model output should be retained if it is both:

1. Part of a contiguous area 0.33 acres or larger
2. Part of a contiguous area with an average depth greater than 0.33 feet

Given that the mapping results are produced by a rain-on-mesh combined hydrologic and hydraulic model, nearly all shallow flooding is contiguous. This process has produced floodplain polygons that include large areas of very shallow flooding on the caprock.

Moreover, the watershed is only partially covered by FEMA-studied areas. This meant that only some of the modeled floodplains could be directly compared to effective FEMA products.

There are three render modes available within RAS Mapper for visualizing floodplains: Horizontal, Sloping, and Hybrid. Currently, only the results from the Horizontal and Sloping render modes can be exported and both have their own limitations. The Horizontal mode generates isolated ponding per cell, resembling "bathtubs," while the Sloping mode produces a phenomenon known as "cupping." Cupping involves a rise in depth in the overbanks, particularly in areas with significant topographic relief such as the riverine portions of this watershed. The US Army Corps of Engineers (USACE) acknowledges this issue, attributing it to an error where the water surface elevation projects to the average elevation of adjacent cells. However, the timeframe for resolving this error remains uncertain. Since the Sloping render mode is used for mapping, cupping is observable in the final mapping products, exemplified by the pink areas in **Figure 14**. The areas of cupping will not be removed or cleaned beyond the extents of the mapping cleanup process discussed in this report. Therefore, cupping is persistent throughout BLE mapping and can be observed in the WSE grids and base flood elevation (BFE) lines.

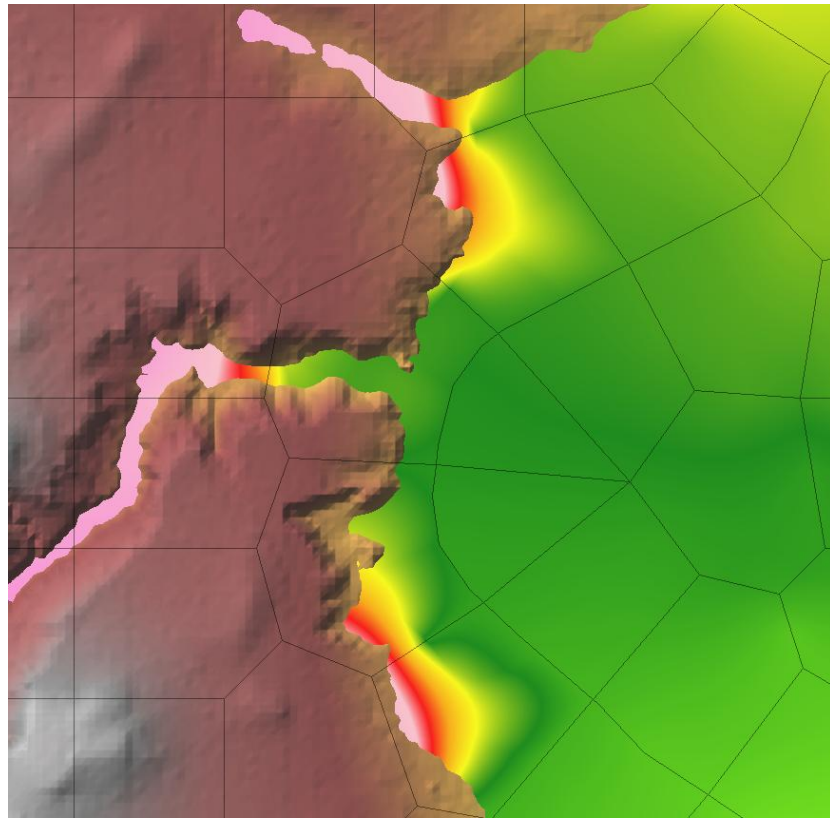


Figure 14: Example of Cupping in BLE Mapping

4.2 Results and Recommendations

The BLE results for the watershed provide an additional estimated SFHA in areas that do not currently have an SFHA mapped. These results provide context for flood risk communication as part of the Discovery process and should be verified through community work map meetings before being applied to a regulatory product. Maps showing the BLE results are included as Appendix A.

As a part of the Base Level Engineering assessment effort, a feature was prepared to detail areas where model refinements may be warranted. The file AOMI_AR feature includes identification of the issue and some recommendations for model refinement.

Additional flood risk products may be developed from the BLE models to help community officials communicate flood risk and manage emergency flooding. An additional flood risk product that would be beneficial to emergency managers in the region would be duration of inundation. The common design practice for the region is to convey runoff through road right of ways so understanding the duration of roadway inundation could help communities prepare for potential flood risk.

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

All the Zone A studies (486.77) in the Upper Prairie Dog Town Fork Red Watershed were classified in CNMS with a validation status of “UNVERIFIED” and status type of “TO BE STUDIED.” For this watershed, any areas where Zone A areas existed were manually checked for missing water lines. In any Zone A areas with CMNS gaps, features were added into S_Studies_Ln, which primarily consisted of playas. The following is a summary of the results of the CNMS validation assessment for the effective Zone A studies in the study area. Initial Assessment checks A1-A5 were evaluated for the CNMS inventory of Zone A studies.

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 Upper Prairie Dog Town Fork Red Watershed study area, the effective Zone A topographic data leveraged a variety of sources, but primarily based upon USGS 7.5 Minute Topo Series 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.

Assessment Check	Pass/Fail	Comments/Notes
A1 - Topography	Fail	LiDAR significantly better than effective USGS topo source/Effective mapping leveraged LiDAR data.
A2 - Hydrology	Pass	Hydrology was completed before 2009 for all studies within the watershed.
A3 - Development	Pass	The only areas with significant landuse change occur outside of Zone A 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 Upper Prairie Dog Town Fork Red 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. The Upper Prairie Dog Town Fork Red 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

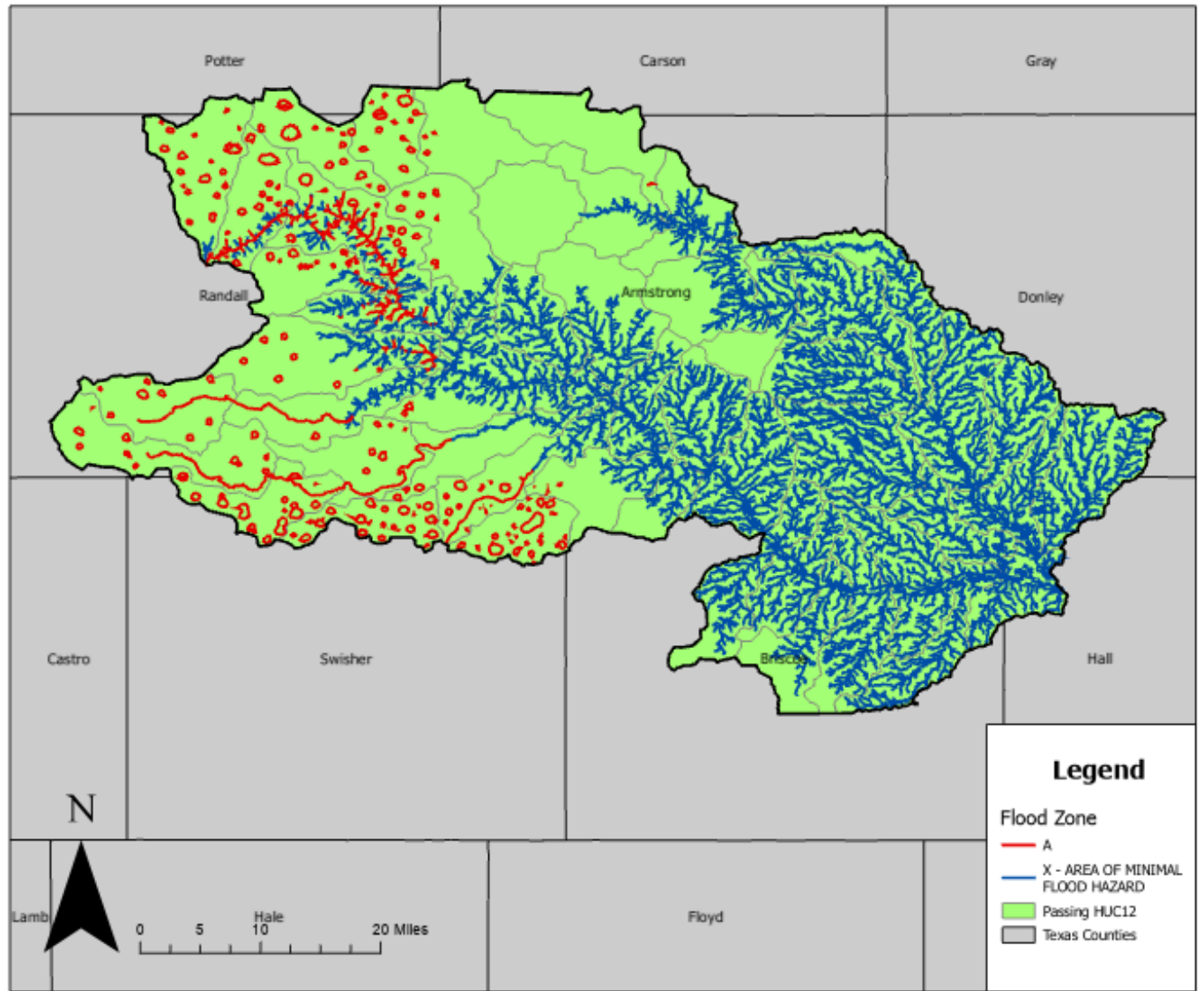
Based on the validation assessments and BLE comparison results described above, the CNMS inventory of Zone A studies in the Upper Prairie Dog Town Fork Red Watershed study area has been updated, total miles in each of these categories are summarized in **Table 15** and illustrated in **Figure 12** below.

Table 22: Zone A Validation Results

Flood Zone	Validation Status	Status Type	Total Miles
A	UNVERIFIED	BEING STUDIED	486.77
AE	UNVERIFIED	TO BE STUDIED	0
AE	VALID	NVUE COMPLIANT	0
X	ASSESSED	BEING STUDIED	3249.39

Table 23: BLE Comparison Results

HUC-12 Watershed		Total FBS Points	Pass	Fail	% Pass	BLE Comparison Pass?
Watershed Name	HUC12 ID					
111201030109	111201030109	177	177	0	100%	PASS
111201030203-Happy Draw	111201030203	375	375	0	100%	PASS
111201030206	111201030206	465	465	0	100%	PASS
Claude Cemetery-City of Claude	111201030504	14	14	0	100%	PASS
Deer Creek-Prairie Dog Town Fork Red River	111201030303	49	49	0	100%	PASS
Happy Canyon-Prairie Dog Town Fork Red River	111201030204	110	110	0	100%	PASS
Jackson Hill	111201030302	589	589	0	100%	PASS
North Cita Creek	111201030110	266	265	1	99.62%	PASS
Palo Duro Club Lake-Prairie Dog Town Fork Red River	111201030102	608	608	0	100%	PASS
Paramount Terrace School-City of Amarillo	111201030101	673	673	0	100%	PASS
Pleasant Creek-Prairie Dog Town Fork Red River	111201030207	492	492	0	100%	PASS
Pony Spring Creek-Prairie Dog Town Fork Red River	111201030112	34	34	0	100%	PASS
Rush Creek	111201030108	150	150	0	100%	PASS
Singleton Lake-Happy Draw	111201030202	586	585	1	99.83%	PASS
South Cita Creek-Cita Creek	111201030111	244	244	0	100%	PASS
Sunday Creek-Prairie Dog Town Fork Red River	111201030105	311	311	0	100%	PASS
Timber Creek	111201030104	183	183	0	100%	PASS
Town of Happy-Happy Draw	111201030201	524	524	0	100%	PASS
Town of Pullman	111201030107	408	408	0	100%	PASS
Town of Washburn-Mulberry Creek	111201030501	39	39	0	100%	PASS
Tradewind Airport-City of Amarillo	111201030106	415	415	0	100%	PASS
West Fork Prairie Dog Town Fork Red River-Prairie Dog Town Fork Red River	111201030103	783	783	0	100%	PASS



6.0 Hazus Loss Estimation

Three Hazus regions were created to estimate losses within the Upper Prairie Dog Town Fork Red watershed. Since census tract boundaries do not line up perfectly with watershed boundaries, engineering judgement was used to assign the census tracts to each region and steps were taken to ensure that losses in each census tract, and therefore census block, were calculated exactly once per event. Separate, but identical Hazus regions were created for the 100 year and 500 year events to reduce Hazus processing errors caused by large amounts of data.

For each HUC8 in the FNI region, the mosaiced, unfiltered HEC-RAS results processed in mapping were re-processed to fit Hazus-MH depth grid preferences. The geoTIFFs were resampled to 50 ft cell size resolution for stability, reprojected to the proper WGS 1984 UTM zone projection, and converted to the ESRI GRID file type. Finally, the rasters for each HUC8 were split up using the Extract by Mask tool in ArcPro with the Hazus region boundary used as the mask. This ensured that the hazard was fully accounted for in census tracts located on the boundaries of the HEC-RAS models. **Table 24** outlines the Hazus regions and their corresponding census tracts.

Table 24: Hazus Regions and Census Tracts

Hazus Region	Census Tracts	Hazus Region	Census Tracts	Hazus Region	Census Tracts
UPD1	48375010100	UPD1	48375014900	UPD1	48381021610
	48375010200		48375015400		48381021611
	48375010300		48375980000		48381021702
	48375010400		48381020100		48381021705
	48375010600		48381020200		48381021706
	48375010700		48381020300		48381021707
	48375011000		48381020400		48381021708
	48375011500		48381020500		48381021802
	48375011600		48381020600		48381021802
	48375011700		48381020800		48381021803
	48375011800		48381020900		48381021803
	48375011900		48381021000		48381021804
	48375012000		48381021101		48381021804
	48375012200		48381021102		48381021900
	48375013200		48381021200		48381022001
	48375013200		48381021300		48381022002
	48375014300		48381021500	UPD 2	48011950100
	48375014300		48381021602		48065950200
	48375014401		48381021603		48129950200
	48375014500		48381021604		48129950300
	48375014701		48381021605	UPD 3	48045950200
	48375014702		48381021606		48191950500
	48375014800		48381021609		48437950200

Once the Hazus regions and hazard depth grids were created, the depth grids were uploaded to the Hazus model using the user input wizard and the Hazus flood scenarios were created. The flood analyses were run using the General Building Stock Damage and Loss analysis. Shapefiles for the building and contents inventory data were mapped using the Building Dollar Exposure mapping feature in Hazus and exported to be used in ArcPro. Similarly, shapefiles for the building and contents loss were mapped using the General Building Stock Direct Economic Loss for Full Replacement Value mapping feature in Hazus and were exported to be used in ArcPro. In Arc Pro, the shapefiles were combined to fit the S_Frac_AR format with Hazus calculated values reported in US dollars. **Table 25** and **Table 26** summarizes the Hazus results for the HUC-8.

Table 25: Hazus 1% Loss Estimation

County Name	Building Loss	Contents Loss	Total Loss
Armstrong	\$2,592,000.00	\$1,659,000.00	\$82,709,000.00
Briscoe	\$58,000.00	\$32,000.00	\$337,000.00
Carson	\$112,000.00	\$63,000.00	\$1,973,000.00
Donley	\$11,000.00	\$5,000.00	\$281,000.00
Hall	\$8,000.00	\$9,000.00	\$85,008.00
Potter	\$66,260,000.00	\$126,216,000.00	\$1,713,656,000.00
Randall	\$173,932,000.00	\$157,065,000.00	\$2,262,696,000.00
Swisher	\$530,000.00	\$367,000.00	\$37,532,000.00
Total	\$243,503,000.00	\$285,416,000.00	\$4,099,269,008.00

Table 26: Hazus 0.2% Loss Estimation

County Name	Building Loss	Contents Loss	Total Loss
Armstrong	\$4,808,000.00	\$3,359,000.00	\$110,305,000.00
Briscoe	\$98,000.00	\$53,000.00	\$493,000.00
Carson	\$180,000.00	\$101,000.00	\$2,649,000.00
Donley	\$56,000.00	\$30,000.00	\$486,000.00
Hall	\$51,000.00	\$78,000.00	\$351,000.00
Potter	\$93,749,000.00	\$184,785,000.00	\$2,030,270,000.00
Randall	\$239,333,000.00	\$219,909,000.00	\$2,732,441,000.00
Swisher	\$853,000.00	\$692,000.00	\$48,587,000.00
Total	\$339,128,000.00	\$409,007,000.00	\$4,925,582,000.00

References

Bibliography list of references used and referred to throughout document.

1. USGS. Multi-Resolution Land Characteristics Consortium. National Land Cover Database 2011. (<http://www.mrlc.gov/nlcd2011.php>).
2. Chow, Ven T. "Development of Uniform Flow and Its Formulas." Open Channel Hydraulics. Caldwell, NJ: Blackburn, 1959. 109-113. Print.
3. FEMA, "Guidance for Flood Risk Analysis and Mapping – First Order Approximation", November 2014. (http://www.fema.gov/media-library-data/1420849667914-c1656173985d814d0e62f80818505969/FOA_Guidance_Nov_2014.pdf).
4. FEMA Region 6, "Base Level Engineering Submittal Guidance", June 2017. (https://rmd.msc.fema.gov/Regions/VI/Ph0_Investment/1/Base%20Level%20Engineering/Submittal%20Guidance/20170615_BLE%20Submittal%20Guidance_R6.pdf).

Appendix A – Exhibits – Base Level Engineering Results

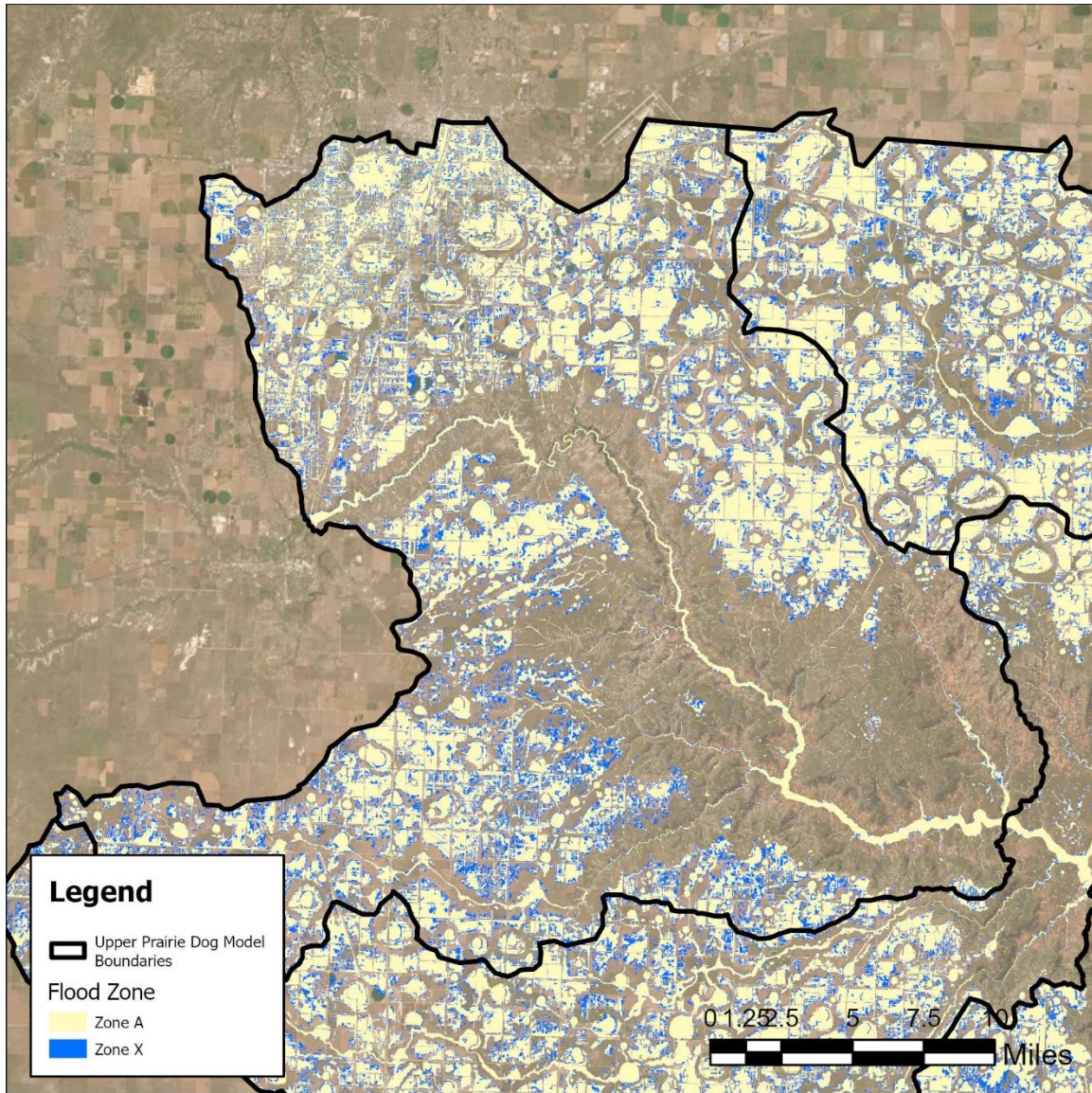


Figure A - 1: 1112010301 Flood Hazard Area

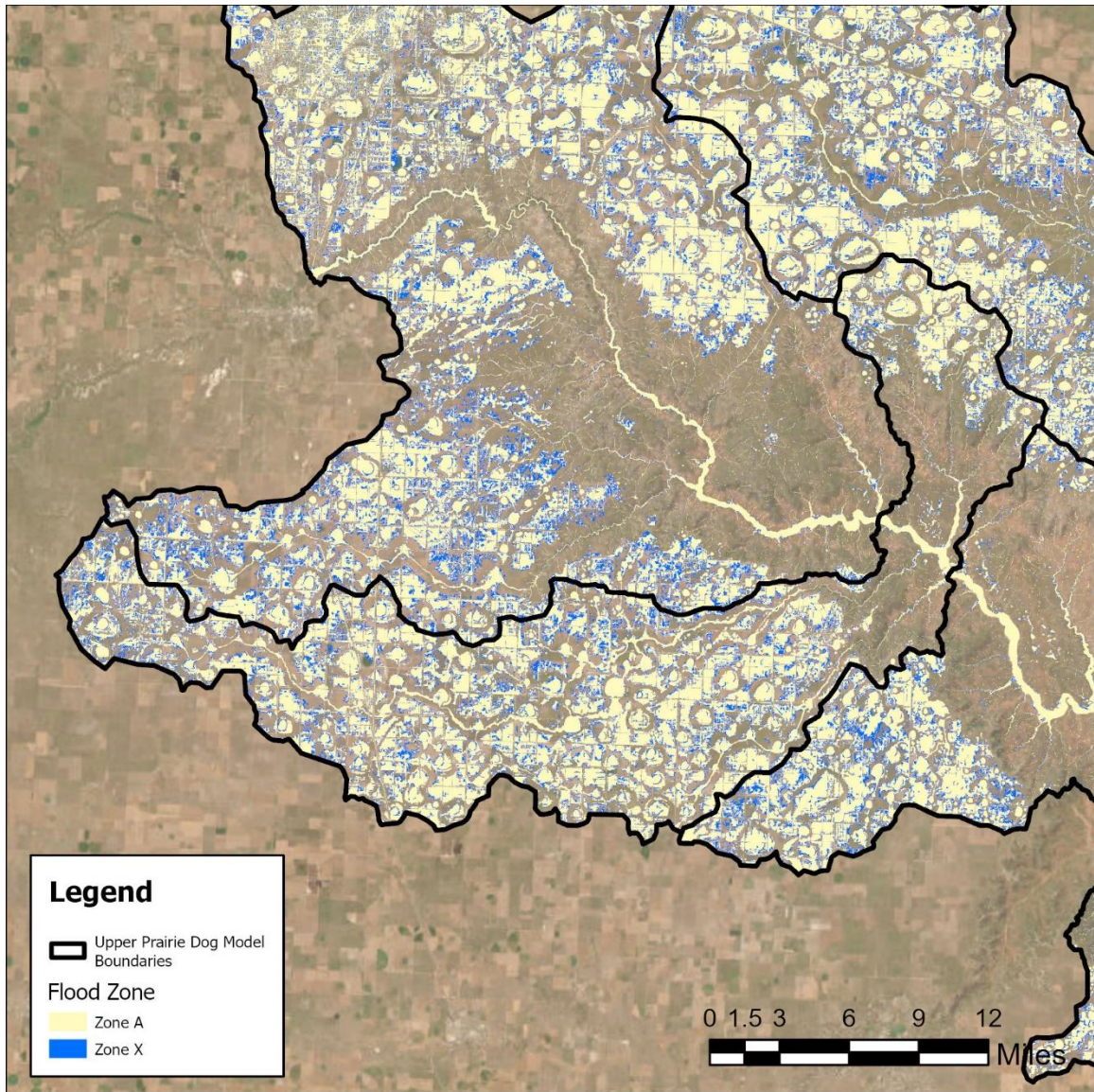


Figure A - 2: 1112010302 Flood Hazard Area

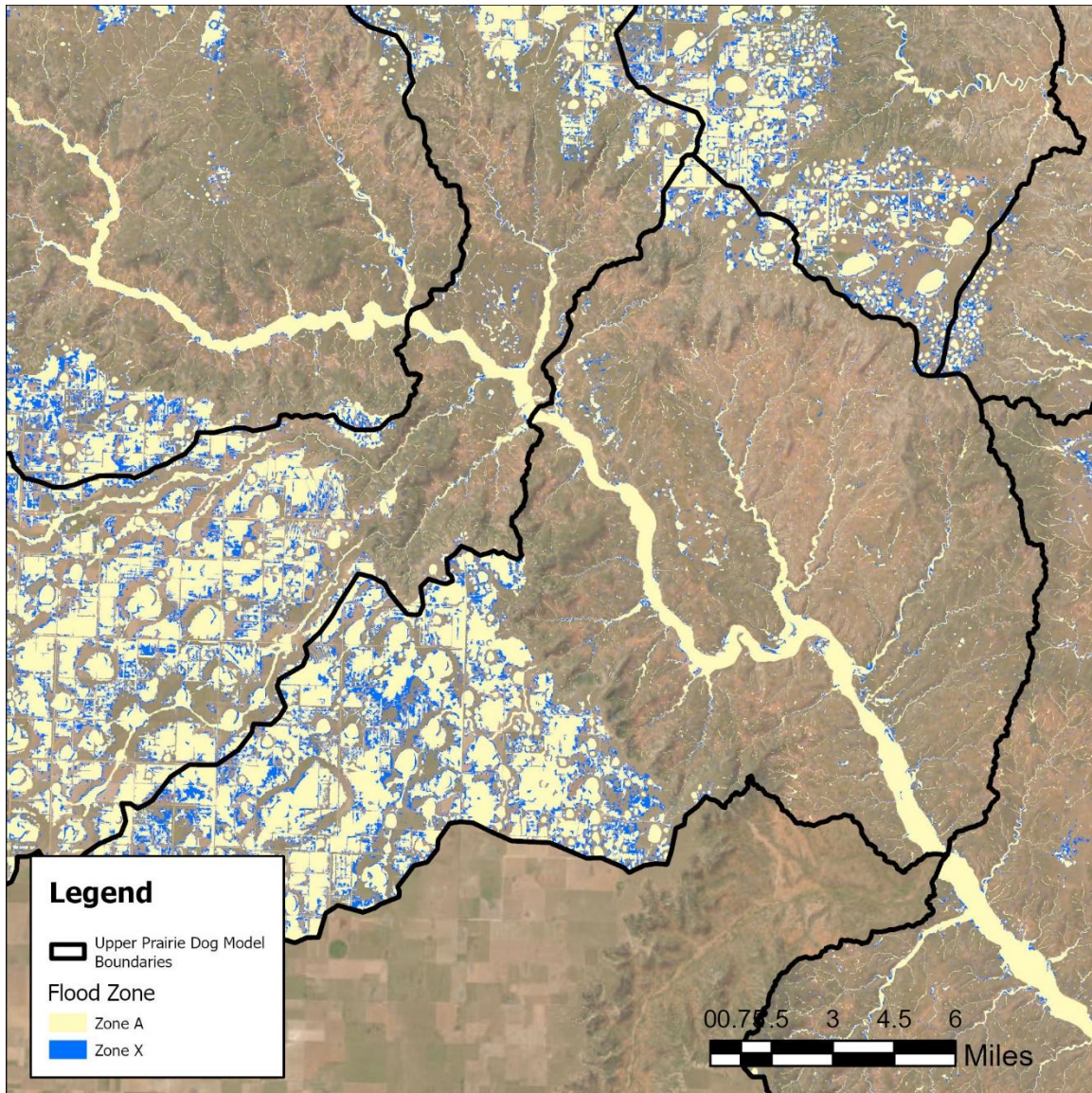


Figure A - 3: 1112010303 Flood Hazard Area

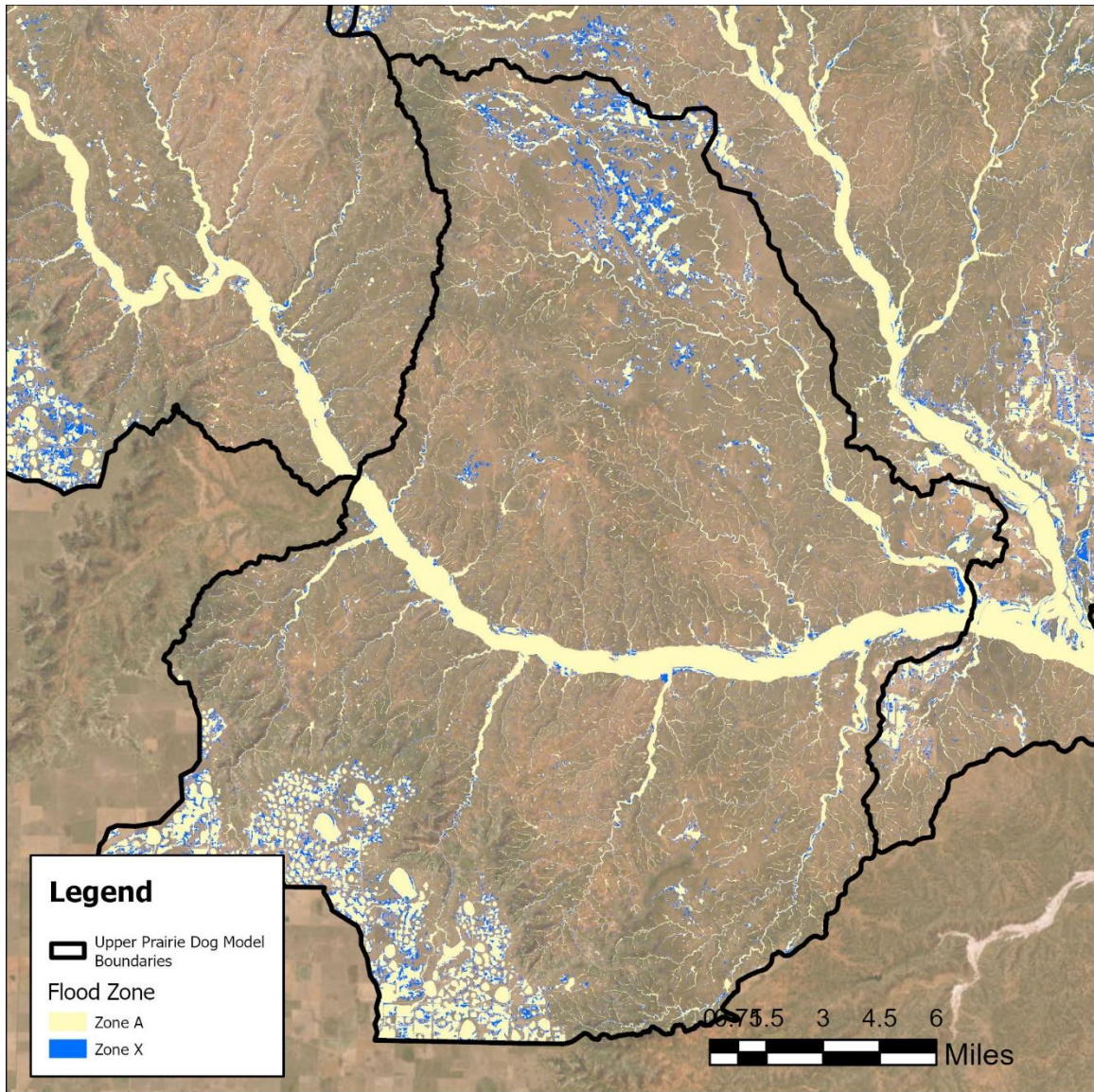


Figure A - 4: 1112010304 Flood Hazard Area

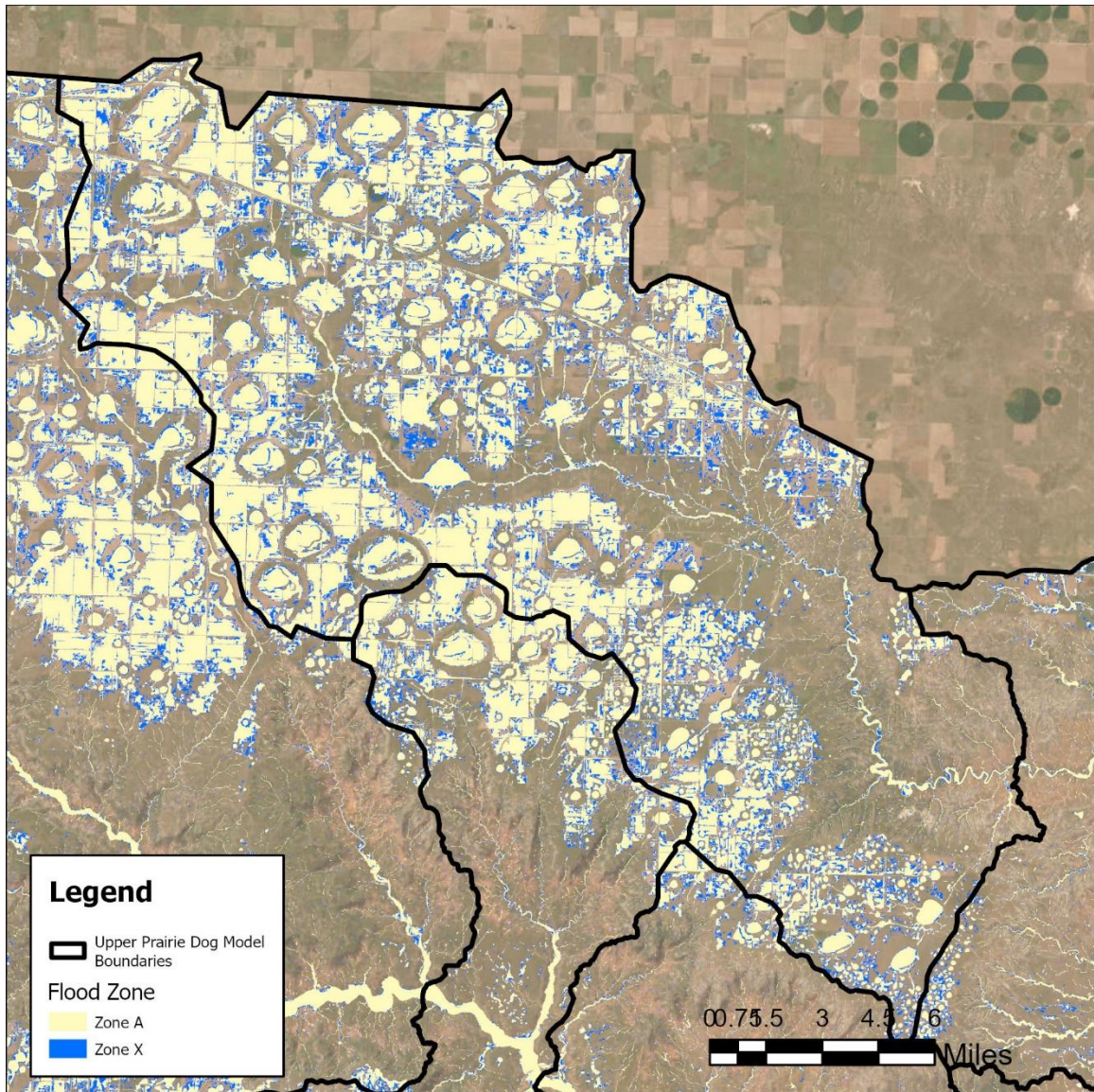


Figure A - 5: 1112010305 Flood Hazard Area

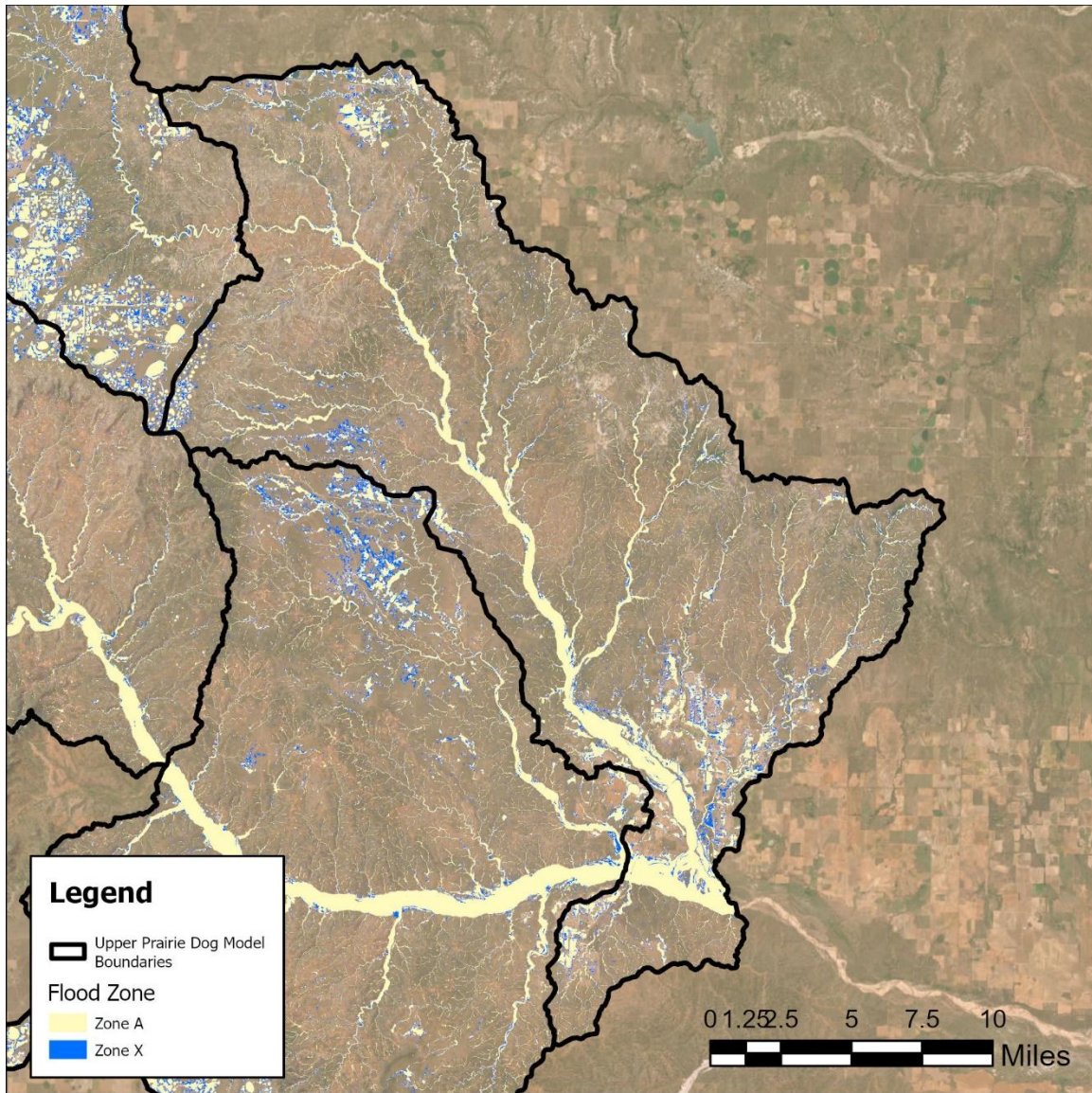


Figure A - 6: 1112010306 Flood Hazard Area

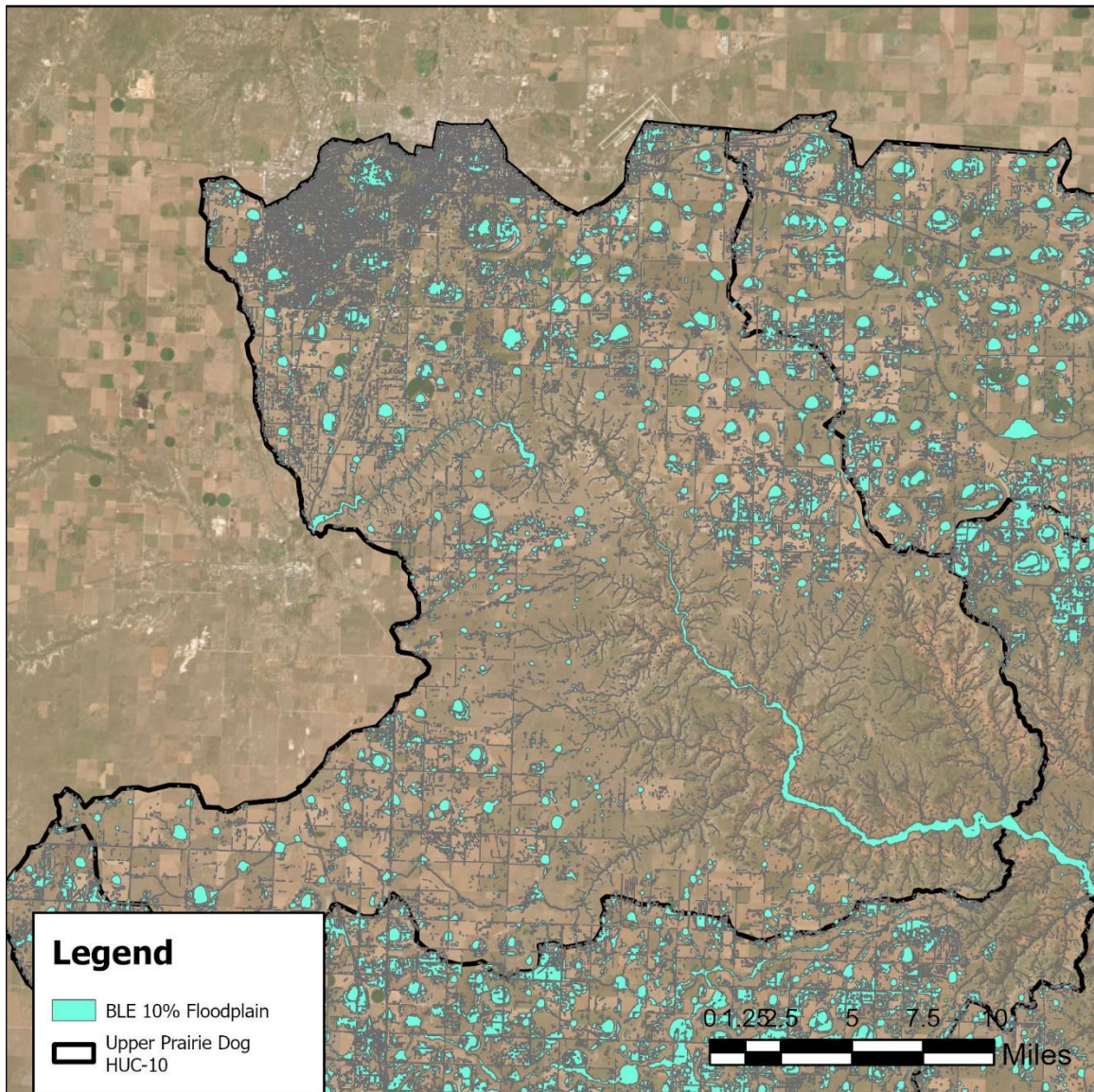


Figure A - 7: 1112010301 10% Floodplain

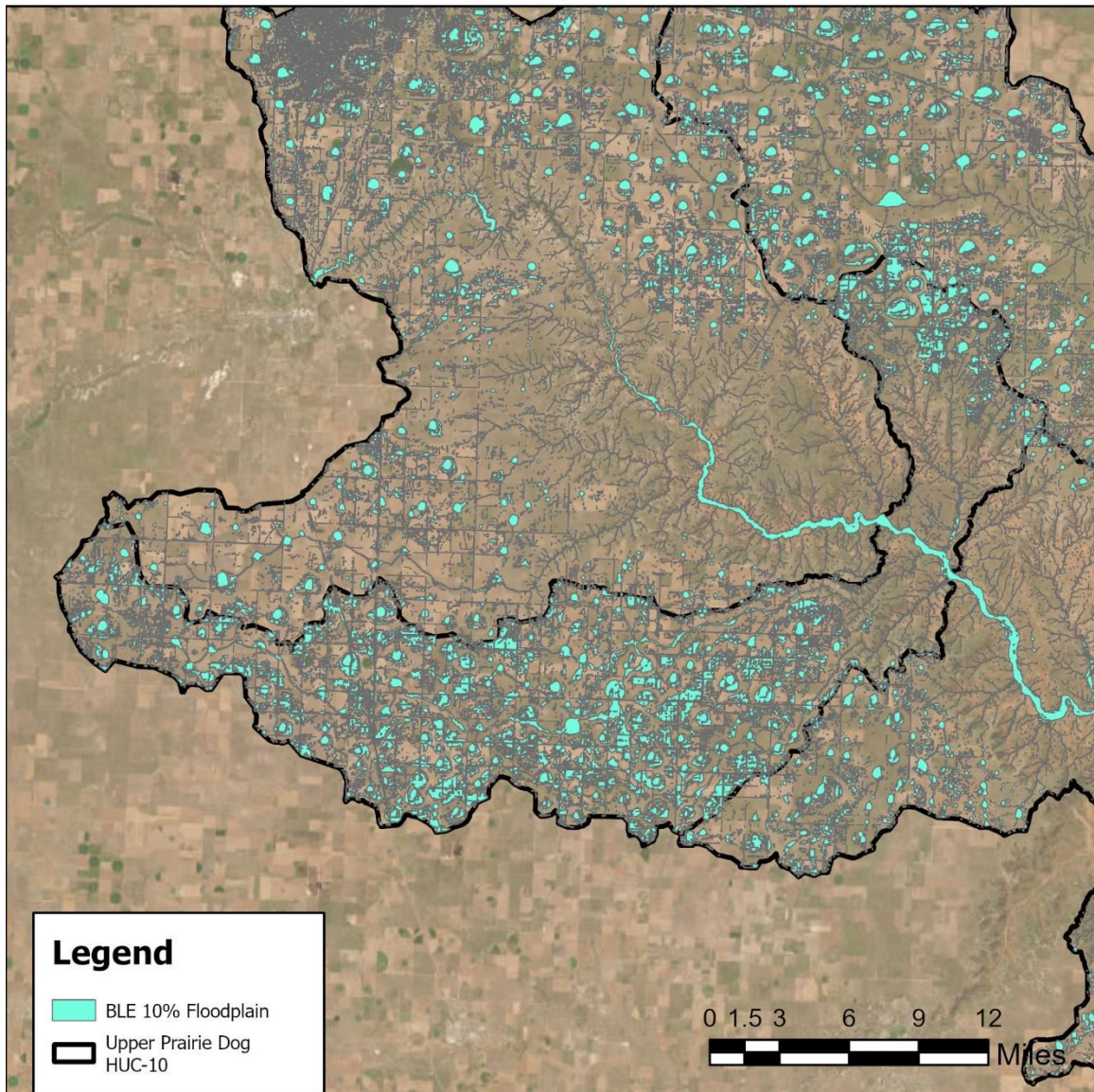


Figure A - 8: 1112010302 10% Floodplain

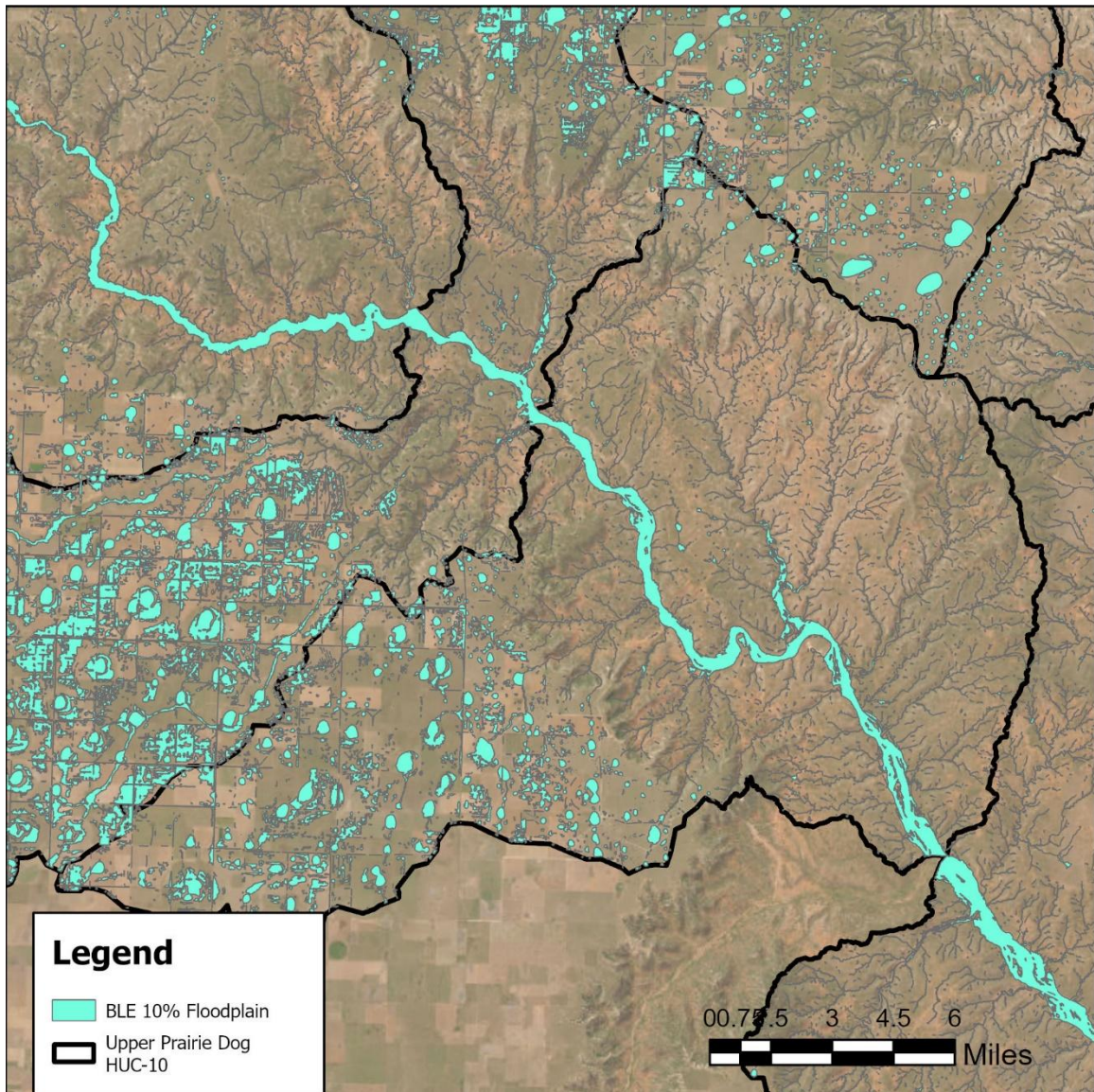


Figure A - 9: 1112010303 10% Floodplain

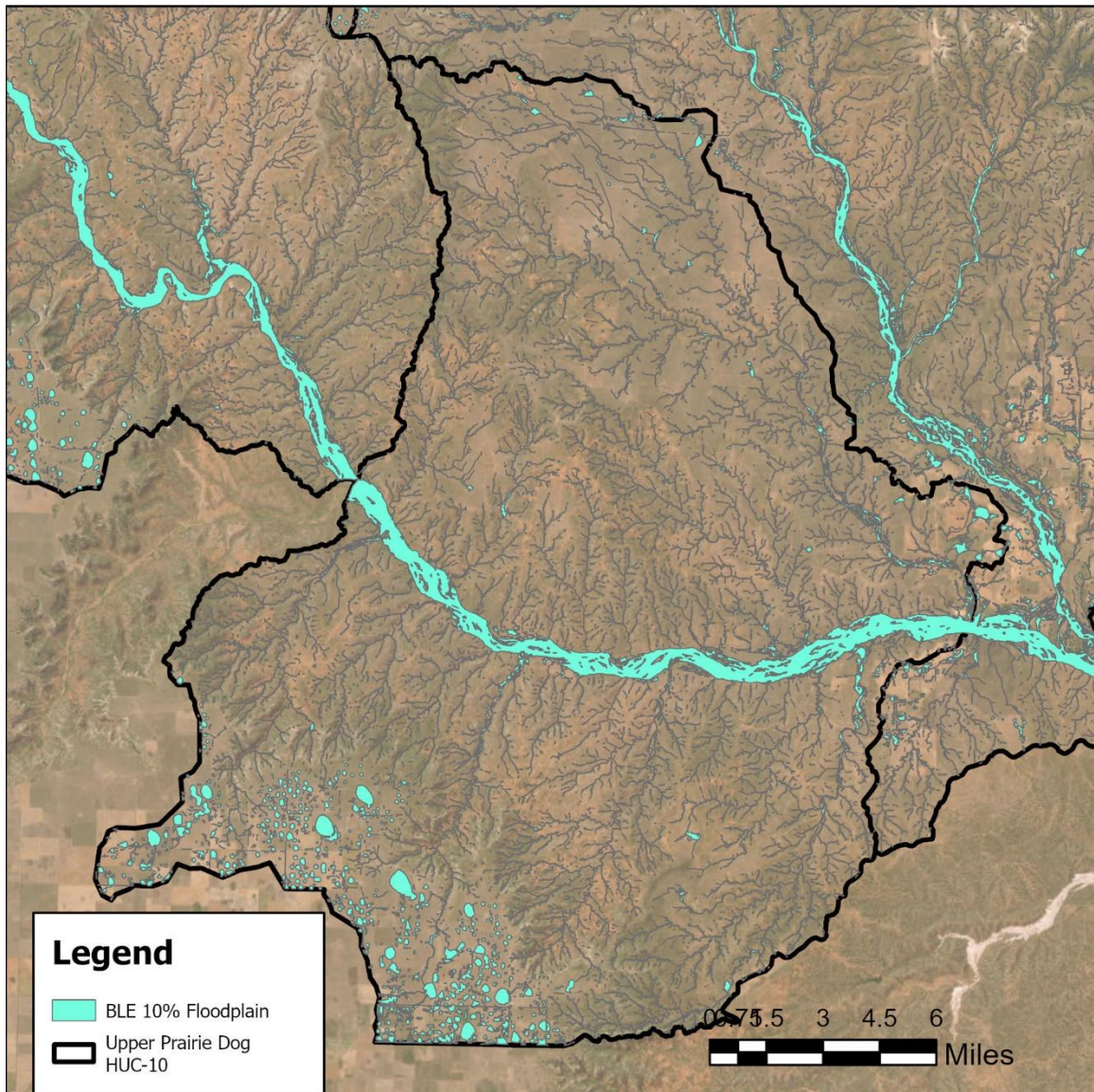


Figure A - 10: 1112010304 10% Floodplain

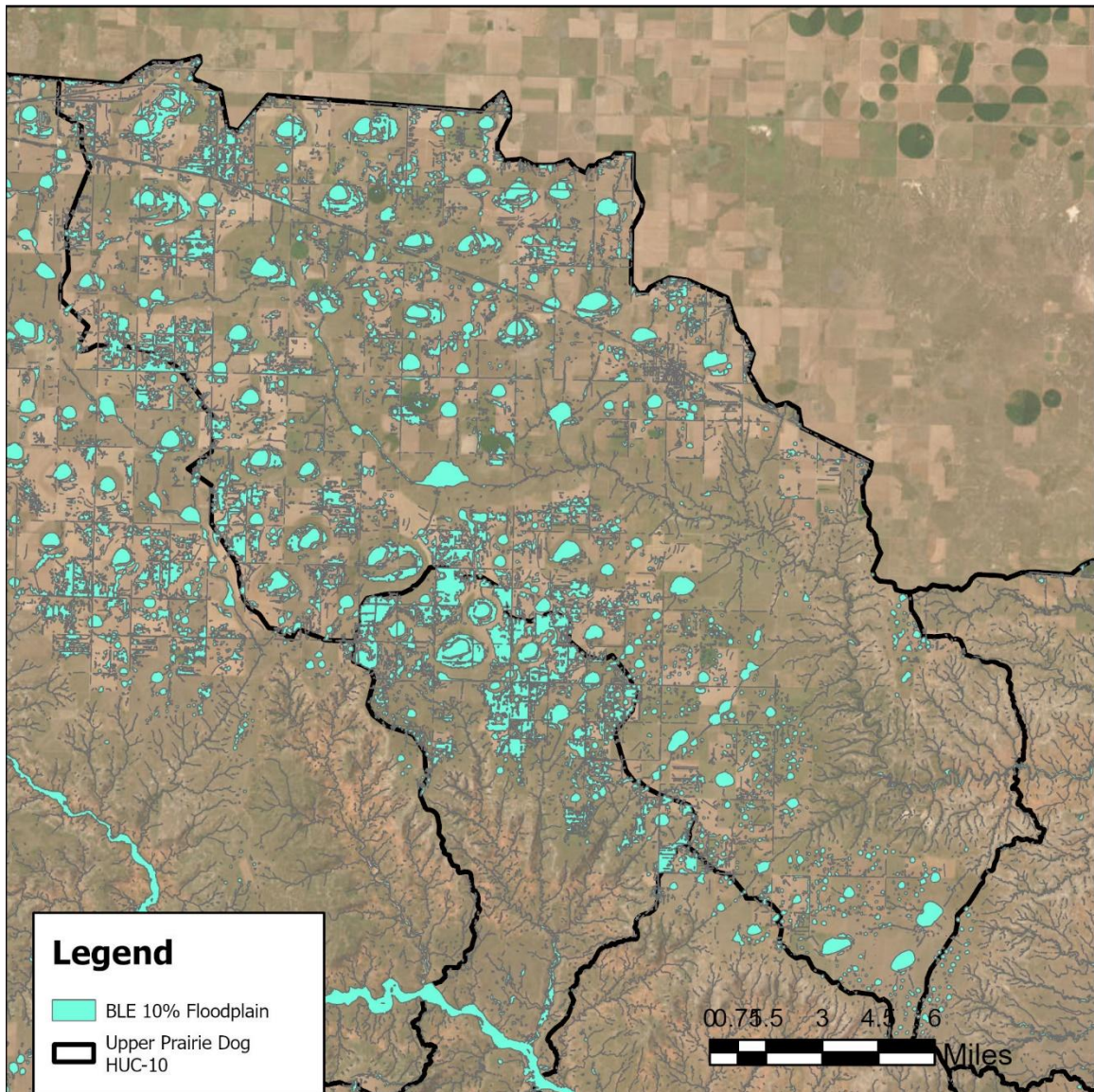


Figure A - 11: 1112010305 10% Floodplain

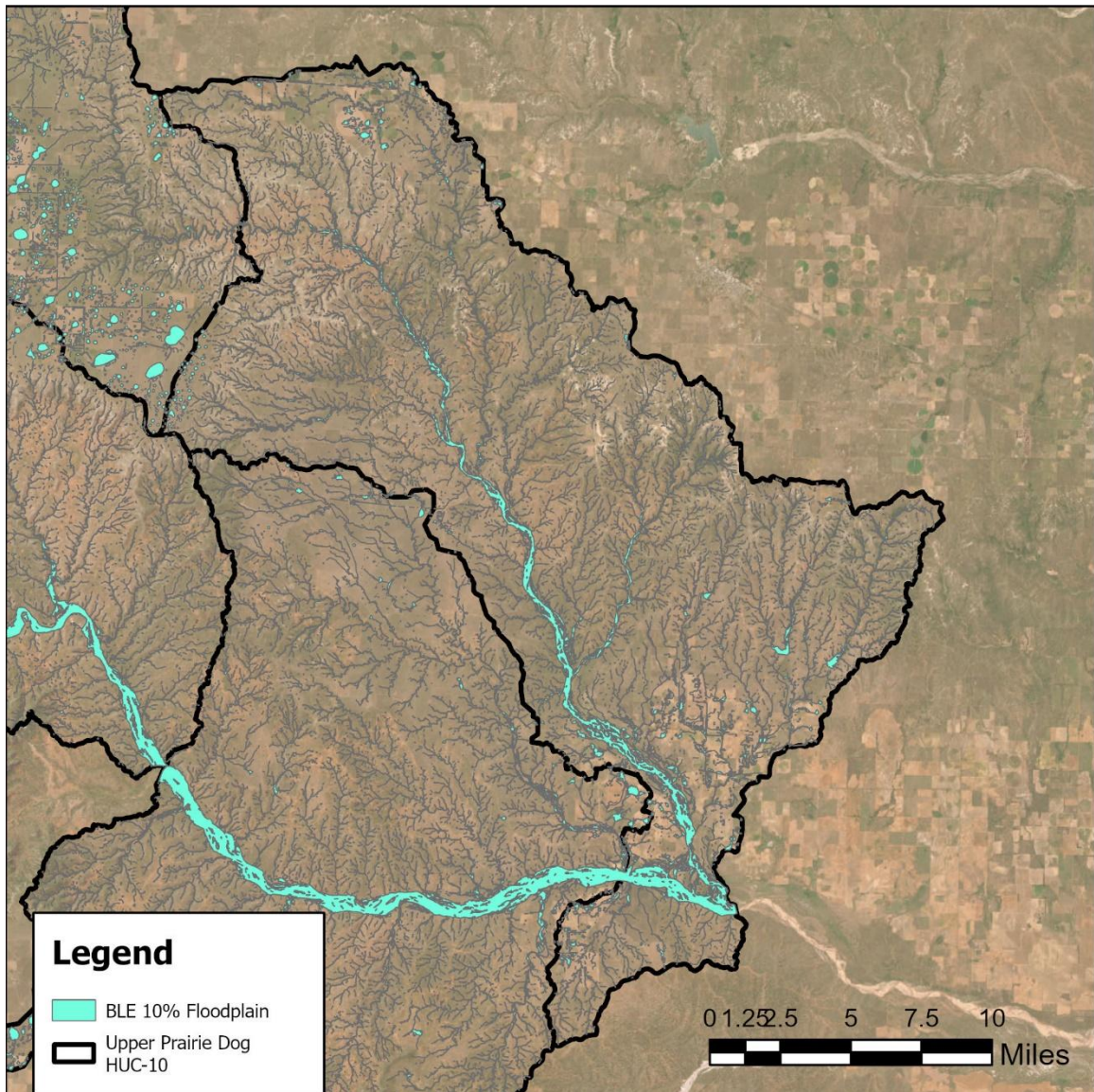


Figure A - 12: 1112010306 10% Floodplain