CHAMP Phase III, Otero County, Colorado
Hydrologic Analyses Report

CWCB CONTRACT # CT PDAA 2017-3860

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Submitted by:

Amec Foster Wheeler
Colorado Center Tower II
2000 South Colorado Blvd., Suite 200
Denver, CO 80222 USA

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List of Abbreviations

CDOT	Colorado Department of Transportation
CHAMP	Colorado Hazard Mapping Program
CWCB	Colorado Water Conservation Board
DEM	Digital Elevation Model
EMA	Expected Moments Algorithm
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling Software
HEC-SSP	Hydrologic Engineering Center – Statistical Software Package
LOMA	Letter of Map Amendment
LPIII	Log-Pearson Type III
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
USDA	United States Department of Agriculture
USGS	United States Geological Survey

Introduction

Amec Foster Wheeler is working with the Colorado Water Conservation Board (CWCB) to develop data in the Flood Risk Project for the Colorado Hazard Mapping (CHAMP) Phase III project for the Federal Emergency Management Agency (FEMA) that may or may not result in new or updated Flood Insurance Rate Maps (FIRM) and Flood Insurance Study (FIS) reports.

Scope

New detailed and approximate hydrology was developed for several streams within Otero County. Detailed hydrology was required for the Zone AE (detailed study) sections of the Arkansas River, King Arroyo, Anderson Arroyo and Crooked Arroyo. The detailed hydrology for these reaches was developed using the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) and using Bulletin 17C stream gage analysis procedures in the Hydrologic Engineering Center – Statistical Software Package (HEC-SSP). A summary of the Zone AE reaches is shown in Table 1. Zone A (approximate study) reaches tributary to these Zone AE reaches were also modeled using these methods. Bulletin 17C flood frequency analysis methods were also used for the Zone A reaches on Horse Creek and the Apishapa River due to their drainage areas being too large for regional regression equations. Regression equations were used to determine the hydrology for all remaining Zone A reaches in the county. The scoped Zone A and Zone AE reaches in Otero County are displayed in Figure 1.

Table 1 – Detailed Study Summary of Methods

Flooding Source	Reach	Stream Miles	Hydrologic Methodology
Anderson Arroyo	Through La Junta	1.9	HEC-HMS
Arkansas River	From North West of Fowler to East of La Junta	42.3	Bulletin 17C Stream Gage Analysis
Crooked Arroyo	West of La Junta	1.0	Bulletin 17C Stream Gage Analysis
King Arroyo	Through La Junta	3.4	HEC-HMS
Timpas Creek	West of Swink	3.1	Bulletin 17C Stream Gage Analysis

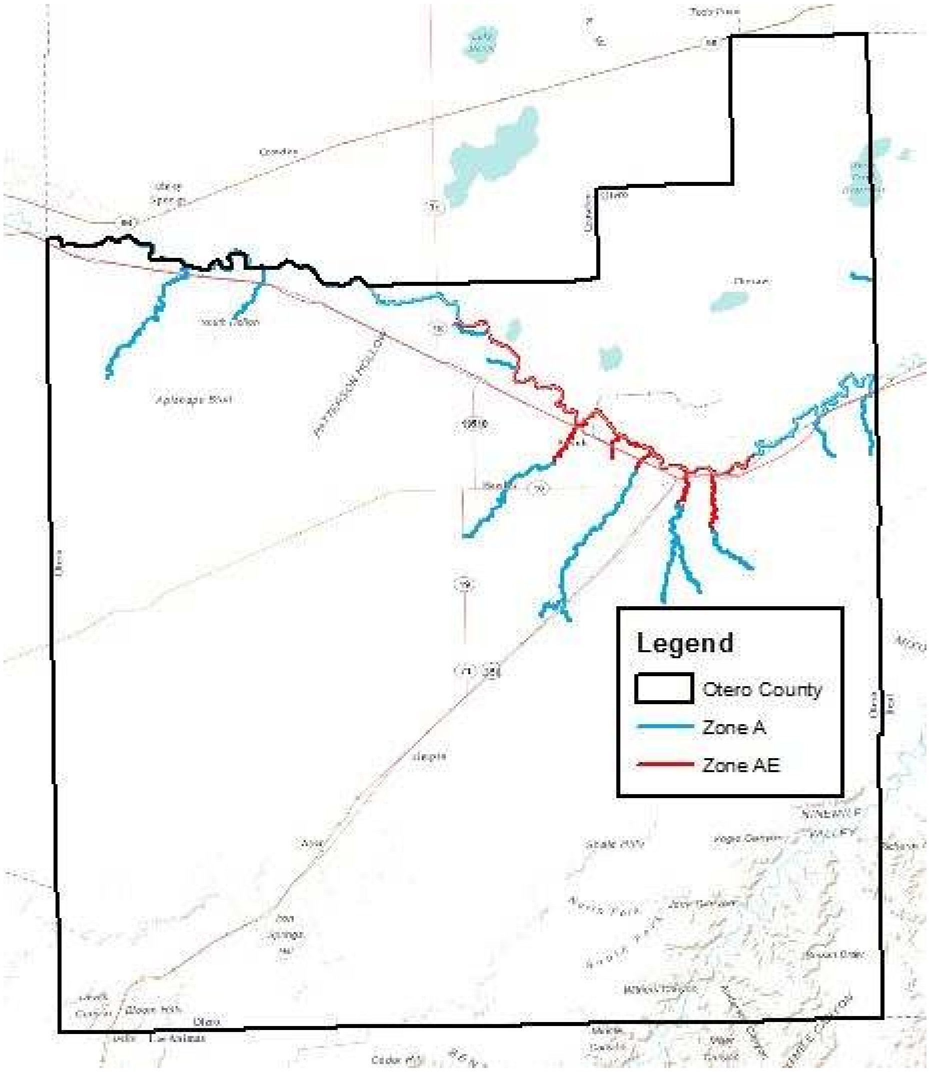

Figure 1 – Zone A and Zone AE reaches in Otero County

Existing Hydrology

Flood Insurance Study

The current Otero County, Colorado studies defines the Arkansas River, Anderson Arroyo, Crooked Arroyo, King Arroyo and Timpas Creek as both Zone A and Zone AE. All other flooding sources are mapped as Zone A.

Letters of Map Amendment

As of October 2017, one Letter of Map Revision (LOMR) and two Letter of Map Amendment (LOMA) were previously completed in the unincorporated area in Otero County. For LOMR, the effective flooding was at Zone A and revised flooding was at Zone C. The effective date was May 31, 2007. Flor LOMA, the effective dates were June 05, 2007 and April 21, 2011. One LOMR and one LOMA were previously completed in the city of Rocky Ford area in Otero County. For LOMR, the effective flooding was at Zone A and revised flooding was at Zone C. The effective date was May 31, 2007. For LOMA, the effective date was Jun 21, 2000.

Proposed Hydrology

Method Selection

Several hydrologic methodologies were used in determining the hydrology for Otero County. Bulletin 17C stream gage analyses were used to determine the hydrology for both the Zone AE and Zone A reaches on the Arkansas River, Crooked Arroyo and Timpas Creek and the Zone A reaches on the Apishapa River and Horse Creek. HEC-HMS models were developed and used to determine the hydrology for the Zone AE reaches on Anderson Arroyo, King Arroyo and their Zone A tributary reaches. Regression analyses were used for the hydrology for all remaining Zone A reaches.

Bulletin 17C Stream Gage Analysis using Log-Pearson Type III and EMA

Five U.S. Geological Survey (USGS) gaging stations were evaluated in the Hydrologic Engineering Center's Statistical Software Package) HEC-SSP Version 2.1.1) using Log-Pearson Type III (LPIII) and Expected Moments Algorithm (EMA) outlined in Bulletin 17C. The gages analyzed were Arkansas River at Catlin Dam, near Fowler (07119700), Horse Creek at Las Animas (07123675), Crooked Arroyo near Swink (07122400), Timpas Creek at Mount near Swink (07121500) and Apishapa River near Fowler (07119500). The annual peak flow data was extracted directly from the USGS websites when performing the HEC-SSP Bulletin 17C analysis. Skew is a measure of the asymmetry of the probability distribution of a real-valued random variable about its mean. Station Skew option is based solely on computing a skew from the data points contained in the dataset. Station skew is chosen due to the significant record length at the gages and the reaches in question being on major streams and not smaller tributaries.

Gage Projection

The methodology outlined in the Water Resources Investigations Report 99-4190 "Analysis of the Magnitude and Frequency of Floods in Colorado" was consulted to project gage results to locations on the same stream. The Crooked Arroyo watershed is located within the Plains

Region so an exponent (x) of 0.40 as used in Equation (3) from the Water Resources Investigations Report.

$$Q_{T(u)} = Q_{T(g)}(A_u/A_g)^x$$

Equation (3): Peak Discharge Projection

Where $Q_{T(u)}$ is the peak discharge, in cubic feet per second, at the ungaged site for T-year recurrence interval; $Q_{T(g)}$ is the weighted peak discharge, in cubic feet per second, at the gaged site for T-year recurrence interval; A_u is the drainage area, in square miles, at the ungaged site; A_g is the drainage area, in square miles, at the gaged site; and x is the average exponent for drainage area. The peak discharge projection was used to project the Bulletin 17C flows from the Crooked Arroyo near Swink gage upstream to the limits of the Zone A and AE reaches past the confluence of Crooked Arroyo and Benton Arroyo. The projected flows are shown in Table 3.

Apishapa River Flows

Regional regression equations were not applicable due to the large drainage area so a stream gage analysis was performed on the Apishapa River near Fowler gage for this Zone A reach. Final flows from the stream gage analysis are shown in Table 3***Table*** .

Arkansas River Flows

The results of the stream gage analysis showed flows in the Arkansas River decreasing downstream of Catlin Dam. Upon further investigation, multiple large irrigation diversions were located on the stream segment above Las Animas. One approximately 7 miles due west of Las Animas, another approximately 3.1 miles east-northeast of Manzanola, Colorado, and one approximately 1.6 miles east-southeast of Swink, Colorado. Similar diversions are seen above La Junta. Because of these structures and others, it was assumed that during flooding events, these structures could be compromised and should not be expected to divert any flood flows. Since the gage data for the La Junta gage is compromised by these irrigation diversions, the flows obtained by the stream gage analysis at the Arkansas River at Catlin Dam near Fowler were projected down to all flow change points along the Arkansas River within Otero County. Table 3***Table 2*** shows the results from the stream gage analysis along the Arkansas River.

Crooked Arroyo and Timpas Creek Flows

Both of these streams have Zone A reaches transitioning to Zone AE reaches downstream. Since a stream gage analysis is being performed for the Zone AE reaches, the Zone A reaches were included in the analysis and the gage results were applied both reaches. Final flows from the stream gage analysis are shown in Table 3.

Horse Creek Flows

Regional regression equations were not applicable due to the large drainage area so a stream gage analysis was performed on the Horse Creek near Las Animas gage for this Zone A reach. Final flows from the stream gage analysis are shown in Table 3***Table*** .

USGS Qualification Codes

USGS qualification codes were available for all data downloaded from the USGS website. Table 2 shows the codes encountered in the gage data for the Arkansas River, Purgatoire River, and Horse Creek along with an approach of how they were incorporated into the FFA.

Table 2 - USGS Qualification Codes and Approach

Code #	Description	Approach
1	Discharge is a Maximum Daily Average	Values are investigated further and possibly increased based on other peak vs. average daily discharge comparison points.
2	Discharge is an Estimate	Data treated as if it were not an estimate due to lack of clear error bounds of each individual sample.
3	Discharge affected by Dam Failure	Changed data type to censored and set high flow range value equal to recorded flow and dropped low value to 0 as flow could have been anything in this range before dame broke.
6	Discharge affected by Regulation or Diversion	No change in approach. Reservoirs have been in operation for a long enough time that data points used in the FFA represent actual conditions and are the best available data for the location.

- Qualification codes were not available for the Crooked Arroyo near Swink Gage.

Table 3 – Bulletin 17C Stream Gage Analysis

Gage/Location		Drainage Area [2] (mi²)	Projection Ratio	Peak Discharge (cfs)					
Number	Name			10%	4%	2%	1%	1% Plus	0.2%
07123675	Horse Creek at Las Animas	1,403	1.00	521	811	1,060	1,340	2,870	2,080
07121500	Timpas Creek at Mouth near Swink	506	1.00	5,250	8,820	12,300	16,600	23,700	30,300
07119700	Arkansas River at Catlin Dam	10,901	1.00	12,200	17,800	23,200	29,900	54,500	51,700
07122400	Crooked Arroyo near Swink	108	1.00	669	1,120	1,590	2,190	4,700	4,290
	Crooked Arroyo Reach 2-Downstream of confluence with Benton Arroyo	82	0.74	598	1,000	1,420	1,960	4,200	3,840
	Crooked Arroyo Reach 2-Upstream of confluence with Benton Arroyo	64	0.59	542	907	1,290	1,770	3,810	3,480
07119500	Apishapa River near Fowler	1,074	1.00	9,610	13,900	17,000	20,100	25,300	26,500

Rainfall-Runoff Method

HEC-HMS models were developed for the Zone AE reaches on King Arroyo and Anderson Arroyo as well as the tributary Zone A reaches. By using HEC-GeoHMS Version 10.2 based on 10-meter LiDAR Digital Elevation Model (DEM), 37 sub-basins were delineated within the Anderson Arroyo watershed and 19 sub-basins were delineated within the King Arroyo watershed.

The sub-basin boundaries, land use data, and hydrologic soil groups were spatially intersected to generate an accurate runoff curve number (CN) for each sub-basin in accordance with the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Runoff Curve Number methodology. This spatial intersection was performed using an Amec Foster Wheeler ArcGIS proprietary tool. Soil and land use data were downloaded from the NRCS website. Soils within the basin are a dominated by hydrologic soil groups D and C. Various cover types exist within the watershed including impervious roadway, commercial and residential, woods, and brush. The curve numbers used in the hydrologic models are presented in Table 5 and Table 6.

National Oceanic and Atmospheric Administration (NOAA) Atlas 14 was used to determine the rainfall depths for the 10-, 25-, 50-, 100-, and 500-year return frequencies. The 100-year plus return frequency was determined by converting the upper 90% confidence interval of the NOAA Atlas 14 100-year flow depth to FEMA’s standard 84% confidence limit. The rainfall depths for each return period for each model are shown in Table 4. The SCS Type II Unit Hydrograph method was used to develop the model hydrographs for each watershed.

Table 4 – NOAA Atlas 14 Rainfall Depths

Watershed	Rainfall Depths (in)					
	10%	4%	2%	1%	1% Plus	0.20%
Anderson Arroyo	2.73	3.32	3.80	4.30	4.99	5.54
King Arroyo	2.74	3.33	3.81	4.31	5.02	5.57

The time of concentration for each sub-basin in both models were calculated following the methodology outlined in Chapter 15 of the National Engineering Handbook and from TR-55 Urban Hydrology for Small Watersheds. The longest flow path, basin topography and the 2-year NOAA Atlas 14 rainfall depth for each sub-basin were inputs into an Amec Foster Wheeler ArcGIS proprietary tool that uses the methodologies outlined in the documents listed above to calculate the time of concentration for each sub-basin. The longest flow path input is a shapefile that segments out sheet, shallow and channel flow sections and provides roughness characteristics. The tool first uses the basin topography to calculate the slope of each segment from the longest flow path shapefile. The 2-year rainfall depth and roughness characteristics are then used with the calculated slopes to determine the velocity of water for each segment. The tool then calculates the time of concentration using the segment lengths and finally dissolves the segments so that there is one time of concentration for each sub-basin. The resulting sub-basin time of concentrations for each model are presented in Table 5 and Table 6.

Table 5 – Anderson Arroyo Sub-Basin Parameters

Sub-basin ID	Area (mi2)	CN (-)	Time of Concentration (hrs)	Storage Coefficient (hrs)
W280	1.42	76	2.49	3.73
W290	1.36	72	1.28	1.92
W300	2.13	71	2.20	3.30
W320	1.58	73	2.96	4.44
W330	1.06	66	2.28	3.42
W350	1.26	66	2.11	3.17
W370	1.31	74	1.76	2.64
W400	1.75	72	2.45	3.67
W410	2.33	69	2.40	3.59
W420	2.54	70	1.91	2.86
W430	0.47	71	2.42	3.63
W440	2.00	73	2.89	4.33
W460	0.47	72	3.24	4.86
W470	1.40	76	3.48	5.21
W510	1.59	74	2.05	3.07
W520	0.70	73	2.33	3.49
W530	1.98	73	3.02	4.53
W540	1.60	73	2.91	4.36
W620	1.34	69	1.90	2.85
W680	1.69	70	2.31	3.46
W820	1.52	73	1.92	2.89
W920	1.51	68	1.99	2.98
W960	0.58	73	2.26	3.39
W1020	0.97	62	1.77	2.66
W1060	1.74	72	2.52	3.78
W1120	1.42	74	2.38	3.57
W1260	1.39	75	2.70	4.05
W1520	2.64	75	2.92	4.38
W1680	1.82	69	1.84	2.76
W1720	1.56	73	2.56	3.84
W1760	1.37	74	2.93	4.39
W1780	1.96	74	2.61	3.91
W1920	1.35	71	1.57	2.35
W1980	2.12	68	2.18	3.27
W2020	0.79	72	3.13	4.69
W2080	2.33	68	2.39	3.58
W2120	1.50	71	2.23	3.35

Table 6 – King Arroyo Sub-Basin Parameters

Sub-basin ID	Area (mi2)	CN (-)	Time of Concentration (hrs)	Storage Coefficient (hrs)
W120	2.23	74	2.56	3.84
W140	1.13	76	1.42	2.14
W150	0.98	75	1.14	1.71
W180	1.60	75	2.57	3.85
W260	1.24	70	2.63	3.95
W310	1.98	75	2.34	3.51
W360	1.30	73	1.66	2.50
W410	1.08	66	2.27	3.40
W450	0.77	74	1.63	2.44
W460	1.55	71	2.25	3.37
W500	1.56	77	1.59	2.38
W510	1.33	77	2.18	3.27
W550	1.29	76	1.66	2.49
W560	1.75	76	1.70	2.55
W600	0.97	75	1.53	2.29
W610	1.08	72	1.72	2.58
W750	1.08	77	1.88	2.82
W850	2.31	72	2.84	4.25
W860	0.81	73	1.72	2.58

The Muskingum-Cunge routing method was used to route the flow from the sub-basins through the watershed. The method is based on the combination of the conservation of mass and the diffusion representation of the conservation of momentum. The routing parameters are recalculated for every time step based on the channel properties and flow depth. Representative channel cross sections taken from the LiDAR DEM were utilized in this method.

Table 7 – Rainfall Runoff Analysis Parameters and Results

Location	Drainage Area (mi^2)	Peak Discharges (cfs)					
		10%	4%	2%	1%	1% Plus	0.2%
Anderson Arroyo Reach 1- At confluence with Arkansas River	56.55	2,090	3,380	4,610	6,000	8,100	9.890
Anderson Arroyo Reach 2- At confluence with Anderson Arroyo Trib 1	51.64	1,960	3.190	4,330	5,630	7,570	9,240
Anderson Arroyo Reach 2- Upstream of confluence with Anderson Arroyo Trib 1	42.73	1,680	2,720	3,670	4,760	6,380	7,770

Location	Drainage Area (mi^2)	Peak Discharges (cfs)					
		10%	4%	2%	1%	1% Plus	0.2%
Anderson Arroyo Trib 1- Upstream of confluence with Anderson Arroyo Reach 2	8.91	334	562	780	1,030	1,410	1,730
Anderson Arroyo Trib 1- Downstream of confluence with unnamed tributary 1,500 feet downstream of County Road 29 crossing.	7.33	272	462	643	851	1,170	1,440
Anderson Arroyo Trib 1-Upstream of confluence with unnamed tributary 1,500 feet downstream of County Road 29 crossing.	6.27	245	413	572	755	1,090	1,270
King Arroyo Reach 1- At confluence with Arkansas River	26.03	2,430	4,050	5,530	7,220	9,810	11,900
King Arroyo Reach 2- 17,220 feet upstream of confluence with Arkansas River	22.63	2,290	3,770	5,130	6,660	8,990	10,900
East Fork King Arroyo- Upstream of confluence with King Arroyo Reach 2	13.91	1,750	2,820	3.790	4,910	6,580	7,880
East Fork King Arroyo- Downstream of confluence with unnamed tributary.	11.68	1,550	2,470	3,310	4,250	5,680	6,790
East Fork King Arroyo- Upstream of confluence with unnamed tributary.	8.79	1,160	1,860	2,500	3,210	4,290	5,130

The HEC-HMS discharges at the confluence with the Arkansas River for Anderson Arroyo and King Arroyo were compared with regression equation results to verify the HEC-HMS results. The 100-year return frequency HEC-HMS discharges for Anderson Arroyo at the Arkansas River confluence and King Arroyo were within 10% of the regression equation results, which is within the regression standard error or prediction. See the Regression Equation Methodology section for the regression equation procedure.

Regression Equation Methodology

The regression equation method is applied for all Zone A streams in Otero County not studied using gage analysis or rainfall-runoff methods. The regression equations are taken from the 2009 USGS report in cooperation with CWCB and the Colorado Department of Transportation (CDOT) titled "*Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado*". The regional regression equations developed in this report are derived from statistical relationships between stream flow records and applicable station, basin and climatic characteristics. Regional regression equations along with predicted uncertainty are generally a reliable and cost-effective means for estimating streamflow statistics at ungagged sites.

The USGS online modeling program, StreamStats, was used to delineate the watershed, generate supporting shapefiles and produce the USGS regression equation peak flow outputs for each stream. Flow change locations along each stream were delineated at regular intervals from the confluence up the streams until there was more than a 10% reduction in peak flow from the previously determined point.

Otero County is split between the Plain Region, the Mountain Region, the Rio Grande Region and the Foothills Region. The regression equations for each respective region are shown in Figure 2, Figure 3, Figure 4 and Figure 5 below. In the regression equations, A is the drainage area in square miles, and P is the mean annual precipitation in inches.

Peak Streamflow Equations for Plains Hydrologic Region

Generalized least-squares (GLS) regression, 69 stations

Approximate range of predictor variables

A: 0.5–2,930 square miles and ${}_6P_{100}$: 2.4–5.1 inches

$Q_2 = 10^{1.26} A^{0.52}\ {}_6P_{100}^{0.35}$	√	$SEP = 183$,	pseudo$R^2 = 40$,	$SME = 174$,
$Q_5 = 10^{0.94} A^{0.57}\ {}_6P_{100}^{1.64}$	√	$SEP = 142$,	pseudo$R^2 = 54$,	$SME = 134$,
$Q_{10} = 10^{0.85} A^{0.59}\ {}_6P_{100}^{2.15}$	√	$SEP = 136$,	pseudo$R^2 = 58$,	$SME = 128$,
$Q_{25} = 10^{0.84} A^{0.61}\ {}_6P_{100}^{2.57}$	√	$SEP = 137$,	pseudo$R^2 = 62$,	$SME = 128$,
$Q_{50} = 10^{0.85} A^{0.62}\ {}_6P_{100}^{2.79}$	√	$SEP = 139$,	pseudo$R^2 = 64$,	$SME = 129$,
$Q_{100} = 10^{0.88} A^{0.63}\ {}_6P_{100}^{2.98}$	√	$SEP = 141$,	pseudo$R^2 = 65$,	$SME = 131$,
$Q_{200} = 10^{0.95} A^{0.63}\ {}_6P_{100}^{3.37}$	√	$SEP = 160$,	pseudo$R^2 = 65$,	$SME = 147$, and
$Q_{500} = 10^{0.81} A^{0.64}\ {}_6P_{100}^{3.59}$	√	$SEP = 141$,	pseudo$R^2 = 70$,	$SME = 128$.

Figure 2 – Regional Regression Equations for the Plains Hydrologic Region

Peak Streamflow Equations for Mountain Hydrologic Region

Generalized least-squares (GLS) regression, 141 stations

Approximate range of predictor variables

A: 1–1,060 square miles; S: 7.6–60.2 percent; and P: 18–47 inches

$Q_2 = 10^{-2.05} A^{0.78} S^{0.17} P^{2.10}$	√	$SEP = 49$,	pseudo$R^2 = 83$,	$SME = 48$,
$Q_5 = 10^{-1.51} A^{0.77} S^{0.16} P^{1.85}$	√	$SEP = 44$,	pseudo$R^2 = 86$,	$SME = 43$,
$Q_{10} = 10^{-1.20} A^{0.77} S^{0.14} P^{1.71}$	√	$SEP = 41$,	pseudo$R^2 = 87$,	$SME = 40$,
$Q_{25} = 10^{-0.90} A^{0.75} S^{0.16} P^{1.55}$	√	$SEP = 40$,	pseudo$R^2 = 88$,	$SME = 39$,
$Q_{50} = 10^{-0.68} A^{0.75} S^{0.16} P^{1.45}$	√	$SEP = 39$,	pseudo$R^2 = 88$,	$SME = 37$,
$Q_{100} = 10^{-0.46} A^{0.75} S^{0.14} P^{1.35}$	√	$SEP = 36$,	pseudo$R^2 = 90$,	$SME = 34$,
$Q_{200} = 10^{-0.28} A^{0.75} S^{0.13} P^{1.26}$	√	$SEP = 36$,	pseudo$R^2 = 90$,	$SME = 34$, and
$Q_{500} = 10^{-0.06} A^{0.74} S^{0.15} P^{1.14}$	√	$SEP = 33$,	pseudo$R^2 = 91$,	$SME = 31$.

Figure 3 – Regional Regression Equations for the Mountain Hydrologic Region

Peak Streamflow Equations for Rio Grande Hydrologic Region

Generalized least-squares (GLS) regression, 44 stations

Approximate range of predictor variables

A: 2–517 square miles and P: 19–45 inches

$Q_2 = 10^{-3.00} A^{1.00} P^{2.46}$	√	$SEP = 67$,	pseudo$R^2 = 80$,	$SME = 64$,
$Q_5 = 10^{-2.04} A^{0.95} P^{2.02}$	√	$SEP = 57$,	pseudo$R^2 = 83$,	$SME = 55$,
$Q_{10} = 10^{-1.55} A^{0.93} P^{1.80}$	√	$SEP = 54$,	pseudo$R^2 = 84$,	$SME = 51$,
$Q_{25} = 10^{-1.01} A^{0.91} P^{1.55}$	√	$SEP = 52$,	pseudo$R^2 = 84$,	$SME = 49$,
$Q_{50} = 10^{-0.66} A^{0.89} P^{1.39}$	√	$SEP = 51$,	pseudo$R^2 = 85$,	$SME = 48$,
$Q_{100} = 10^{-0.19} A^{0.87} P^{1.17}$	√	$SEP = 51$,	pseudo$R^2 = 85$,	$SME = 48$,
$Q_{200} = 10^{-0.03} A^{0.86} P^{1.11}$	√	$SEP = 52$,	pseudo$R^2 = 84$,	$SME = 49$, and
$Q_{500} = 10^{0.52} A^{0.84} P^{0.85}$	√	$SEP = 54$,	pseudo$R^2 = 84$,	$SME = 49$.

Figure 4 – Regional Regression Equations for the Rio Grande Hydrologic Region

Peak-Streamflow Equations for the Foothills Hydrologic Region

Generalized-least squares regression, 89 streamgages

A, drainage area in square miles; ${}_6P_{100}$, 6-hour, 100-year precipitation; C, amount of clay in basin in percent; E_{out}, basin outlet elevation in feet; $Q_{0.5}$, $Q_{0.2}$, $Q_{0.1}$, $Q_{0.04}$, $Q_{0.02}$, $Q_{0.01}$, $Q_{0.005}$, $Q_{0.002}$, discharge with an annual exceedance probability of 0.5, 0.2, 0.1, 0.04, 0.02, 0.01, 0.005, 0.002, respectively

Approximate range of predictor variables

A: 0.60–2,850 square miles, ${}_6P_{100}$: 2.38–4.89 inches, C: 9.87–37.5 percent, and E_{out}: 4,290–8,270 feet

$Q_{0.5} = 10^{9.952} A^{0.626} {}_6P_{100}^{1.401} C^{0.836} E_{out}^{-2.774}$	$SEP = 117$,	pseudo$R^2 = 68$,	$SME = 111$,
$Q_{0.2} = 10^{11.424} A^{0.594} {}_6P_{100}^{2.052} C^{0.935} E_{out}^{-3.164}$	$SEP = 87$,	pseudo$R^2 = 77$,	$SME = 82$,
$Q_{0.1} = 10^{12.107} A^{0.584} {}_6P_{100}^{2.372} C^{0.974} E_{out}^{-3.341}$	$SEP = 80$,	pseudo$R^2 = 79$,	$SME = 76$,
$Q_{0.04} = 10^{12.675} A^{0.578} {}_6P_{100}^{2.725} C^{0.998} E_{out}^{-3.486}$	$SEP = 80$,	pseudo$R^2 = 80$,	$SME = 75$,
$Q_{0.02} = 10^{12.977} A^{0.575} {}_6P_{100}^{2.963} C^{1.010} E_{out}^{-3.564}$	$SEP = 83$,	pseudo$R^2 = 79$,	$SME = 79$,
$Q_{0.01} = 10^{13.244} A^{0.572} {}_6P_{100}^{3.190} C^{1.013} E_{out}^{-3.631}$	$SEP = 88$,	pseudo$R^2 = 78$,	$SME = 83$,
$Q_{0.005} = 10^{13.495} A^{0.570} {}_6P_{100}^{3.386} C^{1.024} E_{out}^{-3.697}$	$SEP = 94$,	pseudo$R^2 = 76$,	$SME = 88$, and
$Q_{0.002} = 10^{13.820} A^{0.566} {}_6P_{100}^{3.621} C^{1.038} E_{out}^{-3.783}$	$SEP = 104$,	pseudo$R^2 = 74$,	$SME = 97$.

Figure 5 – Regional Regression Equations for the Foothills Hydrologic Region

Most of the Zone A streams in Otero County are Arkansas River and its tributaries. Watersheds for these tributaries are delineated by specifying drainage points at tributaries just upstream of their confluences with Arkansas River in StreamStats. Table 8 shows a summary of the regression equation results as well as the error bounds for the expected values. Error bounds listed in the table may not reflect those in the tables above as many of the streams encompass multiple hydrologic regions and the error bounds are a composite. The StreamStats reports for the scoped approximate streams are included in Appendix C.

Table 8 – Regression Analysis Parameters and Results

Location	Drainage Area (mi²)	Peak Discharges (cfs)					
		10%	4%	2%	1%	1% Plus	0.2%
Arkansas River Tributary 3- At confluence with Arkansas River	10.6	988 (0 – 2,010) 103% Error	1,820 (0 – 3,880) 113% Error	2,710 (0 – 6,040) 123% Error	3,870 (0 – 9,130) 136% Error	9,130	7,860 (0 – 21,200) 170% Error
Benton Arroyo- At confluence with Crooked Arroyo	17.9	674 (0 – 1,370) 103% Error	1,290 (0 – 2,750) 113% Error	1,950 (0 – 4,350) 123% Error	2,850 (0 – 6,730) 136% Error	6,730	6,030 (0 – 16,300) 170% Error
Robinson Arroyo- 2 miles South of US-50	2.55	499 (0 – 1,010) 103% Error	919 (0 – 1,960) 113% Error	1,360 (0 – 3,030) 123% Error	1,950 (0 – 4,600) 136% Error	4,600	3,930 (0 – 10,600) 170% Error
Vandiver Arroyo- At confluence with Arkansas River	13.7	1,260 (0 – 2,560) 103% Error	2,340 (0 – 4,980) 113% Error	3,490 (0 – 7,780) 123% Error	5,010 (0 –11,800) 136% Error	11,800	10,200 (0 – 27,500) 170% Error

MIP Submittal File Structure

All hydrologic data development TSDN files have been submitted digitally along with this TSDN. The contents have been structure according to the May 2017 Data Capture Standards (DCS) Technical Reference.

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