CHAMP Phase III, Bent County, Colorado
Hydrologic Analyses Report

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List of Abbreviations

CDOT	Colorado Department of Transportation
CWCB	Colorado Water Conservation Board
DEM	Digital Elevation Model
EMA	Expected Moments Algorithm
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 Bent County. Detailed hydrology was required for the Zone AE sections of the Arkansas and Purgatoire Rivers near the city of Las Animas. The detailed hydrology for these reaches was developed using Bulletin 17C stream gage analysis procedures and a proportional additive approach. A summary of the Zone AE reaches is shown in Table 1. Regression equations were used to determine the hydrology for all Zone A reaches in the county. The scoped Zone A and Zone AE reaches in Bent County are displayed in Figure 1.

Table 1 – Detailed Study Summary of Methods

Flooding Source	Reach	Stream Miles	Hydrologic Methodology
Purgatoire River	South of Las Animas; upstream of the confluence	4.5	Bulletin 17C Stream Gage Analysis
Arkansas River	North of Las Animas; upstream of the confluence	4.7	Bulletin 17C Stream Gage Analysis
Arkansas River	East of Las Animas; downstream of the confluence	0.3	Addition of Bulletin 17C Stream Gage Analyses

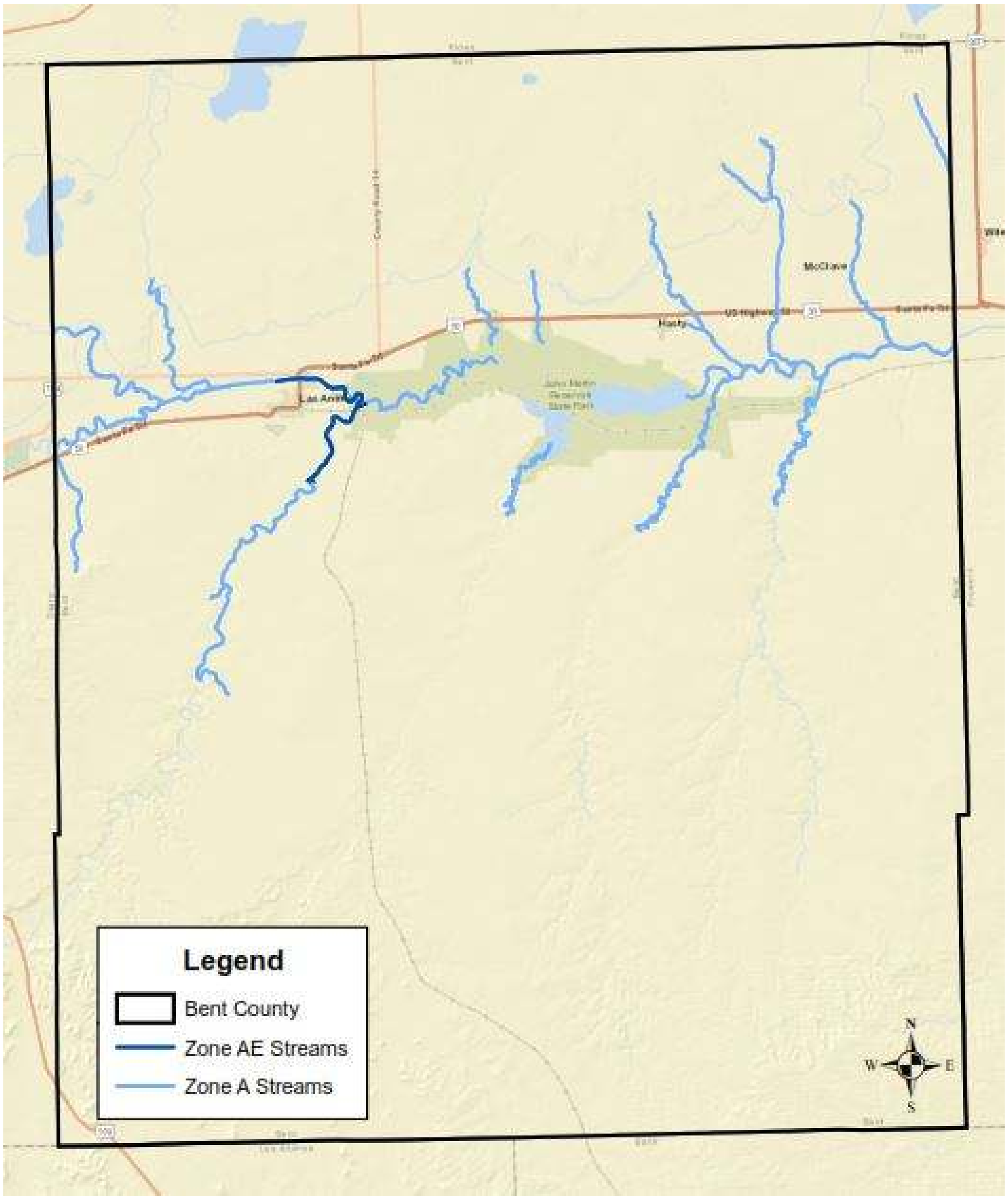

Figure 1 – Zone A and Zone AE reaches in Bent County

Existing Hydrology

Flood Insurance Study

The current Bent County, Colorado and Unincorporated Areas FIRM defines the Arkansas River through Bent County as Zone A. Therefore, no detailed study has been previously performed and no detailed hydrology exists. No effective FIS exists for Bent County.

Letters of Map Amendment

As of June 2017, there are no Letters of Map Amendment (LOMA) within Bent County.

Proposed Hydrology

Method Selection

Several hydrologic methodologies were used in determining the hydrology for Bent County. Bulletin 17C stream gage analysis and a proportional additive method were used to determine the hydrology for the Zone AE reaches. Regression analyses were used for the hydrology for all Zone A reaches. Bulletin 17C was chosen for the Zone AE reaches because both the Arkansas and Purgatoire River Basins are too large for an HEC-HMS analysis and there is adequate stream gage information on both streams near the detailed study area. However, there is not a stream gage on the Arkansas River between the confluence with the Purgatoire River and John Martin Reservoir. Therefore, to determine the hydrology for this 0.3 mile Zone AE section of the Arkansas River downstream of the confluence, The projected flows for both the Purgatoire River and Arkansas River were added together to provide the most conservative values for this short reach before flow enters John Martin Reservoir. For more detail on this additive method, see the Purgatoire-Arkansas Combined Flows section below.

Bulletin 17C Summary

Bulletin 17C updated the peak flow frequency analysis (FFA) by combining future work outlined in Bulletin 17B, new statistical methods, and flood processes from post-Bulletin 17B investigations (England, et al., 2015). The changes between Bulletin 17C (Recommended Draft – April 2017), and Bulletin 17B (published September 1981) are fairly pronounced:

- A new statistical approach called the Expected Moments Algorithm which allows the user to add “interval estimates” or data ranges, rather than individual explicit data points.
- An improvement to the Grubbs-Beck Test allowing for multiple outliers to be censored.
- An improvement to the method used to compute confidence intervals.

Bulletin 17C computes distribution parameters by combining non-standard, censored, or historical data, which performs as a more integrated method compared to Bulletin 17B (Cohn, Lane, & Baier, 1997). EMA is applied to calculate parameters of the Log Pearson Type III distribution in Bulletin 17C (US Army Corps of Engineers, 2016). The results from Bulletin 17C analysis also include improved confidence intervals of frequency curve, which accounts for the uncertainties influenced by censored value and historical data.

The Bulletin 17C manual specifically states that the procedures do not apply to “watersheds where flood flows are appreciably altered by reservoir regulation…”. However, due to the length of records at the gages after reservoir construction was completed, it was determined that using the Bulletin 17C analysis procedures would still be appropriate under the assumption that the reservoirs would continue to function as they have done in the past, and that each of the records from the post-reservoir era, represented an independent record which could theoretically occur again in the future.

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.
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.
7	Discharge is an Historic Peak	Data type changed to historical in HEC-SSP

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

U.S. Geological Survey (USGS) gaging stations near Las Animas were evaluated by flood frequency analysis using the Hydrologic Engineering Center’s Statistical Software Package (HEC-SSP Version 2.1.1) using the Log-Pearson Type III (LPIII) and Expected Moments Algorithm (EMA) outlined in Bulletin 17C: the Arkansas (07124000) and Purgatoire (07128500) River USGS gaging stations. The annual peak flow data was extracted directly from the USGS website using the internal tool within HEC-SSP. 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 extended record length at both gages.

Two additional USGS gaging stations along Arkansas River upstream of the county boundary were examined using flood frequency analysis per the Bulletin 17C guidelines as flows at the Arkansas River at Las Animas were lower than anticipated: the Arkansas River at La Junta (07123000) and Arkansas River at Catlin Dam near Fowler (07119700). The results of the FFA showed flows 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 Las Animas and La Junta gages are compromised by these irrigation diversions, the flows obtained by the FFA at the Arkansas River at Catlin Dam near Fowler were projected down to all flow change points until just upstream of the Purgatoire River. Final results of the FFA analysis are shown in Table 3.

For the Purgatoire River, the Purgatoire River near Las Animas Gage (07128500) was used for the FFA for both the Zone A and AE areas of the river. The Purgatoire River is controlled by Trinidad Lake, a state managed facility operated by Colorado State Parks which provides flood control protection for the City of Trinidad and all other areas below the city along the Purgatoire River. This reservoir was completed in 1977 by the US Army Corps of Engineers and impacted the subsequent flow readings at the Las Animas gage on the Purgatoire River since its construction. The reservoir's operational rules cap discharges at 3,000 cfs. Due to this reservoir, the flood frequency analysis (FFA) was revised to only include data from after the reservoir was put into operation in 1977. Prior to this change, the FFA was producing flows on the Purgatoire River which were 3-4 times higher than the flows on the Arkansas River despite having a much smaller tributary area. By limiting the FFA to only the post-reservoir values, the FFA produced results which were much more in line with the Arkansas River flows and the rest of the flows within the county. Final flows from the FFA analysis are shown in Table 3.

Purgatoire-Arkansas Combined Flows

The stream segment between the Purgatoire River/Arkansas River Confluence and John Martin Reservoir is beyond the length that can have the Arkansas River at Catlin Dam Gage applied to it as it is beyond the 1.5 drainage area limit due to the large tributary area coming in from the Purgatoire River. The segment has too large of a tributary area for regression or a HEC-HMS model, so local gages must be used, however the closest Arkansas River gage, Arkansas River at Las Animas, is not being used in favor of projecting the Catlin Dam gage. To remain consistent with the gages being used, the approach taken was to project the Catlin Dam gage to just upstream of the Arkansas/Purgatoire confluence and project the Purgatoire River at Las Animas gage down to just upstream of the confluence as well. The projected flows from each of these locations were then added together to produce a conservative result which assumes both watersheds are experiencing a storm with the same return period at the same time. While this approach is more conservative, the short reach length between the confluence and John Martin Reservoir and the lack of any other alternative resulted in this methodology.

For the Zone A reaches of the Arkansas River below John Martin Reservoir, regression was not possible as the tributary area is too large and it is directly controlled by a reservoir. Because of this, a FFA was performed using the Arkansas River at John Martin Reservoir gage. The station skew for the Arkansas River below John Martin Reservoir gage is well above the recommended -0.5 to 0.5 range as most of the data points are controlled by the reservoir. Increasing the low outlier threshold made the skew worse. Per Bulletin 17C, Plate 1 from Bulletin 17B is no longer appropriate to use for Bulletin 17C analyses to develop regional skews from. Based on a desktop search, no local skew determinations have been performed recently in this area which could be used to develop appropriate regional skew values. Because there is no better data available and the gage data accurately depicts reservoir operations, the station skew was selected to continue to be used and the results applied to the Zone A reach below the reservoir. Final flows from the combination are shown in Table 3.

Horse Creek Flows

One of the major tributaries to the Arkansas River is Horse Creek which has a large drainage basin spanning up past Colorado Springs to the north. Due to the size of this basin, both regression and HEC-HMS were not feasible so a FFA was performed on the Horse Creek near Las Animas Gage. Final flows from the FFA analysis are shown in Table 3.

The full HEC-SSP analysis for all six gage stations are presented in Appendix A.

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
07119700	Arkansas River at Catlin Dam	10,901	1.00	12,200	17,800	23,200	29,900	54,500	51,700
	Arkansas River at CR-37 (County Boundary) [1]	12,100	1.11	12,700	18,600	24,200	31,200	56,800	53,900
	Approximately 4,500 feet upstream of US-50/N Bent Avenue [1]	14,245	1.31	13,600	19,800	25,900	33,300	60,700	57,600
	Arkansas River Upstream of Purgatorie River	14,300	1.31	13,600	19,800	25,900	33,300	60,700	57,600
	Arkansas River Downstream of Purgatoire River [2]	17,800	-	17,400	24,500	31,300	39,500	68,700	65,800
07130500	Arkansas River below John Martin Reservoir	18,494	1.00	2,510	3,130	3,650	4,230	5,350	5,880
07128500	Purgatoire River near Las Animas	3,441	1.00	3,750	4,660	5,390	6,160	8,030	8,170

[1] Per WRIR 99-4190 - Coefficient for Plains Region for projecting gaging stations on the same stream is 0.40 and is only applicable when drainage areas are between 0.5 and 1.5 times the drainage area of the projected gage.

[2] Flow developed by adding the projected flows from Arkansas River and Purgatoire River upstream of respective confluences, due to projected flow of Arkansas River from Catlin Dam being outside projection ratio limits (1.63 > 1.5)

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. Bent County is entirely located within the Plains Region so an exponent (x) of 0.40 was 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 flows from the Arkansas River at Catlin Dam near Fowler Gage to all downstream river segments above the confluence with the Purgatoire River. The projection was also used for Horse Creek and the Purgatoire River for the Zone A segments on those reaches.

For the Zone AE sections of the Purgatoire and Arkansas Rivers, the gages are located in the middle of both stream sections with the reach lengths being short compared to the overall basin size so no projection was made, the gage flows were applied directly to the reaches.

Regression Equation Methodology

The regression equation method was used for all Zone A streams in Bent County. The regression equations are taken from the 2016 USGS report for the Plains and Foothills hydraulic regions and from the 2098 USGS report for the Rio Grande hydraulic regions 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. StreamStats allows the user to obtain streamflow statistics for both gaged and ungaged sites by selecting a specific stream location on a map interface. If user selects the location of a USGS streamgage, the user will receive previously published information for the streamgage from a database. If the location of interest lacks a streamgage, StreamStats delineates the basin upstream from the selected location, computes basin and climatic characteristics, and provides estimates of the streamflow statistics using the latest regional regression equations.

Flow change locations along each stream were delineated at regular intervals from the outlet up the streams. A flow change location was determined by finding the location on the stream where an approximate 8% reduction in the 100-year peak flow occurs compared to the outlet. From the first point after the outlet on, the user delineated up the stream until an approximate 10%

reduction in the 100-year peak flow from the previously determined point was found and determined to be the next flow change location.

Bent County is split between the Plains, Rio Grande and the Foothills Regions. The regression equations for each respective region are shown in Figure 2, Figure 3, and Figure 4 below.

Peak-Streamflow Equations for the Plains Hydrologic Region

Generalized-least squares regression, 99 streamgages

A, drainage area in square miles; S, mean basin slope in percent; C, amount of clay in basin in percent; $Q_{0.5}$, $Q_{0.2}$, $Q_{0.1}$, $Q_{0.04}$, $Q_{0.02}$, $Q_{0.01}$, $Q_{0.005}$, $Q_{0.002}$, 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: 0.26–3,560 square miles, S: 0.41–21.9 percent, C: 5.20–38.5 percent

$Q_{0.5} = 10^{-1.033} A^{0.378} S^{0.683} C^{1.742}$ $SEP = 131$, pseudo$R^2 = 49$, $SME = 126$,

$Q_{0.2} = 10^{-0.934} A^{0.385} S^{0.652} C^{2.046}$ $SEP = 102$, pseudo$R^2 = 57$, $SME = 98$,

$Q_{0.1} = 10^{-0.877} A^{0.390} S^{0.640} C^{2.190}$ $SEP = 103$, pseudo$R^2 = 58$, $SME = 98$,

$Q_{0.04} = 10^{-0.797} A^{0.396} S^{0.621} C^{2.329}$ $SEP = 113$, pseudo$R^2 = 55$, $SME = 107$,

$Q_{0.02} = 10^{-0.728} A^{0.399} S^{0.606} C^{2.408}$ $SEP = 123$, pseudo$R^2 = 53$, $SME = 117$,

$Q_{0.01} = 10^{-0.654} A^{0.403} S^{0.593} C^{2.470}$ $SEP = 136$, pseudo$R^2 = 50$, $SME = 129$,

$Q_{0.005} = 10^{-0.577} A^{0.407} S^{0.581} C^{2.518}$ $SEP = 150$, pseudo$R^2 = 48$, $SME = 142$, and

$Q_{0.002} = 10^{-0.473} A^{0.412} S^{0.567} C^{2.567}$ $SEP = 170$, pseudo$R^2 = 44$, $SME = 160$.

Figure 2 – Peak Streamflow Equations for the Plains Hydrologic Region.
[SEP, standard error prediction; SME standard model error]

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 3 – Peak Streamflow Equations for the Rio Grande Hydrologic Region
[SEP, standard error prediction; SME standard model error]

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

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

Figure 4 – Peak Streamflow Equations for the Foothills Hydrologic Region

[SEP, standard error prediction; SME standard model error]

Most of the Zone A streams in Bent County are tributaries to the Arkansas River. Watersheds for these tributaries are delineated by specifying drainage points at tributaries just upstream of their confluences with Arkansas River in StreamStats. In many cases to be conservative, the highest flows obtained from within the basin were applied to the entire reach. In most cases, the highest flows were at the bottom of the reach, but in some cases, flows from the middle of the reach were higher than the other areas. This was attributed to the variability of the amount of clay in the basin. This variable varied widely, especially in the smaller basins and caused continuity issues within the basin. To remedy this issue, the highest flows from a variety of locations within the basin were applied to the entire basin. Table 4 shows a summary of the regression equation results as well as the error bounds for the expected values. The drainage areas listed reflect the location of the point, however the peak discharges listed reflect the highest flows on the reach being applied. The StreamStats reports for the scoped approximate streams are included in Appendix B.

Table 4 – Regression Analysis Parameters and Results

Location	Drainage Area (mi^2)	Peak Discharges (cfs)					
		10%	4%	2%	1%	1% Plus	0.2%
Adobe Creek/Reach 1- Confluence of Arkansas River	697	3,370 (0 – 6840) 103% Error	6,660 (0 – 14200) 113% Error	10,300 (0–23,000) 123% Error	15,400 (0 – 36,300) 136% Error	36,300	33,900 (0 – 91,500) 170% Error

Location	Drainage Area (mi²)	Peak Discharges (cfs)					
		10%	4%	2%	1%	1% Plus	0.2%
Adobe Creek/Reach 1-North of CO-194	694	3,370 (0 – 6840) 103% Error	6,660 (0 – 14200) 113% Error	10,300 (0–23,000) 123% Error	15,400 (0 – 36,300) 136% Error	36,300	33,900 (0 – 91,500) 170% Error
Adobe Creek/Reach 2-East of CR-5.5 and South of Dawn Reservoir	694	3,370 (0 – 6840) 103% Error	6,660 (0 – 14200) 113% Error	10,300 (0–23,000) 123% Error	15,400 (0 – 36,300) 136% Error	36,300	33,900 (0 – 91,500) 170% Error
Adobe Creek/Reach 2-Noth of Fort Lyon Canal Rd and East of County Road 6.5	678	3,360 (0 – 6820) 103% Error	6,650 (0 – 14200) 113% Error	10,300 (0–23,000) 123% Error	15,300 (0 – 36,100) 136% Error	36,100	33,800 (0 – 91,300) 170% Error
Arkansas River/Trib 1-Confluence with Arkansas River	6.21	504 (0 – 1020) 103% Error	914 (0 – 1950) 113% Error	1350 (0 – 3010) 123% Error	1910 (0 – 4510) 136% Error	4510	3830 (0 – 10300) 170% Error
Arkansas River/Trib 1-Trib inlet south of County Rd. Y and East of Otero and Bent County border	0.11	504 (0 – 1020) 103% Error	914 (0 – 1950) 113% Error	1350 (0 – 3010) 123% Error	1910 (0 – 4510) 136% Error	4510	3830 (0 – 10300) 170% Error
Caddoa Creek-Confluence with Arkansas River North of CR GG and East of CR 25.75	174	1760 (0 – 3570) 103% Error	3220 (0 – 6860) 113% Error	4770 (0 – 10600) 123% Error	6830 (0 – 16100) 136% Error	16100	14000 (0 – 37800) 170% Error
Caddoa Creek-Confluence with Arkansas River East of CR 23 North of CR Y	149	1760 (0 – 3570) 103% Error	3220 (0 – 6860) 113% Error	4770 (0 – 10600) 123% Error	6830 (0 – 16100) 136% Error	16100	14000 (0 – 37800) 170% Error
Gageby Creek – Within John Martin Reservoir	86.4	1040 (0 – 2110) 103% Error	2000 (0 – 4260) 113% Error	3050 (0 – 6800) 123% Error	4470 (0 – 10500) 136% Error	10500	9540 (0 – 25800) 170% Error
Gageby Creek – Mid-Basin	74.4	953 (0 – 1940) 103% Error	1830 (0 – 3900) 113% Error	2780 (0 – 6200) 123% Error	4080 (0 – 9630) 136% Error	9630	8700 (0 – 23500) 170% Error
Graveyard Creek – Confluence with the Arkansas River	20.2	749 (0 – 1520) 103% Error	1420 (0 – 3020) 113% Error	2140 (0 – 4770) 123% Error	3110 (0 – 7340) 136% Error	7340	6510 (0 – 17600) 170% Error

Location	Drainage Area (mi²)	Peak Discharges (cfs)					
		10%	4%	2%	1%	1% Plus	0.2%
Graveyard Creek – North of confluence with the Arkansas River and South of HWY 50	15.3	690 (0 – 1400) 103% Error	1310 (0 – 2790) 113% Error	1970 (0 – 4340) 123% Error	2860 (0 – 6750) 136% Error	6750	5980 (0 – 16100) 170% Error
Graveyard Creek – North of CO-196 and East of CR-32	9.11	617 (0 – 1250) 103% Error	1160 (0 – 2470) 113% Error	1760 (0 – 3920) 123% Error	2540 (0 – 5990) 136% Error	5990	5290 (0 – 14300) 170% Error
Graveyard Creek – North of CO-NN and East of CR-32	6.86	565 (0 – 1150) 103% Error	1070 (0 – 2280) 113% Error	1610 (0 – 3590) 123% Error	2330 (0 – 5500) 136% Error	5500	4840 (0 – 13100) 170% Error
Graveyard Creek – South of Detention Pond East and West of Fort Lyon Canal Rd. bend	5.53	505 (0 – 1030) 103% Error	952 (0 – 2030) 113% Error	1440 (0 – 3210) 123% Error	2080 (0 – 4910) 136% Error	4910	4320 (0 – 11700) 170% Error
Graveyard Creek – Inlet of detention pond East and West of Fort Lyon Canal Rd. bend	1.01	254 (0 – 516) 103% Error	474 (0 – 1010) 113% Error	712 (0 – 1590) 123% Error	1020 (0 – 2410) 136% Error	2410	2100 (0 – 5670) 170% Error
Limestone Creek – Confluence with the Arkansas	31.4	1030 (0 – 2090) 103% Error	1950 (0 – 4150) 113% Error	2940 (0 – 6560) 123% Error	4280 (0 – 10100) 136% Error	10100	8960 (0 –24200) 170% Error
Limestone Creek – South of the Fort Lyon Canal bend	19.6	1000 (0 – 2030) 103% Error	1890 (0 – 4030) 113% Error	2850 (0 – 6360) 123% Error	4130 (0 – 9750) 136% Error	9750	8610 (0 – 23200) 170% Error
Limestone Creek – South of the Fort Lyon Canal bend	11.2	801 (0 – 1630) 103% Error	1510 (0 – 3220) 113% Error	2270 (0 – 5060) 123% Error	3280 (0 – 7740) 136% Error	7740	6810 (0 – 18400) 170% Error
Limestone Creek – East of CR 30 North of CR 31	9	712 (0 – 1450) 103% Error	1340 (0 – 2850) 113% Error	2020 (0 – 4500) 123% Error	2920 (0 – 6890) 136% Error	6890	6040 (0 – 16300) 170% Error
Limestone Creek – East of CR 30	6.52	615 (0 – 1250) 103% Error	1160 (0 – 2470) 113% Error	1740 (0 – 3880) 123% Error	2510 (0 – 5920) 136% Error	5920	5190 (0 – 14000) 170% Error
McRaeArroyo – Within John Martin Reservoir	12.2	745 (0 – 1510) 103% Error	1400 (0 – 2980) 113% Error	2110 (0 – 4710) 123% Error	3040 (0 – 7170) 136% Error	7170	6290 (0 – 17000) 170% Error

Location	Drainage Area (mi²)	Peak Discharges (cfs)					
		10%	4%	2%	1%	1% Plus	0.2%
McRaeArroyo – Below Fort Lyon Canal Rd.	0.97	745 (0 – 1510) 103% Error	1400 (0 – 2980) 113% Error	2110 (0 – 4710) 123% Error	3040 (0 – 7170) 136% Error	7170	6290 (0 – 17000) 170% Error
Mud Creek – Confluence with the Arkansas River	195	1870 (0 – 3800) 103% Error	3450 (0 – 7350) 113% Error	5120 (0 – 11400) 123% Error	7350 (0 – 17300) 136% Error	17300	15100 (0 – 40800) 170% Error
Mud Creek – North of CR CC and West of CR 28	177	1870 (0 – 3800) 103% Error	3450 (0 – 7350) 113% Error	5120 (0 – 11400) 123% Error	7350 (0 – 17300) 136% Error	17300	15100 (0 – 40800) 170% Error
Powers Arroyo – Confluence with Arkansas River	54.5	921 (0 – 1870) 103% Error	1760 (0 – 3750) 113% Error	2670 (0 – 5950) 123% Error	3910 (0 – 9230) 136% Error	9230	8290 (0 – 22400) 170% Error
Powers Arroyo- East of CR 27 3/10	39.9	921 (0 – 1870) 103% Error	1760 (0 – 3750) 113% Error	2670 (0 – 5950) 123% Error	3910 (0 – 9230) 136% Error	9230	8290 (0 – 22400) 170% Error
Powers Arroyo – South of US-50 and East of CR 26.5	29.1	822 (0 – 1670) 103% Error	1570 (0 – 3340) 113% Error	2380 (0 – 5310) 123% Error	3470 (0 – 8190) 136% Error	8190	7340 (0 – 19800) 170% Error
Powers Arroyo – North of Fort Lyon Canal Rd. and South of CR 23.5	20.9	705 (0 – 1430) 103% Error	1340 (0 – 2850) 113% Error	2040 (0 – 4550) 123% Error	2980 (0 – 7030) 136% Error	7030	6290 (0 – 17000) 170% Error
Powers Arroyo – North of CR PP	19.5	705 (0 – 1430) 103% Error	1340 (0 – 2850) 113% Error	2040 (0 – 4550) 123% Error	2980 (0 – 7030) 136% Error	7030	6290 (0 – 17000) 170% Error
Powers Arroyo/Trib 1 – Confluence with Powers Arroyo	9.57	528 (0 – 1070) 103% Error	1000 (0 – 2130) 113% Error	1520 (0 – 3390) 123% Error	2210 (0 – 5220) 136% Error	5220	4640 (0 – 12500) 170% Error
Powers Arroyo/Trib 1 – West of confluence with Powers Arroyo and South of US-50	9.24	517 (0 – 1050) 103% Error	982 (0 – 2090) 113% Error	1490 (0 – 3320) 123% Error	2170 (0 – 5120) 136% Error	5120	4540 (0 – 12300) 170% Error
Purgatoire River/Trib 1- Confluence with the Purgatoire River	13.9	344 (0 – 698) 103% Error	648 (0 – 1380) 113% Error	979 (0 – 2180) 123% Error	1420 (0 – 3350) 136% Error	3350	2990 (0 – 8070) 170% Error

Location	Drainage Area (mi²)	Peak Discharges (cfs)					
		10%	4%	2%	1%	1% Plus	0.2%
Purgatoire River/Trib 1-West of CR-8	13	344 (0 – 698) 103% Error	648 (0 – 1380) 113% Error	979 (0 – 2180) 123% Error	1420 (0 – 3350) 136% Error	3350	2990 (0 – 8070) 170% Error
Rule Creek – John Martin Reservoir	493	2840 (0 – 5770) 103% Error	5110 (0 – 10900) 113% Error	7460 (0 – 16600) 123% Error	10600 (0 – 25000) 136% Error	2500	21400 (0 – 57800) 170% Error
Rule Creek – North of CR-BB and West of CR-19	473	2840 (0 – 5770) 103% Error	5110 (0 – 10900) 113% Error	7460 (0 – 16600) 123% Error	10600 (0 – 25000) 136% Error	2500	21400 (0 – 57800) 170% Error
Tarbox Arroyo – Confluence with Purgatoire River	20.3	962 (0 – 1950) 103% Error	1820 (0 – 3880) 113% Error	2750 (0 – 6230) 123% Error	3990 (0 – 9420) 136% Error	9420	8320 (0 – 22500) 170% Error
Tarbox Arroyo – South of confluence with Purgatoire River East of CR-7 North of CR-Y	19.8	962 (0 – 1950) 103% Error	1820 (0 – 3880) 113% Error	2750 (0 – 6230) 123% Error	3990 (0 – 9420) 136% Error	9420	8320 (0 – 22500) 170% Error
Unnamed Stream – North of Cord Railroad on CR-1	375	1570 (0 – 3190) 103% Error	3050 (0 – 6500) 113% Error	4690 (0 – 10500) 123% Error	6940 (0 – 16400) 136% Error	16400	15100 (0 – 40800) 170% Error
Unnamed Stream – South of CR VV West of CR-35	346	1570 (0 – 3190) 103% Error	3050 (0 – 6500) 113% Error	4690 (0 – 10500) 123% Error	6940 (0 – 16400) 136% Error	16400	15100 (0 – 40800) 170% Error
West Limestone Creek – Confluence with Limestone Creek	8.42	678 (0 – 3180) 103% Error	1270 (0 – 2710) 113% Error	1910 (0 – 4260) 123% Error	2750 (0 – 6490) 136% Error	6490	5680 (0 – 15300) 170% Error
West Limestone Creek – West of CR-30	6.92	678 (0 – 3180) 103% Error	1270 (0 – 2710) 113% Error	1910 (0 – 4260) 123% Error	2750 (0 – 6490) 136% Error	6490	5680 (0 – 15300) 170% Error
West Limestone Creek – West of CR-30	5.95	607 (0 – 3190) 103% Error	1140 (0 – 2430) 113% Error	1710 (0 – 3810) 123% Error	2470 (0 – 5830) 136% Error	5830	5090 (0 – 13700) 170% Error
West Limestone Creek – West of CR-30	5.79	584 (0 – 3190) 103% Error	1100 (0 – 2340) 113% Error	1650 (0 – 3680) 123% Error	2380 (0 – 5620) 136% Error	5620	4910 (0 – 13300) 170% Error
West Limestone Creek – West of CR-30	3.81	584 (0 – 3190) 103% Error	1100 (0 – 2340) 113% Error	1650 (0 – 3680) 123% Error	2380 (0 – 5620) 136% Error	5620	4910 (0 – 13300) 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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