Final Report

Boulder Creek Hydrologic Analysis

Phase 2: Boulder Creek above St. Vrain Creek

Prepared for

Colorado Department of Transportation

June 10, 2015

CH2MHILL®

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Tables

Acronyms and Abbreviations

AMC	Antecedent Moisture Condition
AWA	Applied Weather Associates
CDOT	Colorado Department of Transportation
CDWR	Colorado Division of Water Resources
cfs	cubic feet per second
CN	curve number
CWCB	Colorado Water Conservation Board
DARF	Depth-Area Reduction Factor
DRCOG	Denver Regional Council of Governments
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GIS	geographic information system
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
LiDAR	Light Detection and Ranging
NED	National Elevation Dataset
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
QC	Quality Control
SCS	Soil Conservation Service
SPAS	Storm Precipitation Analysis System
SWMM	Storm Water Management Model
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

I hereby affirm that this report and hydrologic analysis for Boulder Creek was prepared by me, or under my direct supervision, for the owners thereof, in accordance with the current provisions of the *Colorado Floodplain and Stormwater Criteria Manual*, and approved variances and exceptions thereto.

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Executive Summary

In late summer 2013, the Colorado Front Range experienced an extensive rainstorm event spanning approximately 10 days from September 9 to September 18. The event generated widespread flooding as the long duration storm saturated soils and increased runoff potential. Flooding resulted in substantial erosion, bank widening, and realigning of stream channels; transport of mud, rock, and debris; failures of dams; landslides; damage to roads, bridges, utilities, and other public infrastructures; and flood impacts to many residential and commercial structures. Ten fatalities were attributed to the floods.

During and immediately following the rainstorm event, the Colorado Department of Transportation (CDOT) engaged in a massive flood response effort to protect the traveling public, rebuild damaged roadways and bridges to reopen critical travel corridors, and engage in assessments and analyses to guide longer-term rebuilding efforts. As part of this effort, CDOT collaborated with the Colorado Water Conservation Board (CWCB) to initiate hydrologic analyses in several key river systems impacted by the floods. The work was contracted to three consultant teams led by the following firms:

Boulder Creek, Little Thompson River	CH2M HILL
Big Thompson River, St. Vrain Creek, Lefthand Creek	Jacobs
Coal Creek, South Platte River	URS

The purpose of the analyses is to ascertain the approximate magnitude of the September flood event in key locations throughout the watershed and to prepare estimates of peak discharge that can serve to guide the design of permanent roadway and other infrastructure improvements along the impacted streams. These estimates of peak discharges for various return periods will be shared with local floodplain administrators for their consideration in revising or updating any current regulatory discharges.

The primary tasks of the hydrologic analyses include the following:

1. Estimate peak discharges that were believed to have occurred during the flood event at key locations along the study streams. Summarize these discharges along with estimates provided by others in comparison to existing regulatory discharges. Document the approximate return period associated with the September flood event based on current regulatory discharges.
2. Prepare rainfall-runoff models of the study watersheds, input available rainfall data representing the September rainstorm, and calibrate results to provide correlation to estimated peak discharges.
3. Prepare updated flood frequency analyses using available gage data and incorporate the estimated peak discharges from the September event.
4. Use rainfall-runoff models to estimate predictive peak discharges for a number of return periods based on rainfall information published by the National Oceanic and Atmospheric Administration (NOAA) (*NOAA Atlas 14*, Volume 8, Updated 2013 [NOAA, 2013]). Compare results to updated flood frequency analyses and unit discharge information and calibrate as appropriate.

The hydrologic analyses were divided into two phases of work. Phase 1 focused on the mountainous areas in the upper portion of the watersheds, extending from the upper divides of the Big Thompson River, Little Thompson River, St. Vrain Creek, Lefthand Creek, Coal Creek, and Boulder Creek watersheds to the mouth of their respective canyons. The Phase 1 analyses have been documented in six reports with the following titles and dates:

1. Hydrologic Evaluation of the Big Thompson Watershed, August 2014
2. Little Thompson River Hydrologic Analysis Final Report, August 2014
3. Hydrologic Evaluation of the St. Vrain Watershed, August 2014
4. Hydrologic Evaluation of the Lefthand Creek Watershed, August 2014, revised December 2014
5. Coal Creek Hydrology Evaluation, August 2014
6. Boulder Creek Hydrologic Evaluation Final Report, August 2014

Copies of these Phase 1 reports can be downloaded from the CWCB website at the following link:

http://cwcb.state.co.us/water-management/flood/pages/2013floodresponse.aspx

Phase 2 of the hydrologic analyses focused on the plains region of the Big Thompson River, Boulder Creek, Little Thompson River, and St. Vrain Creek from the downstream limit of the Phase 1 studies at the mouth of the canyons to the downstream confluences of the watersheds with their respective receiving streams. The hydrologic analyses were contracted to two consultant teams led by the following firms:

Boulder Creek, Little Thompson River	CH2M HILL
Big Thompson River, St. Vrain Creek	Jacobs

Phase 2 hydrologic analyses for each of the watersheds included flows from the original Phase 1 watersheds, as appropriate: the downstream reach of the Big Thompson River was modeled to include flows from the Little Thompson River. Likewise, the downstream reach of St. Vrain Creek included flows from Lefthand Creek and Boulder Creek, with Boulder Creek, in turn, receiving flows from Coal Creek.

This report documents the hydrologic evaluation for Boulder Creek from the Canyon Mouth to the confluence with St. Vrain Creek. An overview map of the study area is provided as **Figure ES-1**.

As part of the evaluation, CH2M HILL developed a rainfall-runoff model to transform the recorded rainfall to stream discharge using the U.S. Army Corps of Engineers' (USACE's) HEC-HMS hydrologic model (USACE, 2010a). The hydrologic model was calibrated to observed September 2013 peak discharges and timing through adjustment of model input values that represent land cover, soil conditions, subbasin runoff response timing, and channel roughness. The calibration of these parameters is common because they take into account the timing of tributary and mainstem runoff responses, vegetative cover, soil structure, topography, land use history, and other considerations important in estimating hydrologic responses. In addition to closely evaluating land use cover and runoff response times, research was also completed to determine the impact of Gross, Barker, Baseline, and Valmont/Leggett/Hillcrest Reservoirs on flows during the September 2013 storm event. The effect of each of these reservoirs was evaluated and included in the calibrated model to avoid under-calibration. **Table ES-1** provides a comparison of modeled peak discharges to peak discharges observed during the September 2013 event along Boulder Creek.

TABLE ES-1
Comparison of Modeled Discharges to Observed Discharges on Boulder Creek [a]

Location	Calibration Data Source	Observed Discharge (cfs)	Modeled Discharge (cfs)	Percent Difference
Boulder Creek near Orodell	Jarrett, in press	2,020	1,738	-14.0%
	CDWR Gage	1,720	1,738	+1.0%
Boulder Creek at Broadway	CDWR Gage	4,965	5,140	+3.5%
Boulder Creek at 28th Street	CWCB	5,300	5,060	-4.5%
Boulder Creek at Valmont Road	URS, 2015	5,700	6,510	+14.2%
Boulder Creek at 75th Street	USGS Gage	8,400	9,830	+17.0%
Boulder Creek at U.S. Hwy 287	URS, 2015	9,000	10,400	+15.5%
Boulder Creek at St. Vrain Creek	USGS Gage	N/E	16,100	-6.1% [b]

[a] Comparison of Modeled Discharges to Observed Discharges on Boulder Creek tributaries provided as Table 12.
[b] Based on comparison of 8,910 cfs daily average discharge at the gage and modeled daily average discharge of 8,370 cfs.

The calibrated model was then modified to develop a predictive hydrologic model to estimate the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges (referred to as the 10-, 25-, 50-, 100-, and 500-year recurrence interval, respectively, for purposes of this Executive Summary[1]) based on a 24-hour Soil

[1] While the term "100-year event" and similar terminology are used in this Executive Summary to better relate the magnitude of the September 2013 event to the general public, it is not an event that occurs explicitly once every 100 years, but rather an event that has a 1 percent chance of occurring in any given year. Thus, a 100-year event could happen in back-to-back years, or not at all for 200 years. For this reason, the current FEMA

Conservation Service (SCS) (now the Natural Resources Conservation Service [NRCS]) Type II Storm and recently released *NOAA Atlas 14* (NOAA, 2013) rainfall values (see **Table ES-2**). While the NRCS has developed new Atlas 14 temporal distributions for the Ohio River Basin and neighboring states, the NRCS Type II temporal distribution is still recommended in the Volume 8 area of Atlas 14 (Midwestern States), where Boulder Creek is located. The predictive hydrologic model was adapted from the calibrated hydrologic model by conservatively disregarding non-dedicated flood storage in Barker, Gross, Baseline, and Valmont-Leggett-Hillcrest Reservoirs and other incidental attenuation effects observed during the September 2013 that could not be relied upon to attenuate flows in the event of a future storm. The modeled discharges were then compared to previous and concurrent alternative estimates of annual chance peak discharges. The assumptions and limitations of the various methodologies were closely reviewed, compared, and contrasted. Considering potentially outdated and un-validated methodologies used in previous studies, the impacts of flow regulation on gage records, and review of current modeling methodology by a team of local engineers and project sponsors, the predictive model developed as part of the current study is proposed as the appropriate model to estimate high-flow hydrology and the recurrence interval of the September 2013 event along Boulder Creek.

Using the predictive hydrologic model to estimate high-flow hydrology along Boulder Creek presented in **Table ES-2**, the peak discharges observed along Boulder Creek during the September 2013 storm event had an estimated recurrence interval that varied from slightly less than a 50-year recurrence interval upstream of Coal Creek near U.S. Highway 287 to approximately a 70-year recurrence interval at the mouth of Boulder Creek, near St. Vrain. This information is also provided graphically in **Figure ES-2**. Simplifying the interpretation of **Table ES-2** and **Figure ES-2**, the September 2013 event was, generally, most comparable to a 50-year recurrence interval event between the mouth of Boulder Canyon, west of the City of Boulder, and the mouth of Boulder Creek at St. Vrain Creek.

TABLE ES-2
Recurrence Interval Estimate of the September 2013 Event

Location	Observed Discharge (cfs)	Modeled Annual Chance Peak Discharge (cfs)					Estimated Recurrence Interval (yr)
		10 Percent	4 Percent	2 Percent	1 Percent	0.2 Percent	
Boulder Creek at Broadway	4,965 [a]	1,450	2,900	4,570	6,770	14,200	~ 50
Boulder Creek at 28th Street	5,300 [b]	1,490	2,950	4,640	6,860	14,400	50 to 100
Boulder Creek at Valmont Road[c]	5,700 [d]	1,630	3,320	5,270	7,490	15,500	~ 50
Boulder Creek at 75th Street	8,400 [e]	2,760	5,690	8,780	12,400	25,200	~ 50
Boulder Creek at U.S. Hwy 287	9,000 [d]	3,070	6,410	9,840	13,500	27,100	~ 50
Boulder Creek at Mouth	16,100 [f]	4,790	9,000	13,700	19,000	37,300	50 to 100

[a] Per Colorado Division of Water Resources (CDWR) BOCOBOCO Gage, Boulder Creek at Boulder.

[b] Per *Rainfall-Runoff Analysis for September 2013 Flood in the City of Boulder, Colorado* (Wright Water Engineers, 2014).

[c] Listed as Valmont Drive in the Boulder County Flood Insurance Study (FEMA, 2012).

[d] Per "Estimated Peak Discharges – Phase 2 (Memorandum)" (URS, 2015).

[e] Per U.S. Geological Survey (USGS) Gage 06730200, Boulder Creek at N. 75th Street.

[f] Per Calibrated Hydrologic Model.

Notes:

cfs = cubic feet per second

N/E = No estimate

standard is to refer to the "100-year event" as the "1-percent annual chance event" and it is important for the reader to note that the labeling of the September 2013 event as a 50-year event, or other recurrence interval, does not preclude the future occurrence of a similar, or greater, flood in the that corresponding timeframe.

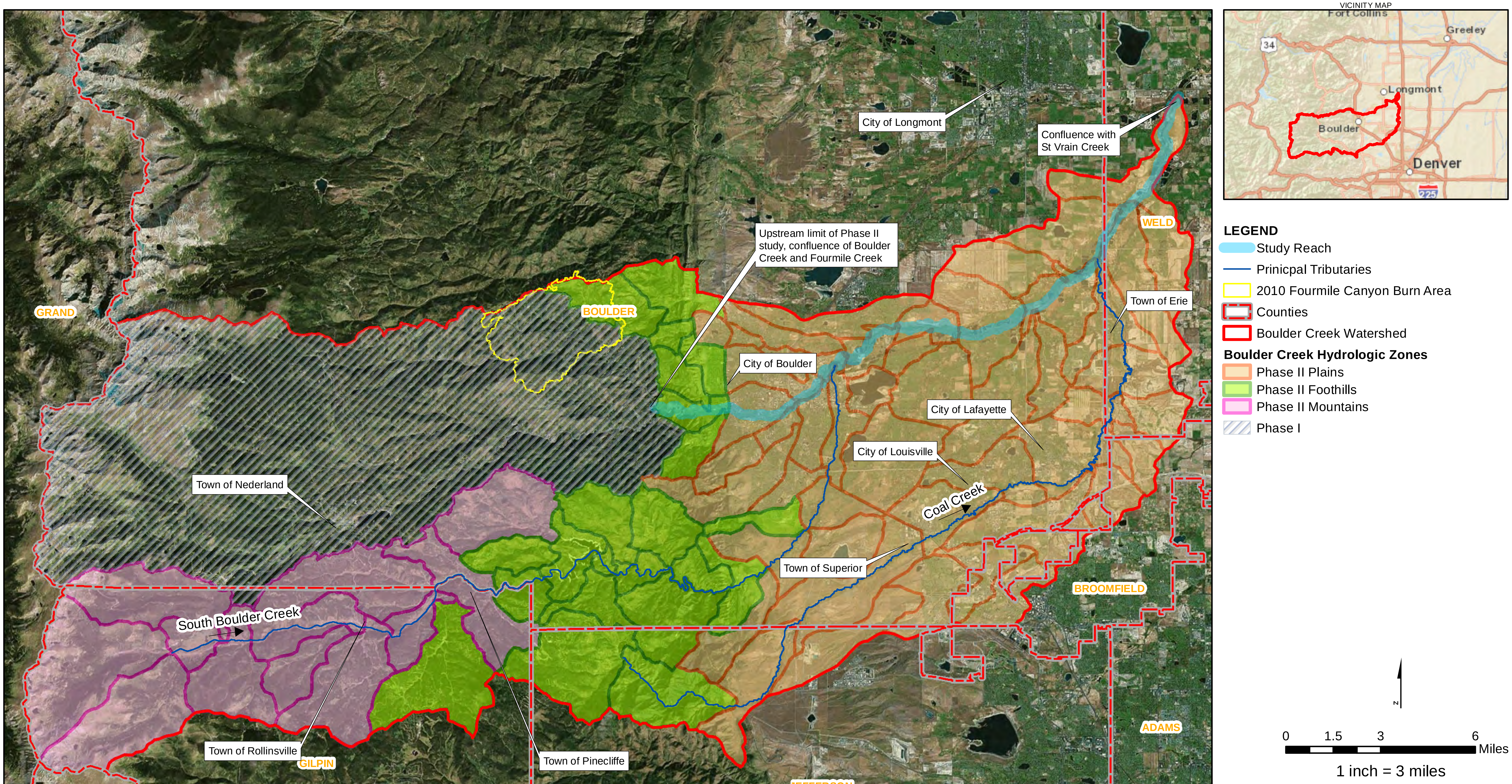
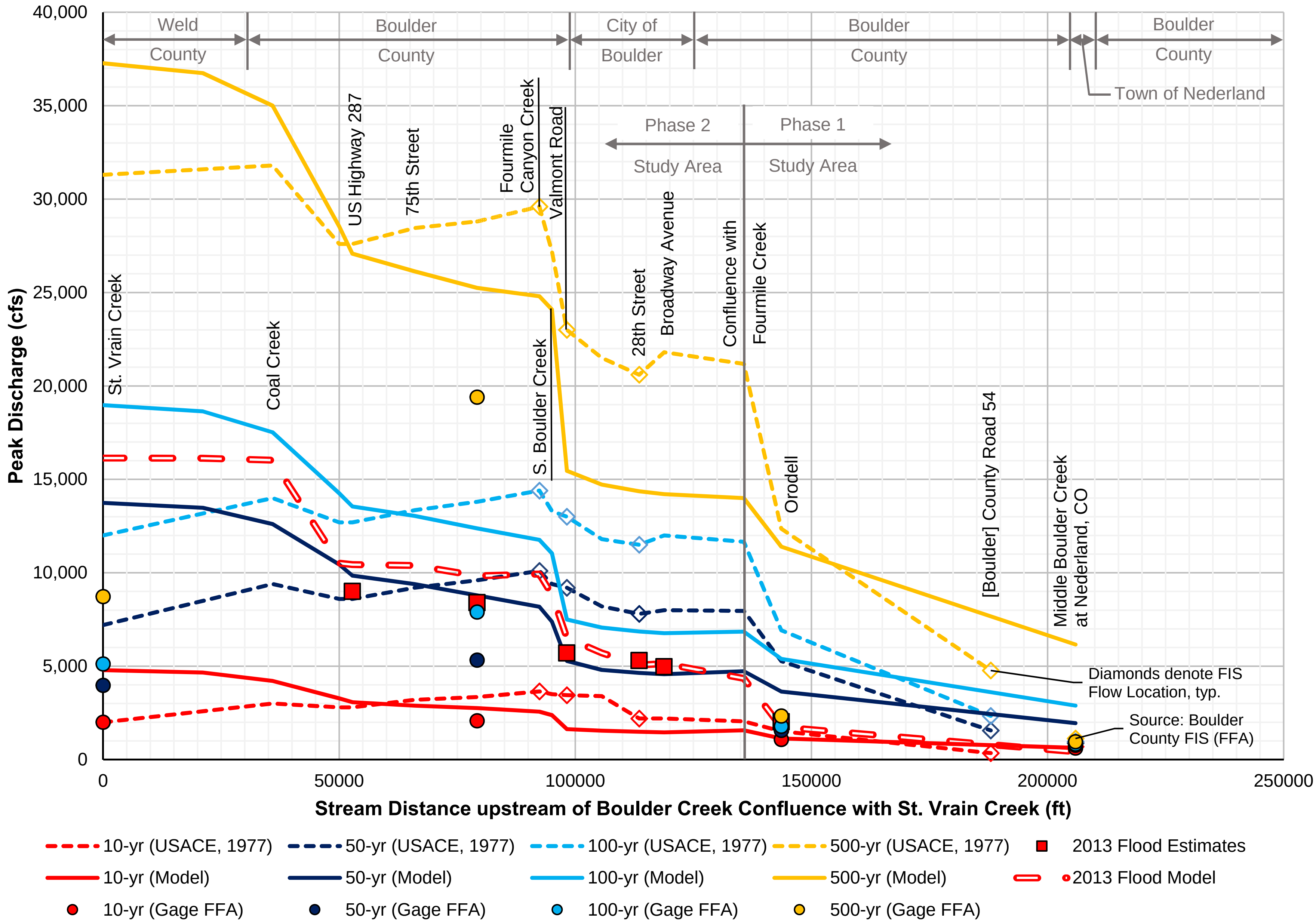


FIGURE ES-1
Vicinity and Watershed Map

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.

Figure ES-2 - Boulder Creek Peak Discharge Profiles



Note: FIS values derived from USACE, 1977 study, unless noted otherwise.

1.0 Purpose and Objective

1.1 Background

In September 2013, the Colorado Front Range experienced an intense, widespread rainfall event that resulted in damaged infrastructure and property loss in multiple watersheds. CH2M HILL was retained by the Colorado Department of Transportation (CDOT) and Colorado Water Conservation Board (CWCB) to evaluate the hydrology of two watersheds that experienced flooding and damage as a part of this storm event: the Little Thompson River and Boulder Creek. Each watershed was evaluated in two phases. The purpose of the Phase 1 Boulder Creek analysis was to determine the approximate magnitude of the September flood event in key locations throughout the Boulder Creek watershed and to prepare estimates of peak discharge that can serve to guide the design of permanent roadway and other infrastructure improvements along the impacted streams. Phase 2 of the Boulder Creek analysis extended the hydrologic study area to encompass the entirety of the Boulder Creek watershed above its confluence with the St. Vrain. Similar to Phase 1, the purpose of Phase 2 was to estimate peak discharges along Boulder Creek to guide the design of permanent infrastructure improvements and assess the recurrence interval of the September 2013 event.

1.2 Project Area Description

The study area of Boulder Creek watershed (comprising approximately the south half of HUC 10190005) is situated largely in southern Boulder County, with some portions of the watershed located in Gilpin, Jefferson, Weld counties. The watershed is generally bounded by the Continental Divide to the west, the Town of Ward and City of Longmont to the north, the City of Broomfield to the east, and the City of Arvada to the south. The Phase 2 study reach begins at the downstream limit of the Phase 1 study reach near Orodell, Colorado, just east of the Boulder Canyon mouth, and encompasses approximately 26 river miles of Boulder Creek through the City of Boulder and the eastern plains to the eastern edge of Longmont, Colorado, where Boulder Creek meets St. Vrain Creek (see **Figure 1** for a vicinity map of the watershed). Principal tributaries along this reach include South Boulder Creek (139 square miles) and Coal Creek (81 square miles), as identified on **Figure 1**. At its confluence with St. Vrain Creek, approximately 447 square miles of area drain to Boulder Creek.

The Phase 2 Boulder Creek watershed has been divided into three general hydrologic zones for purpose of discussion. The three zones are defined based on inferred differences in high-flow hydrology related to differences in land use, climatology, vegetative cover, and flooding history. In addition to the Phase 1 watershed, the three hydrologic zones are identified on **Figure 1** and divided to identify zones characterized as mountains, foothills, and plains. In general, high-flows on Boulder Creek transition from snowmelt-driven in mountainous areas with abundant vegetation and higher annual rainfall to rainfall-driven in lower-elevation, more arid areas. Each of these zones is described in detail in the following subsections.

1.2.1 Mountainous Areas

The headwaters of Boulder Creek, including North Boulder Creek and Middle Boulder Creek of the Phase 1 study area and South Boulder Creek of the Phase 2 study area, begin at the Continental Divide and generally include areas that are dominated by steep terrain, alpine lakes, and frequent rock outcroppings. With the exception of small mountain towns including Nederland, Rollinsville, and Pinecliffe, this area is widely undeveloped, forested land with various intermittent mountain streams primarily driven by snowmelt runoff in the spring.

While development is generally low in mountainous areas, several dams have been constructed for irrigation and water supply and generally have a marginal impact on attenuating high flows. Two exceptions are Barker Reservoir, located in the Phase 1 study area and immediately downstream of the Town of Nederland, and Gross Reservoir, located in the Phase 2 study area downstream of Pinecliffe. Constructed in the 1910s as a water supply reservoir, and owned and operated by the City of Boulder since 2002, Barker Reservoir has approximately 11,300 acre-feet of storage capacity below the spillway elevation for water supply (City of Boulder, 2013a). Similarly, Gross Reservoir is owned and operated by Denver Water for municipal water storage; completed in 1954, Gross Reservoir has 45,200 acre-feet of storage capacity (Denver Water, 2014). While neither Gross Reservoir nor Barker Reservoir are explicitly operated as flood control dams, the large storage volume available at the reservoirs has the potential to provide significant attenuation of high flows.

1.2.2 Foothill Areas

The foothill areas of Boulder Creek generally begin where the Colorado Piedmont[2] transitions to the Front Range, such as the Boulder Flatirons. The foothill areas of the Boulder Creek watershed includes Boulder Creek Canyon, the majority of Fourmile Creek, South Boulder Creek in the vicinity of Gross Reservoir, and the upper portions of Fourmile Canyon Creek, Twomile Canyon Creek, and Coal Creek. The foothill areas are, in a sense, a transition from high-elevation, rural, mountainous areas to the more densely populated Colorado Piedmont. Lower elevations and decreased annual rainfall impart a semi-arid climate on this area and vegetation transitions from evergreen forests at high elevations to sagebrush. High flows along the foothills are generally driven by rainfall events that can be orographic or convective in nature; rarely, weather systems emanating from the Gulf of Mexico have “stalled” over foothill subbasins and have driven some of the most devastating flooding witnessed along Colorado’s Front Range. In combination with decreased vegetative cover and intense rainfall, flash flooding is a primary risk along foothill streams. Considering the higher population densities along these streams, especially at the transition of these streams to the Colorado Piedmont, and these streams pose some of the greatest flood risks to residents of the Front Range.

Compounding the hydrologic threat of foothill streams is the increased risk of wildfire due to increased recreational use, drought, and challenging terrain. As an example, in 2010, the Fourmile Canyon Fire burned approximately 10 square miles of land near Salina, Colorado, before being successfully contained. Of the 10-square-mile burn area, the majority occurred within the 24-square-mile Fourmile Creek watershed, as illustrated in **Figure 1**. The fire also impacted Fourmile Canyon Creek. During the Fourmile Canyon Fire, more than 160 homes were destroyed, resulting in $217 million in insurance claims. Since 2010, new vegetation has emerged in the sub-watershed, although this area has not fully restored to pre-fire conditions.

1.2.3 Plains Area

The plains area of the Boulder Creek watershed provide a sudden change in topography as canyons in mountain and foothill areas give way to relatively open, mildly sloping terrain as Boulder Creek flows through the western-most portion of the Great Plains and the Colorado Piedmont before draining to St. Vrain Creek east of Longmont, Colorado. The plains area is extensively developed, with the cities of Boulder, Louisville, and Lafayette connected by arterial highways and separated by sub-developments, livestock pasture, and irrigated fields. Canals cross the landscape, and while they predominantly convey controlled flows within and out of the basin to reservoirs, other tributaries, and farms, they can also exacerbate flooding problems in the event a canal headgate overtops or fails during a high-flow event. Flash flooding remains a primary concern in plains areas where convective storms can turn dry washes into raging rivers in the course of an hour.

1.3 Effective Flood Insurance Studies

The Boulder Creek watershed extends across portions of four counties: Boulder, Jefferson, Weld, and Gilpin. With the exception of Gilpin County, where no Flood Insurance Study (FIS) was available on the Federal Emergency Management Agency (FEMA) Map Server for unincorporated areas, each county has its own FIS. The publication date of the most recent revision of the FIS for the other three counties are as follows: Boulder County, December 18, 2012 (FEMA, 2012); Jefferson County, February 5, 2014 (FEMA, 2014); and Weld County, September 22, 1999 (FEMA, 1999). Although no FIS exists for unincorporated areas of Gilpin

[2] A geologic term referring to an alluvial landform created at the foot of a mountain range by debris and sediments deposited by shifting streams.

County, Flood Insurance Rate Map (FIRM) panels, dated 1977, are available for Gilpin County. Relevant FIS cover pages and associated summaries of discharge along Boulder Creek and tributaries are provided in **Appendix A**.

Boulder Creek itself is a FEMA-designated Zone AE floodplain (special flood hazard area corresponding to the zone inundated by the 1 percent annual chance discharge). Boulder Creek flood hazard areas are delineated on several FIRM, of which there are 20 panels within Boulder County and two panels within Weld County. FEMA FIRM documentation for Boulder Creek is presented in **Appendix A**.

Since the publication of the most recent FIS, several LOMRs have also been approved and adopted by FEMA for Boulder Creek and/or its tributaries. While two LOMRs were issued revising the hydrology of Boulder Creek, these changes were limited to conditions where channel topography resulted in a split flow condition and a portion of the flow in Boulder Creek was divided to a floodplain channel. While the FEMA hydrology was changed, this change was a result of hydraulic conditions rather than a re-study of Boulder Creek hydrology. Therefore, as documented in the current FISs, the current effective hydrology along the study reach is based on a 1977 hydrologic study prepared by the U.S. Army Corps of Engineers (USACE) (FEMA, 1999; FEMA, 2012; FEMA, 2014).

1.4 Mapping

Elevation data for the study area were derived from the U.S. Geological Survey (USGS) National Elevation Dataset (NED), which provides 1/3 arc-second (approximately 30 feet) coverage across the Boulder Creek watershed (USGS, 2013). NED raster tile ID “n40w106” and “n41w106” covered the entirety of the watershed. In addition to the NED dataset, 2013 Light Detection and Ranging (LiDAR) data, in LAS format, was provided by the project sponsors for use on this project. The LiDAR survey was sponsored by FEMA and collected after the September 2013 event; thus, it includes any horizontal channel or floodplain changes that may have occurred during the September 2013 event (FEMA, 2013a). Both the NED and LiDAR data were converted to the NAVD 88 US Survey Foot vertical datum and the NAD 83 Colorado State Plane Central (FIPS 0502) US Survey Foot horizontal datum used in the study. Aerial photography (2012) from the Environmental Systems Research Institute (ESRI) ArcGIS online data catalog was used for the background imagery (ESRI, 2013).

1.5 Data Collection

For this analysis, CH2M HILL collected a range of data covering the Boulder Creek watershed, including recent hydrologic studies, gage data, and hydrologic parameters. Detailed explanations of how the data were used during this analysis is described in the subsequent sections. The primary references used for this study are documented in **Table 1**.

1.6 Flood History

1.6.1 Historical Flood Events

The USGS and Colorado Department of Water Resources (CDWR) maintain several stream gages along Boulder Creek and its tributaries. Available gage records, summarized in **Table 2**, extend back to 1889 with a gage on Boulder Creek near Boulder operated intermittently by the USGS from 1889 to 1908 while continuous gage records extend back to 1907 and 1908 for Middle Boulder Creek at Nederland and Boulder Creek at Orodell. Reviewing the long gage record of Boulder Creek at Orodell, just upstream of Fourmile Creek and the City of Boulder, the two largest peak discharges on record prior to the September 2013 flood event occurred on June 6, 1921, and May 7, 1969, with 2,500 and 1,220 cubic feet per second (cfs) recorded at the gage, respectively. Both the 1921 and 1969 events were recorded as having been caused by large storms that generated intense rainfalls across the Boulder Creek basin (USGS, 1948 and FEMA, 2012), providing some evidence that flooding along the lower-elevation portions Boulder Creek has historically been caused by rainfall events.

TABLE 1
Data Collected for Boulder Creek

Document Type	Source	Description
Aerial Imagery	ESRI, 2011	Aerial Raster
LiDAR LAS	Federal Emergency Management Agency (sponsor), 2013a	Raw LiDAR survey data
GIS Raster	U.S. Geological Survey, 2013	Elevation data for approximately 30' by 30' grid
GIS Shapefile	U.S. Geological Survey, 2013	Land Use Cover
GIS Shapefile	U.S. Department of Agriculture, 2014	Soil Classification
Flood History	U.S. Geological Survey, 1948	*Water-Supply Paper 997: Floods in Colorado*
Flood History	Smith, 1987	*History of Floods and Flood Control in Boulder, Colorado*
Flood Frequency Analysis	Ayres Associates, 2014	Flood Frequency Analyses
Gage Data	Colorado Division of Water Resources; U.S. Geological Survey	Historical stream flow data
Hydrologic Study	U.S. Army Corps of Engineers, 1969	*Floodplain Information: Boulder Creek and South Boulder Creek, Volume II, Boulder Metropolitan Region, Colorado*
Hydrologic Study	U.S. Army Corps of Engineers, 1977	*Water and Related Land Resources Management Study, Metropolitan Denver and South Platte River and Tributaries, Colorado, Wyoming, and Nebraska, Volume V – Supporting Technical Reports Appendices, Appendix H – Hydrology* (source of most effective FEMA peak discharges)
Hydrologic Study	U.S. Army Corps of Engineers, undated	*Review Report, Boulder Creek* (details on hydrologic parameters for effective discharges)
Hydrologic Study	Anderson Consulting Engineers, 2009	*Hydrology Verification Report for Boulder Creek*
Hydrologic Study	CH2M HILL, 2014	*Final Report, Boulder Creek Hydrologic Analysis [Phase 1]*
Peak Discharge Estimates	Jarrett, in press	*Estimates of September 2013 peak discharges using indirect methods*
Peak Discharge Estimates	Wright Water Engineers, 2014	*Rainfall-Runoff Analysis for September 2013 Flood in the City of Boulder, Colorado*
Peak Discharge Estimates	URS, 2015	*Estimated Peak Discharges – Phase 2* (Memorandum)
Rainfall Data (Frequency tables)	National Oceanic and Atmospheric Administration, 2014	*NOAA Precipitation Frequency Data Server*
Rainfall Data (September 2013)	Applied Weather Associates, 2014	5-minute rainfall data at subbasin centroids from September 8, 2013, to September 18, 2013
Rainfall Data (site-specific DARF)	Applied Weather Associates, 2015	Colorado Front Range 24-Hour Rainfall Areal Reduction Factors

TABLE 2
Stream Gage Flooding History Summary

Gage Name	Gage Operator	Gage ID	Period of Record	September 2013 Peak Discharge (cfs)	Pre-2013 Historical Peak Discharge (cfs)	Date of Historical Peak Discharge
Boulder Creek near Orodell, CO	CDWR	BOCOROCO	1907 to Present	1,720	2,500	June 1921
Boulder Creek near Boulder, CO	USGS	06728000	1889 to 1892; 1895 to 1901; 1905 to 1908	N/A	1,600	June 1897
Boulder Creek at Boulder, CO	CDWR	BOCOBOCO	2004 to Present	4,965	973	July 2011
Boulder Creek at North 75th Street near Boulder, CO	USGS	06730200	1987 to Present	8,400	2,050	May 2003
Boulder Creek at Mouth near Longmont, CO	USGS	06730500	1927 to 1955; 1979 to Present	N/A	4,410	Sept. 1938
Coal Creek near Plainview, CO	CDWR	COCREPCO	1959 to 1982; 1993 to Present	N/A	2,060	May 1969
Fourmile Canyon Creek near Sunshine, CO	USGS	06730160	2012 to Present	1,090 [b]	108	July 2012
Fourmile Creek at Logan Mill Road near Crisman, CO	USGS	06727410	2010 to Present	2,040 [a]	820	July 2011
Fourmile Creek at Orodell, CO	USGS	06727500	1992 to Present	2,510 [b]	770	July 2011
Middle Boulder Creek at Nederland, CO	CDWR	BOCOMIDCO	1908 to Present	409	811	June 1914
South Boulder Creek near Pinecliffe, CO	CDWR	BOCPINCO	1979 to 1980; 2006 to 2014	781	1,150	Jun 1979
South Boulder Creek near Rollinsville, CO	USGS	06729000	1911 to 1917; 1945 to 1949	N/A	718	June 1949
South Boulder Creek below Gross Reservoir	CDWR	BOCBGRCO	1991 to Present	285	775	June 1995; May 2003
South Boulder Creek near Eldorado Springs, CO	CDWR	BOCELSCO	1991 to Present	N/A	845	June 1995

[a] Affected by debris flows.

[b] Manual measurement

Prior to the period of record for the stream gage at Orodell, several flood events were recorded in local newspapers and are summarized in **Table 3** along with descriptions of more recent flood events. Of the floods pre-dating systematic gage records on Boulder Creek, particularly damaging floods occurred in May 1876 and May 1894. Little is known about the magnitude of the 1876 flood other than what was reported in local newspapers of the time. The reports chiefly recounted the loss of rail service in the City of Boulder (USGS, 1948) and the loss of farmland in the lower reaches of Boulder Creek where flooding tributaries contributed to flood extents that were described as a “mile and a half wide” (Smith, 1987). More is known about the flood in 1894, which was reported as a general storm with rainfall depths of 8.9 inches recorded in a 60-hour period at Ward, Colorado, approximately 13 miles northwest of Boulder. While no estimates of the discharge were made at that time, the 1894 event was studied in 1912 by Metcalf & Eddy, a Boston-based consulting engineering firm that estimated a peak discharge between 9,000 and 10,000 cfs. If accurate, the peak discharge of the 1894 is the largest peak discharge recorded for Boulder Creek.

TABLE 3
Summary of Flooding Events Documented for Boulder Creek

Date	Summary of Flood Event
Spring 1844	Large storm; river bottom was said to have flooded between the bluffs for Cherry Creek and the South Platte River; flooding prevented crossing the river for 9 days.
June 1864	General storm; storm was reported to have lasted for 50 hours.
May 1867	General storm; lower Boulder Creek floodplain was said to have been a mile and a half wide.
May 21-23, 1876	General storm; “At least 4 inches of rain fell during the 24 hours, and three-fourths of an inch in 2 hours on Monday evening”; inundated farm land and disrupted rail service.
May 1885	General storm; floodplain was said to have been a mile and a half wide.
June 2, 1894	General storm; 5.75 inches of rainfall at Gold Hill (on Fourmile Creek), with 5.25 inches recorded in 2 days; “melting snow was less important a factor in causing high water in this flood than in 1921”; highway and railroad destroyed up to Fourmile Canyon; estimated flow between 9,000 and 10,000 cfs on Boulder Creek through the City of Boulder.
May 1897	General storm; Boulder Creek flow estimated at 1,000 cfs; sandbags placed in strategic areas along the creek.
June 2, 1914	1 inch of rain on North Boulder Creek watershed on significant snowpack; estimated flow of 5,000 cfs in Boulder; maximum peak discharge of 811 cfs recorded at Nederland gage.
June 21, 1921	General storm; maximum peak discharge of 2,500 cfs recorded at Orodell.
May 4-8, 1969	General storm; 9.34 inches of rain recorded near Barker Reservoir; Bear Canyon, Skunk, and Twomile Canyon Creeks overflowed their banks; streets and bridges damaged; recorded flow of 1,220 cfs at Orodell gage.

Source: USGS, 1948; Smith, 1987; FEMA, 2012.

While a review of historical flood events, summarized in **Table 3**, supports the assessment in the Boulder County FIS that identifies the principal cause of flooding in the Boulder Creek watershed as widespread rain or rain-on-snow events (FEMA, 2012), it is worth noting that several localized storms have caused damaging floods along Boulder Creek tributaries. Specifically, in 1909, a cloudburst over Twomile Canyon and Fourmile Canyon Creeks caused flooding that resulted in two fatalities (Smith, 1987). A thunderstorm again caused significant flooding in the Boulder area in 1938 when the peak discharge of South Boulder Creek was estimated as 7,390 cfs at the mouth of the canyon and contributed significant flow and flooding downstream (HDR, 2007). Although downstream flooding was noted, the historical peak discharge of 4,410 cfs measured at the gage at the Boulder Creek at Mouth gage that same year was less than half of the estimated 1894 flood upstream at the City of Boulder. Considering these records, while thunderstorms are undoubtedly a concern in the Boulder Creek watershed, the flood history of Boulder Creek would suggest that high flows are most often the result of multiple-day general storms that encompass the entire watershed and have generally occurred during the spring months, frequently coinciding with snowmelt runoff in the upper watershed.

1.6.2 September 2013

The high-flow event in September 2013 was one of only a few high-flow events on record for Boulder Creek that did not occur in the typical peak snowmelt months of May, June, and July. The days preceding the event saw record-breaking heat and high humidity throughout the Front Range of Colorado. The heat and influx of tropical moisture from the Gulf of Mexico combined over Colorado's Front Range to saturate the atmosphere and develop conditions ideal for heavy sustained rainfall.

The Boulder Creek watershed experienced rainfall from September 9, 2013, to September 16, 2013, with the maximum rainfall exceeding 1 inch per hour in several areas. As illustrated in **Figure 2**, peak rainfall intensities were observed during the late evening of September 11 and significant rainfall continued through the early morning of September 13. Rainfall intensities were generally highest near the leading edge of the Front Range with rainfall intensities up to 1.6 inches per hour observed across the City of Boulder and the maximum rainfall intensity of 2.2 inches per hour observed in the vicinity of Coal Creek near Plainview. At higher elevations towards the western portion of the watershed, peak rainfall intensities were generally on the order of 0.40 inches per hour. Further from the Front Range along the eastern portions of the watershed, rainfall intensities were on the order of 0.60 to 1.00 inches per hour.

The steady rain, which varied in intensity across the event, produced multiple runoff peaks over the 8-day period, illustrated in **Figure 2**. The period of peak rainfall, occurring late evening of September 11, caused a rapid rise in runoff along tributary streams and Boulder Creek and generated the first wave of major flooding in the watershed. A second flood wave occurred the following evening, September 12, after a separate burst of rainfall the evening of September 12. Of interest is the fact that while the peak rainfall occurred in the late evening of September 11, peak runoff occurred the following evening after the smaller September 12 rainfall. This is interpreted to be a result of the September 11 peak rainfall saturating soils in the watershed, which decreased the infiltration capacity of the soils and resulted in a greater peak discharge late evening September 12 to early morning September 13. It is also important to mention that while the September 2013 high-flow event was the event of record for many Boulder Creek stream gages downstream of the Boulder Flatirons, these discharges were significantly reduced by flow attenuation provided via Barker Reservoir on Middle Boulder Creek and Gross Reservoir on South Boulder Creek. Prior to the storm, Barker Reservoir was approximately 11 feet below capacity due to the drought conditions Colorado experienced during 2012 and 2013. Although Barker Reservoir was and is not operated as a flood control dam, City of Boulder records indicated that Barker Reservoir stored almost the entirety of runoff that occurred prior to the evening of September 15, discharging an average of 4 cfs before the storage capacity was exceeded and the emergency spillway engaged. Similarly, available storage capacity in Gross Reservoir was used to store the majority of inflows and limit downstream releases to less than 50 cfs from September 12 to September 16 when the most intense flooding occurred in the City of Boulder.

Property loss and damage to infrastructure occurred across the Front Range and, specifically, varied in magnitude across the Boulder Creek watershed. The upper portions of the Boulder Creek watershed experienced little to no flood damage. Towards the confluence with Fourmile Creek, stream bank erosion threatened private drives and some roadway infrastructure. The more severe damage occurred downstream of Fourmile Canyon and through the City of Boulder where flooding was more extensive, with several tributary streams in addition to Boulder Creek overflowing their banks and finding alternate flow paths through backyards, irrigation canals, and roadways. The magnitude of the September 2013 event led to significant impacts to irrigation infrastructure, including damage to headgates, headgate failures, and ditch sedimentation. Significant erosion also occurred along Boulder Creek and tributary streams that threatened infrastructure and resulted in the breaching of several gravel pit embankments lateral to Boulder Creek. Maps produced by the City of Boulder, provided as **Figures 3a** and **3b**, summarize the flood damage to urban stream and irrigation infrastructure, respectively, that occurred during the September 2013 flood event (City of Boulder, 2013b; City of Boulder, 2013c).

2.0 Hydrologic Analyses

When determining an appropriate method to develop watershed hydrology, it is common to compare several statistical-, physical-, and model-based estimates. Statistical-based estimates include the regression analysis of historical peak flow measurements to estimate the magnitude of infrequent high-flow events using statistical distributions; *Bulletin 17B: Guidelines for Determining Flood Flow Frequency* recommends a minimum of 10 years of data to perform such an analysis (USGS, 1982). Physical-based estimates estimate peak discharges based on watershed characteristics, high-water marks, hydraulic parameters, or other physically relevant parameters. Model-based estimates are based on conceptual or theoretical hydrologic models that estimate discharges based on watershed characteristics and meteorological conditions.

For this analysis, it was concluded that a rainfall-runoff model would be used to determine peak discharges for the 10, 4, 2, 1, and 0.2 percent annual chance events due to the availability of calibration data, general acceptance of calibrated rainfall-runoff models to predict infrequent discharges, inability of physical-based estimates to predict future flood hydrology, and limitations in statistical-based estimates, discussed in subsequent sections. Physical- and statistical-based methods discussed in the following sections of this report were used for calibration or comparison purposes to validate the rainfall-runoff model.

2.1 Previous Studies

Over the past half-decade, numerous hydrologic and hydraulic studies have been published along Boulder Creek and its tributaries. Of these studies, there have been six detailed hydrologic studies of the mainstem Boulder Creek that have estimated the magnitude of infrequent high-flow events at key locations along Boulder Creek. Subsequent Flood Hazard Area Delineations (FHAD), FISs, and other hydraulic studies and designs have referenced the hydrology estimates developed as part of these studies. **Table 4** provides a summary of the 1 percent annual chance peak discharge at key locations along the mainstem Boulder Creek estimated as part of previous hydrologic studies; a detailed summary of each hydrologic study is provided in the following subsections in addition to a detailed summary of two drainageway master plans developed for portions of Boulder Creek to reduce flood risks.

TABLE 4
Previous Estimates of Peak Discharge at Key Locations along Boulder Creek

Location	Source	1 Percent Annual Chance Peak Discharge (cfs)
Orodell, CO (west of Boulder)	USACE, 1977	6,920
	Anderson Consulting Engineers, 2009	6,270 [a]
	CH2M HILL, 2014	5,390
Boulder, CO (Upstream of South Boulder Creek)	USACE, 1969	7,400
	USACE, 1977	13,050
	Anderson Consulting Engineers, 2013	13,470 [a]
Downstream of South Boulder Creek	USACE, 1969	11,000
	USACE, 1977	13,300
Boulder-Weld County Line	Leonard Rice Consulting Engineers, 1975	11,000
	USACE, 1977 [a]	13,750

[a] Re-study confirmed use of previous USACE, 1977 estimates
[b] Per *Lower Boulder Creek Flood Hazard Area Delineation* (Muller Engineering Company, Inc., 1983)

2.1.1 *Floodplain Information: Boulder Creek and South Boulder Creek, Volume II, Boulder Metropolitan Region, Colorado* (USACE, 1969)

In response to an application from the Denver Regional Council of Governments (DRCOG) via the CWCB, USACE conducted a study to "define the flood characteristics on portions of Boulder and South Boulder Creeks near Boulder, Colorado" (USACE, 1969). As part of the study, USACE estimated the magnitude of two high-flow events: an "Intermediate Regional Flood," representative of the 1 percent annual chance peak discharge, and "Standard Project Flood," representative of the "reasonable upper limit of expected flooding" (USACE, 1969). The 1 percent annual chance peak discharges were estimated by analyzing gage records using Log-Pearson Type III regression analysis methodology in accordance with *Bulletin No. 15: A Uniform Technique for Determining Flood Flow Frequencies* (Water Resources Council [WRC], 1967). Additional description of the 1969 USACE analysis found in *Review Report, Boulder Creek* (USACE, undated) notes that statistical parameters from the Boulder Creek at Orodell gage (USGS Gage #06727000) were used in conjunction with a regional standard deviate distribution to estimate the 1 percent annual chance discharge along Boulder Creek. Although documentation of the exact methodology is lacking, **a 1 percent annual chance peak discharge of 7,400 cfs for Boulder Creek above South Boulder Creek and 11,000 cfs for Boulder Creek below South Boulder Creek were reported** (USACE, 1969).

2.1.2 *Flood Hazard Area Delineation: Boulder Creek and Dry Creek* (Leonard Rice Consulting Water Engineers, Inc., 1975)

To assist Boulder County in implementation of floodplain zoning and land use ordinances, Leonard Rice Consulting Engineers, Inc. (Leonard Rice), was contracted to delineate the flood hazard area between the downstream end of the USACE's 1969 study and the Boulder-Weld County Line. While no hydrologic analysis was completed, Leonard Rice estimated the average travel time of a flood peak along Boulder Creek as 1.5 miles per hour and surmised that the peak discharge along Boulder Creek would not increase as significant floodplain storage and peaking of tributaries ahead of the mainstem Boulder Creek flood peak would balance out the increases in peak discharge due to tributary contributions (Leonard Rice, 1975). Therefore, the Intermediate Regional Flood peak discharge at the downstream limit of the USACE, 1969 study was adopted as the peak discharge to delineate flood hazard areas along the study reach extending from approximately U.S. Highway 287 to the Boulder-Weld County Line (Leonard Rice, 1975). Thus, **11,000 cfs was reported as the 1 percent annual chance peak discharge for Boulder Creek at the Boulder-Weld County Line**.

2.1.3 *Water and Related Land Resources Management Study, Metropolitan Denver and South Platte River and Tributaries, Colorado, Wyoming, and Nebraska, Volume V – Supporting Technical Reports Appendices, Appendix H – Hydrology* (USACE, 1977) and *Review Report, Boulder Creek* (USACE, undated)

Following its 1969 study, USACE re-analyzed the high-flow hydrology of Boulder Creek as part of the larger Metropolitan Denver, South Platte River, and Tributaries Study and Flood Hazard Evaluation project. To develop estimates of the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges along Boulder Creek, the USACE used the U.S. Environmental Protection Agency's (USEPA's) Storm Water Management Model (SWMM) and the USACE's Missouri River Division diffusion routing technique; the former was used to estimate rainfall-runoff across the entire basin while the latter technique was used to route the high-flows in the "lower basin" downstream of the Flatirons (USACE, 1977). While the USACE, 1977 reports results of the hydrologic analysis for Boulder Creek upstream of the mouth of South Boulder Creek, an undated review report of the hydrologic model documents that the hydrologic model extended to the mouth of Boulder Creek at its confluence with St. Vrain Creek (USACE, undated). Discharge-probability profiles downstream of South Boulder Creek presented in the undated *Review Report, Boulder Creek* are identified as "preliminary"; however, the final discharge-probability profile is reproduced as Figure 3 in the *Lower Boulder Creek Flood Hazard Area Delineation* (Muller Engineering Company, Inc., 1983).

Discussion of the Boulder Creek model calibration, verification, or comparison to previous studies in the USACE, 1977 report was limited to "the final parameter selection was based on achieving probability relationships that compared favorably with the discharge-probability curve determined from the fragmentary record for Boulder Creek at Boulder and with the regional criteria presented in *Technical Manual No. 1*" (USACE, 1977). Similarly, *Review Report, Boulder Creek* noted that the discharge-probability curve determined from the 15-year gage record for Boulder Creek at Boulder was selected as the primary comparison for model calibration. It should be noted that three historical floods not included in the systematic gage record were included in the development of flow estimates using gage data, in accordance with *Technical Manual No. 1* (Jarrett and McCain, 1976) methodology (USACE, undated). Including such historical floods may result in an overestimation of high-flow magnitudes because extreme historical floods were "added" to the systematic gage record with no weighting to consider intervening flow years of presumably low-to-moderate discharges, as is standard for current Bulletin 17B (USGS, 1982) methodology. Detailed discussion of the following parameters was provided in the two documents to describe model development:

- **Detention Storage:** It was noted that the model was quite sensitive to detention storage parameters; 0.5 was used in lieu of the default 1.84 but no description of the physical relevance of these parameters was provided (USACE, undated).
- **Flood Routing:** Due to evident overbank storage downstream of the Flatirons, the Missouri River Division's diffusion routing technique, an unsteady finite-difference hydraulic model, was used to route flows in the lower basin.
- **Infiltration Losses:** It was noted that rainfall-runoff relationships were not readily available and, on the basis of a few infiltrometer studies, a constant infiltration rate of 1.0, 0.5, and 0.0 inch per hour (i.e., no infiltration) were used for the mountain, plains, and urban areas, respectively (USACE, 1977). It was noted that the infiltration rates for plains and mountains were approximately 50 percent of the field-measured average infiltration rates (USACE, 1977).
- **Overland, Channel, and Overbank Roughness:** Sensitivity testing indicated that the hydrologic model was sensitive to selection of roughness values (USACE, undated). Calibration studies on lower Cherry Creek, near and within Denver, Colorado, was used to select roughness values of 0.12 for overland areas. Observations of channel and overbank material were used to select roughness values of 0.06 to 0.09 for channel and overbank areas (USACE, undated).
- **Rainfall:** A 6-hour duration storm divided into 30-minute intervals was developed from a study of hourly precipitation data recorded for major storms in the South Platte River basins and subsequently used as the design rain event in the SWMM model (USACE, 1977). Five rainfall depths were used across the watershed to reflect the varying depth of rainfall that would occur across the basin. (USACE, undated). Rainfall-frequency relationships were obtained from 1973 National Oceanic and Atmospheric Administration (NOAA) publications (NOAA, 1973), adjusted for expected probability based "on [an] equivalent rainfall record length of 48 years," and an area-depth correction applied based on the 155-square-mile study area (USACE, undated). The 6-hour rainfall distribution was provided as shown in **Table 5**. Discussion of the hyetograph in comparing USACE, 1977 results to the rainfall-runoff model estimates is provided in Section 3.
- **Rainfall-Runoff Transformation:** Kinematic wave routing was used in the SWMM model employed by USACE to transform rainfall-runoff into an outflow hydrograph (Anderson Consulting Engineers, 2009). Parameters for the kinematic wave routing were determined from the development of a calibrated model for the May 1973 flood event downstream of Cherry Creek Dam, an urbanized portion of the high plains in the Denver suburbs (USACE, 1977).

TABLE 5
Rainfall Distribution for Effective Rainfall-Runoff Model (per USACE, 1977)

End of Period (minutes)	Percent of Total 6-Hour Precipitation (percent)	End of Period (minutes)	Percent of Total 6-Hour Precipitation (percent)
30	2	210	40
60	4	240	10
90	4	270	6
120	5	300	4
150	9	330	4
180	10	360	2

Using the methodology and parameters described above, the USACE, 1977 study **estimated the 1 percent annual chance peak discharge at Orodell and Boulder as 6,270 and 11,650 cfs, respectively. The 1 percent annual chance peak discharge below South Boulder Creek and at the mouth, at St. Vrain Creek, were estimated as 13,000 cfs and 11,900 cfs, respectively**, per the *Lower Boulder Creek Flood Hazard Area Delineation* (Muller Engineering Company, Inc., 1983). Discussion of the peak discharge estimates was limited to stating they were greater than estimates provided in the 1969 USACE study and that the revised estimates were more realistic based on 1) the 1894 Boulder Creek flood, estimated as 11,000 cfs at the Boulder Creek at Boulder gage and previously assumed as the 1 percent annual chance flow by the USGS in 1969, and 2) the then-recent 1976 Big Thompson Flood.

2.1.4 *Major Drainageway Planning, Boulder Creek, Phase B Preliminary Plan* (URS Company, 1979)

Following the City of Boulder's adoption of the USACE, 1977 hydrology in May 1977, the City of Boulder, Boulder County, and the Urban Drainage and Flood Control District entered into an agreement with the URS Company to "develop a hydraulically sound and aesthetically pleasing master plan based on the Corps of Engineers' plan concepts that would strike a balance between improvements required to convey the 100-year discharge and preservation of the existing environment" (URS Company, 1979). The extent of the URS Company, 1979 Boulder Creek Major Drainageway Plan stretched from the Canyon Mouth to 55th Street, approximately the confluence with South Boulder Creek. Primary recommendations proposed in the Major Drainageway Plan include the following:

- Minor channel work between the Canyon Mouth and 17th Street in addition to channelization of Boulder Creek between 24th and 28th Streets.
- Removal and relocation of flood-prone structures: flood-prone structures would be relocated if the cost to relocate was less than the present (1979) worth of damages. Additional structures would be removed in the event they are damaged during natural events (flood, fire, etc.).
- Modification or replacement of undersized bridges to increase conveyance capacity.

2.1.5 *Major Drainageway Planning, Boulder Creek – South Boulder Creek Confluence Area, Development of Preliminary Plan – Phase B* (Simons, Li, and Associates, Inc., 1984)

Following preparation of major drainageway improvement alternatives as Phase A of the discussed study, Simons, Li, and Associates, Inc. utilized the project sponsors' selection of alternatives to prepare a preliminary design of major drainageway improvements for Boulder Creek and South Boulder Creek in the vicinity of their confluence, approximately bound by 55th Street, Arapahoe Avenue, and Sawhill Ponds. Major recommendations of the Master Plan include the following:

- Participation in the National Flood Insurance Program and enforcement of floodplain regulations;
- Elevation of the then-proposed Pearl Street above the 100-year flood elevation;
- Removal of the 61st Street roadway and bridge crossing;
- Provide 100-year conveyance capacity at the 55th Street bridge;
- Remove the Union Pacific Railroad embankment;
- Excavation of the floodway and construction of a flood overflow channel; and
- Construction of a flood levee on the right bank of Boulder Creek between 55th Street and Valmont Road (listed as Valmont Drive in the Boulder County Flood Insurance Study [FEMA, 2012]).

It should be noted that several of the proposed recommendations were dependent on the then-proposed location of Pearl Street on the *left* bank of Boulder Creek. Since the publication of the Major Drainageway Plan, Pearl Street has been constructed on the *right* bank of Boulder Creek and it is likely that many of the proposed improvements are no longer valid or should be modified given the constructed location of Pearl Street.

2.1.6 *Hydrology Verification Report for Boulder Creek* (Anderson Consulting Engineers, 2009)

Prior to revising the regulatory flood hazard delineation along Boulder Creek through the City of Boulder, the City contracted with Anderson Consulting Engineers to evaluate and verify the appropriateness of the USACE, 1977 Boulder Creek hydrology between the Canyon Mouth and the mouth of South Boulder Creek. The majority of the report described the creation of the duplicate effective model using modern versions of SWMM to replicate hydrology estimates from the USACE, 1977 study. Discussion of high-flow estimates were limited to comparing the modeled discharges to discharges estimated using regression equations developed by USGS for the Plains Region (USGS, 2009) and by CWCB for the Central Foothills Sub-Region (CWCB, 2009). The modeled 1 percent annual chance flow compared well with regression estimates except for at the Orodell gage, where the modeled flow was 37 and 34 percent lower, respectively, than that estimated from the USGS and CWCB regression and outside the CWCB regression's 23 percent standard error of estimate. No comparison of modeled discharges to the statistical analysis of gage records was made on the grounds that Barker Reservoir negated the appropriateness of such an analysis. Although no detailed evaluation of the parameters used in the original (and duplicate) hydrologic model was performed, it was **concluded that the 1 percent annual chance flow at Orodell and above South Boulder Creek of 6,270 and 13,050 cfs, respectively, remained appropriate.**

2.1.7 *Boulder Creek Hydrologic Analysis [Phase 1]* (CH2M HILL, 2014)

In September 2013, the Colorado Front Range experienced an intense, widespread rainfall event that resulted in damaged infrastructure and property loss in multiple watersheds. CH2M HILL was retained by the CDOT and the CWCB to evaluate high-flow hydrology of Boulder Creek above the confluence of Boulder Creek and Fourmile Creek near Orodell, Colorado. As part of the hydrologic evaluation, CH2M HILL developed a hydrologic model of the watershed using the USACE's Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), version 3.5 (USACE, 2010a). The HEC-HMS model was calibrated to estimates of the magnitude and timing of September 2013 peak discharges and accounted for variations in rainfall and hydrologic response across the watershed as well as the significant attenuation provided by Barker Reservoir. The calibrated hydrologic model was then used to develop a predictive hydrologic model to predict the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges along Boulder Creek and assess the recurrence interval of the September 2013 flood event. Based on implementation of the predictive hydrologic model, the **1 percent annual chance flow at Orodell was estimated as 5,390 cfs.** In general, the peak discharges estimated in the CH2M HILL, 2014 study were less than those estimated in the USACE, 1977 study: peak discharges at Orodell were slightly less than those predicted by USACE and the estimated peak discharge at the study watershed outlet (the confluence with Fourmile Creek) was 6,850 cfs, considerably less than that of the USACE, 1977 study, mostly due to a decrease in estimated peak discharges along Fourmile Creek. When comparing the peak discharge estimates from the two studies, it was noted that the CH2M HILL, 2014 estimates better agreed with stream gage records than did the USACE, 1977 estimates.

2.2 Stream Gage Analysis

Eleven stream gages are currently operated within the Boulder Creek watershed and an additional three have been historically operated on Boulder Creek or a major drainageway; a summary of the period of record, peak historical discharge, date of peak historical discharge, and September 2013 peak discharge, if recorded, are summarized for the thirteen Boulder Creek stream gages in **Table 2**.

Ayres Associates performed flood frequency analyses at six stream gages to supplement the hydrologic evaluation of Boulder Creek and its major tributaries. The analyses followed the methods described in the document Guidelines for Determining Flood Flow Frequency published by USGS on behalf of the Interagency Advisory Committee on Water Data, dated September 1981 (USGS, 1982). This document is commonly known as Bulletin 17B. Following the Bulletin 17B methods using the computer program HEC-SSP, Ayres Associates conducted flood frequency analyses using the annual peak flow records at the following gages:

- USGS Gage 06730200, Boulder Creek at North 75th Street near Boulder, Colorado;
- USGS Gage 06730500, Boulder Creek at Mouth, near Longmont, Colorado;
- CDWR Gage COCREPCO / USGS Gage 06730300, Coal Creek near Plainview, Colorado;
- USGS Gage 06729000, South Boulder Creek near Rollinsville, Colorado;
- CDWR Gage BOCBGRCO, South Boulder Creek below Gross Reservoir; and
- CDWR Gage BOCELSCO / USGS Gage 06729500, South Boulder Creek near Eldorado Springs, Colorado.

Summarizing its stream gage analysis for the report, Ayres Associates stated:

> *Stream gage analysis by Bulletin 17B methods requires as input the highest peak discharge for every available year of record. The engineer must also decide how to treat the skew coefficient. The possible options include the following:*
>
> 1. *Using a weighted skew coefficient in which the station skew is weighted with a regional skew determined from the map included in Bulletin 17B. A drawback to this method is that the stream flow data used to develop that map were from the 1960s).*
> 2. *Weighting the skew coefficient with a regional coefficient developed from a current regional regression analysis. The initial attempts to use this approach had the drawback that very few gages were available for the regression analysis that had measured or approximated peak values for the September 2013 flood. Furthermore, many of the available gages were missing peak flows from other known large flood events. The results from this approach appeared unreliable at several gages, in that the resulting 100-year flow values were lower than two or three of the observed peaks in periods of record no more than 120 years.*
> 3. *Use the station skew coefficient, without any regional skew weighting. This approach yielded the most reasonable results and was adopted for this study.*

The detailed input to and output from HEC-SSP is included as part of **Appendix C**. The results of the flood frequency analyses are summarized in **Table 6**. Comparison of flood frequency results to September 2013 discharges is provided in Section 3.2.

TABLE 6
Discharge-Frequency Based on Flood Frequency Analysis of Gage Records

Exceedance Recurrence Interval (years)	Boulder Creek at North 75th Street near Boulder, CO		Boulder Creek at Mouth, Near Longmont, CO		Coal Creek Near Plainview, CO	
	Discharge (cfs)	Unit Discharge (cfs/mi^2)	Discharge (cfs)	Unit Discharge (cfs/mi^2)	Discharge (cfs)	Unit Discharge (cfs/mi^2)
2	741	2.4	714	1.6	51	3.4
5	1,359	4.4	1,384	3.1	169	11.1
10	2,079	6.8	2,001	4.5	332	21.8
50	5,326	17.3	3,972	8.9	1,166	76.7
100	7,895	25.7	5,119	11.5	1,857	122.2
500	19,399	63.2	8,722	19.5	4,941	325.1

TABLE 6 (cont'd)
Discharge-Frequency Based on Flood Frequency Analysis of Gage Records

Exceedance Recurrence Interval (years)	South Boulder Creek Near Rollinsville, CO		South Boulder Creek Below Gross Reservoir		South Boulder Creek Near Eldorado Springs, CO	
	Discharge (cfs)	Unit Discharge (cfs/mi^2)	Discharge (cfs)	Unit Discharge (cfs/mi^2)	Discharge (cfs)	Unit Discharge (cfs/mi^2)
2	433	10.1	529	5.5	446	4.0
5	540	12.6	638	6.7	751	6.8
10	613	14.4	700	7.3	1,064	9.6
50	782	18.3	819	8.5	2,250	20.3
100	858	20.1	863	9.0	3,061	27.6
500	1,047	24.5	957	10.0	6,131	55.2

2.3 Peak Discharge Estimates

To quantify the magnitude of peak discharges that occurred during the September 2013 event and to provide calibration data for the rainfall-runoff model discussed in detail in Section 2.4, the following direct and indirect methods were used to estimate peak discharges during the September 2013 event:

1. **Direct Observation from Stream Gages:** peak discharge estimates were collected directly from stream gage records and/ or manual field measurements.
2. **Indirect Observation from Critical-Depth Method Application**: cross-sections and high-water marks were surveyed at select locations and peak discharge was estimated by assuming critical depth occurred at the surveyed cross-sections.
3. **Indirect Observation from Bridge Hydraulic Modeling**: cross-sections and high-water marks were surveyed at select bridge crossings and a hydraulic model developed to iterate peak discharges until observed high-water marks were reproduced using the hydraulic model.
4. **Indirect Observation from Other Studies**: peak discharge estimates developed as part of independent studies were also utilized as calibration data.

Detailed discussions of each peak discharge estimate method is provided in the following sections.

2.3.1 Stream Gage Measurements

Of the 11 stream gages operated by CDWR and USGS within the watershed, five were damaged during the September 2013 high-flow event and only six remained operational and recorded discharge. Of the six stream gages that remained in operation, estimates of peak discharge, time-of-peak discharge, and runoff volume were able to be extracted and subsequently used to provide calibration data to develop the rainfall-runoff model discussed in Section 2.4. Peak discharge estimates and the time-of-peak discharge, or the recorded time that the peak discharge was observed, were extracted directly from the gage record. Measured peak discharges, which also include two manual measurements of peak discharge made by field crews at two damaged stream gages, are provided in **Table 2**. Where stage measurements were recorded at damaged stream gages, times-of-peak discharge were also extracted directly from the gage record, although based on the occurrence of the measured peak depth as discharge measurements were not available. Runoff volume was extracted from the gage record by post-processing the gage record to convert observed discharges to a resulting volume (by multiplying discharge, a measure of volume per unit time, by the time interval of the gage measurements) across the 24-hour period used to calibrate rainfall-runoff model.

2.3.2 Critical-Depth Method Estimates

One technique for estimating the peak discharge after a significant storm event is to apply indirect methods that utilize observed high-water marks, channel geometry, and hydraulic properties to estimate recent peak discharges. USGS has been actively developing and applying indirect methodologies to estimate peak discharges in various watersheds along the Front Range. In fact, USGS has validated one such methodology, the critical-depth method, to be accurate to within 15 percent of direct discharge measurements for streams with gradients exceeding 0.005 foot/foot, such as the streams in the affected Front Range area (Jarrett, 2013). This methodology was applied by Applied Weather Associates (AWA) and its subconsultant, Bob Jarrett, to estimate peak discharges along Front Range streams that witnessed high flows during the September 2013 event. The evaluated locations are identified in **Figure 4** and the peak discharge estimates for each location are provided in **Table 7** (Jarrett, In press). Where critical-depth estimates were provided at a functioning gage location, critical-depth estimates compared favorably, within ± 15 percent, to gage estimates: at the Boulder Creek near Orodell gage, the critical-depth estimate of 2,020 cfs compared favorably with the gage measurement of 1,720 cfs; at the Fourmile Creek gage near Orodell, the critical-depth estimated yielded 2,300 cfs and the USGS field measurement yielded 2,510 cfs. Given the reported accuracy of the critical-depth method, relative density of critical-depth estimates, and satisfactory comparison to peak discharges measured at functioning stream gages, critical-depth estimates provided in **Table 7** were considered reliable estimates of peak discharges and as such were used to calibrate the rainfall-runoff hydrologic model.

2.3.3 Bridge Hydraulic Modeling Method Estimates

CDOT and CWCB contracted URS (recently AECOM) to obtain peak discharge estimates within the Phase 2 portion of the Boulder Creek watershed following the September 2013 storm event; the final memorandum summarizing the analysis is provided as **Appendix E** (URS, 2015). For the analysis, URS surveyed at least four cross-sections, collected bridge information for hydraulic modeling, and surveyed high-water marks at peak discharge estimate locations identified in **Figure 4**. URS used USACE’s Hydrologic Engineering Center River Analysis System (HEC-RAS) Version 4.1 (USACE, 2010b) model to construct a hydraulic model of each location and subsequently calibrated the model to high-water marks under subcritical and supercritical flow regimes. Generally, the subcritical flow regime was deemed more appropriate and used to develop peak discharge estimates at studied locations. URS noted that peak discharge estimates where bridges were overtopped were more uncertain due to greater uncertainty in assessing high-water marks and more complex hydraulic conditions at locations where flow overtopped the approach roadway, rather than the bridge itself. However, none of the bridges in the Boulder Creek watershed was noted as having overtopped.

Locations and magnitude of peak discharge estimates developed from hydraulic modeling of bridges that were used to calibrate the rainfall-runoff hydrologic model are summarized in **Table 8**.

TABLE 7
Critical-Depth Method Peak Discharge Estimates and Locations

Location	Description	Drainage Area (square miles)	Peak (cfs)
Site #70	Bear Canyon Creek at Mohawk Drive	4.56	1,330
Site #40	Boulder Creek Near Orodell	102	2,020
Site #25	Coal Creek about 1 mile downstream of Bear Creek	9.30	1,110
Site #6	Coal Creek near Plainview (UDFCD Site)	15.2	3,900
Site #72	Fourmile Canyon Creek at Pinto Drive	4.01	1,080 [a]
Site #45	Fourmile Canyon Creek upstream of Broadway Avenue	7.68	1,460 [a]
Site #71	Fourmile Canyon Creek upstream of Diagonal Highway	10.4	2,300 [a]
Site #48	Fourmile Creek Upstream of Burned Area	9.0	490
Site #52	Fourmile Creek Downstream of Emerson Gulch (Sheila Murphy's WQ Site)	14.7	1,070
Site #43	Fourmile Creek Downstream of Poorman Road and Upstream of #1267 Fourmile Creek Road near Orodell	21.4	2,300
Site #31	North Boulder Creek downstream CO Hwy 72	26.0	340
Site #35	North Boulder Creek Upstream of Boulder Creek and CO Hwy 119 near Orodell	36.0	740
Site #24	South Boulder Creek at Rollinsville	45.2	410
Site #7	South Boulder Creek at Eldorado Springs	111	2,120
Site #69	South Boulder Creek at South Boulder Creek Road	134	3,600
Site #46	Second Creek near North Cedar Brook Road	1.10	1,210
Site #44	Wonderland Creek at 15th Street	1.60	170

[a] Estimate not used in model calibration due to observed peaking of the stream on early morning September 12, prior to the calibration analysis window (Bob Harberg, personal communication, November 11, 2014).

Source: Jarrett, In press.

TABLE 8
Bridge Hydraulic Modeling Method Peak Discharge Estimates and Locations

Location	Description	Drainage Area (square miles)	Peak Discharge (cfs)
BC-1	Boulder Creek at Pearl Parkway / Valmont Road	156	5,700
BC-3	Boulder Creek at N. 107 Street / U.S. Hwy 287	331	9,000
BC-6	Coal Creek at U.S. Hwy 287	35.1	5,000
BC-9	Coal Creek at S. 120th Street	35.7	3,500
BC-5	Coal Creek at Erie, CO	76.9	6,000
BC-8	Rock Creek at S. 120th Street	21.8	1,500

Source: URS, 2015.

2.3.4 Other Estimates

Additional September 2013 peak discharge estimates along Boulder Creek and South Boulder Creek were available as part of Wright Water Engineers' *Rainfall-Runoff Analysis for September 2013 Flood in the City of Boulder, Colorado*, prepared for the City of Boulder and Urban Drainage and Flood Control District (UDFCD) (Wright Water Engineers, 2014). Additional peak discharge estimates referenced from the Wright Water Engineers, 2014 report that were used to calibrate the rainfall-runoff model are provided in **Table 9**.

TABLE 9
Additional Peak Discharge Estimates and Locations

Description	Drainage Area (square miles)	Peak Discharge (cfs)	Source [a]
Boulder Creek at 28th Street	136	5,300	CWCB
South Boulder Creek at Sans Souci / CO Hwy 93	123	5,600	UDFCD

[a] As referenced in Wright Water Engineers, 2014

Source: Wright Water Engineers, 2014

2.4 Rainfall-Runoff Modeling

2.4.1 Overall Modeling Approach

In general, hydrologic modeling of Boulder Creek entailed the development and calibration of a hydrologic model to the September 2013 high-flow event, which was then used to estimate the magnitude of the 10, 4, 2, 1, and 0.2 percent annual chance peak discharge. Given that the September 2013 high-flow event and historical high-flow events noted during the literature review were driven by substantial rainfall, a rainfall-runoff model was used to evaluate hydrologic conditions within Boulder Creek. The USACE's HEC-HMS version 3.5 (USACE, 2010a) was selected to model the hydrologic conditions within Boulder Creek due to FEMA approval of HEC-HMS version 1.1 and newer to model single-event flood hydrographs (FEMA, 2013b) and the ability to incorporate complex calibration data and modeling parameters into the program. The hydrologic modeling process entailed the development of two separate hydrologic models to evaluate hydrologic conditions in Boulder Creek:

- A *calibrated hydrologic model* was developed to model the September 2013 event. Hydrologic conditions unique to the September 2013 event (e.g., measured rainfall, storage capacity of reservoirs) were used to calibrate remaining model parameters to match modeled peak discharges, time-of-peak discharge, and runoff volume to observations and direct measurements collected during the September 2013 event and indirect measurements collected after the September 2013 event.
- Following development of the calibrated hydrologic model, a *predictive hydrologic model* was developed to estimate discharge-frequency relationships based on calibrated model parameters, rainfall-frequency relationships, and adjusted hydrologic conditions that reflected anticipated flood conditions, rather than the unique conditions preceding the September 2013 event.

Detailed discussion of difference between the two hydrologic models is provided in following sections.

Beyond the selection of the hydrologic model itself, selection of modeling methodologies would control the subsequent calibration and implementation of the hydrologic model: selection of an infiltration loss method, which controls the conversion of rainfall to runoff; selection of a transformation method, which controls the transformation of runoff volume to an outflow hydrograph; and selection of a routing method, which controls the routing of hydrographs from various watersheds to the downstream outlet. The Soil Conservation Service (SCS, now the Natural Resources Conservation Service [NRCS]) curve number (CN) method was selected to model infiltration losses due to its relative simplicity, acceptance in the *Colorado*

Floodplain and Stormwater Criteria Manual (CWCB, 2008), and its ability to reflect varying land use conditions and infiltration properties of underlying soils. The Snyder's unit hydrograph was used also due to its acceptance in the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008) and its ability to calibrate the transformation method to observed data. The Muskingum-Cunge routing methodology was selected to route runoff hydrographs due to the method's ability to attenuate runoff based on a specified hydraulic roughness and channel-floodplain cross section.

2.4.2 Summary of Modeling Approaches Considered

Throughout the development of the rainfall-runoff model, modeling methodology was reviewed and discussed between a joint team of local engineers and project sponsors; meeting minutes from these discussions and responses to review comments are provided as part of **Appendix D**. Several modeling methodologies were considered, applied, evaluated, and subsequently discarded over the course of developing the Phase 1 hydrologic model so as to assess the performance of alternative modeling methodologies or to synchronize model development efforts with other consultants. The following alternative modeling methodologies were considered in the development of the Phase 1 Boulder Creek Hydrologic Model and are documented in the final Boulder Creek [Phase 1] Hydrologic Analysis (CH2M HILL, 2014): Calibration of Model to Entirety of September 2013 Event, Calibration of Model using Green-Ampt Loss Method, and Calibration of Fourmile Creek Sub-Model and Prediction of 6-hour Peak Discharges. As each of these alternative modeling methodologies was ultimately not adopted, the development of the Phase 2 hydrologic model followed the same methodology used to develop the Phase 1 hydrologic models, as described in subsequent sections. Although the development of the Phase 2 hydrologic models ultimately followed the same process as the Phase 1 hydrologic model, one additional alternative modeling methodology was considered during the development of the Phase 2 predictive hydrologic model and is described in the following subsection.

Predictive Hydrologic Modeling of Spatially Concentrated Storms

During the process of predictive hydrologic modeling, it was suggested during regular Hydrology Coordination meetings that the peak discharge at a study location may not be the result of a general storm distributed over the entire watershed area but rather a more-intense storm concentrated over a smaller portion of the watershed. The 2007 hydrologic study of South Boulder Creek is an example of the application of this concept: while traditional hydrologic modeling of a general storm over the entire watershed generated a peak discharge of 4,220 at the confluence with Boulder Creek, hydrologic modeling of a "thunderstorm" event that occurred only over portions of the watershed downstream of Gross Reservoir generated a peak discharge of 8,910 cfs at the same location (HDR, 2007). Thus, downstream of Eldorado Springs, the "thunderstorm" event was more critical to the estimation of high-flow hydrology along South Boulder Creek.

Spatially concentrated storms, "thunderstorms" in the South Boulder Creek study, were evaluated using the predictive hydrologic model to determine the controlling rainfall event to estimate high-flow hydrology along Boulder Creek. To do so, several potentially critical storms were delineated across portions of the Boulder Creek watershed according to the following general guidelines:

- Potentially critical storms were delineated across adjacent subbasins to reflect that a single thunderstorm is more likely to occur than several independent, but simultaneous, thunderstorms dispersed across the watershed.
- Potentially critical storms were concentrated over portions of the watershed with relatively higher runoff potential (such as the City of Boulder) and higher NOAA Atlas 14 rainfall depths.
- Potentially critical storms were located downstream of the influence of Gross and Barker Reservoirs as both reservoirs would attenuate the flow and result in the reduction of downstream peak discharge estimates.

- After noting that general storms for design points upstream of decreases in the Depth-Area Reduction Factor (DARF, see Section 2.4.5 for further discussion) did not control peak discharges for downstream design points (e.g., the General Storm for Boulder Creek at 75th Street, with DARF = 0.92, did not control over the General Storm for Boulder Creek at Coal Creek, with DARF = 0.78), potentially critical storms were, with one exception, limited to areas of less than 100 square miles, at which point the DARF would have been the same as the General Storm at most locations along Boulder Creek.

Using these guidelines, the following potentially critical storms were considered in detail:

- Potentially critical storm concentrated over Boulder Canyon, City of Boulder, and foothills tributaries draining through City of Boulder (approximately 50 square miles).
- Potentially critical storm concentrated over the City of Boulder (approximately 25 square miles).
- Potentially critical storm concentrated over portions of the Boulder Creek watershed downstream of Barker Reservoir and upstream of downtown City of Boulder (approximately 65 square miles).
- Potentially critical storm concentrated over portions of Boulder Creek and South Boulder Creek downstream of Gross and Barker Reservoirs (approximately 160 square miles).
- Potentially critical storm similar to that outlined in HDR, 2007, a controlling thunderstorm that is concentrated over South Boulder Creek and adjacent Boulder Creek tributaries (approximately 65 square miles)

After delineating the potentially critical storm areas, rainfall depths for the subbasins underlying the potentially critical storm were adjusted using a DARF for the area of storm, rather than the total watershed drainage area used in hydrologic modeling of general storm events; thus the peak intensity of rainfall increased in the underlying subbasins as a result of the increased DARF resulting from the more-concentrated storm event. At the same time, rainfall depths for subbasins outside of the potentially critical storm were changed to zero (no rainfall). To assess the sensitivity of the model to spatially concentrated storms, all spatially concentrated storms were modeled using the 24-hour NRCS Type II unit rainfall hyetograph (discussed in subsequent sections).

Evaluation of the results of hydrologic modeling of spatially concentrated storms yielded that in all cases, peak discharges along Boulder Creek estimated using a general storm above the design point were greater than peak discharge estimates developed through modeling of spatially concentrated storms. To further consider differences in spatially concentrated storms over general storms, spatially concentrated storms were also modeled as shorter duration events with theoretically higher rainfall intensities. When the spatially concentrated storms were modeled using a 6-hour NRCS Type II unit rainfall hyetograph and conservative approximations of the 6-hour rainfall depths, modeled peak discharges using the 6-hour spatially concentrated storms were less than the modeled peak discharge for the co-located 24-hour spatially concentrated storm. Considering these hydrologic modeling results of spatially concentrated storms, it was determined that the 24-hour general storm was the critical event for high-flow hydrology along Boulder Creek.

2.4.3 Basin Delineation

In general, the delineation of Phase 2 subbasins followed subbasin delineations used in the South Boulder Creek Climatology and Hydrology Report (HDR, 2007) and UDFCD’s Electronic Data Management Map (UDFCD, 2014). Minor adjustments to subbasins used in the aforementioned studies were made based on review of USGS topography maps and/or to coincide subbasin boundaries with locations of calibration data, FEMA discharge summary locations, stream confluences, gaging stations, reservoirs, or bridges. In areas where steep valley conditions occur along the channel corridor, the basins were delineated extending from the high point along the overbank to the channel centerline, resulting in subbasins on both the left and right overbanks of the stream. This was done to better represent the runoff response from the steep valley slopes. Except where such delineation would have unnecessarily divided a homogeneous subbasin, delineated subbasin areas were less than 5 square miles and conformed to recommendations provided in the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008).

Including the Phase 1 subbasins upstream of the confluence of Boulder Creek and Fourmile Creek, 127 subbasins were used to model the Boulder Creek Study area upstream of the confluence with St. Vrain Creek. Resulting subbasin areas ranged from 1.0 square mile in areas of higher population densities, topographic complexity, and land use diversity to 11.6 square miles in areas of lower population density and relatively homogenous land use condition and topography; areas of each subbasin are provided in **Table B-1** in **Appendix B**. Resulting delineated subbasins are superimposed on aerial imagery as part of **Figure 5**. In regard to naming convention, subbasins were named in accordance with abbreviations of the FEMA-studied feature they first drained to,[3] e.g., "MBC" for Middle Boulder Creek.

2.4.4 Basin Characterization

The Boulder Creek watershed upstream of the confluence of Boulder Creek and St. Vrain Creek is a diverse one, as Boulder Creek drains both undeveloped mountainous areas and more heavily-developed areas of the Colorado Piedmont. At the watershed scale, the headwaters of Boulder Creek include the eastern slopes of the Continental Divide including the Indian Peaks wilderness. The upper portion of the watershed is generally composed of long, steep-walled alpine valleys with mountaintops above timberline. Several miles from the Continental Divide, these alpine valleys converge and form the three major high-elevation tributaries to Boulder Creek: North Boulder Creek, Middle Boulder Creek, which runs through Nederland, and South Boulder Creek, which runs through Rollinsville and Pinecliffe. As the three high-elevation tributaries flow downstream, the channels frequently become confined in V-shaped valleys with steep, frequently rocky valley walls that drain laterally to the receiving tributaries such that runoff responses to rainfall are generally rapid and large. Two large irrigation and municipal water storage reservoirs were constructed in this vicinity: Barker Reservoir on Middle Boulder Creek and Gross Reservoir on South Boulder Creek. While not operated as flood control dams, both reservoirs have the potential to store and attenuate large portions of basin runoff.

Downstream of Barker Reservoir, V-shaped valleys continue to define the topography where Middle Boulder Creek and North Boulder Creek confluence to form Boulder Creek. As Boulder Creek continues to flow through the confined Boulder Creek Canyon, Boulder Creek is joined by the mid-elevation Fourmile Creek. This portion of the Boulder Creek watershed, particularly Fourmile Creek, have been the historical source of flooding on downstream portions of Boulder Creek (USACE, 1977). The steep, lateral drainage to receiving streams and comparatively less dense vegetation cover, at least compared to the upper portion of the watershed, result in conditions that lead to comparatively rapid runoff response time and high runoff potential. Recognizing that this portion of watershed is within a few miles of the leading edge of the Front Range, orographic effects caused by the elevation increase result in conditions conducive to intense rainfalls. In conjunction with the high runoff potential and rapid response times, physical processes in this portion of the Boulder Creek watershed support the USACE, 1977 assessment that downstream flooding is frequently driven by rainfall and runoff from the foothills portion of the Boulder Creek watershed.

As Boulder Creek exits Boulder Canyon and enters the Colorado Piedmont, it flows directly through the City of Boulder and forms part of the City's Greenway. East of Boulder Canyon, numerous irrigation diversions divert water to and from Boulder Creek and transfer it across the watershed to storage reservoirs and water rights holders both inside and outside of the watershed. In addition to water withdrawals and transbasin contributions, several smaller tributaries including Fourmile Canyon Creek, Goose Creek, and Bear Canyon Creek confluence with and contribute flow to Boulder Creek. While these tributaries are generally small, many of these subbasins drain rocky, steep portions of the leading edge of the Front Range as well as heavily

[3] BC = Boulder Creek; BCC = Bear Canyon Creek; CC = Coal Creek; DC = Dry Creek No. 3; FCC = Fourmile Canyon Creek; FMC = Fourmile Creek; MBC = Middle Boulder Creek; NBC = North Boulder Creek; RC = Rock Creek; SBC = South Boulder Creek; SC = Skunk Creek; TCC = Twomile Canyon Creek; WC = Wonderland Creek

developed portions of the Colorado Piedmont, both of which have contributed to the high runoff potential and historical flash flooding of these watersheds.

At the eastern edge of the City of Boulder, the contributing drainage area nearly doubles as the 139-square mile drainage area of South Boulder Creek joins Boulder Creek. Similar to Boulder Creek, downstream of Gross Reservoir, South Boulder Creek flows through V-shaped canyons before exiting Eldorado Canyon near Eldorado Springs. From there, South Boulder Creek flows through urbanized portions of the City of Boulder and intersects irrigation infrastructure in several locations. Downstream of Gross Reservoir, two major off-channel reservoirs interact with South Boulder Creek: Baseline Reservoir, which has historically been flooded by South Boulder Creek, and Valmont Reservoir, operated as a cooling reservoir for Xcel Energy.

Downstream of the confluence with South Boulder Creek, Boulder Creek flows through relatively flat agricultural land and is flanked by several gravel pits before it confluences with St. Vrain Creek near Longmont, Colorado. Along this portion of its flow path, historical observations of Boulder Creek flooding noted a floodplain up to a mile and a half wide. While tributaries along these portions of Boulder Creek have a history of flash flooding following localized cloudbursts, flooding of Boulder Creek itself is generally driven by upstream snowmelt and rainfall (FEMA, 2012). A few miles upstream of its confluence with St. Vrain Creek, Boulder Creek intercepts its last major tributary, Coal Creek, which drains portions of the leading edge of the Front Range, agricultural land, and developed areas including the City of Louisville and Lafayette.

2.4.5 Model Development

The developed HEC-HMS hydrologic models used “hydrologic elements” in the form of subbasins, junctions, reaches, and reservoirs to convert input rainfall to output hydrographs. Subbasin elements contain parameters to estimate infiltration losses and convert the resultant runoff to an outflow hydrograph. Reach elements route inflow hydrographs based on the hydraulic characteristics of the conveying element, e.g., Boulder Creek, while reservoir elements route inflows based on reservoir storage capacity and outlet works. Junction elements have no hydrologic function other than congregating multiple inflows to a single outflow. A description of input parameters, presented by hydrologic elements and then hydrologic order, is provided next.

Rainfall Analysis

The Storm Precipitation Analysis System (SPAS) was used to analyze the rainfall for the September 2013 event. SPAS uses a combination of climatological base maps and NEXRAD weather radar data that is calibrated and bias corrected to rain gage observations (considered ground truth) to spatially distribute the rainfall accumulation each hour over the entire domain of the storm. Therefore, through the use of climatological base maps and weather radar data, SPAS accounts for topography and locations of rain gages. For quality control (QC), SPAS storm analyses withheld some rain gages observations and ran the rainfall analysis to see how well the magnitude and timing fit at the withheld rain gage locations. In nearly all cases, the analyzed rainfall was within 5 percent of the rain gage observations and usually within 2 percent. In data-sparse regions where there are a limited number of rain gages, there can be increased uncertainty in traditional rainfall analyses, especially in topographically significant regions. For the September 2013 storm, this was not the case. Excellent weather radar coverage existed as well as many rainfall observations with excellent overall spatial distributions at both low- and high-elevation locations (AWA, 2014).

Rainfall Hyetographs

AWA provided rainfall data for the September 2013 storm event through the methodology described in the preceding section (AWA, 2014). **Figure 6** illustrates the total precipitation depth measured during this period (AWA, 2014). Individualized rainfall hyetographs were generated by AWA for each modeled subbasin using weighting techniques to adjust precipitation gage measurements collected during the event to the centroid of each subbasin. Individualized rainfall hyetographs were provided as 5-minute incremental rainfall depths from 1 a.m. on September 8, 2013, to 1 a.m. on September 18, 2013. **Figure 2** provides the incremental rainfall depth measured at representative locations and points of interest across the Boulder Creek watershed.

The 24-hour rainfall depths for the 10, 4, 2, 1, and 0.2 percent annual chance precipitation were developed for each subbasin from *NOAA Atlas 14* (NOAA, 2013) point precipitation frequency estimates by inputting the centroid of each basin into NOAA's online, geographic information system (GIS)-based precipitation frequency database server (NOAA, 2014). The reported NOAA rainfall estimates used in the hydrologic model are the 50th percentile rainfall depths estimated from a population frequency curve of expected rainfall depths at each of the subbasin centroids. Therefore, in addition to providing the 50th percentile rainfall depths, the NOAA tables also provide the bounding 90 percent confidence intervals for expected rainfall depth at each of the subbasin centroids, thereby providing an estimate of uncertainty in the rainfall-frequency estimates. In general, the 90 percent confidence intervals vary ± 25 percent from the 50th percentile rainfall depth. 24-hour rainfall-frequency curves for each subbasin centroid are provided in **Table B-2** in **Appendix B**. In addition, total measured rainfall depths for the modeled 24-hour period of the September 2013 event are also provided in **Table B-2** in **Appendix B** to provide a comparison of September 2013 rainfall to NOAA rainfall-frequency estimates (NOAA, 2014). In general, measured rainfall depths during the modeled 24-hour period of the September 2013 event ranged significantly across watershed. In the upper portions of the watershed (North, Middle, and South Boulder Creeks) and far-eastern plains portions of the watershed, the recurrence intervals of 24-hour rainfall depths during the model calibration window were less than 10 years. In contrast, 24-hour rainfall depths recorded during the 24-model calibration window for subbasins in the vicinity of the leading edge of the Front Range witnessed recurrence intervals closer to 50 years, with some subbasins (Coal Creek near Plainview and South Boulder Creek near Viele Lake) witnessed recurrence intervals exceeding 500 years.

Per the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008), the standard NRCS 24-hour Type II rainfall distribution was used as the design hyetograph to distribute the 24-hour rainfall depths to generate hydrographs for the 10, 4, 2, 1, and 0.2 percent annual chance events. The NRCS 24-hour Type II rainfall distribution was incorporated into the hydrologic model as a dimensionless cumulative rainfall distribution ("unit hyetograph"), subdivided into 5-minute increments. While the NRCS has developed new Atlas 14 temporal distributions for the Ohio River Basin and neighboring states, the NRCS Type II temporal distribution is still recommended in the Volume 8 area of Atlas 14 (Midwestern States), where Boulder Creek is located. A table of the NRCS Type II rainfall distribution input to the model is provided as **Table B-3** in **Appendix B**; a graph of the dimensionless rainfall distribution is provided as **Figure 7**.

Drainage Area Reduction Factor

Prior to generating runoff hydrographs for the 10, 4, 2, 1, and 0.2 percent annual chance events, depth-area reduction factors (DARFs) were applied to NOAA 50th percentile point precipitation estimates. The depth-area reduction factor accounts for the gradual decrease in precipitation depth with increasing distance from the storm centroid and corrects the NOAA point precipitation estimate to the average rainfall that would occur over the spatial extent of the storm. While DARF curves provided in NOAA Atlas 2 were used in the Phase 1 hydrologic analysis of studied watersheds, the NOAA Atlas 2 DARF curves only covered drainage areas up to 400 square miles. As total drainage areas of the Big Thompson River, Boulder Creek, and St. Vrain Creek each exceeded 400 square miles, CDOT and CWCB contracted AWA to derive a site-specific 24-hour DARF curve for use in the hydrologic analysis of these large watersheds. A memo documenting AWA's work is provided as **Appendix F**. Providing a summary of its "Colorado Front Range 24-hour Rainfall Areal Reduction Factors Memorandum for Record" (AWA, 2015) for inclusion in this report, AWA stated the following of the analysis:

> *Applied Weather Associates analyzed nine storm events along the Front Range of the Rocky Mountains extending from northern New Mexico through southern Canada, including the September 2013 event. Each storm event utilized in this analysis represented meteorological and topographical characteristics that were similar to each other and to the September 2013 event. These storms were*

selected to derive storm specific areal reduction factors (DARF). The individual storm DARFs were then utilized to derive a site-specific set of 24-hour DARF values to be used in the Phase 2 hydrologic analyses along the northern Front Range of Colorado (Big Thompson River, Boulder Creek, and St. Vrain Creek). These site-specific storm based 24-hour DARF values were used to extend those provided in NOAA Atlas 2 for area sizes greater than 400 square miles. This analysis resulted in 24-hour DARF values that varied significantly from NOAA Atlas 2 values [**Figure 8**] *demonstrating the need for the updated analysis to capture the unique storm characteristics along the Front Range and to more accurately capture the DARFs for larger basins in the region.*

To avoid significant reductions in the predicted 10, 4, 2, 1, and 0.2 percent annual chance peak discharges at the interfaces between the Phase 1 and Phase 2 study areas that would occur if the site-specific AWA DARF curve was strictly adopted for the Phase 2 hydrology analysis, a transition curve between the higher NOAA Atlas 2 DARF curve and the AWA site-specific DARF curve was developed by the Jacobs consultant team. The transition curve started at 315 square miles, which allowed for a consistent approach to be used between the two study phases and all the watersheds, as a DARF of 0.92 was utilized to estimate predictive hydrology for a drainage area of 315 square miles in the Phase 1 hydrologic analysis of the Big Thompson River. The transition curve then dropped down and tied into the AWA curve at 500 square miles providing a smooth transition between the two curves. This transition curve was tested at several design points with areas between 315 and 500 square miles, and it produced reasonable results when compared against current regulatory values and expected unit discharges. For modeling purposes, a step function was developed to break the combined DARF curve into about a dozen area increments. The stepped area increments reasonably represent the actual DARF value for all of the modeled design points (within 1 percent) and significantly reduces the number of model runs necessary to produce results at each design point. **Figure 8** provides the various DARF curves, the design point areas for each watershed, and the stepped area increments used to represent the design points. **Table 10** provides the area increments and resulting DARF values used in the Phase 2 hydrologic analysis.

TABLE 10
Drainage Area Reduction Factors

Area Range (mi²)		DARF	Area Range (mi²)		DARF	Area Range (mi²)		DARF
Low	High		Low	High		Low	High	
0	10	1.00	315	350	0.90	500	570	0.70
10	30	0.98	350	400	0.86	570	800	0.68
30	50	0.96	400	425	0.80	800	1000	0.66
50	100	0.94	425	450	0.78			
100	315	0.92	450	500	0.75			

Given the scale of the Boulder Creek watershed, the recommended DARF provided in **Table 10** varied from 0.78 at the watershed outlet at St. Vrain Creek to 0.92 at the upstream junction of the Phase 2 study reach. To more accurately estimate the 10, 4, 2, 1, and 0.2 percent annual chance peak discharge along Boulder Creek, the suite of design recurrence storms were each run using three different DARFs to account for the reduction in average rainfall depths associated with varying drainage area at each study point. In accordance with **Table 10**, the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges along Boulder Creek from Broadway Avenue to North 75th Street were estimated using a DARF of 0.92; Boulder Creek from the Confluence of Dry Creek No. 3 to the Confluence with Bullhead Gulch, a DARF of 0.90; and Boulder Creek from the Confluence with Coal Creek to the watershed outfall at St. Vrain Creek, a DARF of 0.78.

Subbasin Parameters (Infiltration Losses and Hydrograph Transformation)

As discussed in previous sections, the NRCS (formerly SCS) method was selected to convert input rainfall to infiltration losses and runoff. The key parameter in the NRCS method is the CN, which defines the runoff potential of a particular land cover, land condition, and underlying soil substrate; a completely impervious surface would be represented by a CN of 100, whereas a forest in good condition with permeable substrate would have a lower CN, e.g., 30. The CN also considers soil saturation as the more saturated a soil becomes, the less interstitial space is available for the storage of rainfall and thus a greater proportion of the rainfall will runoff. The NRCS method accounts for soil saturation by assigning an Antecedent Moisture Condition (AMC) based on the rainfall during the preceding 5 days. AMCII is considered a "normal" condition and is generally assumed. AMCIII conditions represent saturated conditions, such as occurs immediately after a moderate to high rainfall, with higher resultant CNs as compared to AMCII. AMCI is a dry condition, such as occurs when no rainfall has occurred for several days, weeks, or months, with a lower resultant CN as compared to AMCII.

Two GIS-based data sources, *Technical Release 55: Urban Hydrology for Small Watersheds* ("TR-55," NRCS, 1986), and engineering judgment were used to develop CNs for each subbasin. TR-55 provides CNs for a given land cover description and hydrologic soil group (a measure of the infiltration capacity of the underlying soil alone). Land cover was delineated using the National Land Cover Dataset (NLCD) to identify land use across the subbasins on a 100-foot by 100-foot scale (USGS, 2006). In areas where development occurred since the NLCD was developed in 2006 (e.g., new subdivisions), the NLCD was adjusted by CH2M HILL utilizing 2011 aerial photography to reflect the new developed conditions. Adjusted NLCD land cover types across the Boulder Creek watershed are provided in **Figure 9**. Delineation of hydrologic soil groups was accomplished using the U.S. Department of Agriculture's (USDA's) Soil Survey (USDA, 2014); delineated hydrologic soil groups are presented in **Figure 10**. The overlapping Soil Survey and NLCDs were then joined by intersecting the two datasets such that each land cover unit was further subdivided by hydrologic soil group. These results were then exported to Microsoft® Excel® where a CN was applied for each unique land cover condition and hydrologic soil group using engineering judgment to correlate observed land cover conditions with a representative land cover description provided in TR-55. Microsoft® Excel® was then used to adjust AMCII CNs to AMCIII CNs as appropriate (discussed later) and area-weight these results in accordance with TR-55 methodology to estimate a single, representative CN for each subbasin.

During the process of model calibration, it was recognized that due to the embankments separating the gravel pits from Boulder Creek, rainfall on the gravel pits adjacent to Boulder Creek did not reach Boulder Creek as a hydrologic response such that the gravel pits effectively acted as sinks.[4] To avoid overestimating runoff potential of subbasins with a significant number of such gravel pits, "water" land cover units were not included in the area or CN calculations for subbasins with a significant area covered by gravel pits (BC-10, BC-11, BC-12B, BC-13, BC-16, BC-17, BC-18A, BC-20, BC-21A, BC-21B, BC-22, and CC-3). As a result of adjusting model parameters for disconnected gravel pits, the effective drainage area of the calibrated Boulder Creek hydrologic model was reduced by 3.1 square miles. As the permanent hydrologic separation of the gravel pits could not be guaranteed into the future, the gravel pits were "re-added" to the predictive hydrologic model to account for their drainage area and CN.

The transformation of runoff volume to an outflow hydrograph was accomplished using the Snyder's unit hydrograph. The shape of the Snyder's unit hydrograph is controlled by two factors: a peaking factor, C_p, and a lag time representative of the time elapsed between the centroid of a hyetograph and the peak of the resultant hydrograph. Lag time was estimated using the following equation (Equation CH9-511) provided in

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[4] The breaching of the gravel pit embankments was inferred to be a result of Boulder Creek overtopping the embankment "towards the gravel pit" rather than accumulated rainfall water within the gravel pit overtopping the embankment "towards Boulder Creek." This was based on a comparison of measured rainfall depths to the average height between the normal gravel pit water surface elevation and the elevation of the gravel pit embankment. Depositional patterns evident in aerial imagery support this inference as the observed depositional patterns suggest flow from Boulder Creek to the gravel pit as the gravel pit embankment was overtopped. What this "direction of breaching" suggests is that water was flowing *into* rather than *out of* the gravel pits as Boulder Creek peaked. Although the gravel pits eventually drained back to Boulder Creek as the flow receded, this "return flow" likely occurred on the receding limb of the hydrograph and, thus, would not have impacted the modeled peak discharge of time-of-peak discharge.

the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008) and recommended for use in subbasins larger than 1 square mile:

$$TLAG = 22.1\ K_n * \left(\frac{L * L_c}{\sqrt{S}}\right)^{0.33}$$

where K_n is the roughness factor for the basin channels, L is the length of longest watercourse, in miles, L_c is the length along longest watercourse measured upstream to a point opposite the centroid of the basin, in miles, and S is the representative slope of the longest watercourse, in feet per mile. **Figure 5** provides a visual depiction of the hydrologic model layout, including delineated flow paths from the centroid of each subbasin and layout of reach elements. Physical parameters were estimated using ArcHydro tools in ArcGIS to analyze the NED digital elevation model (USGS, 2013). Flow paths for watersheds characterized by hillslopes and gulches draining directly to the main channel were determined using the watershed of a representative gulch. Roughness factors, K_n, were assigned per Table CH9-T505 of the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008), up to a maximum of 0.09, using aerial imagery to assess land use type. Snyder's C_p was predominantly assigned based on the degree of development: low values of Snyder's peaking factor, C_p, were assigned to rural subbasins and higher values were assigned to more developed subbasins where it was assumed that drainage infrastructure would increase the peak discharge compared to undeveloped conditions. Selection of the appropriate peaking factors, C_p, and roughness factors, K_n, were confirmed during the calibration process when modeled results approximated available calibration data, as discussed in subsequent sections. Hydrograph transformation parameters for each individual subbasin are provided in **Table B-4** in **Appendix B**.

Reach Parameters (Hydrograph Routing)

Both the Muskingum-Cunge and Modified Puls routing methodologies were used to route inflow hydrographs along basin streams, but the Modified Puls method was only used in the calibrated hydrologic model (not the predictive hydrologic model) and was used only after a timing calibration was achieved using the Muskingum-Cunge method. During the preliminary model calibration, the Muskingum-Cunge routing methodology was used to model all basin streams due to the methodology's solution of the continuity and momentum equations to estimate lag time and flow attenuation; thus, the Muskingum-Cunge method is based on channel hydraulics, including channel roughness, cross section, and slope. Eight-point cross sections were used to model the channel cross section shape to allow for the incorporation of channel floodplains that convey a significant portion of high flows. Eight-point cross sections were derived using ArcGIS tools and manually transposed to the hydrologic model. The NED 1/3 arc-second data (USGS, 2013a) was utilized to develop cross sections along South Boulder Creek upstream of Rollinsville, Twomile Canyon Creek, Wonderland Creek, Skunk Creek, and Dry Creek; 2013 post-flood LiDAR (FEMA, 2013b) was used to develop cross-sections along the remaining stream corridors. A single cross section was selected for each reach based on visual identification of a representative cross section, erring slightly towards flatter, wider reaches that are likely to provide the majority of floodplain storage and flow attenuation. The location of the Phase 2 model reach locations are provided in the connectivity maps, **Figures 5a** through **5f**, and the model eight-point cross sections are provided in **Figures 11a** and **11h**.

Manning's roughness values were selected based on recommended values for channel and floodplain conditions, as provided in Chow, 1959. Aerial imagery was used to visually assess a representative channel and floodplain condition. As described in the calibration section of the report, the initial estimates of Manning's roughness values were then adjusted to match observed hydrograph timing. With the exception of reaches through the City of Boulder, calibrated Manning's roughness values were within values recommended in Chow, 1959. For reaches through the City of Boulder, calibrated Manning's roughness values were much greater than values recommended in Chow, 1959. This was assumed to be the result of real-world backwater effects, energy losses, and obstructions not accounted for in the Muskingum-Cunge method and, thus, were deemed to be reasonable. However, it should be noted that these unaccounted-for hydraulic effects were removed from the Manning's roughness values used in the predictive hydrologic model, as it must be assumed that hydraulic losses caused by manmade infrastructure in the regulatory floodplain will be reduced or eliminated at some point in the future.

As alluded to previously, the Modified Puls method was used to model select reaches of Boulder Creek in the calibrated hydrologic model. The reaches of Boulder Creek modeled using the Modified Puls method are identified in **Table B-2** of **Appendix B** and correspond to approximately the reach of Boulder Creek between Broadway Avenue and North 75th Street. During the calibration process, *after* the model had been time-calibrated using the Muskingum-Cunge routing methodology, it was observed that the routing reaches provided minimal attenuation of the peak discharge in comparison to expectations and results of unsteady, two-dimensional hydraulic modeling of South Boulder Creek provided in the *South Boulder Creek Hydraulic Modeling Report* (HDR, 2008). Considering the Modified Puls method models the routing reach as a series of level pools, similar to a reservoir, it was determined that it may more accurately model the backwater effects that occurred in stream reaches with multiple bridge crossings. To leverage the time-calibration achieved using the Muskingum-Cunge methodology, the eight-point cross-sections and calibrated Manning's roughness parameters were input into USACE'S HEC-RAS to develop a rating curve and stage-storage curve for the eight-point cross-section, which was then transferred to the hydrologic model and used as input to the Modified Puls method. The Modified Puls methodology was executed assuming three level pools; three level pools for each Boulder Creek routing element was deemed appropriate based on the average number of bridges in each reach (theoretically, each bridge causing one "pool") and conformance with the time-calibration achieved using the Muskingum-Cunge methodology. Following confirmation of the Modified Puls routing parameters, it was noted that the attenuation of peak discharge along the Modified Puls routing reach increased in relation to the Muskingum-Cunge methodology, as desired. Routing reaches modeled using the Modified Puls methodology in the calibrated hydrologic model were modeled using the Muskingum-Cunge methodology in the predictive hydrologic model to discount unintended attenuation effects (e.g., backwater at bridges and split flow paths) that would likely be a focus of potential future drainageway improvements.

A final adjustment was made to two routing elements, SBC-R14 and SBC-R15, roughly South Boulder Creek between U.S. Highway 36 and the confluence with Boulder Creek, to account for significant backwater effects and split flows that occurred during September 2013. While HEC-HMS is not explicitly capable of modeling the hydraulics of backwaters and split flows, an exfiltration loss was applied to routing elements SBC-R14 and SBC-R15 to replicate the reduction in peak provided by these hydraulic conditions (assuming the split flow and backwatered volume would lag the peak discharge on Boulder Creek and thus not contribute to peak discharges): an exfiltration loss of 25 percent and 9 percent were applied to routing reaches SBC-R14 and SBC-R15, respectively, to replicate the results of unsteady, two-dimensional modeling of the 100-year event performed by HDR showing a net 40 percent reduction in peak discharge of South Boulder Creek between U.S. Highway 36 and Boulder Creek. Both exfiltration losses were omitted in the predictive hydrologic model as it is expected that split flows and significant backwater effects cannot be guarantee to exist in perpetuity as infrastructure is potentially retrofitted or replaced in the future.

Reservoir Parameters (Hydrograph Routing)

Four major reservoirs are located within the Boulder Creek watershed: Barker Reservoir on Middle Boulder Creek, Gross Reservoir on South Boulder Creek, Baseline Reservoir on Dry Creek (with diversions from South Boulder Creek), and the Valmont / Leggett / Hillcrest Reservoir Complex ("Valmont Reservoir") on South Boulder Creek. All four reservoirs were considered in the development of the calibrated hydrologic models because they provided flood storage during the September 2013 event. Although water supply reservoirs are typically not modeled in hydrologic models, the decision was made to account for the aforementioned reservoirs in the calibrated model due to their storage of a significant portion of the inflow during the September 2013 storm event. Although not expressly operated as flood control dams, Barker Reservoir and Gross Reservoir were also included in the development of the predictive hydrologic model as both reservoirs are in-stream and passively attenuate inflows (i.e., flood flows must pass through these two reservoirs and regardless of intent, the reservoirs would provide attenuation). Each reservoir is described in detail in the following sections.

Barker Reservoir. At Barker Reservoir, a water supply reservoir downstream of Nederland, Colorado, on Middle Boulder Creek, a peak inflow of approximately 400 cfs on September 13 was measured by the upstream CDWR gage Middle Boulder Creek at Nederland, whereas flow releases, as measured by the City of Boulder, from Barker Reservoir were approximately 4 cfs until the emergency spillway activated several days later on September 15 (City of Boulder, 2013d). Considering the 99 percent reduction in peak discharge provided by the 11 feet of storage available in Barker Reservoir prior to the start of the September 2013 storm event (see **Table B-5** in **Appendix B**), the decision was made to include Barker Reservoir in the calibrated model. Neglecting the storage provided by Barker Reservoir and routing the entirety of the inflow hydrograph to the downstream reaches would have resulted in the underestimation of calibration parameters because modeled downstream discharges would have included discharge from Middle Boulder Creek that did not actually occur and, thus, decrease the runoff contribution from other sub-watersheds. In the calibrated model, Barker Reservoir was effectively modeled as a “sink”: reservoir releases in the hydrologic model were controlled according to hourly outflow discharges from September 11 to September 25, 2013, as provided by the City of Boulder (City of Boulder, 2013d).

In the predictive model, Barker Reservoir was removed as a reservoir element and replaced as a routing element to conservatively estimate the downstream hydrograph. Such an approach allowed for the time attenuation of flow, i.e., modeled the time elapsed between inflow and outflow peaks, but did not allow for volumetric attenuation of the flow because Barker Reservoir is not explicitly operated as a flood control dam. The time lag associated with Barker Reservoir was determined by measuring the time elapsed between the peak modeled inflow and peak modeled outflow at Barker Reservoir on September 15 using a model calibrated to the entirety of the storm event and assuming that Barker Reservoir outflow is entirely controlled by a 63-foot weir (measured from Google Earth™) at the maximum reservoir stage. This flow peak occurred following a moderate rainfall when Barker Reservoir was nearly or completely full and it, therefore, represents a realistic estimate of the time attenuation provided by Barker Reservoir when no storage is available. Using this methodology, a time lag of 4.5 hours was measured. As illustrated in **Figure 12**, the modeled outflow compares favorably with observed flow downstream of Barker Reservoir.

Gross Reservoir. Similar to Barker Reservoir, Gross Reservoir also provided significant attenuation of the September 2013 storm event: a peak discharge in excess of 800 cfs was observed at CDWR’s Pinecliffe gage located 2.5 miles upstream of Gross Reservoir, whereas discharge measured by the USGS gage less than 1 mile downstream of Gross Reservoir, the measured hydrograph of which is provided as **Figure 13**, did not exceed 300 cfs. Of this 300 cfs, 171 cfs was a controlled release from Gross Reservoir according to the September 2013 daily flow release schedule provided by Denver Water and included as **Table B-6** in **Appendix B** (Denver Water, 2013a). To account for the storage and attenuation provided by Gross Reservoir, reservoir releases in the hydrologic model were controlled according to the September 2013 daily flow release scheduled provided by Denver Water (Denver Water, 2013a). Review of Gross Reservoir elevation-storage records (Denver Water, 2013b) indicate that the spillway of Gross Reservoir did not activate until September 18 when the recorded reservoir elevation first exceeded the reported spillway elevation of 7282.0 (Denver Water, 2014a), thus, the daily flow release schedule accounts for all outflows from Gross Reservoir that occurred during the calibration period.

In the predictive model, Gross Reservoir was modeled as a reservoir element using elevation-storage-discharge modeling to account for the time and volumetric attenuation of inflows that would be passively provided by Gross Reservoir regardless of its status as a flood control reservoir or not. Also, modeling Gross Reservoir using elevation-storage-discharge modeling maintained consistency to the effective hydrologic model of South Boulder Creek (HDR, 2007). To develop the elevation-storage-discharge information required to model Gross Reservoir, the Gross Reservoir elevation-storage curve (Denver Water, 2014b) and Gross Reservoir elevation-discharge curve (Denver Water, 2014a) were input to HEC-HMS. To be conservative and avoid the use of storage capacity that may not be available in the event of a high-flow event, the starting water surface elevation for Gross Reservoir was assumed equal to the spillway elevation of 7282.0.

Baseline Reservoir. While Baseline Reservoir is an off-channel reservoir, personnel communications with the City of Lafayette indicated that overland flooding emanating from South Boulder Creek flowed, uncontrolled, into Baseline Reservoir (Bradley Dallam, PE, personal communication, June 13, 2014). Measurements of gage height, reservoir contents, inflows, and outflows at Baseline Reservoir provided by the City of Lafayette, and included as **Table B-7** in **Appendix B**, support this observation as the reservoir rose several feet between September 11 and September 14, although no controlled inflows were measured and controlled releases on the order of 75 cfs (150 acre-feet per day) were recorded (Baseline Reservoir Company, 2013). The possibility that rainfall caused the reservoir to fill was also ruled out, as the drainage area to Baseline Reservoir contains little area outside of the reservoir itself and over the entire 10-day period, a maximum of 21 inches fell anywhere in the Boulder Creek watershed (i.e., the maximum rise in reservoir gage height over the 10-day period due to rainfall, assuming no outflows, would have been 21 inches). Furthermore, two-dimensional hydraulic modeling of South Boulder Creek indicating flow from South Boulder Creek to Baseline Reservoir (HDR, 2007) provides further evidence that overland flooding from South Boulder Creek to Baseline Reservoir occurred during September 2013.

To account for flow from South Boulder Creek to Baseline Reservoir, results from HDR's 2007 two-dimensional modeling of South Boulder Creek were used to develop an inflow-diversion relationship at South Boulder Road that was incorporated into the calibrated hydrologic model to divert flow from South Boulder Creek to Baseline Reservoir. This inflow-diversion relationship was removed from the predictive hydrologic model. As the Baseline Reservoir element had no inflows, Baseline Reservoir was effectively not modeled in the predictive hydrologic model (although it was included in the calculation of subbasin area and CN for the subbasin of which it was part).

Valmont / Leggett / Hillcrest Reservoir Complex. Based on the observation that Valmont Reservoir did not flood to South Boulder Creek per the City of Boulder's Urban Flooding Extents Map (City of Boulder, 2014), Valmont Reservoir was effectively removed from the calibrated hydrologic model by setting the initial abstraction for the subbasin draining to and including Valmont Reservoir (SBC-21) to 18 inches, a value greater than the observed rainfall at that subbasin. This approach effectively eliminated runoff from the subbasin but allowed efficient re-incorporation of SBC-21 into a future predictive hydrologic model where Valmont Reservoir, as a cooling reservoir for Xcel Energy, could not be relied upon to intercept and store the entirety of runoff draining to it.

In the predictive hydrologic model, the initial abstraction of 18 inches was removed for SBC-21 and HEC-HMS allowed to compute initial abstraction based on the input CN. While Valmont Reservoir was not modeled as a reservoir element, subbasin unit hydrograph parameters were adjusted to approximate the time and volumetric attenuation that would be provided for inflows draining to Valmont Reservoir: the roughness parameter, K_n, was set to 0.15 and Snyder's peaking factor, C_p, was set to 0.20.

Transbasin Inflows and Outflows

Two transbasin inflows and one transbasin outflow were incorporated into the calibrated hydrologic model: Moffat Tunnel in the upper portion of South Boulder Creek, Boulder Creek Supply Canal from Boulder Reservoir, and South Platte Supply Canal downstream of the Boulder Creek at 75th gage, respectively. Gage measurements for each transbasin transfer were available from CDWR and subsequently incorporated into the calibrated hydrologic model as a source or diversion, as appropriate. No transbasin inflow or transbasin outflow was included in the predictive hydrologic model.

2.4.6 Model Calibration

Model calibration is the iterative process of adjusting model parameters so that simulated results match real-world observations (measurements). Model calibration provides a degree of certainty beyond that achieved through the use of parameters reported in literature because calibrated parameters ideally account for unique attributes of a particular watershed. The following sections describe the calibration of the Boulder Creek HEC-HMS hydrologic model.

Calibration Event

Reviewing the flood history of Boulder Creek, summarized in **Table 3**, it can be surmised that the largest discharges observed along Boulder Creek were the result of large, long-duration “general storms” rather than localized and intense convective storms (“cloudbursts”). The majority of historical high-flow events follow a pattern characterized by a slow, steady rainfall occurring over several days punctuated by a short period of comparatively intense rainfall that drives downstream flooding. As previously discussed, such a pattern was followed during the September 2013 event and suggests that the September 2013 event is generally representative of infrequent high-flow events. As such, and given the hydrologic data available for the September 2013 event, the calibration of the predictive hydrologic model using the September 2013 event was deemed appropriate to accurately assess the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges.

As discussed previously, the hydrologic model was calibrated to a 24-hour period of the September 2013 event to better align the hydrologic modeling effort with the assumptions associated with the development of the NRCS infiltration loss equations. Peak discharges recorded at Boulder Creek stream gages, illustrated in **Figure 2**, occurred between 9:55 p.m. on September 12 and 5:30 a.m. September 13. The 24-hour period of rainfall associated with peak discharges along Boulder Creek was selected as 6 a.m. on September 12 to 6 a.m. on September 13. In addition to capturing the period of time leading up to the peak discharges along Boulder Creek, the selected calibration window starts and ends in a relative “break in the storm” and is highlighted in reference to Boulder Creek hydrographs and measured rainfall as part of **Figure 2**.

Although the September 2013 event occurred after a relatively dry period, the 24-hour calibration period occurred several days into the storm after 1.3 to 11.1 inches of rain observed prior to the calibration period had partially or fully saturated the watershed soils and expended much of the initial infiltration capacity of the soils. While a rainfall burst during the late evening of September 11 drove peak flooding of Fourmile Canyon Creek, Twomile Canyon Creek, and Wonderland Creek (Bob Harberg, personal communication, November 11, 2014), major tributaries, including South Boulder Creek, Coal Creek, and the upper portions of Boulder Creek, also peaked during the late evening of September 12 and were considered more critical to the calibration of the Boulder Creek hydrologic model.

Calibration Process

Model calibration is the iterative process of adjusting model parameters so that simulated results match real-world observations (measurements). Model calibration requires careful consideration of which modeling parameters are best considered “fixed” and those that are most appropriately adjusted to avoid the manipulation of parameters beyond physical reality to achieve desired results. For example, modeled discharges may be “calibrated” to measured discharges by increasing subbasin roughness parameters to an unreasonably high value that results in the offsetting of two previously co-occurring inflows. While the model may be “calibrated” computationally, it would not be calibrated realistically because careful review of the calibrated parameters would suggest that the resultant time lags are not consistent with physical processes. In a similar sense, topographically-derived parameters including the slope of routing elements and subbasin area, were considered fixed – while these parameters affect the model results, there is little justification to change their value short of re-defining the watershed subbasins and flow paths. Considering the empirical or physical nature of model parameters, it was determined that adjustment of the following parameters was most justified to calibrate the hydrologic model: Manning’s roughness coefficient, subbasin roughness factor, K_n, Snyder’s Peaking factor, C_p, and CN.

After identifying parameters to be calibrated, model calibration should also consider the sensitivity of model results to these parameters – special attention should be paid to “sensitive” parameters that have large effect on model results. As various parameters were adjusted during the calibration process to match observations, the sensitivity of the model results to various parameters was noted. As a result of this process, this assessment of the sensitivity of the model results to the following parameters was made:

- **Subbasin Roughness Factor, K_n:** Of the calibration parameters, subbasin roughness factor had the greatest impact on modeled times-of-peak discharge. Subbasin roughness factor also had a significant impact on modeled peak discharges; however, these impacts were generally mediated by concurrent decreases in Snyder's peaking factor and/or CN to calibrate peak discharges.
- **Manning's Roughness Coefficient, n:** Within smaller drainages, e.g., Fourmile Canyon Creek, drastic changes in Manning's roughness coefficient had a minor effect on estimated peak discharge (± 5 percent) and time-of-peak discharge (± 15 minutes). On the watershed scale, Manning's roughness coefficient had a moderate impact on estimated peak discharges as the non-concurrent or concurrent timing of tributary peak discharges could affect mainstem peak discharges as much as ± 20 percent.
- **Snyder's Peaking Factor, C_p:** No effect on modeled runoff volume; moderate effect on modeled peak discharge and time-of-peak. In general, decreased Snyder's peaking factor lengthened the duration of the hydrograph, decreased peak discharge, and resulted in later time-of-peak discharge. However, individual manipulation of Snyder's peaking factor by subbasin (dependent on subbasin topology and hydrologic conditions) could affect modeled time-of-peak discharge by as much as 2 hours as the impact of individual subbasins on downstream time-of-peak discharge increased or decreased.
- **CN:** One of two parameters that affected modeled runoff volume; greatest impact on modeled peak discharges (in excess of ± 50 percent). CN had negligible effect on the time-of-peak discharge.

In general, calibration of the model followed the process outlined below:

1. Coarse-scale adjustment of CN to approximately match modeled runoff volume to runoff volume observed at stream gages that remained operational through the September 2013 event.
2. Adjust subbasin roughness factor, K_n, and Manning's roughness coefficient, n, to match modeled times-of-peak discharge to observed times-of-peak discharge. To the extent possible, "global" rules were used to assign values, e.g., subbasins classified as "Irrigated Agriculture" were assigned a subbasin roughness factor of 0.09.
3. Adjust Snyder's peaking factor, C_p, to approximate modeled peak discharges to observed peak discharges. To the extent possible, "global" rules were used to assign values, e.g., high-density developed areas were assigned a Snyder's peaking factor of 0.70.
4. Replacement of Muskingum-Cunge routing methodology with Modified Puls routing methodology for routing elements along developed portions of Boulder Creek with numerous stream crossings.
5. Fine-scale adjustment (by land use and hydrologic soil group) of CN to improve calibration of modeled peak discharges while maintaining calibration of modeled runoff volume.
6. Review of modeled times-of-peak discharge and assessment of sensitivity to runoff from particular subbasins impacting modeled times-of-peak discharge.
7. Repetition of steps 2 to 6 until modeled results best achieved calibration targets, recognizing that some calibration targets were not attainable (e.g., significant downstream decrease in peak discharges). In general, achieving calibration targets along Boulder Creek was prioritized over achieving calibration targets on tributary drainages, although consideration was given to both sets of targets.

After preliminary time-calibration of the calibrated hydrologic model (Step 2), the timing of the model was mildly sensitive to adjustments of Snyder's peaking factor and negligibly sensitive to adjustments of CN such that subsequent calibration of the model focused primarily on calibration of peak discharges and runoff volumes. While modeled peak discharges were mildly sensitive to Snyder's peaking factor, CN was the main parameter adjusted to calibrate modeled peak discharges to observed peak discharges. While recommendations for CN based on land use and hydrologic soil group exist in the literature, calibration of CNs is relatively common for single-event storms due to the unique vegetative cover, soil structure, depth to bedrock, topography, land use history, and other factors that impact infiltration capacity but are not readily quantifiable.

In regards to Step 1 of the Calibration Process outlined above, initial estimates of CNs based on interpretation of aerial imagery and land cover classifications yielded modeled discharges that were significantly less than observed flows and indicated a need to drastically increase CNs to calibrate the model. Given that significant rainfall was measured in the days preceding the selected 24-hour period, with some basins receiving upwards of 11 inches of rain over the previous 72 hours, there was a reasonable probability that watershed soils were saturated and had a significantly reduced infiltration capacity not represented by standard CNs, which assume a 5-day antecedent rainfall of less than 2.1 inches (Novotny, 2011). AMCs were considered by estimating the total rainfall in the 5 days prior to the selected 24-hour period. Subbasins that received more than approximately 2.1 inches of rainfall were classified AMCIII; those that received less were classified as AMCII (Novotny, 2011). Five subbasins: MBC-1A, MBC-1B, and MBC-2 (Phase 1 study area), SBC-1A, and SBC-1B (Phase 2 study area), all near the Continental Divide, had 5-day antecedent rainfalls that identified these five basins as AMCII, whereas the remaining subbasins were AMCIII; this information is also provided in **Table B-2** of **Appendix B**. This identification agrees with observations that runoff from these was generally less than the 2013 snowmelt peak of that year (Jarrett, In Press). CNs for AMCIII were estimated from AMCII CNs in literature using the following equation (Novotny, 2011):

$$CN_{AMCIII} = \frac{23CN_{AMCII}}{10 + 0.13CN_{AMCII}}$$

To limit the possibility of unrealistic estimates of CNs, calibration of CNs relied on the re-assignment of TR-55 land cover descriptions to NLCD land covers (USGS, 2006). The re-assignment of land cover description was mostly limited to assigning a “fair condition” instead of a “good condition” originally assigned. In general, CNs were re-assigned at the watershed scale but also at the scale of major hydrologic zones composing the Boulder Creek watershed and outlined in Section 1.2: Mountainous areas, Foothill areas, and Plains areas, where justified. For example, “shrub/scrub” land cover in Foothills areas was re-assigned as “Sagebrush,” in contrast to greener, “herbaceous” used in Mountainous areas, due to the drier conditions and increased density of grasses, weeds, and semi-arid shrubs in the Foothills regions.

Calibration Results

As discussed above, the timing of runoff was critical to the calibration of peak discharge as the simultaneous peaking of two streams could greatly increase the combined modeled peak discharge in comparison to if the two peaks were separated by a moderate amount of time. Review of observed discharges in **Figure 4** provides direct evidence that times-of-peak discharge for many tributaries were out-of-sync with Boulder Creek and each other as the summation of observed upstream discharges greatly exceeded the observed estimate downstream on Boulder Creek and further suggests that runoff timing is critical to calibration of modeled peak discharges. In addition, as discussed in the previous section, after initial calibration of the model timing, the timing of the hydrologic model was relatively insensitive to adjustments of CN to calibrated modeled peak discharges.

Modeled times-of-peak discharge are compared to observed times-of-peak discharge in **Table 11**. With the exceptions noted as footnotes to **Table 11**, modeled times-of-peak discharge were generally within 20 minutes of observed times-of-peak discharge. As modeled peaks on streams like Fourmile Canyon Creek generally occurred over an hour, timing calibration within 20 minutes was considered satisfactory.

TABLE 11
Comparison of Modeled Time-to-Peak to Observed Time-to-Peak

Location	Calibration Data Source	Observed Time of Peak Discharge	Modeled Time of Peak Discharge	Difference
Boulder Creek near Orodell	CDWR Gage	9/12 23:30	9/12 23:30	± 0 minutes
Boulder Creek at Fourmile Creek	UDFCD ALERT	9/12 22:48	9/12 23:00	+ 12 min (late)
Boulder Creek at Broadway	UDFCD ALERT	9/12 22:30	9/12 22:50	+ 20 min (late)
Boulder Creek at 75th Street	USGS Gage	9/13 2:50	9/13 2:20	- 30 min (early)
Boulder Creek at Mouth	UDFCD ALERT	9/13 5:30	9/13 5:25	- 5 min (early)
Coal Creek near Plainview	CDWR Gage	9/12 22:30	9/12 22:20	- 10 min (early)
Fourmile Canyon Creek near Sunshine	UDFCD ALERT	9/12 22:40 [a]	9/12 21:55	- 45 min (early) [a]
Fourmile Creek near Orodell	UDFCD ALERT	9/12 22:45	9/12 22:45	± 0 minutes
Middle Boulder Creek at Nederland	CDWR Gage	9/13 02:15 [b]	9/13 2:55	+ 40 min (late)
South Boulder Creek near Pinecliffe	CDWR Gage	9/13 4:30	9/13 4:15	- 15 min (early)
South Boulder Creek below Gross Reservoir	CDWR Gage	9/12 22:00	9/12 21:50	- 10 min (early)
South Boulder Creek near Eldorado Springs	UDFCD ALERT	9/12 22:00	9/12 22:15	+ 15 min (late)
South Boulder Creek at CO Hwy 93	UDFCD ALERT	9/12 19:40 [c]	9/12 23:00	+ 3 h 20 min (late) [c]
South Boulder Creek at South Boulder Road	UDFCD ALERT	9/12 19:25 [c]	9/12 22:05	+ 2 h 40 min (late) [c]

[a] Gage is located two miles upstream of model junction; lag time estimated at 15 to 30 minutes based on routing reach.

[b] Observed peak of 409 cfs was measured from 2 a.m. to 2:30 a.m.; HEC-HMS results report the earliest time (2 a.m.).

[c] Likely impacted by railroad embankment breach along Doudy Draw.

Calibrated timing parameters, including subbasin unit hydrograph parameters and routing reach parameters, are provided in **Table B-4** and **Table B-8** of **Appendix B**, respectively.

After achieving a timing calibration of the calibrated hydrologic model, incorporation of AMC effects and re-classification of CNs achieved satisfactory calibration results; comparison of modeled peak discharges are compared with observed peak discharges in **Table 12**. Reviewing **Table 12**, modeled discharges generally calibrated to within ± 20 percent of observed values except as footnoted in **Table 12** and at locations where there was a significant decrease in peak discharge in the downstream direction (for example, Coal Creek at 120th Street) and some uncertainty existed as to the accuracy of the observed peak discharge estimate. Along Boulder Creek itself, modeled discharges were generally 15 percent greater than observed discharges. In comparison to under-calibration of model parameters, this slight over-calibration of Boulder Creek would be considered conservative as incorporation of the over-calibrated parameters into a predictive hydrologic model would be expected to generate higher peak discharge estimates. Trends in modeled peak discharges were generally consistent with observations of flood intensity by hydrologic area, with modeled peak discharges increasing significantly through the foothills region from Boulder Creek Canyon to approximately Fourmile Canyon Creek at the western edge of the City of Boulder; similar trends also were observed along South Boulder Creek and Coal Creek.

Resultant calibrated CNs are provided by subbasin are provided in **Table B-1** in **Appendix B** and the corresponding classification of land use condition is provided as **Table B-9** in **Appendix B**. Comparison of modeled discharges to observed discharges is provided in **Table 12**.

TABLE 12
Comparison of Modeled Discharges to Observed Discharges

Location	Calibration Data Source	Observed Discharge (cfs)	Modeled Discharge (cfs)	Percent Difference
Bear Canyon Creek at Mohawk Drive	Jarrett, in press	1,330 [a]	873	-34.4%
Boulder Creek near Orodell	Jarrett, in press	2,020	1,740	-13.8%
	CDWR Gage	1,720	1,740	+1.2%
Boulder Creek at Broadway	CDWR Gage	4,965	5,140	+3.5%
Boulder Creek at 28th Street	CWCB	5,300	5,060	-4.5%
Boulder Creek at Valmont Road	URS, 2015	5,700	6,510	+14.2%
Boulder Creek at 75th Street	USGS Gage	8,400	9,830	+17.0%
Boulder Creek at U.S. Hwy 287	URS, 2015	9,000	10,400	+15.5%
Boulder Creek at St. Vrain Creek	USGS Gage	N/E	16,100	-6.1% [b]
Coal Creek downstream of Bear Creek	Jarrett, in press	1,110	1,220	+9.9%
Coal Creek near Plainview (UDFCD Site)	Jarrett, in press	3,900	2,390	-38.7%
Coal Creek at U.S. Hwy 287	URS, 2015	5,000	4,440	-11.2%
Coal Creek at 120th Street	URS, 2015	3,500	4,430	+26.6%
Coal Creek at Erie Parkway	URS, 2015	6,000	5,580	-7.0%
Fourmile Creek Upstream Burned Area	Jarrett, in press	490	385 [c]	-21.4%
Fourmile Creek downstream of Emerson Gulch	Jarrett, in press	1,070	888 [c]	-17.0%
Fourmile Creek near Orodell	Jarrett, in press	2,300	2,380	+3.5%
	Field-measured	2,510	2,380	-5.2%
Middle Boulder Creek at Nederland	CDWR Gage	409	422	+3.2%
North Boulder Creek d/s CO Hwy 72	Jarrett, in press	340	331	-2.6%
North Boulder Creek at Confluence with Middle Boulder Creek	Jarrett, in press	740	720	-2.7%
Rock Creek at 120th Street	URS, 2015	1,500	1,140	-24.0%
South Boulder Creek at Rollinsville	Jarrett, in press	410	360	-12.2%
South Boulder Creek near Pinecliffe	CDWR Gage	781	784	+0.4%
S. Boulder Creek below Gross Reservoir	CDWR Gage	144	140	-2.8%
S. Boulder Creek at Eldorado Springs	Jarrett, in press	2,120	2,570	+21.2%
South Boulder Creek at CO Hwy 93	WWE, 2014	5,600 [d]	4,370	-22.0%
S. Boulder Creek at S. Boulder Creek Rd	Jarrett, in press	3,600 [d, e]	3,750	+4.1%

[a] Affected by debris flow (Wright Water Engineers [WWE], 2014).
[b] Based on comparison of 8,910 cfs daily average discharge at the gage and modeled daily average discharge of 8,370 cfs.
[c] Interpolated between HEC-HMS junctions based on contributing drainage area.
[d] Possibly affected by railroad embankment breach on Doudy Draw.
[e] May not account for overtopping of bridge and upstream flow splits to Dry Creek No. 2.

Comparisons of modeled runoff volume to total volume recorded at CDWR and USGS gages are provided in **Table 13**. It should be noted that a direct comparison of runoff volumes are difficult because of the calibration process – as the 24-hour analysis window occurred in the middle of the September 2013 event, runoff from the preceding days of rainfall was not incorporated into the model whereas it was a component of the total volume recorded by the gage measurements. **Figure 14a** provides a breakdown of the runoff volume measured at the Boulder Creek at Broadway and Boulder Creek at 75th Street gages to illustrate the percentage of measured runoff that may be attributable to rainfall that occurred prior to and during the 24-

hour analysis window. As a result of the model not incorporating the runoff from days preceding the calibration period, the lesser volume of the modeled runoff reported in **Table 13** was expected. For comparison, **Figure 14a** illustrates the sub-division of runoff at the Boulder Creek at Broadway gage based on time-origin of the runoff, where approximately 10 to 65 percent of the observed hydrograph was due to runoff from rainfall that occurred prior to the analysis period.

TABLE 13
Comparison of Modeled Runoff Volume to Observed Runoff Volume (24-Hour Calibration Period)

Gage	Calibration Data Source	Observed Volume (acre-feet)	Modeled Volume (acre-feet)	% Difference
Boulder Creek near Orodell, CO	CDWR Gage	1,817	1,300	-28.5%
Boulder Creek at Broadway	CDWR Gage	5,678	3,660	-35.5%
Boulder Creek at 75th Street	USGS Gage	10,435	8,510	-18.4%
Middle Boulder Creek at Nederland, CO	CDWR Gage	430	231	-46.3%
South Boulder Creek near Pinecliffe, CO	CDWR Gage	850	601	-29.3%
S. Boulder Creek below Gross Reservoir	CDWR Gage	96	132	+ 37.5%

2.4.7 Predictive Model Implementation

Development of the predictive hydrologic model required slight modification of the calibrated model to account for differences between the September 2013 event and a theoretical design event as some of the unique conditions that occurred during the September 2013 event would not be conservative in the estimation of high-flow hydrology and could not be guaranteed to occur again the future. The following modifications, discussed in detail in the Model Development section of the report and summarized below, were made to the calibrated model to develop the predictive model as follows:

- The calibrated AMCIII CNs were converted back to AMCII to maintain consistency with procedures detailed in the *Colorado Floodplain and Stormwater Criteria Manual* (CWCB, 2008) for the estimation of peak discharges using the NRCS method.
- Gravel pit areas were re-included in the calculation of subbasin area and CN.
- All transbasin inflows and outflows were removed.
- The Muskingum-Cunge routing methodology was used for all routing elements; Modified Puls routing methodology was not used in the predictive hydrologic model.
- For routing elements with high-calibrated Manning's roughness values assumed to be the result of hydraulic losses, backwater effects, and obstructions not explicitly modeled by HEC-HMS, the Manning's roughness values were reduced to 0.045 for channel areas and 0.060 for floodplain areas to account for potential future floodway improvements.
- Exfiltration losses in South Boulder Creek routing elements SBC-R14 and SBC-R15 used to account for backwater effects and flow splits not explicitly modeled by HEC-HMS were removed.
- The volume attenuation effects of Barker Reservoir were removed from the hydrologic model. Because Barker Reservoir is operated as a water supply reservoir and not a flood control reservoir, the reservoir was assumed full and not capable of controlling outflow releases or providing flood storage. However, the lag time that would occur as a flood wave passes through an initially full Barker Reservoir was considered in the model, as described in previous sections.
- Gross Reservoir was modeled as a reservoir element, with time and volumetric attenuation included in the predictive hydrologic model. Initial reservoir water surface elevation was set equal to the elevation of the reservoir spillway.

- Diversions from South Boulder Creek to Baseline Reservoir were removed.
- Initial abstraction for SBC-21, representing the drainage area of Valmont Reservoir, was reset to automatic computation based on CN.

With the revisions described above, the predictive model was used to estimate peak discharges throughout the watershed for the 10, 4, 2, 1, and 0.2 percent annual chance events assuming a standard 24-hour NRCS Type II rainfall distribution, as described previously.

3.0 Hydrologic Model Results

3.1 Estimate of Design Peak Discharge Magnitudes

The 10, 4, 2, 1, and 0.2 percent annual chance peak discharges along Boulder Creek, Coal Creek, and South Boulder Creek are provided in **Table 14** and were estimated using the predictive hydrologic model with the model parameters described in Section 2.4 and respective percent annual chance rainfall depths. As this study is focused on the main stem of Boulder Creek, peak discharge estimates developed for any tributaries to Boulder Creek are for the purpose of determining the tributary's contribution to peak discharges on Boulder Creek rather than peak discharges on the tributary itself. Peak discharges provided in **Table 14** are provided only as documentation of the results of the predictive hydrologic model; annual chance peak discharge estimates considered to the best estimate available and candidate to be considered for adoption by FEMA are provided in Section 4. The reported peak discharges in **Table 14** utilize a DARF appropriate to the drainage area at that location, as provided in **Table 10**. The 10, 4, 2, 1, and 0.2 percent annual chance peak discharge estimates at key locations along minor Boulder Creek tributaries (Fourmile Canyon Creek, Dry Creek No. 3, etc.) are provided for reference only as **Table B-10**. Modeled hydrographs at key design points in the watershed are provided in **Figure 14**. The peak discharge profiles for Boulder Creek, South Boulder Creek, and Coal Creek are provided in **Figure 15a, Figure 15b, and Figure 15c,** respectively. Detailed model results, including peak discharge and runoff volume by subbasin, are provided in **Table B-11** in **Appendix B**. Assessment of the recurrence interval of the September 2013 event at the various study locations is provided in Section 4.2.

TABLE 14
Modeled 10, 4, 2, 1, and 0.2 Percent Chance Peak Discharge along Study Reach and Principal Tributaries [a]

Location	DARF	Observed Discharge (cfs)	Annual Chance Peak Discharge (cfs)				
			10 Percent	4 Percent	2 Percent	1 Percent	0.2 Percent
Boulder Creek at Broadway	0.92	4,965	1,450	2,900	4,570	6,770	14,200
Boulder Creek at 28th Street	0.92	5,300	1,490	2,950	4,640	6,860	14,400
Boulder Creek at Valmont Road	0.92	5,700	1,630	3,320	5,270	7,490	15,500
Boulder Creek at 75th Street	0.92	8,400	2,760	5,690	8,780	12,400	25,200
Boulder Creek at U.S. Hwy 287	0.90	9,000	3,070	6,410	9,840	13,500	27,100
Boulder Creek at Mouth	0.78	16,100 [b]	4,790	9,000	13,700	19,000	37,300
Coal Creek downstream Beaver Cr.	1.00	1,110	795	1,360	1,890	2,520	4,290
Coal Creek near Plainview	0.98	3,900	1,000	1,750	2,470	3,330	5,790
Coal Creek at U.S. Hwy 287	0.96	5,000	1,630	2,990	4,340	5,790	9,750
Coal Creek at 120th Street	0.96	3,500	1,630	2,970	4,320	5,760	9,750
Coal Creek at Erie Parkway	0.94	6,000	3,250	5,970	8,530	11,400	18,800
South Boulder Creek at Rollinsville	0.96	410	86	301	677	1,300	4,090
South Boulder Creek near Pinecliffe	0.94	781	249	661	1,260	2,200	6,170
S. Boulder Cr. below Gross Reservoir	0.94	144	282	731	1,330	2,220	5,800
S. Boulder Creek at Eldorado Springs	0.92	2,120	485	1,100	1,760	2,650	6,840
South Boulder Creek at CO Hwy 93	0.92	5,600 [c]	754	1,700	2,710	4,020	8,220
S. Boulder Cr. at S. Boulder Cr. Rd.	0.92	3,600 [c, d]	810	1,810	2,870	4,270	8,840

[a] See Table 19 for peak discharge estimates proposed as the best available estimate of high-flow hydrology.
[b] Per 24-hour calibrated hydrologic model.
[c] Possibly affected by railroad embankment breach on Doudy Draw
[d] May not account for overtopping of bridge and upstream flow splits to Dry Creek No. 2

Modeled peak unit discharges, defined as peak discharge per square mile of contributing area, are provided in **Table 15**. Peak unit discharge by subbasin are provided as **Table B-11** in **Appendix B** and plotted against subbasin area in **Figure 16.** In general, peak unit discharges increases from areas classified as mountainous to areas classified as Plains. This general trend is consistent with expectations and previous studies that flooding on Boulder Creek is primarily driven by runoff from subbasins near the transition of the Front Range, rather than upper portions of the watershed.

TABLE 15
Modeled 10, 4, 2, 1, and 0.2 Percent Chance Unit Peak Discharge along Study Reach and Principal Tributaries

Location	Drainage Area (mi^2)	Observed Unit Discharge (cfs/mi^2)	Annual Chance Peak Unit Discharge (cfs/mi^2)				
			10 Percent	4 Percent	2 Percent	1 Percent	0.2 Percent
Boulder Creek at Broadway	135	36.8	10.7	21.5	33.9	50.1	105
Boulder Creek at 28th Street	136	39.0	10.9	21.7	34.1	50.4	105
Boulder Creek at Valmont Road	156	36.5	10.4	21.3	33.8	48.0	99.1
Boulder Creek at 75th Street	307	27.4	9.0	18.5	28.6	40.3	82.2
Boulder Creek at U.S. Hwy 287	331	27.2	9.3	19.4	29.7	40.9	81.8
Boulder Creek at Mouth	447	19.9 [a]	10.8	20.3	31.0	42.5	83.4
Coal Creek downstream Beaver Cr.	9.3	132	85.9	147	204	272	463
Coal Creek near Plainview	15.2	157	65.8	115	163	219	381
Coal Creek at U.S. Hwy 287	35.1	127	46.4	85.2	124	165	278
Coal Creek at 120th Street	35.7	124	45.7	83.2	121	161	273
Coal Creek at Erie Parkway	76.9	72.5	42.3	77.6	111	148	244
South Boulder Creek at Rollinsville	45.2	8.0	1.9	6.7	15.0	28.8	90.5
South Boulder Creek near Pinecliffe	72.7	10.8	3.4	9.1	17.3	30.3	84.9
S. Boulder Cr. below Gross Reservoir	95.8	1.5	2.9	7.6	13.9	23.2	60.5
S. Boulder Creek at Eldorado Springs	111	23.2	4.4	9.9	15.9	23.9	61.6
South Boulder Creek at CO Hwy 93	123	35.5	6.1	13.8	22.0	32.7	66.8
S. Boulder Cr. at S. Boulder Cr. Rd.	134	28.1	6.0	13.5	21.4	31.9	66.0

[a] Daily average.

3.2 Comparison of Boulder Creek Peak Discharge Estimates to Previous Studies, FEMA Effective Hydrology, and Stream Gage Analyses

Comparisons of the modeled 1 percent annual chance peak discharge estimates to estimates cited in previous studies, FEMA effective hydrology, and flood frequency analyses of stream gage records are provided in **Table 16**. Comparison of the measured September 2013 rainfall depths to NOAA rainfall-frequency curves was discussed as part of Section 2.4.5 and analyzed by subbasin in **Table B-2** of **Appendix B**. It should be noted that with the exception of Boulder Creek at 28th Street and Boulder Creek at Valmont Road, the FIS does not provide estimates of the 1 percent annual chance peak discharge at locations identified in **Table 16** even though the effective USACE, 1977 hydrology study provided peak discharge estimates along the entirety of Boulder Creek downstream of Orodell. While peak discharge estimates at all of the locations in **Table 16** were provided in the effective USACE, 1977 hydrology study, the information was only presented in a peak discharge profile that was difficult to read given the age and scanning quality of the document. Therefore, the peak discharge estimates from the effective USACE, 1977 hydrology study provided in **Table 16** were determined from data summary tables provided in effective Boulder Creek Flood Hazard Area Delineations reports (FHAD), as referenced in **Table 16**.

TABLE 16
Comparison of Modeled 1 Percent Annual Chance Discharge to Other Estimates along Boulder Creek Study Reach

		Estimated 1 Percent Annual Chance Peak Discharge (cfs)					
Location	**Drainage Area (mi²)**	**Predictive Model**	**USACE, 1969**	**USACE, 1977**	**FEMA Effective Hydrology [a]**	**Anderson Consulting Engineers, 2009**	**Gage Analysis**
Boulder Creek at Broadway	135	6,770	7,400	12,000 [b]	N/E	11,170	N/E
Boulder Creek at 28th Street	136	6,860	N/E	11,500 [b]	11,500	N/E	N/E
Boulder Creek at Valmont Road	156	7,490	N/E	13,050 [b]	13,000	13,400	N/E
Boulder Creek at 75th Street	307	12,400	11,000 [c]	13,800 [d]	N/E	N/E	7,895
Boulder Creek at U.S. Hwy 287	331	13,500	N/E	12,700 [d]	N/E	N/E	N/E
Boulder Creek at Mouth	448	19,000	N/E	12,000 [d]	N/E	N/E	5,119

[a] Per *Boulder County FIS* (FEMA, 2012).

[b] As reported in Table II: Floodplain and Floodway Reference Data of *Boulder Creek Flood Hazard Area Delineation* (Muller Engineering Company, 1983), which in turn references USACE, 1977 for hydrology.

[c] Reported only as "Boulder Creek below South Boulder Creek Confluence."

[c] As reported in Table IV: 100-Year Floodplain and Floodway Reference Data of *Lower Boulder Creek Flood Hazard Area Delineation (Valley View Road to Boulder-Weld County Line)* (Muller Engineering Company, 1983), which in turn references USACE, 1977 for hydrology.

Note:

N/E: No estimate.

Review of **Table 16** (also shown graphically in **Figure 17**) indicates that estimates of the 1 percent annual chance peak discharges along the Boulder Creek study reach vary considerably between studies and methodologies, which is consistent with the findings of the Boulder Creek Phase 1 Hydrologic Study (CH2M HILL, 2014). In general, the modeled 1 percent annual chance peak discharges compared favorably with the results of the now-superseded USACE, 1969 study but otherwise varied in comparison to other studies' and methodologies' estimates at similar locations: peak discharge estimates generated from flood frequency analyses provided the lower bound of peak discharge estimates whereas the USACE, 1977 provided the upper bound, except below Coal Creek where the modeled peak discharges were the greatest of any of the considered methodologies and past studies. As illustrated in **Figure 17**, there is also considerable variability between USACE, 1977 estimates (by location) and FIS estimates (by location). In contrast, the predictive hydrologic model estimates follow a distinct trend line and minor deviations are explained by confluences with major tributaries. Detailed comparison of the results of the predictive hydrologic model to the USACE, 1977 estimates and flood frequency estimates are provided in the following sections.

3.2.1 Comparison to Previous Hydrologic Studies

Similar to the results of the Boulder Creek Phase 1 Hydrologic Study (CH2M HILL, 2014), estimates of the 1 percent annual chance exceedance peak discharge at the mouth of Boulder Canyon (western edge of the City of Boulder) are approximately 40 percent less than those estimated in the effective USACE, 1977 hydrologic study. Progressing downstream, the USACE, 1977 discharge-frequency curves generally flatten out and the modeled peak discharges generally increase and approach the USACE, 1977 estimates. Upstream of the confluence with Coal Creek, the difference between modeled peak discharge estimates between the two studies are approximately 10 percent, well within the typical range of hydrologic uncertainty. Differences in modeling and calibration methodologies likely account for a substantial portion of the observed differences between the hydrologic model and the USACE, 1977 hydrologic model upstream of Coal Creek. Differences in modeling methodologies and their expected impact are discussed briefly below:

- **Difference in Infiltration Parameters and Rainfall Hyetograph:** Infiltration parameters for the USACE, 1977 study were uniformly set to a constant 1 inch per hour in mountainous areas, regardless of soil type or vegetative cover. As an example, utilizing the average depth of rainfall of 3.2 inches over Fourmile Creek as provided in the *Upper Boulder Creek and Fourmile Creek Floodplain Information Report* (Gingery and Associates, 1981) and the rainfall hyetograph provided as **Table 5**, a maximum runoff intensity of 1.60 inches per hour would be calculated. For comparison, runoff rates ranging from 0.61 to 1.37 inches per hour (median of 1.00 inch per hour) were estimated using the predictive hydrologic model. If infiltration rates used in the USACE, 1977 study were input to the predictive model, modeled peak discharges on Fourmile Creek would increase approximately 45 percent from those reported in the Boulder Creek Phase 1 Hydrology Study (CH2M HILL, 2014). As concluded in the discussion of other modeling approaches, an average CN of 93 (comparable to CNs for heavily urbanized areas and thus considered unrealistically high) would have been required in the HEC-HMS model to replicate the peak discharge estimates along Fourmile Creek provided in the USACE, 1977 study.
- **Difference in Routing Parameters:** In accordance with the USACE, 1977 study, both in-stream and basin roughness parameters were estimated from a separate calibration study performed downstream of Cherry Creek Dam near Denver. Because the area downstream of Cherry Creek dam was, even at that time, urban and entirely located on the plains, roughness parameters were likely underestimated for Fourmile Creek such that runoff and routing times were probably underestimated as well. Decreased runoff and routing times would result in increased runoff hydrographs and increase the overlap of peak portions of runoff hydrographs that may not have occurred had roughness parameters been calibrated to the Boulder Creek watershed specifically.

At the eastern-most portions of Boulder Creek between the confluence with Coal Creek and St. Vrain Creek, the discharge-frequency curves estimated via the predictive hydrologic model exceed those of the USACE, 1977 study. One reason appears to be the relatively small increase in peak discharge resulting from Coal Creek in the USACE, 1977 study (2,000 cfs) whereas in the predictive hydrologic model, Coal Creek peaks increases the peak discharge approximately 5,500 cfs. Given that estimates of the magnitude of peak discharges along Coal Creek using the predictive hydrologic model compared favorably to recent estimates of peak discharges along Coal Creek (see Section 3.3), the decreased contribution of Coal Creek to high-flows along Boulder Creek in the USACE, 1977 study is likely the result of the time separation of the peak discharge from Coal Creek and the peak discharge on Boulder Creek. Although no peak discharge estimate or timing information for Coal Creek was provided as part of the USACE, 1977 report to confirm this assumption, it does not appear an unreasonable assumption as the routing parameters of the USACE, 1977 model were calibrated to urbanized portions of Denver rather than the study area itself. Thus, given that portions of Coal Creek were time-calibrated in the calibrated hydrologic model that formed the basis for the predictive hydrologic model, Coal Creek's contributions to downstream flooding on Boulder Creek were considered to be better represented by the predictive hydrologic model than the USACE, 1977 hydrologic model. Therefore, the increase in the peak discharge estimates of Boulder Creek downstream of Coal Creek appear reasonable.

3.2.2 Comparison to Gage Analysis Results

In general, peak discharge estimates generated via gage analyses were not considered in the selection of proposed high-flow hydrology except for the use of 10 percent annual chance peak discharge estimates to provide some verification of the results of the predictive hydrologic model. While the decrease in peak discharge estimates between the gage at N. 75th Street and the downstream Mouth gage is atypical and may not be representative of actual conditions (conceptually, an increase would be expected as a result of the increased drainage area, especially considering contributions from the relatively unregulated Coal Creek and the lack of major reservoirs along Boulder Creek), flood frequency analyses were not used to develop high-flow hydrology as the result of two conditions:

1. Upstream regulation, primarily via Barker and Gross Reservoirs, provides incidental storage and attenuation of flood peaks. As neither Barker nor Gross Reservoir has dedicated flood storage, the historical flood attenuation provided by the reservoirs and recorded in the gage record is not a reliable condition to base high-flow hydrology estimates upon; and,
2. The apparent low estimates derived by gage analyses may be due to the mixed-flood gage analysis performed: the gage analysis considered annual peak discharge regardless of what meteorological event caused the discharge. Gage analysis of annual peak flows caused only by rain and/or rain-on-snow events, which historically have caused flooding on Boulder Creek (FEMA, 2012), could possibly estimate an increased magnitude of the 1 percent annual chance discharge.

Because the flood-frequency results are based on gage records that include the effects of peak attenuation at Gross and Barker reservoirs that cannot be relied upon for future flood control, the flood-frequency estimates are likely underestimates of high-flow hydrology. As the current state of the practice for rainfall-runoff modeling does not account for this incidental storage, peak discharge estimates generated via a rainfall-runoff models should, at a minimum, be greater than flood-frequency estimates that do account for this incidental storage. Such is the case for both the USACE, 1977 and predictive hydrologic models: modeled peak discharges are greater than flood-frequency analysis derived estimates of peak discharge. Thus, flood-frequency results provide one check on the results of the predictive hydrologic model.

Despite the limitations of using a flood-frequency analysis to estimate high-flow hydrology, it is also informative to compare the predictive hydrologic model results to flood-frequency analyses that formed the basis of the USACE, 1969 hydrologic study. The USACE, 1969 flood-frequency analysis was based on gage records that extended as far back as 1887, prior to the construction of Gross and Barker Reservoirs and therefore at least a portion of the analyzed gage record was unaffected by incidental storage of flood peaks at these reservoirs. Therefore, the USACE, 1969 peak discharge estimates may be more representative of high-flow hydrology than current flood-frequency estimates such that the favorable comparison of USACE, 1969 peak discharge estimates to the predictive hydrologic model peak discharges estimates were considered as some degree of verification of the predictive hydrologic model.

As discussed previously, current flood-frequency analysis estimates of the 10 percent annual chance exceedance peak discharge were compared to similar peak discharge estimates generated using the predictive hydrologic model to provide another check on the results of the predictive hydrologic model. Ideally, the flood-frequency based estimate of the peak discharge for the 10 percent annual chance exceedance recurrence interval should be fairly accurate for the 26 and 62 year gage records, respectively, at the Boulder Creek at N. 75th Street Gage and Boulder Creek at Mouth, near Longmont Gage. Comparing the two estimates:

- The modeled 10 percent annual discharge estimate at the N. 75th Street gage (2,755 cfs) compared favorably with the correlating flood-frequency analysis estimate (2,079 cfs) and was within the range of calculated uncertainty associated with the flood-frequency analysis (1,619 cfs to 2,938 cfs. This agreement provides some verification of the predictive hydrologic model.
- At the Boulder Creek at Mouth gage, the modeled 10 percent annual discharge estimate (4,787 cfs) did not compare favorably to the flood-frequency analysis estimate (2,001 cfs). However, the flood-frequency analysis at the Boulder Creek at Mouth gage is somewhat uncertain, as the peak discharge estimate for September 2013, the flood of record at the gage, used in the analysis was an average daily discharge rather than an instantaneous discharge. Preliminary assessment of the sensitivity of the flood frequency analysis to the magnitude of the September 2013 event was determined by incorporating the peak discharge estimate of the September 2013 event via the calibrated model into the flood frequency analysis in place of the average daily discharge recorded by the USGS. Incorporating this change, high-flow estimates increased, with the 100-year peak discharge increasing approximately 20 percent.

Comparing USACE, 1977 peak discharge estimates to flood-frequency analyses, the opposite is true:

- The USACE, 1977 study estimated the 10 percent annual peak discharge at N. 75th Street at 3,350 cfs, which did not agree as well with the flood-frequency analysis of 2,079 cfs and was not within the calculated uncertainty range (1,619 to 2,938 cfs).
- At the Boulder Creek at Mouth gage, the USACE, 1977 estimate of 2,000 cfs compares almost exactly to the flood-frequency analysis estimate (2,001 cfs). However, as noted earlier, the flood-frequency analysis estimate may not be reliable.

Re-visiting the Phase 1 Hydrologic Study of Boulder Creek, a comparison of modeling methodologies and previous studies indicated that the high-flow hydrology estimates generated using the predictive hydrologic model agreed substantially better with the gage record at the Boulder Creek at Orodell gage than did the high-flow hydrology estimates generated by the USACE, 1977 study. Leveraging the 106-year period of record at the Orodell gage, the Phase 1 Hydrologic Report found that the USACE, 1977 10 percent annual chance peak discharge estimate had been exceeded once prior to the September 2013 event. Conversely, the 10 percent annual chance peak discharge estimated via the Phase 1 predictive hydrologic model was exceeded seven times in that same period (compared to a theoretical 10 to 11 times) and thus the predictive hydrologic model was considered more representative of high-flow hydrology in the Phase 1 study reach of Boulder Creek. Considering that the Phase 2 predictive hydrologic model was built upon the Phase 1 predictive hydrologic model and the favorable comparison between the predictive hydrologic model and flood-frequency analysis estimates of the 10 percent annual chance exceedance peak discharges at the Boulder Creek at N. 75th Street gage, the peak discharge estimates generated using the predictive hydrologic model were considered representative of high-flow hydrology along portions of Boulder Creek between these two gages.

3.3 Comparison of Principal Tributary Peak Discharge Estimates to Previous Studies, FEMA Effective Hydrology, and Stream Gage Analyses

3.3.1 South Boulder Creek

Given that South Boulder Creek drains a significant portion (31 percent) of the greater Boulder Creek watershed, comparisons of peak discharge estimates along South Boulder Creek are provided for reference as **Table 17**. The following observations generally summarize **Table 17**:

- With the exception of the gage analysis estimate at Eldorado Springs being within 20 percent of the predictive model peak discharge estimate, gage analysis estimates varied widely from peak discharge estimates determined via the predictive hydrologic model and previous hydrologic studies; the difference at Rollinsville are likely due to the prevalence of snowmelt-induced flooding, whereas the difference below Gross Reservoir is likely due to the incidental attenuation of floods historically provided by Gross Reservoir.
- Modeled peak discharge estimates were within approximately 20 percent of the peak discharges estimated in HDR, 2007, for a general storm event, which provides some degree of verification for the predictive hydrologic model as the HDR, 2007 hydrologic model was both calibrated and validated using an independent storm event.
- Modeled peak discharges were up to 50 percent lower than the effective hydrology at Eldorado Springs, but within 5 percent at the mouth of South Boulder Creek. This pattern is a result of the use of highly researched and highly detailed site-specific criteria to develop the controlling hydrology that resulted in increased flows across the upper portion of South Boulder Creek and the subsequent use of an unsteady, 2D hydraulic model that accounted for attenuation and split flow paths that resulted in the decreased peak discharge downstream of U.S. Highway 36.

TABLE 17

Comparison of Modeled 1 Percent Annual Chance Discharge to Other Estimates along South Boulder Creek

		Estimated 1 Percent Annual Chance Peak Discharge (cfs)				
Location	**Drainage Area (mi^2)**	**Predictive Model**	**USACE, 1969**	**FEMA Effective Hydrology [a]**	**HDR, 2007 [b]**	**Gage Analysis**
South Boulder Creek at Rollinsville	45.2	1,300	N/E	N/E	N/E	858
South Boulder Creek near Pinecliffe	72.7	2,200	N/E	N/E	N/E	N/E
South Boulder Cr. below Gross Reservoir	95.8	2,210	N/E	N/E	N/E	863
South Boulder Creek at Eldorado Springs	111	2,650	5,000 [c]	4,340	2,230	3,061
South Boulder Creek at CO Hwy 93	123	4,020	N/E	6,200	3,490	N/E
South Boulder Creek at Boulder Creek	139	4,750	N/E	4,980	4,220 [f]	N/E

[a] Per *Boulder County FIS* (FEMA, 2012). Per the Boulder County FIS, South Boulder Creek Effective Hydrology was determined from the *South Boulder Creek Hydraulic Modeling Report* (HDR, 2008)

[b] As reported for the General Storm (the Thunderstorm was adopted as FEMA effective hydrology) in Table 22: Rainfall/Runoff Model Results of *South Boulder Creek Climatology and Hydrology Report* (HDR, 2007).

[c] Reported only as “South Boulder Creek.”

Note:

N/E: No estimate.

3.3.2 Coal Creek

Given that Coal Creek drains a significant portion (17 percent) of the greater Boulder Creek watershed, comparisons of peak discharge estimates along Coal Creek are provided for reference as **Table 18**. The following observations generally summarize **Table 18**:

- The gage analysis at Plainview is approximately half of the peak discharge estimated by both the predictive hydrologic model and the 2014 URS study.
- Predictive hydrology model results at U.S. Highway 287 and 120th Street were approximately 40 and 25 percent greater than the effective FIS and RESPEC, 2012 peak discharges. Aside from that location, the results of the predictive hydrologic model were generally within 15 percent of the effective FIS and peak discharge estimates along Coal Creek documented in RESPEC, 2012, and URS, 2014.

TABLE 18

Comparison of Modeled 1 Percent Annual Chance Discharge to Other Estimates along Coal Creek

		Estimated 1 Percent Annual Chance Peak Discharge (cfs)				
Location	**Drainage Area (mi^2)**	**Predictive Model**	**FEMA Effective Hydrology [a]**	**RESPEC, 2012**	**URS, 2014**	**Gage Analysis**
Coal Creek downstream of Beaver Creek	9.26	2,520	N/E	N/E	2,930	N/E
Coal Creek near Plainview	15.2	3,330	N/E	N/E	3,330	1,857
Coal Creek at CO Hwy 93	20.6	4,160	N/E	N/E	3,790	N/E
Coal Creek at U.S. Hwy 287	35.1	5,790	4,110	4,610 [b]	N/E	N/E
Coal Creek at 120th Street	35.7	5,760	4,120 [c]	N/E	N/E	N/E
Coal Creek at Erie Parkway	76.9	11,400	12,250 [d]	11,200 [b, c]	N/E	N/E

[a] Per *Boulder County FIS* (FEMA, 2012). Per the Boulder County FIS, Coal Creek Effective Hydrology was determined from the *Flood Hazard Analyses for Coal Creek and Rock Creek, Boulder and Weld Counties, Colorado* (USDA SCS, 1976)

[b] As reported for the 2012 Existing Conditions Land Use in Table 3.6-1: Comparison of Peak Flows to Previous Studies of *Coal Creek and Rock Creek Major Drainageway Plan* (RESPEC, 2012).

[c] Reported as Coal Creek at BNSF Railway.

[d] Reported as Coal Creek at Union Pacific Railroad near Erie.

Note:

N/E: No estimate.

4.0 Conclusions and Recommendations

The assumptions and limitations of the hydrologic model, concurrent studies, and previous studies were closely reviewed, compared, and contrasted as part of this report. Considering these previous discussions, the quality of calibration data, model validation via gage records and comparison to historical observations, and continuous review of modeling methodology by a team of local engineers and project sponsors, the predictive hydrologic model is proposed as the appropriate model to estimate high-flow hydrology along the Phase 2 study reach of Boulder Creek. Peak discharge estimates based on gage analysis were considered non-applicable due to the influence of Barker and Gross Reservoirs and regression analysis of mixed-flood hydrology that may not be representative of the rainfall-induced flows that have historically caused floods in the Boulder Creek watershed. However, flood-frequency estimates provided a degree of assurance in the fact that the predictive hydrologic model estimates were greater than the flood frequency results, which are likely underestimated for the reasons previously discussed. USACE, 1977 peak discharge estimates were concluded to be overly conservative and outdated due to the selection of modeling parameters calibrated during studies of separate and dissimilar watersheds, availability of new and better information and tools, and the lack of model validation. Favorable comparison to USACE, 1969 flood-frequency analyses that included pre-reservoir peak discharges provided further justification for the predictive hydrologic model.

Given the focus of the hydrologic modeling effort was on Boulder Creek and not specifically on Coal Creek or South Boulder Creek, the predictive hydrologic model is not recommended as the appropriate model or method to estimate high-flow hydrology along Boulder Creek tributaries. While the evaluation of South Boulder Creek and Coal Creek provides valuable insight into the flooding mechanisms of this watershed, these watersheds may respond differently to rainfall events than the larger watershed evaluated in this study. Thus, the peak discharge estimates presented as part of the larger Boulder Creek hydrologic analysis may not be representative of the most conservative flood risk along South Boulder Creek and Coal Creek.

4.1 Design Peak Discharge Magnitudes

Table 19 presents modeled discharge-frequency relationships at physically relevant locations located in close proximity to hydrologic model junctions; comparison of estimated 1 percent chance peak discharges between high-flow prediction methods and previous hydrologic studies were provided previously as part of **Table 15**. Discharge-frequency relationships presented in **Table 19** were rounded up to three significant figures to maintain a consistent level of precision as the effective FIS. Based on the discussion in previous sections, the peak discharges presented in **Table 19** are considered the best estimate of high-flow hydrology for the Phase 2 Boulder Creek study reach between Orodell, Colorado, and the confluence with St. Vrain Creek.

4.2 Assessment of September 2013 Event

In accordance with the purpose of the study, the peak discharges observed during the September 2013 event were compared to the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges estimated using the predictive hydrologic model to assess the recurrence interval of the September 2013 event. For purposes of this discussion, the 10, 4, 2, 1, and 0.2 percent annual chance peak discharge have been referred to their common term, the 10, 25, 50, 100, and 500 year recurrence interval, respectively. As provided in **Table 20**, and shown graphically in **Figure 15a**, the September 2013 event appears to generally have been approximate to a 50-year event on Boulder Creek east of the Flatirons. Through the City of Boulder and also downstream of Coal Creek, the recurrence interval of the September 2013 event was between a 50- and 100-year event, erring closer to a 50-year event. Between approximately the Walden Ponds area and immediately upstream of Coal Creek, the recurrence interval of the September 2013 event was slightly less than that of the bounding reaches: between a 25- and 50-year event, erring close to a 50-year event.

TABLE 19

Proposed 10, 4, 2, 1, and 0.2 Percent Chance Peak Discharge

Location	Drainage Area (mi^2)	Annual Chance Peak Discharge (cfs)				
		10 Percent	4 Percent	2 Percent	1 Percent	0.2 Percent
Boulder Creek at Orodell	*102*	*1,130*	*2,290*	*3,640*	*5,390*	*11,400*
Boulder Creek below Fourmile Creek	*129*	*1,570*	*3,030*	*4,730*	*6,850*	*14,000*
Boulder Creek at Broadway	135	1,450	2,900	4,570	6,770	14,200
Boulder Creek at 28th Street	136	1,490	2,950	4,640	6,860	14,400
Boulder Creek below Bear Canyon Creek	145	1,550	3,060	4,800	7,070	14,700
Boulder Creek at Valmont Road	156	1,630	3,330	5,280	7,490	15,500
Boulder Creek below South Boulder Creek	292	2,380	4,830	7,380	11,000	24,100
Boulder Creek below Fourmile Canyon Creek	303	2,560	5,310	8,180	11,800	24,800
Boulder Creek at N. 75th Street	307	2,760	5,690	8,790	12,400	25,200
Boulder Creek below Dry Creek No. 3	324	2,890	6,080	9,390	13,000	26,100
Boulder Creek at U.S. Hwy 287	331	3,070	6,410	9,840	13,500	27,100
Boulder Creek below Bullhead Gulch	339	3,280	6,820	10,400	14,200	28,500
Boulder Creek below Coal Creek	426	4,210	8,300	12,600	17,500	35,000
Boulder Creek at [Weld] County Road 16 1/2	442	4,660	8,830	13,500	18,700	36,700
Boulder Creek above St. Vrain Creek	447	4,790	9,010	13,700	19,000	37,300

Note: Italics denote results of Boulder Creek [Phase 1] Hydrologic Analysis (CH2M HILL, 2014).

TABLE 20

Recurrence Interval Estimate of the September 2013 Event

Location	Observed Discharge (cfs)	Modeled Annual Chance Peak Discharge (cfs)					Estimated Recurrence Interval (yr)
		10 Percent	4 Percent	2 Percent	1 Percent	0.2 Percent	
Boulder Creek at Orodell	*2,020*	*1,130*	*2,290*	*3,640*	*5,390*	*11,400*	*~ 25*
Boulder Cr. below Fourmile Cr.	*4,818* [a]	*1,570*	*3,030*	*4,730*	*6,850*	*14,000*	*25 to 50*
Boulder Creek at Broadway	4,965	1,450	2,900	4,570	6,770	14,200	~ 50
Boulder Creek at 28th Street	5,300	1,490	2,950	4,640	6,860	14,400	50 to 100
Boulder Creek at Valmont Road	5,700	1,630	3,320	5,270	7,490	15,500	~ 50
Boulder Creek at 75th Street	8,400	2,760	5,690	8,780	12,400	25,200	~ 50
Boulder Creek at U.S. Hwy 287	9,000	3,070	6,410	9,840	13,500	27,100	~ 50
Boulder Creek at Mouth	16,100 [a]	4,790	9,010	13,700	19,000	37,300	50 to 100

N/E = No estimate

Note: Italics denote results of Boulder Creek [Phase 1] Hydrologic Analysis (CH2M HILL, 2014).

[a] Per Calibrated Hydrologic Model.

The general assessment of the 50-year recurrence interval of Boulder Creek peak discharges during the September 2013 event is approximately a blend of the recurrence intervals for measured precipitation depths recorded across the watershed (see **Table B-2** in **Appendix B** that compares rainfall depths across the 24-hour calibration window to NOAA Atlas 14 [NOAA, 2013] point rainfall-frequency depth estimates). Measured rainfall depths in the upper mountainous portions and eastern-most plains portions of the watershed were generally less than a 10-year recurrence interval whereas the recurrence interval of measured rainfall depths along the foothills of the Front Range were frequently on the order of a 100- to 500-years, with two subbasins near Coal Creek Canyon and Eldorado Canyon witnessing recurrence intervals of measured rainfall in excess of 500 years.

4.3 Discussion of September 2013 Event

Reviewing **Table 20**, the peak discharge along Boulder Creek during the September 2013 event was most comparable to a 2 percent annual chance exceedance event, or as it is commonly referred to as, a 50-year event. The assessment of the September 2013 event as a 2 percent annual chance event on Boulder Creek corresponds well to the approximate median of the estimated recurrence intervals for rainfall depths measured during the 24-hour calibration window (provided in **Table B-2**). While rainfall recurrence intervals have often been cited by citizens to characterize the September 2013 event as a 500-year or less frequent event, recurrence intervals of this frequency occurred only in isolated portions of the watershed. As streams naturally aggregate inputs (e.g., rainfall) from the entirety of their contributing watershed, it is more accurate to cite the recurrence interval of the September 2013 event in reference to the measured rainfall as a mathematical aggregation (e.g., average) of the observed rainfall across the entire watershed rather than a singular estimate representative of a few percent of the total watershed area. On this note and similar to peak discharges on tributaries, the rainfall-based recurrence interval estimates for tributaries and select portions of the watershed do defer from that of the Phase 2 Boulder Creek study reach.

Although the September 2013 event was unique in volume and duration, the greatest rainfall depths were concentrated to a relatively small area of the leading edge of the Front Range including the City of Boulder and decreased substantially beyond that area, as evidenced by the substantial decrease in DARF estimated for the September 2013 storm over Boulder Creek illustrated in **Figure 8**. Had rainfall intensity been less concentrated to the foothills portions of the Front Range and distributed more closely to the NOAA Atlas II or AWA's recommended DARF curves, peak discharges through the City of Boulder and downstream through to St. Vrain Creek could have been much greater. For context, the peak discharge from smaller Boulder Creek tributaries including Fourmile Canyon Creek and Bear Canyon Creek, where greater rainfall depths were observed, was greater than the peak discharge estimated in Boulder Creek at Orodell, despite the two former watersheds being less than a tenth the size of the Boulder Creek watershed upstream of Orodell. Even recognizing the increased runoff potential and rainfall potential of these foothills tributaries, the comparable size of peak discharges on Boulder Creek near Orodell and much smaller tributary systems located nearer to the epicenter of the September 2013 storm provides some context as to the magnitude of event that could have occurred along Boulder Creek had the September 2013 storm event been more evenly distributed across the watershed. On this note, estimates of design peak discharge magnitudes reflect this occurrence: the magnitude of the September 2013 event in terms of peak discharge and flooding on Boulder Creek was estimated to have been most comparable to a 2 percent annual chance exceedance event.

Additionally, it should be noted that the pool heights for both Barker and Gross Reservoirs were low due to a preceding drought and seasonal operation that left the reservoirs relatively low in the fall months (operation of both reservoirs as water supply reservoirs would prioritize filling of the reservoir to provide drinking water to downstream users, and thus, it is likely to be full in the spring/summer following typical snowmelt and during the time of expected flood-causing storms). Thus, storage capacity not normally available in the reservoirs was utilized in September 2013 to store nearly the entirety of the peak flow pulse measured above the reservoirs, thereby reducing downstream outflow and peak discharges. Were the September 2013 event to occur earlier in the season, such as in the spring, which is when **Table 3** indicates Boulder Creek flooding has historically occurred, and in a non-drought year, Barker and Gross Reservoirs would likely have had less storage capacity. Decreased storage capacity would result in a greater outflow and increased peak discharges and flood risk downstream. Therefore, it is important to note that while the September 2013 event was destructive, the timing of the event, both in terms of season and occurrence during a drought year, and distribution of rainfall prevented downstream flooding from being worse.

As **Table 20** demonstrates, the September 2013 event was closer in a magnitude to a 50-year event (2 percent annual chance exceedance event) than a 100-year event as had been rumored. Despite that most infrastructure is designed to the 1 percent annual chance peak discharge, the September 2013 event caused significant damage in the Boulder Creek watershed and resulted in the loss of life (although the event did exceed the 1 percent annual chance peak discharge in some tributaries). Considering the relative magnitude of the September 2013 event in relation to the 1 percent annual chance peak discharge and the resulting damage, it is important for flood response officials, engineers, politicians, and the public to be aware of the potential impact that would occur during a 1 percent annual chance high-flow, and how key decisions related to flood recovery and flood management could worsen or lessen that potential impact.

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Figures

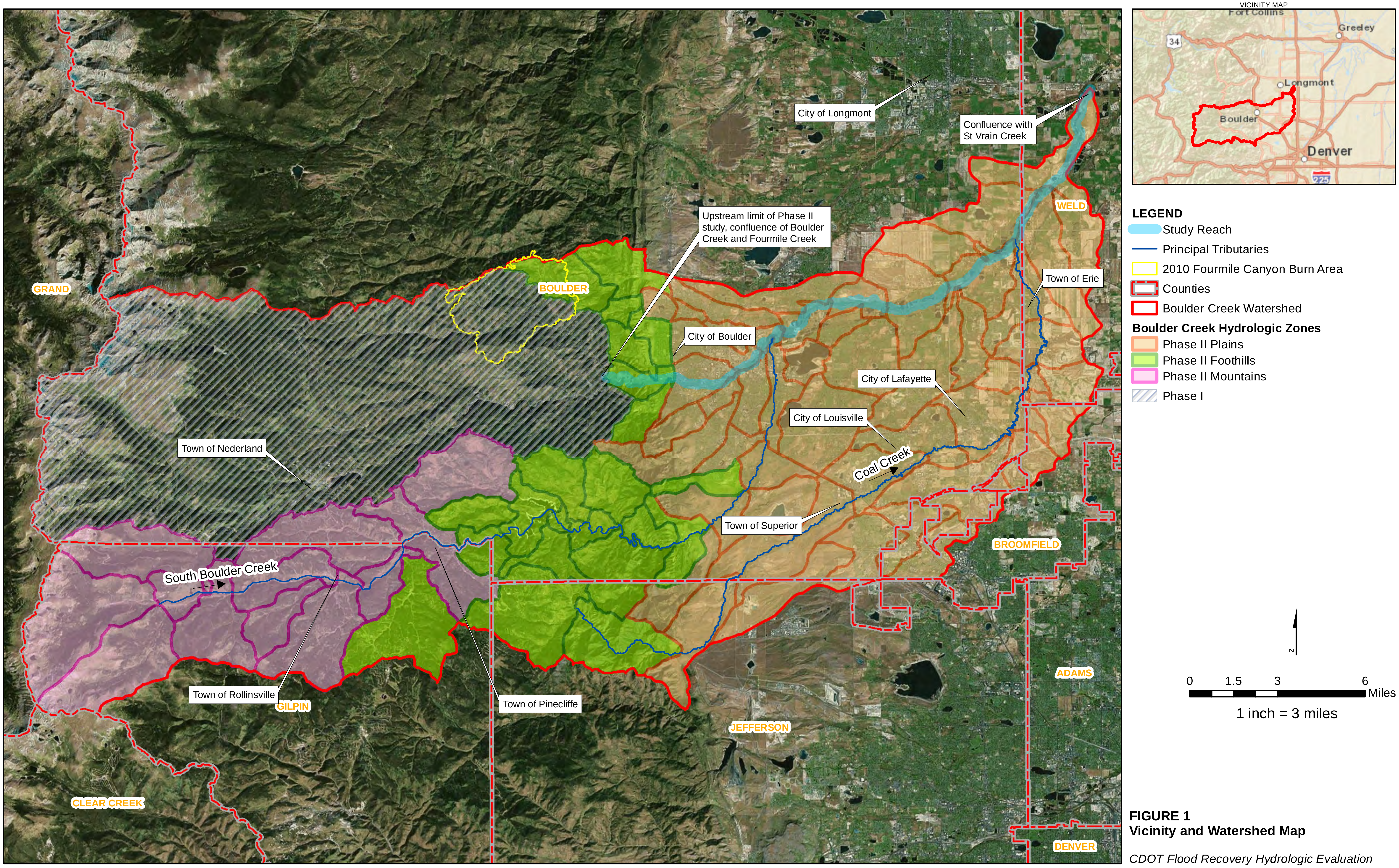
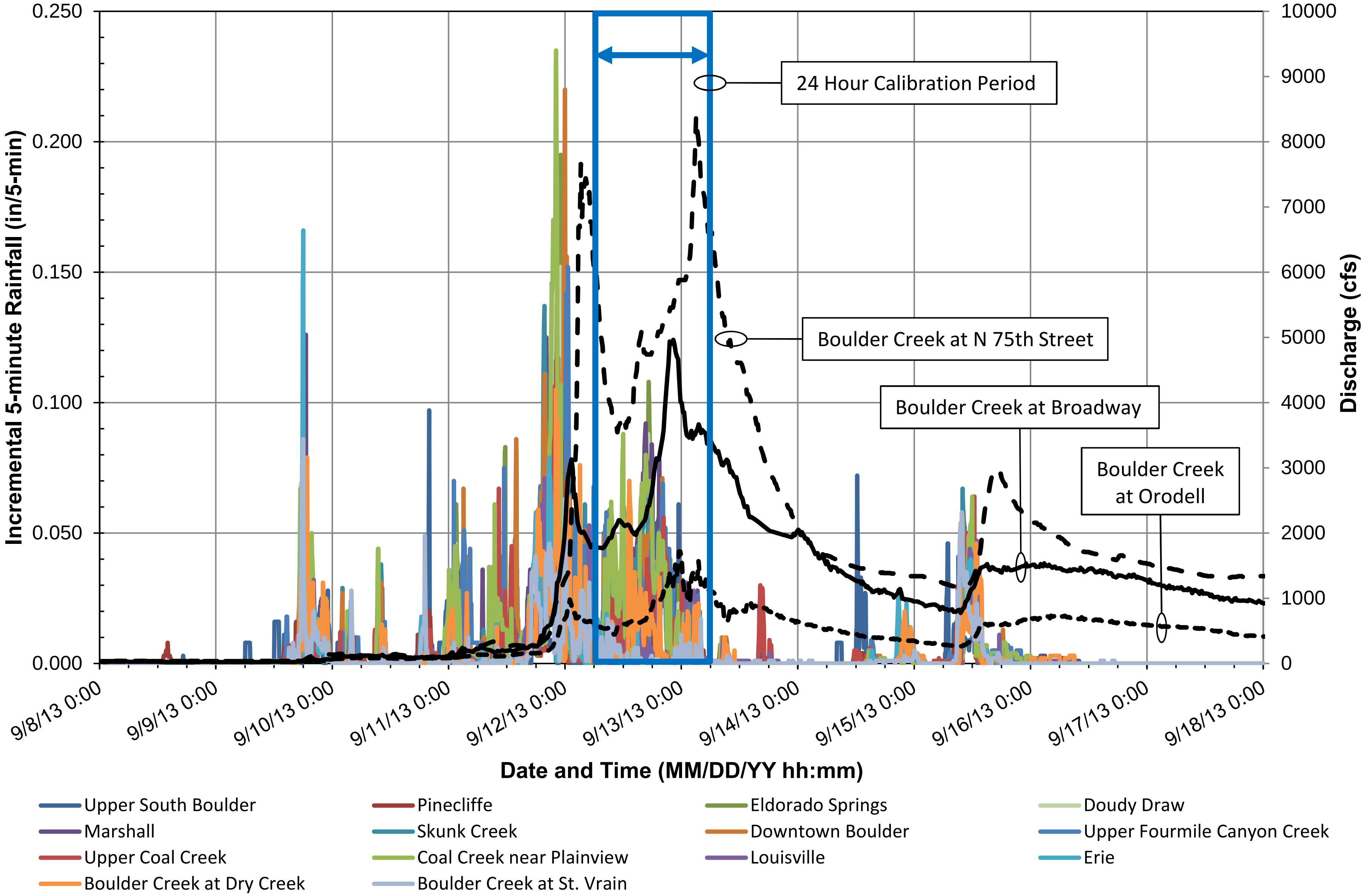


FIGURE 1
Vicinity and Watershed Map

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.

Figure 2 - Boulder Creek 5-minute Increment SPAS Rainfall and Stream Gage Records during September 2013 event



Urban Stream and Ditch Condition

Map 8 — *September 2013 Flood - City of Boulder, Colorado*

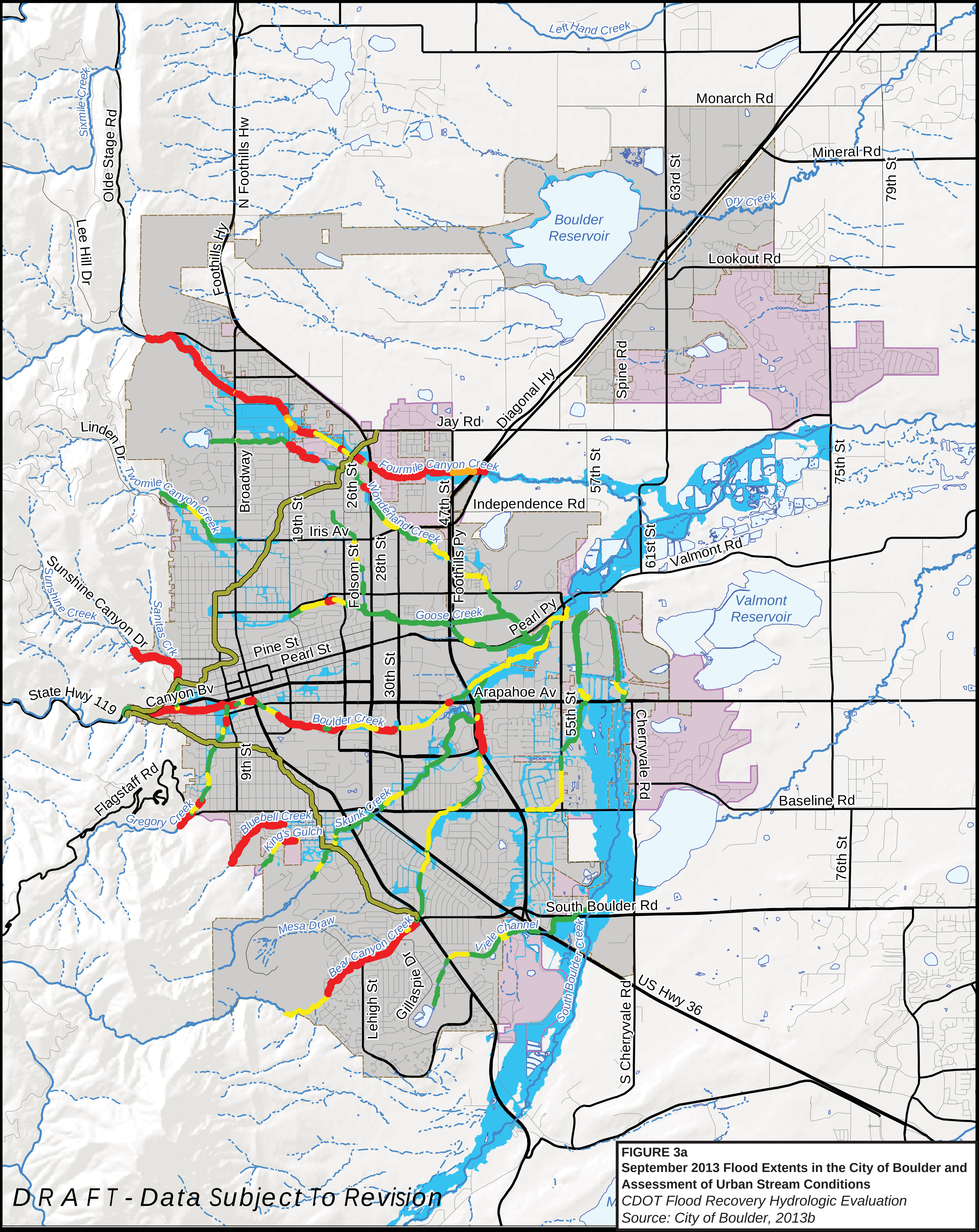


FIGURE 3a
September 2013 Flood Extents in the City of Boulder and Assessment of Urban Stream Conditions
CDOT Flood Recovery Hydrologic Evaluation
Source: City of Boulder, 2013b

Post Flood Urban Stream Condition
- 1- Excellent
- 2- Good
- 3- Fair
- 4- Poor
- 5- Very Poor

Heavy Ditch Sediment
Preliminary Urban Flooding Extents

City Limits | Highway | Minor Road | Creek | Lakes
BVCP Area 2 | Major Road | Local Street | Intermitent Creek

*Map Revision Date: 11/19/13 - *

NOTE: The preliminary urban flood extent data was developed using field surveys completed by City of Boulder staff and consultants, Digital Globe worldview-2 satellite imagery (9/13/2013), and public input from the Boulder Crowd Sourcing online map as well as discussions with affected property owners. Only drainages with a FEMA mapped floodplain were surveyed. Areas of Open Space and Mountain Parks land without a regulatory floodplain were not included. The flood extent data is current as of 10/16/13 and does not reflect information received from recent community meetings. The City of Boulder will make additional updates to this data to incorporate relevant information.

The preliminary urban flood extent data does not supersede the Special Flood Hazard Area Designation (SFHA), or 100 year floodplain, used by FEMA for Digital Flood Insurance Rate Maps or the proposed floodplain delineations from ongoing flood studies.

The information depicted on this map is provided as graphical representation only. The City of Boulder provides no warranty, expressed or implied, as to the accuracy and/or completeness of the information contained hereon.

CITY OF BOULDER

N

0 — 1 Miles

12/2/2013 Council_Update_Dec3_PostFlood_StreamEvaluation.mxd

OSMP Ditch/Headgate/Dam Damage Assessment

Map 11 — *September 2013 Flood - City of Boulder, Colorado*

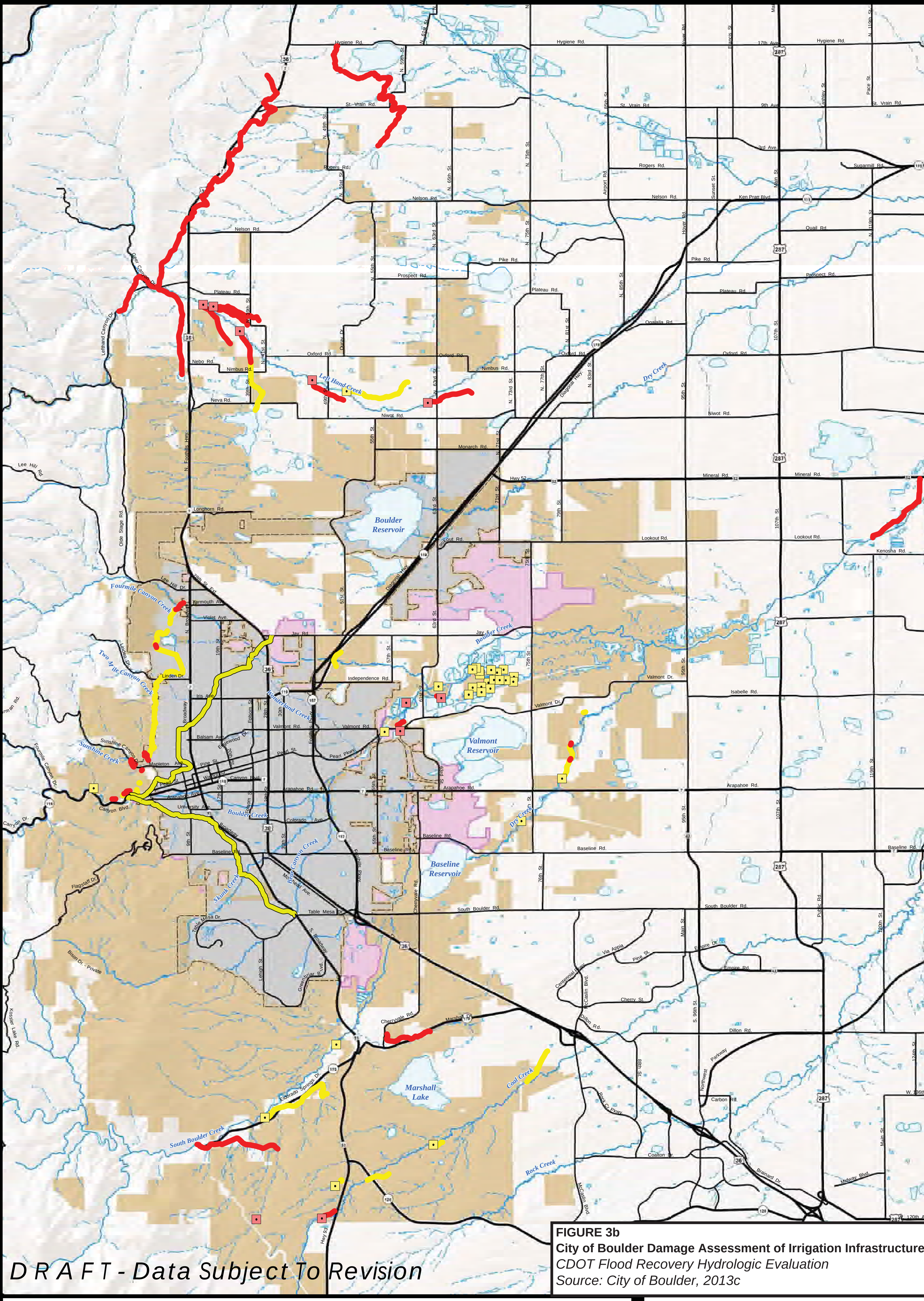


FIGURE 3b
City of Boulder Damage Assessment of Irrigation Infrastructure
CDOT Flood Recovery Hydrologic Evaluation
Source: City of Boulder, 2013c

Headgates & Dams — Significant — Severe

Ditches — Significant — Severe — Heavy Ditch Sediment

City Limits — Creek — Lakes
BVCP Area 2 — Intermitent Creek — OSMP Land

NOTE: The information depicted on this map is provided as graphical representation only. The City of Boulder provides no warranty, expressed or implied, as to the accuracy and/or completeness of the information contained thereon. The data is currently under review by the City of Boulder attorney's office.

N — 0 — 1 — 2 Miles

11/27/2013 Council_Update_Dec3_OSMP_DamageAssessment.mxd

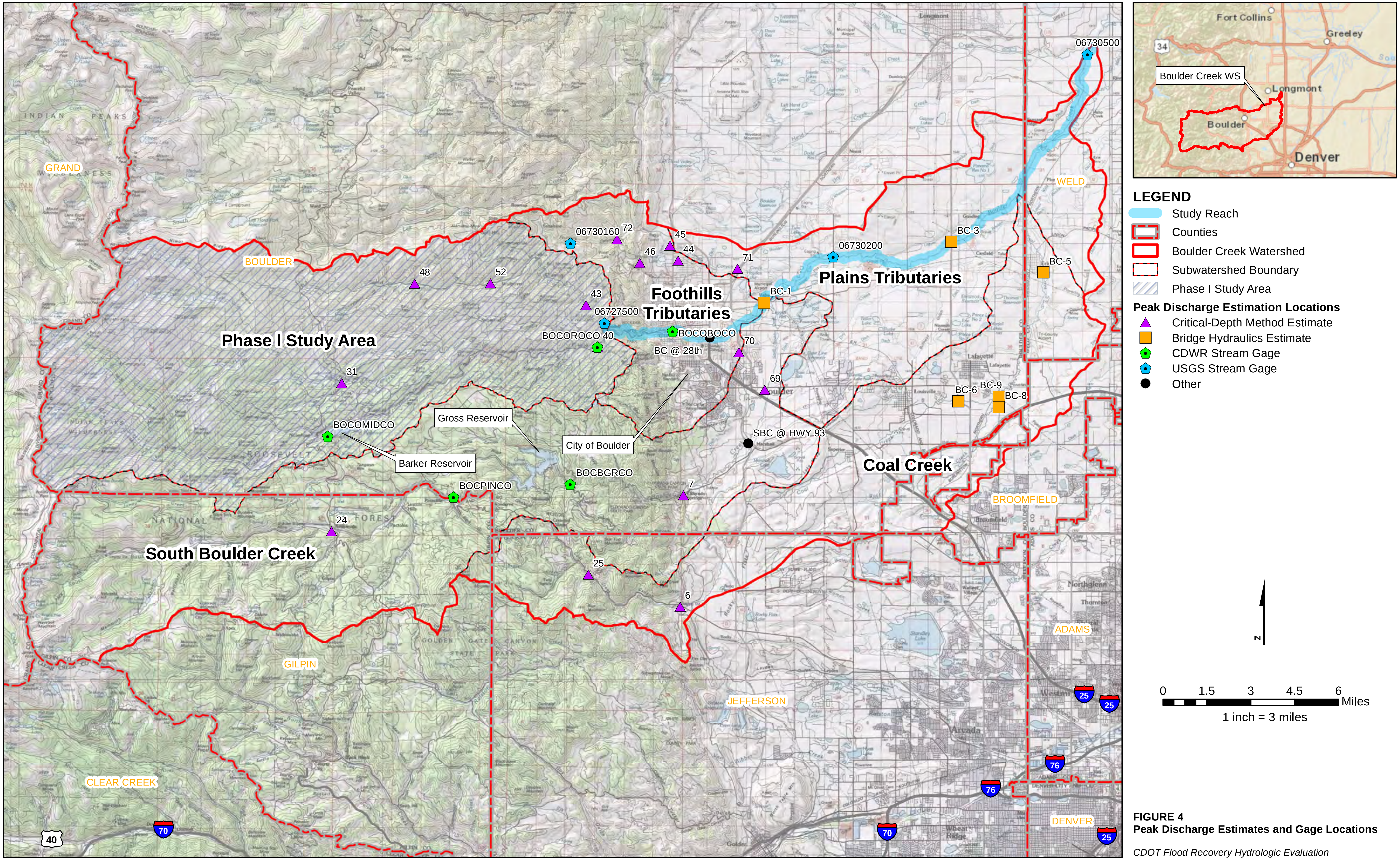
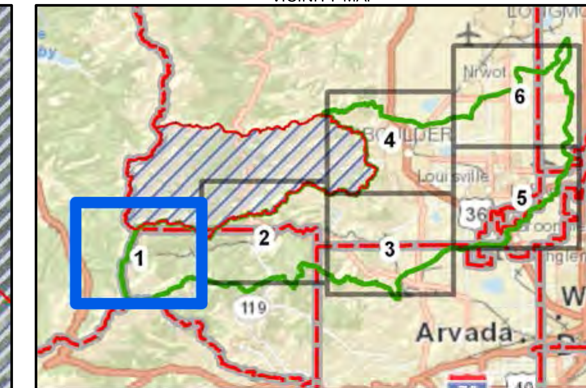


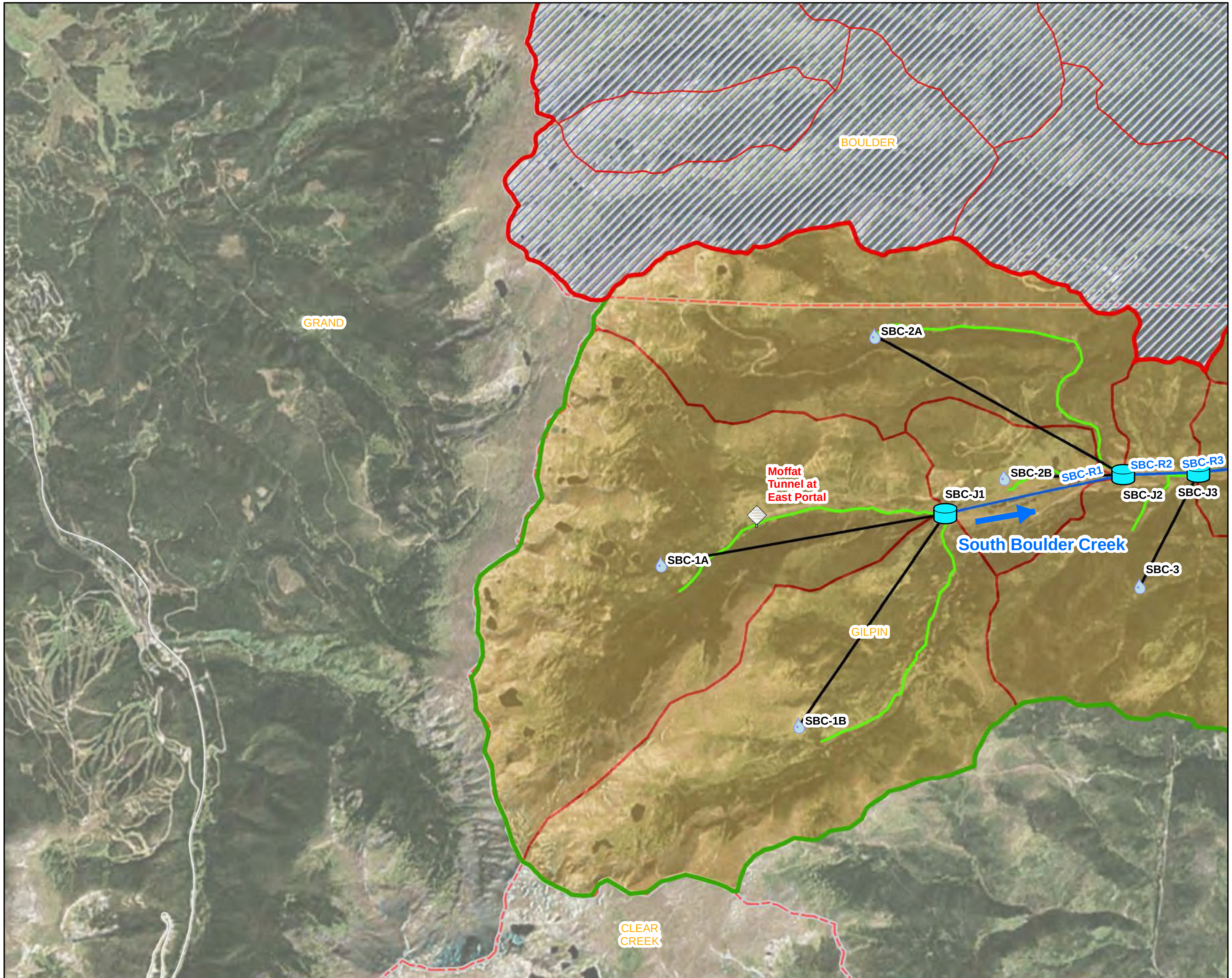
FIGURE 4
Peak Discharge Estimates and Gage Locations

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL

VICINITY MAP





LEGEND

- Model Precipitation Gage

Subbasin Routing

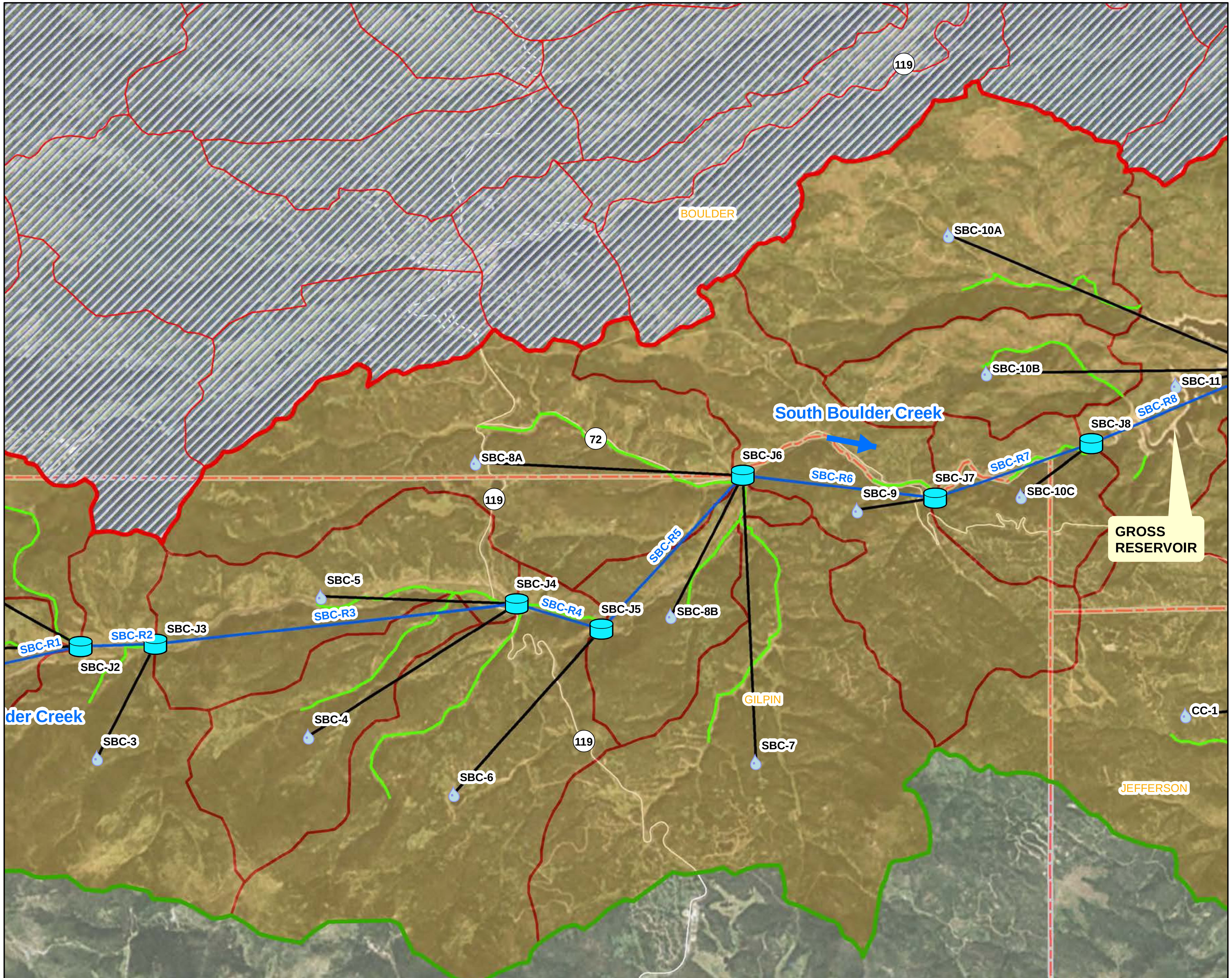
- Reach Segment
- Basin Connection
- Model Junctions
- Transbasin Transfer
- Study Reach
- Phase I Model Subbasins
- Phase II Model Subbasins
- Flow Paths to Subbasin Centroid
- Phase I Model Watershed
- Phase II Model Watershed
- Counties

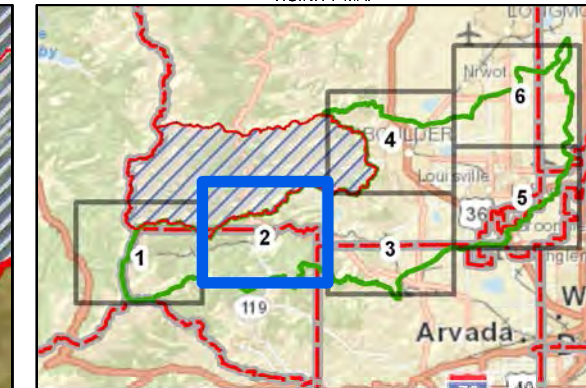
0 0.5 1 2 Miles

1 inch = 1 mile

FIGURE 5a
Phase II Connectivity Map - Page 1 of 6

CDOT Flood Recovery Hydrologic Evaluation





LEGEND

- Model Precipitation Gage

Subbasin Routing

- Reach Segment
- Basin Connection
- Model Junctions
- Transbasin Transfer
- Study Reach
- Phase I Model Subbasins
- Phase II Model Subbasins
- Flow Paths to Subbasin Centroid
- Phase I Model Watershed
- Phase II Model Watershed
- Counties

0 0.5 1 2 Miles

1 inch = 1 mile

FIGURE 5b
Phase II Connectivity Map - Page 2 of 6

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.

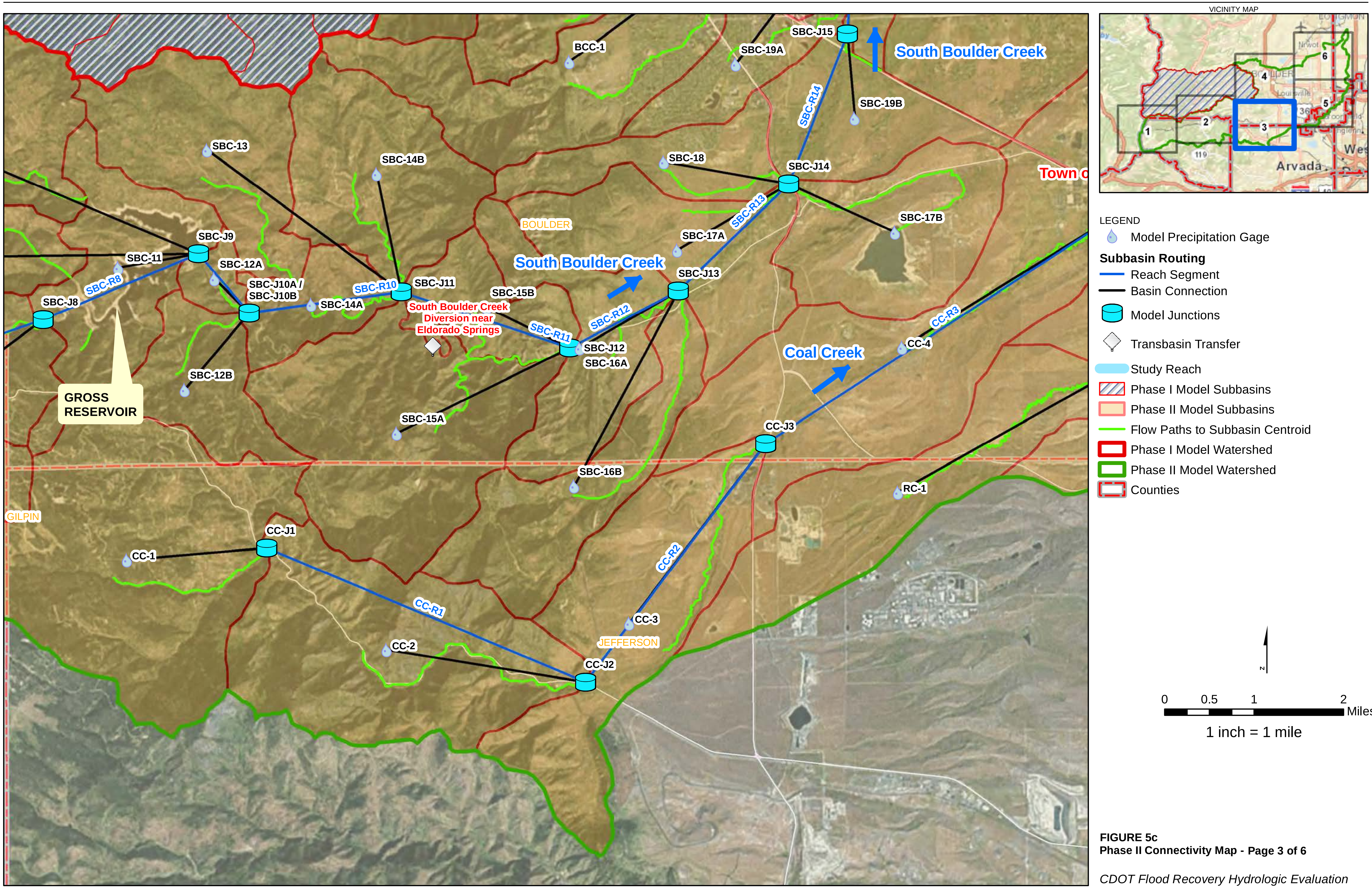


FIGURE 5c
Phase II Connectivity Map - Page 3 of 6

CDOT Flood Recovery Hydrologic Evaluation

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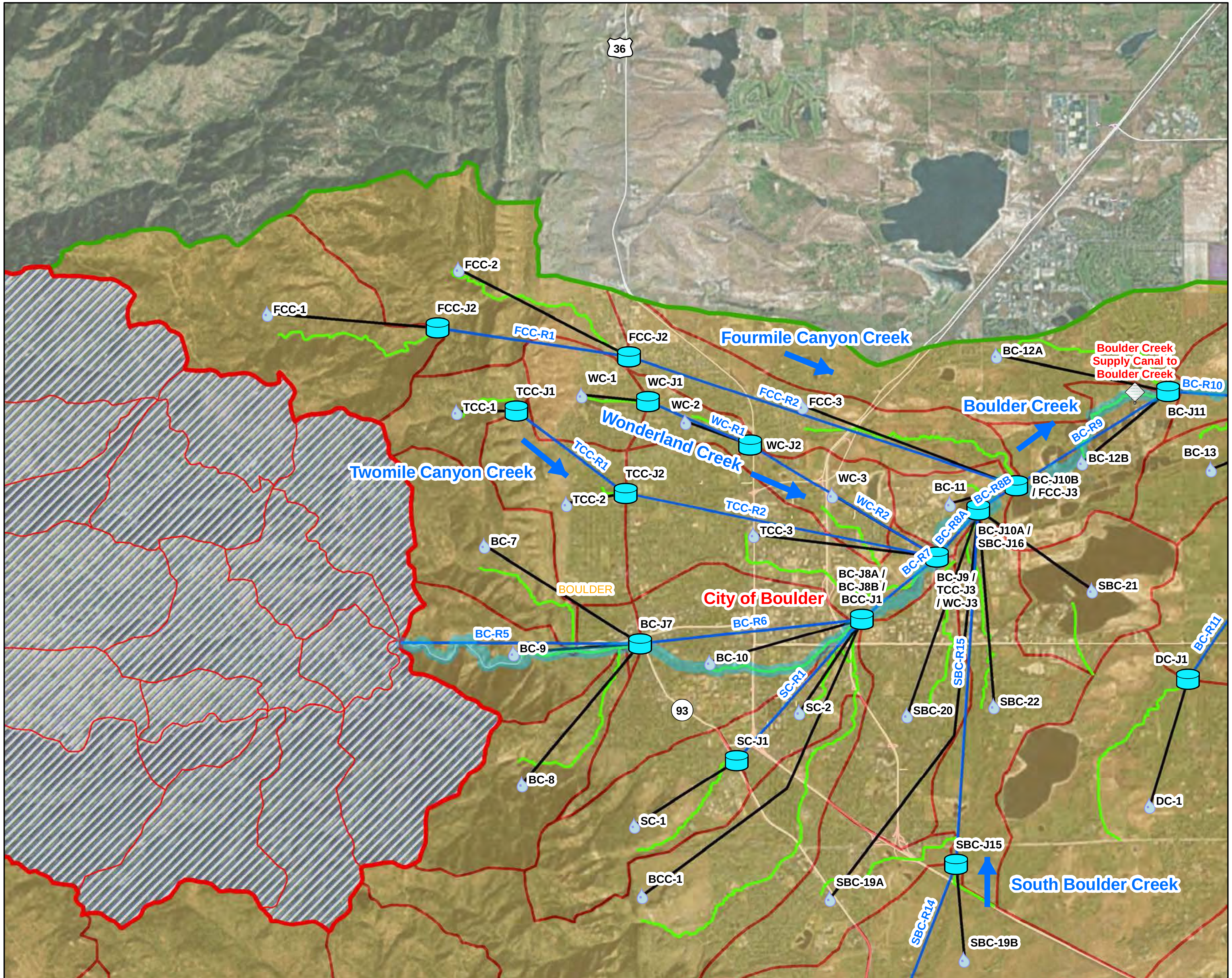
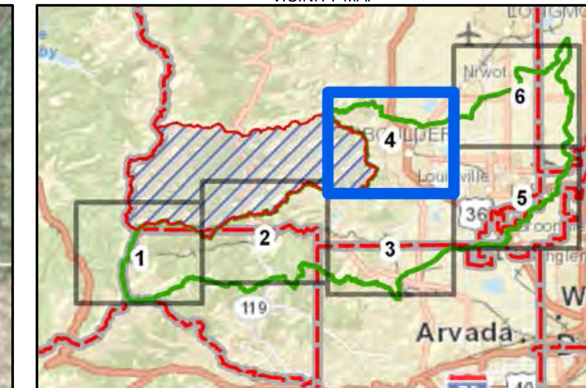
UNK \\GECKO\GROUPS\TBG\481085-482330 CDOT EMERGENCY RESPONSE SERVICES\390_DESIGN_ELEMENTS\DRAINAGE\GIS_PHASE_II\MAPFILES\REPORT\BOULDERCONNECTIVITYMAP_PHASE_II.MXD BBETTAG 1/16/2015 3:12:46 PM





LEGEND

- Model Precipitation Gage

Subbasin Routing

- Reach Segment
- Basin Connection
- Model Junctions
- Transbasin Transfer
- Study Reach
- Phase I Model Subbasins
- Phase II Model Subbasins
- Flow Paths to Subbasin Centroid
- Phase I Model Watershed
- Phase II Model Watershed
- Counties

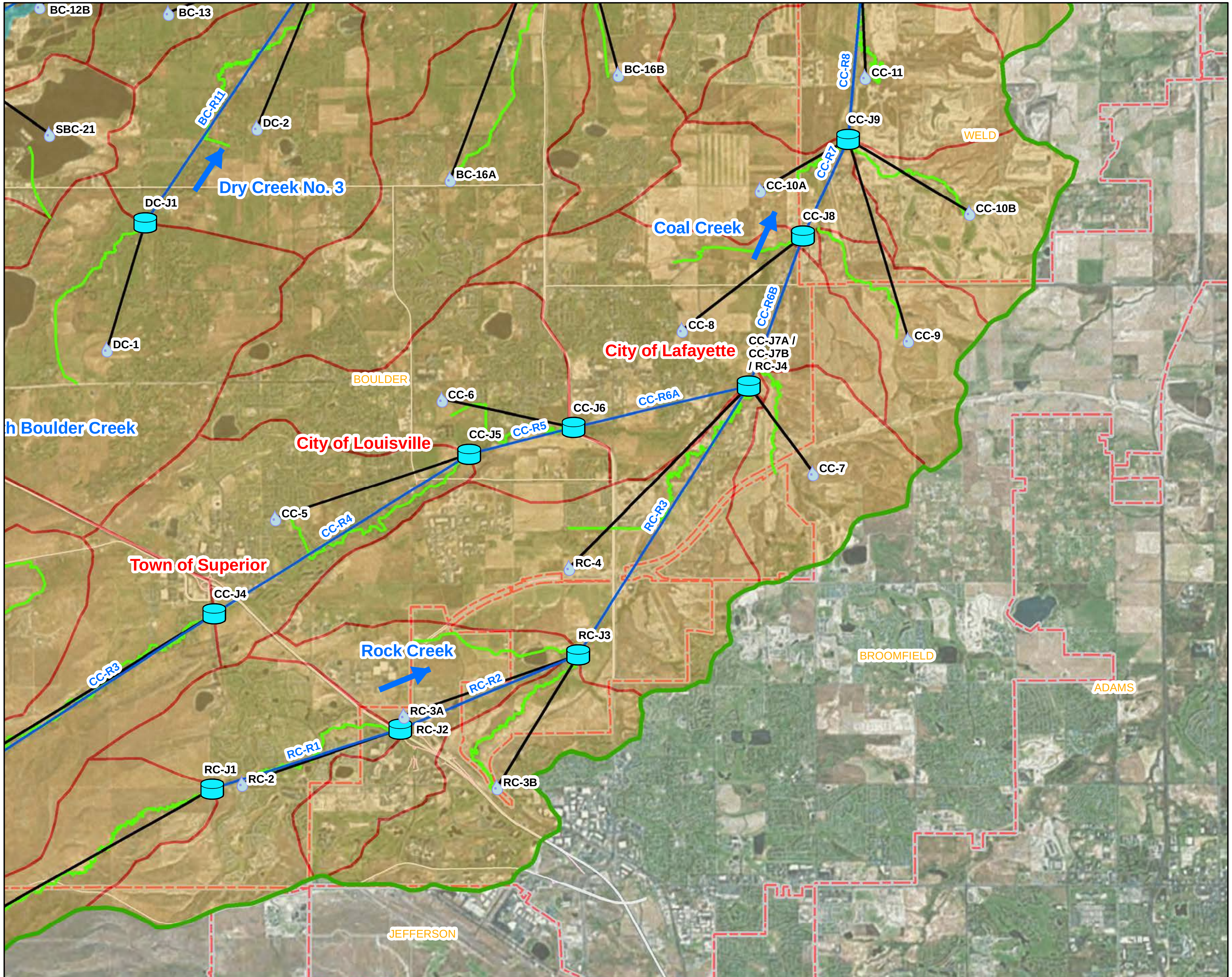
0 0.5 1 2 Miles

1 inch = 1 mile

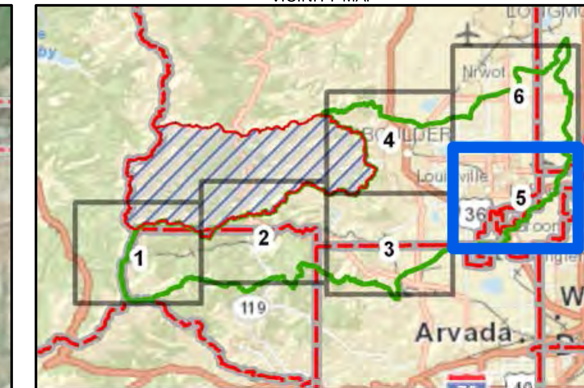
FIGURE 5d
Phase II Connectivity Map - Page 4 of 6

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.



VICINITY MAP



LEGEND

- Model Precipitation Gage

Subbasin Routing

- Reach Segment
- Basin Connection
- Model Junctions
- Transbasin Transfer
- Study Reach
- Phase I Model Subbasins
- Phase II Model Subbasins
- Flow Paths to Subbasin Centroid
- Phase I Model Watershed
- Phase II Model Watershed
- Counties

N

0 0.5 1 2 Miles

1 inch = 1 mile

FIGURE 5e
Phase II Connectivity Map - Page 5 of 6

CDOT Flood Recovery Hydrologic Evaluation

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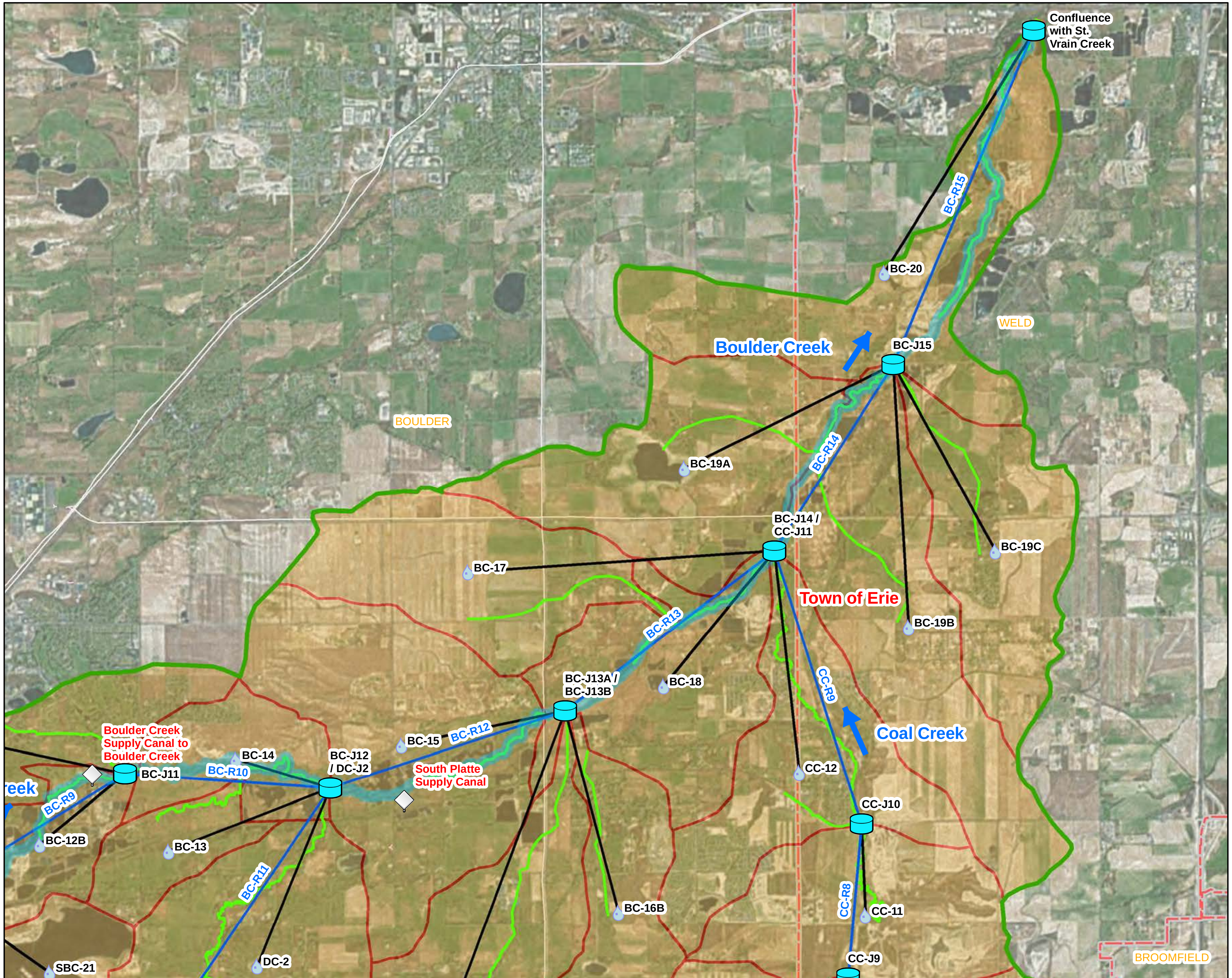
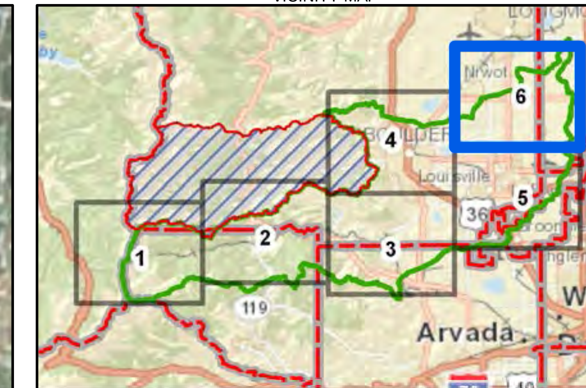


VICINITY MAP



LEGEND

Model Precipitation Gage

Subbasin Routing

Reach Segment

Basin Connection

Model Junctions

Transbasin Transfer

Study Reach

Phase I Model Subbasins

Phase II Model Subbasins

Flow Paths to Subbasin Centroid

Phase I Model Watershed

Phase II Model Watershed

Counties

N

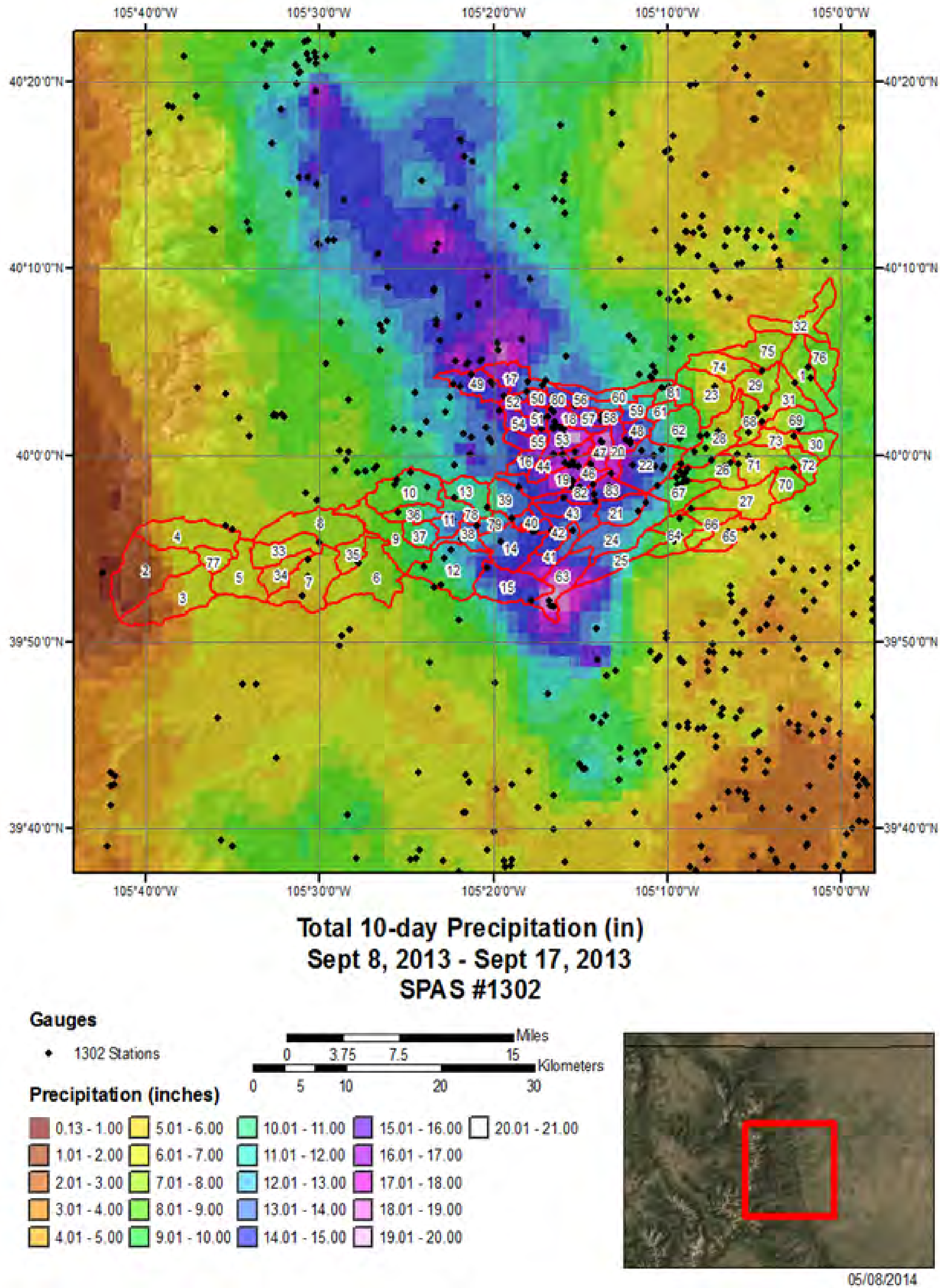
0 0.5 1 2 Miles

1 inch = 1 mile

FIGURE 5f
Phase II Connectivity Map - Page 6 of 6

CDOT Flood Recovery Hydrologic Evaluation

Figure 6 – AWA 10 Day Precipitation (Phase 2)



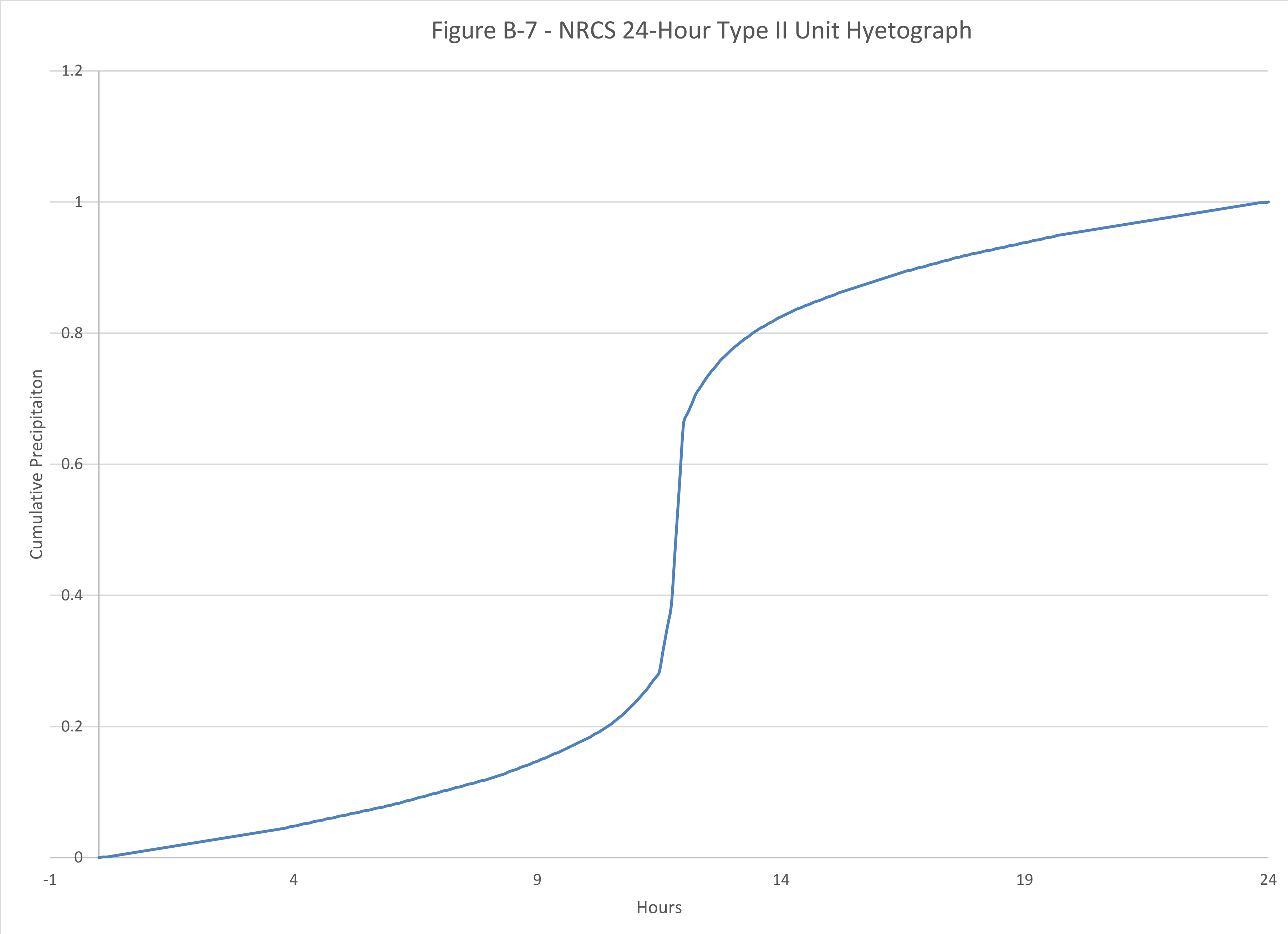
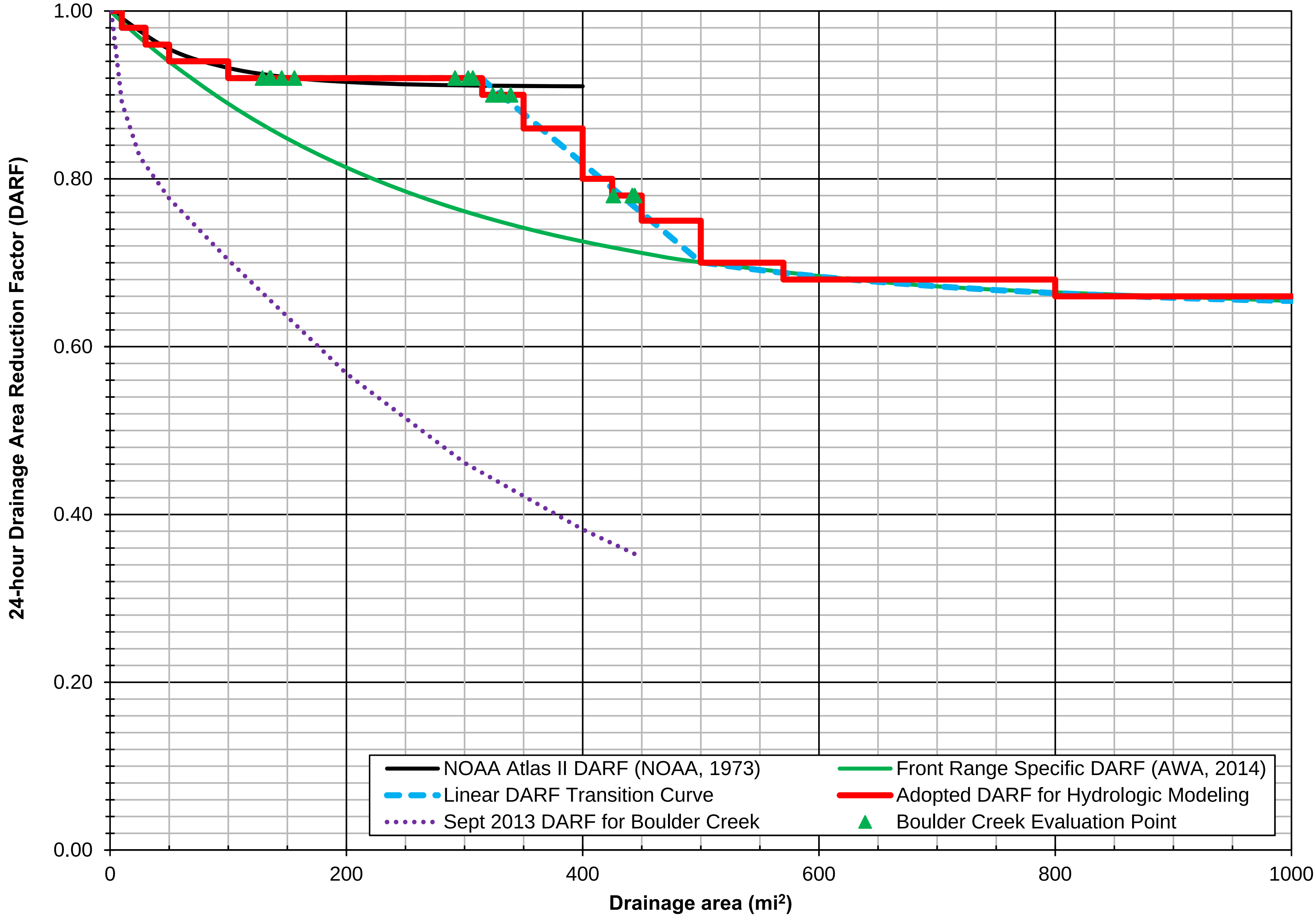


Figure B-7 - NRCS 24-Hour Type II Unit Hyetograph
1.2
1
0.8
0.6
0.4
0.2
0
Cumulative Precipitaiton
-1
4
9
14
19
24
Hours

Figure 8 - 24-hour Depth-Area Reduction Factor (DARF) Curves



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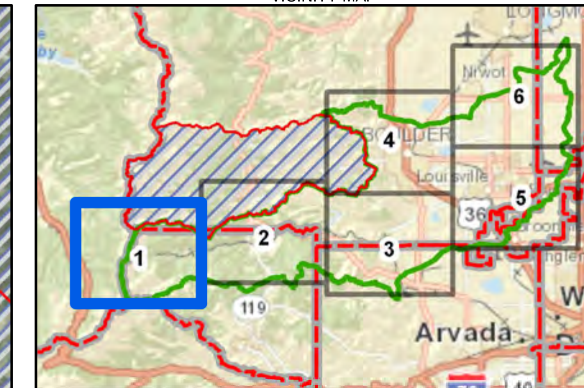

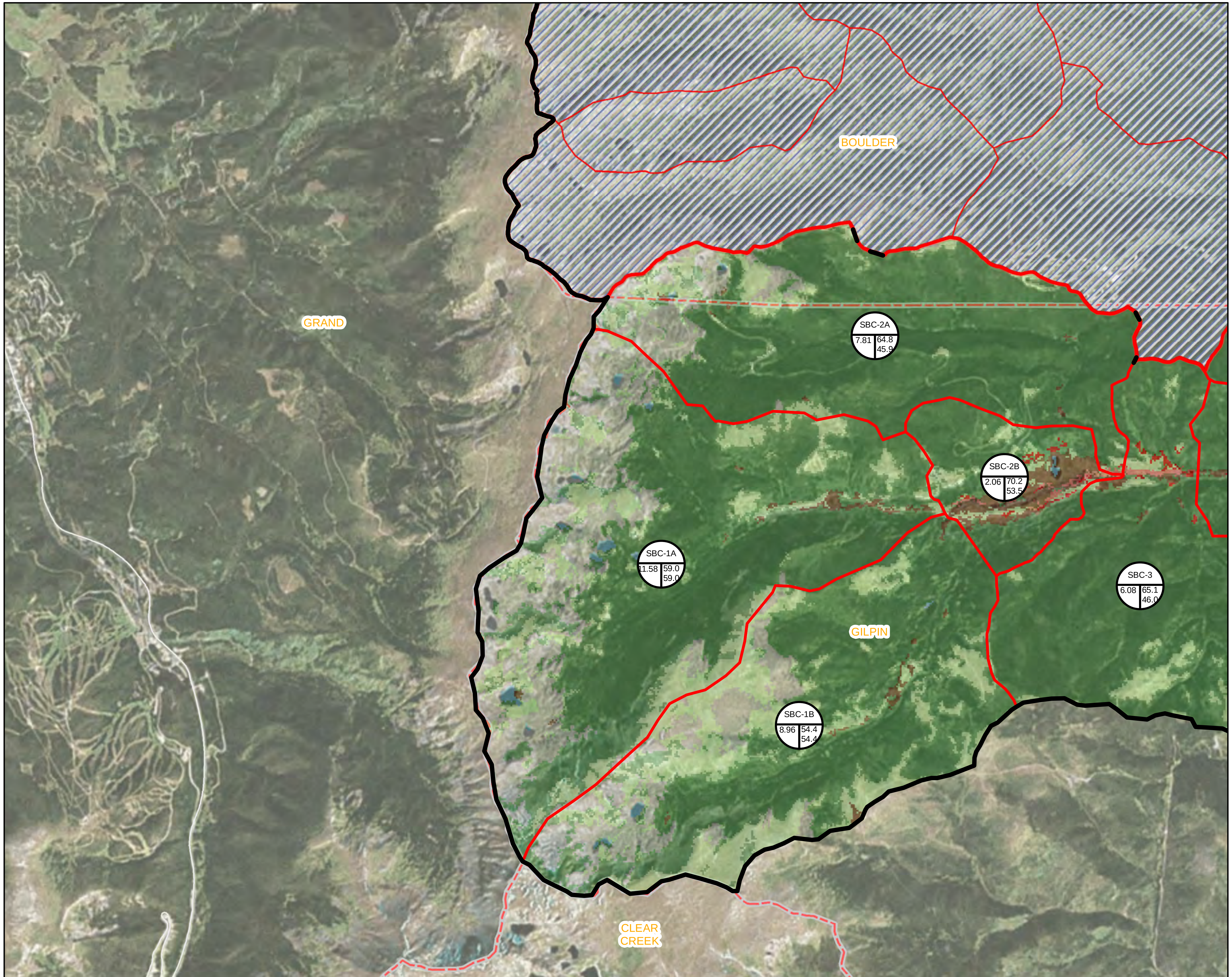

LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Land Use

- Open Water
- Perennial Ice/Snow
- Developed Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Deciduous Forest - Oak / Aspen
- Shrub/Brush
- Grassland/Pasture
- Row Crops
- Woody Wetlands, Herbaceous
- Counties

Basin # / Area (mi²) / C-CN / D-CN — Landuse Label
(C-CN - Calibrated Curve Number)
(D-CN - Design Curve Number)

N

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 9a
Phase II Land Use Map - Page 1 of 6

CDOT Flood Recovery Hydrologic Evaluation

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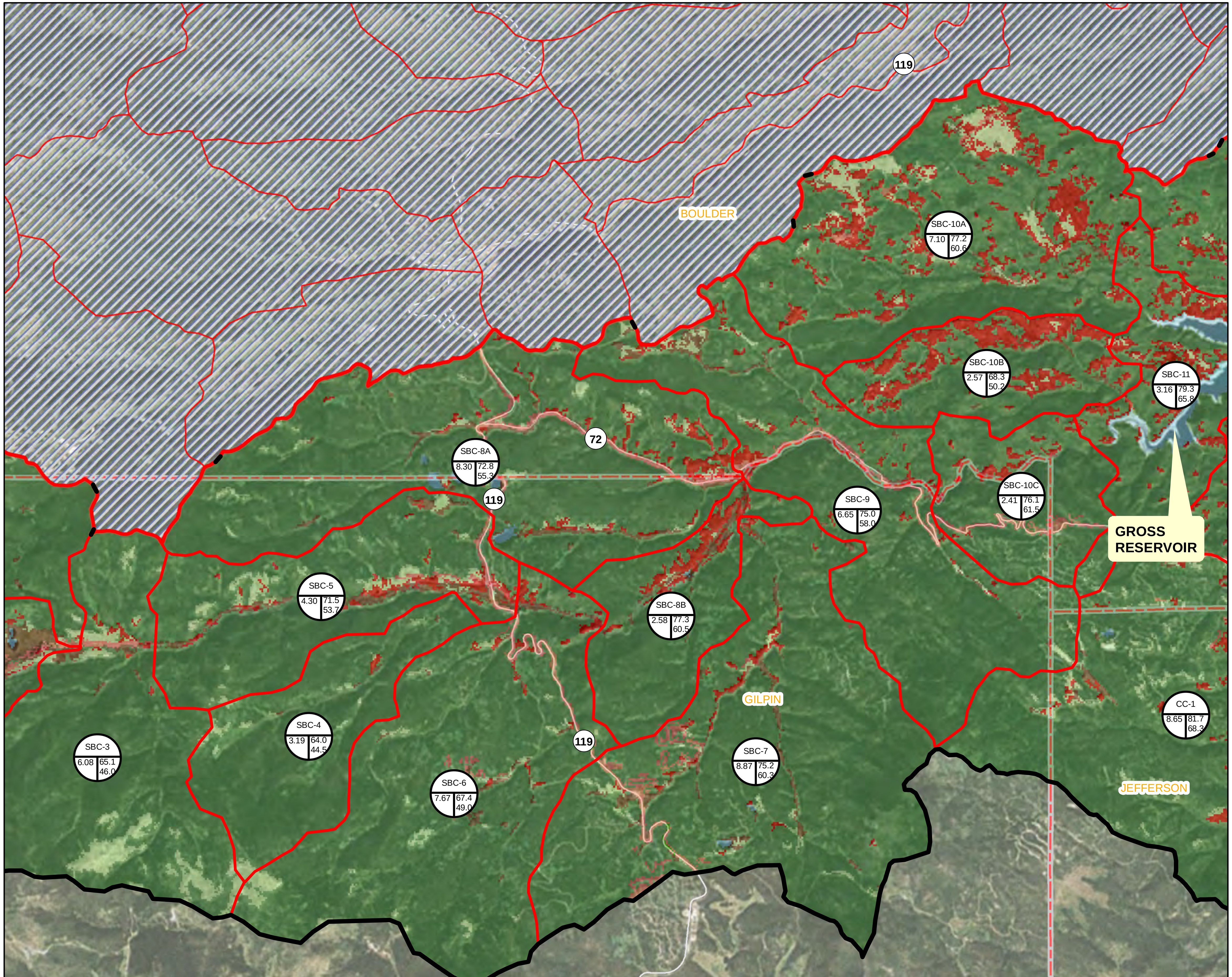

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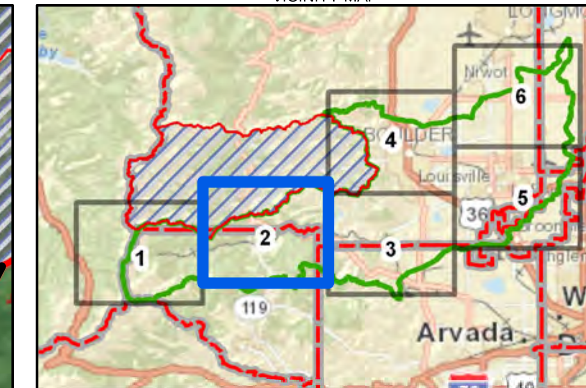


LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Land Use

- Open Water
- Perennial Ice/Snow
- Developed Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Deciduous Forest - Oak / Aspen
- Shrub/Brush
- Grassland/Pasture
- Row Crops
- Woody Wetlands, Herbaceous
- Counties

Basin # / Area (mi^2) / C-CN / D-CN — Landuse Label
(C-CN - Calibrated Curve Number)
(D-CN - Design Curve Number)

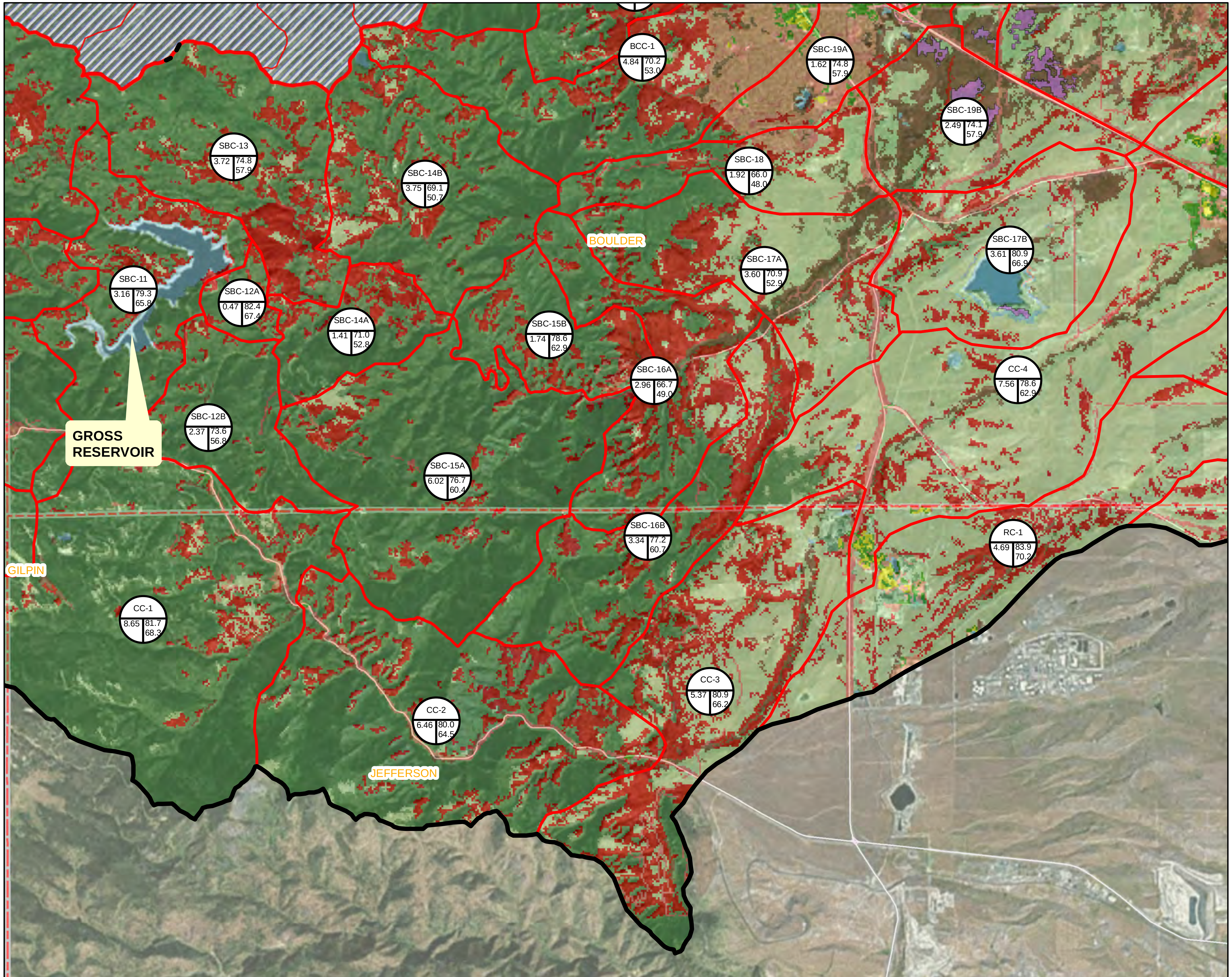
N

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 9b
Phase II Land Use Map - Page 2 of 6

CDOT Flood Recovery Hydrologic Evaluation



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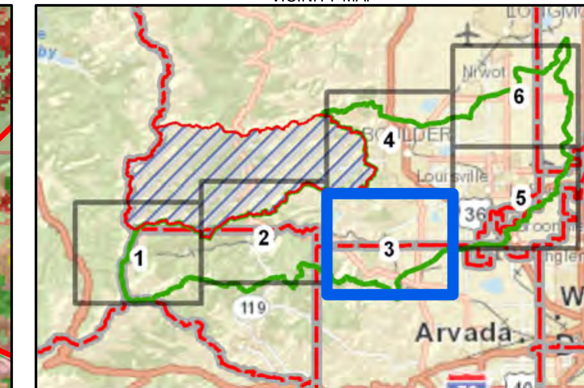

LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Land Use

- Open Water
- Perennial Ice/Snow
- Developed Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
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- Grassland/Pasture
- Row Crops
- Woody Wetlands, Herbaceous
- Counties

Basin # / Area (mi²) / C-CN / D-CN — Landuse Label (C-CN - Calibrated Curve Number) (D-CN - Design Curve Number)

N

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 9c
Phase II Land Use Map - Page 3 of 6

CDOT Flood Recovery Hydrologic Evaluation

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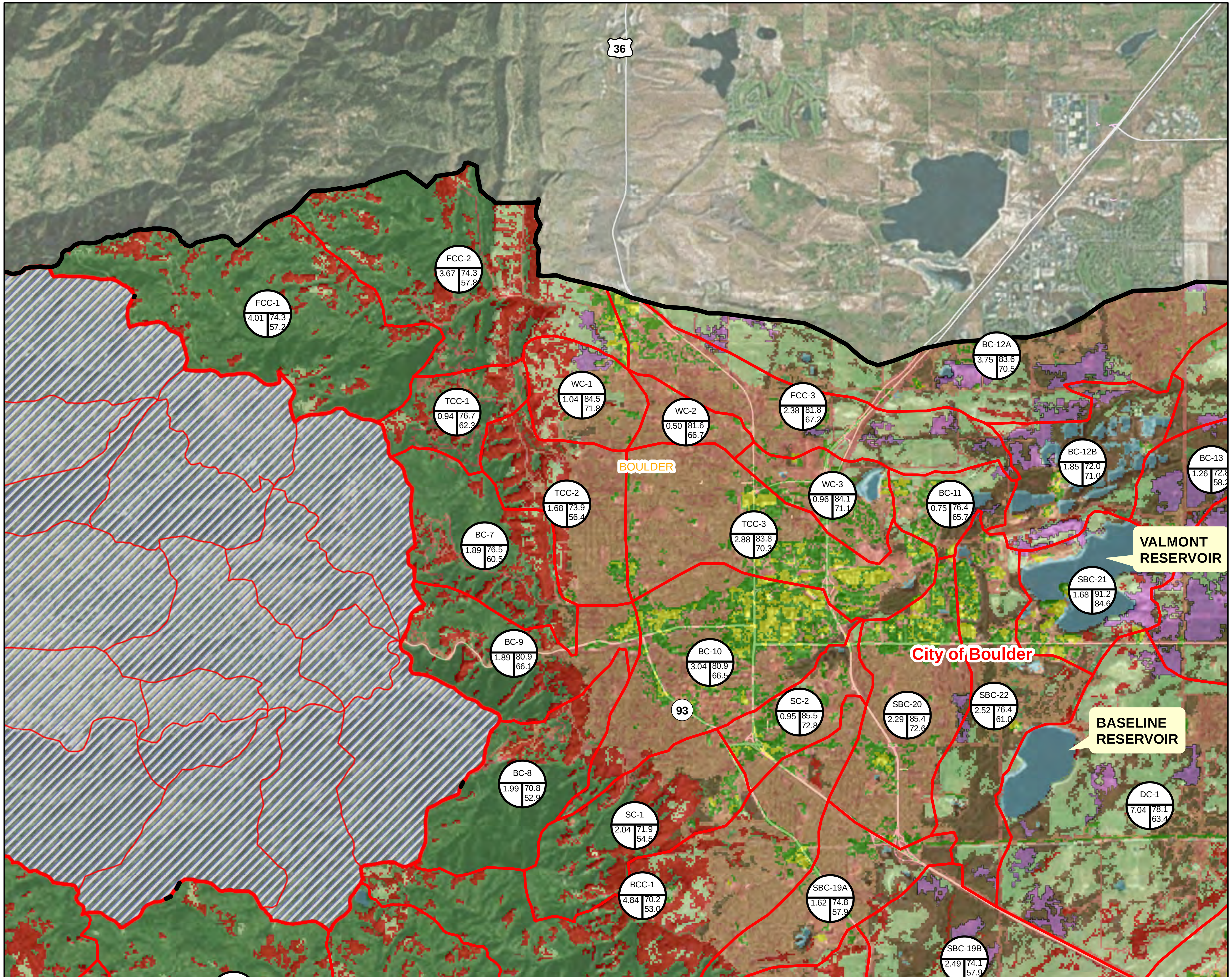

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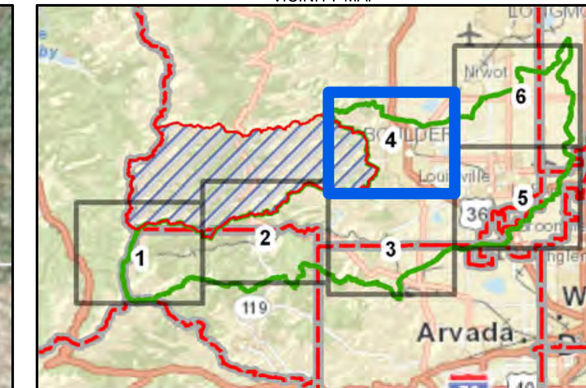

LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Land Use

- Open Water
- Perennial Ice/Snow
- Developed Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Deciduous Forest - Oak / Aspen
- Shrub/Brush
- Grassland/Pasture
- Row Crops
- Woody Wetlands, Herbaceous
- Counties

Basin # / Area (mi²) / C-CN / D-CN

Landuse Label
(C-CN - Calibrated Curve Number)
(D-CN - Design Curve Number)

N

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 9d
Phase II Land Use Map - Page 4 of 6

CDOT Flood Recovery Hydrologic Evaluation

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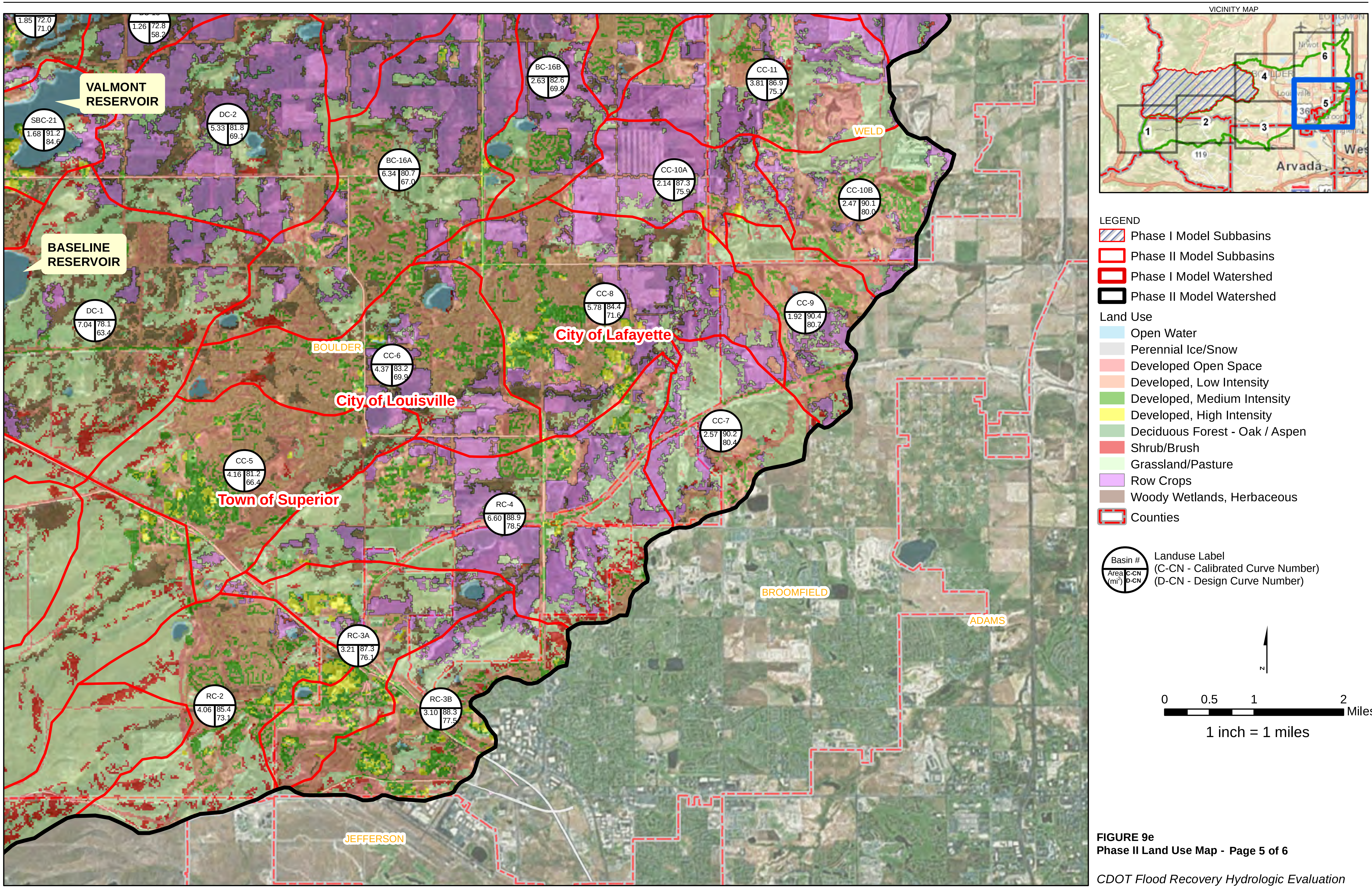
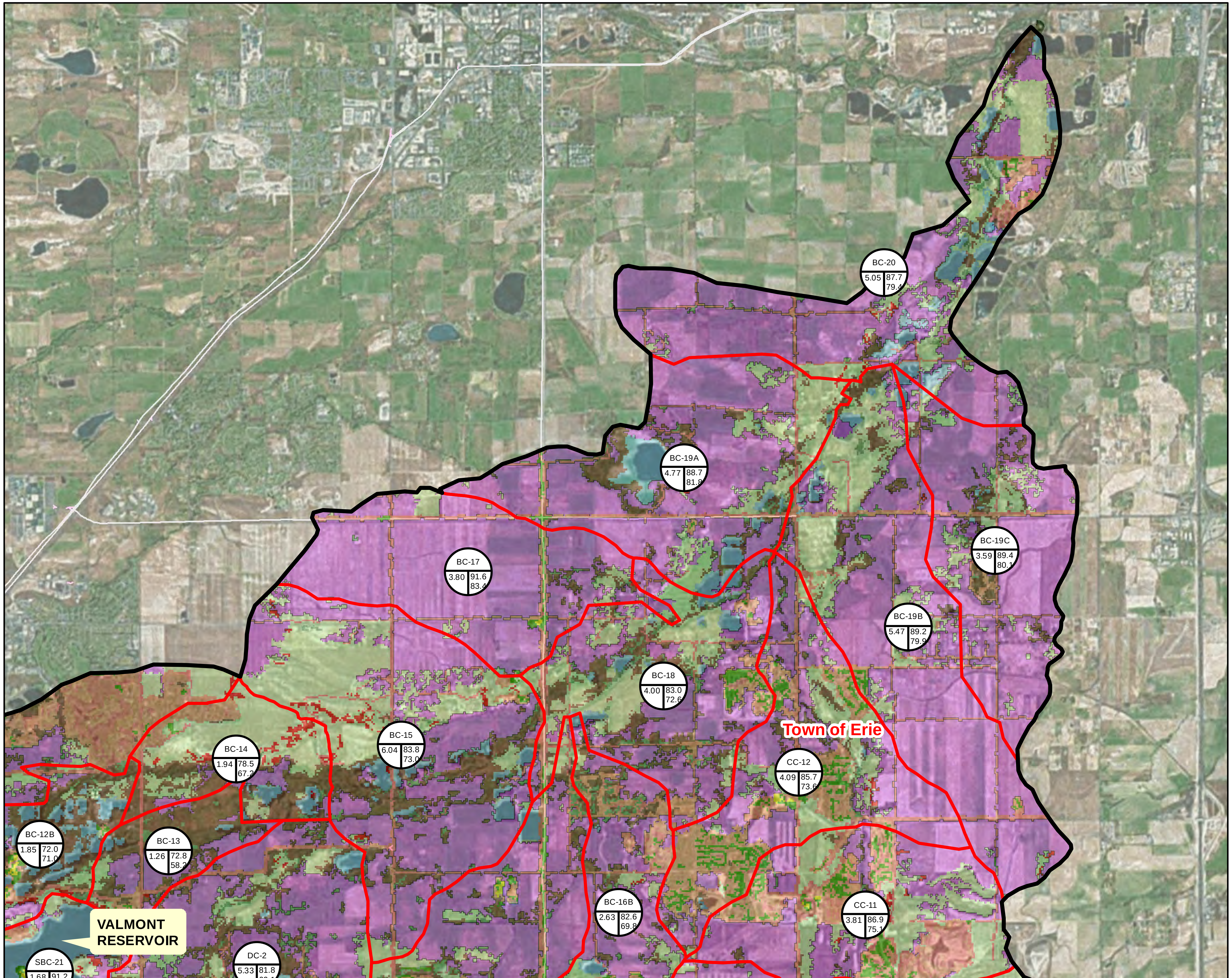


FIGURE 9e
Phase II Land Use Map - Page 5 of 6

CDOT Flood Recovery Hydrologic Evaluation



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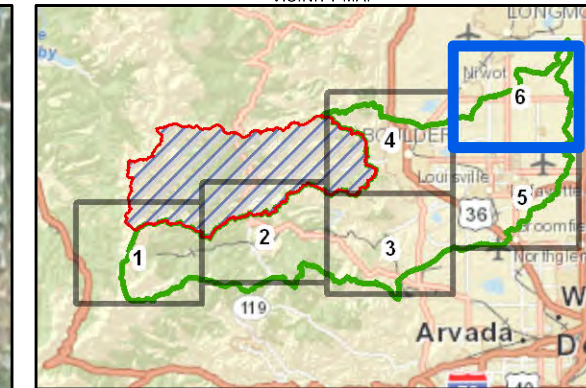


LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed
- Counties

Basin # / Area (mi²) / C-CN / D-CN — Landuse Label (C-CN - Calibrated Curve Number) (D-CN - Design Curve Number)

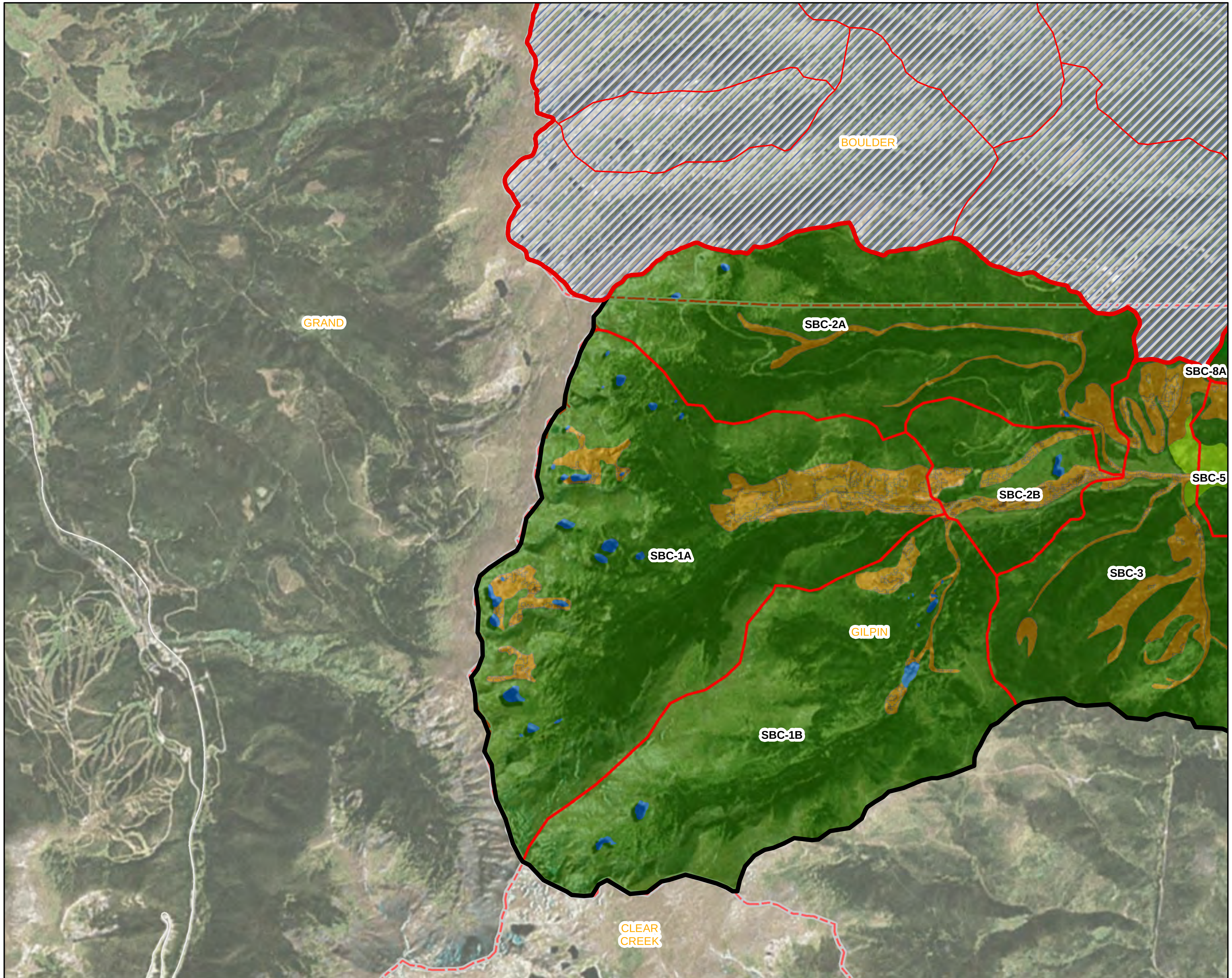
N

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 9f
Phase II Land Use Map - Page 6 of 6

CDOT Flood Recovery Hydrologic Evaluation



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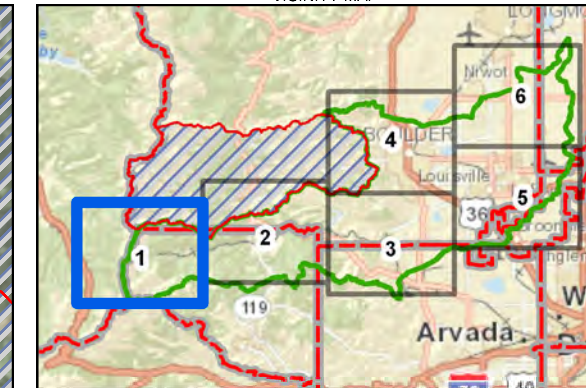


LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Hydrologic Soil Group

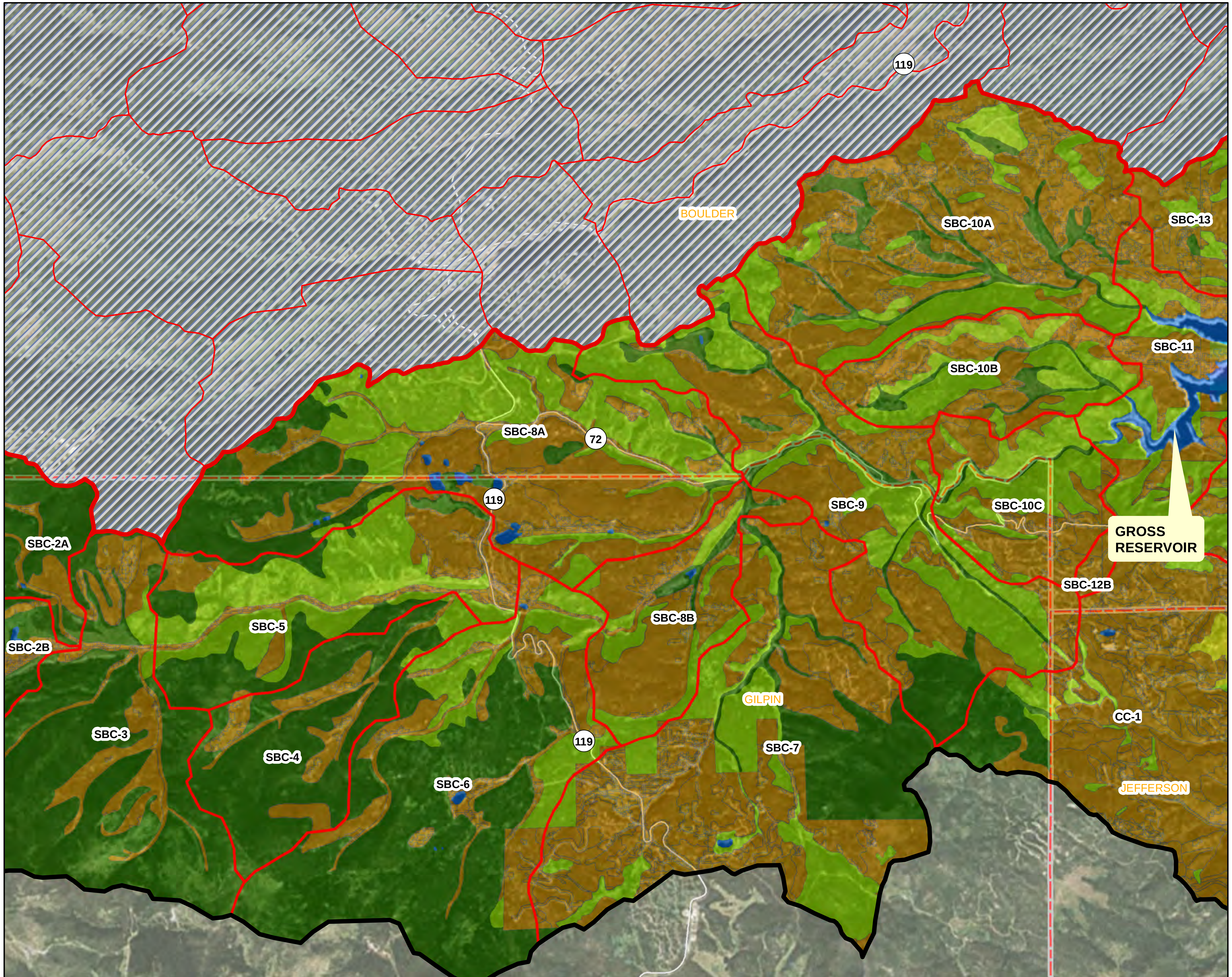
- A
- B
- C
- D
- Water
- Counties

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 10a
Phase II Soils Map - Page 1 of 6

CDOT Flood Recovery Hydrologic Evaluation



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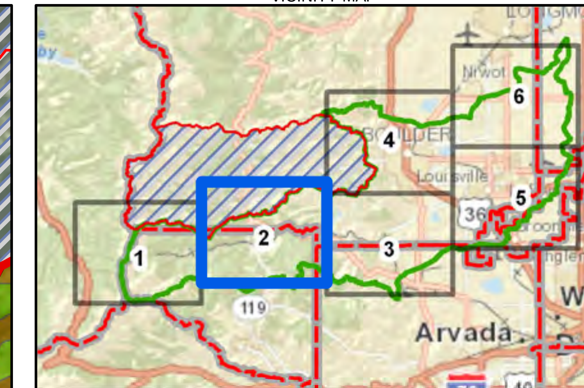


LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Hydrologic Soil Group

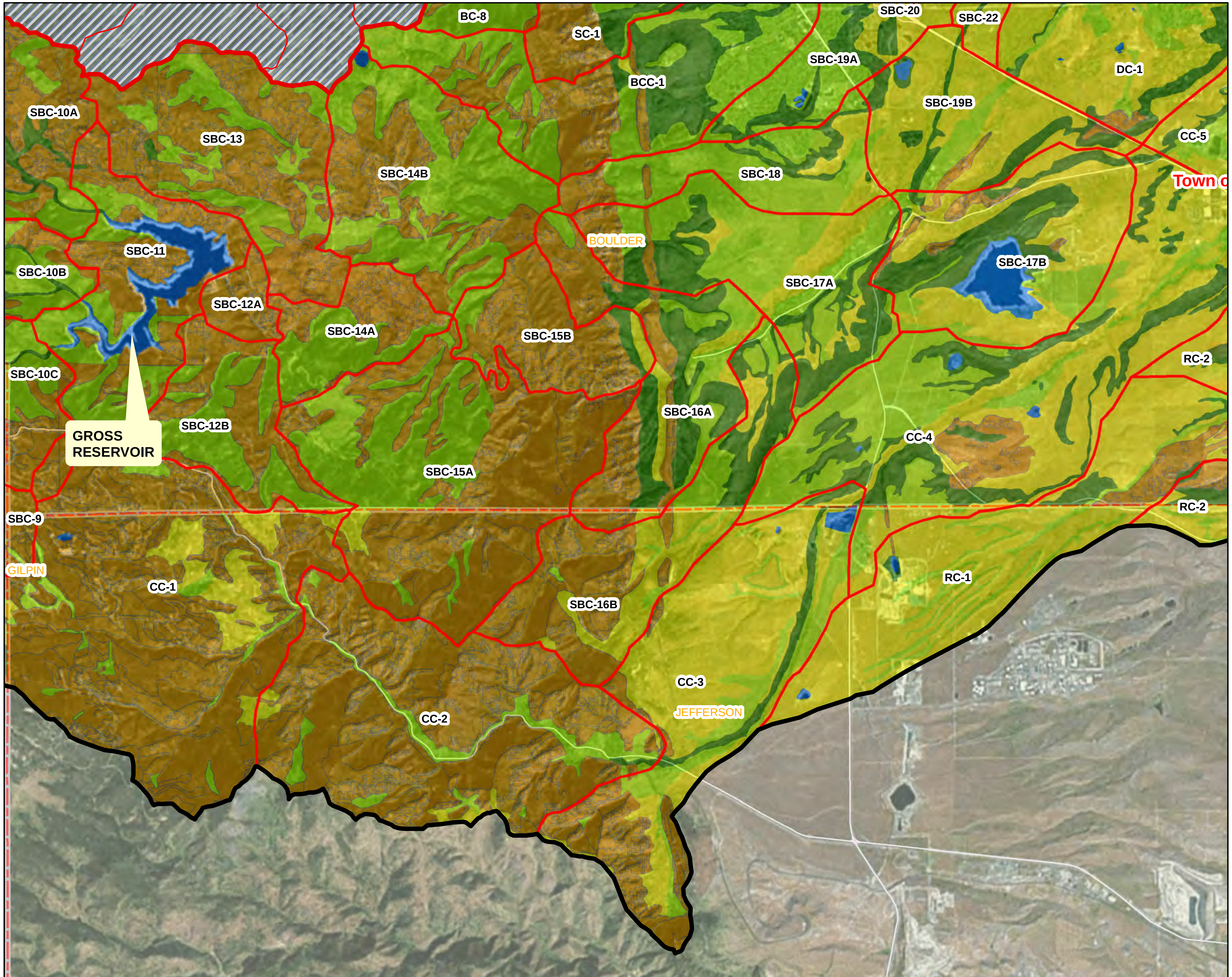
- A
- B
- C
- D
- Water
- Counties

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 10b
Phase II Soils Map - Page 2 of 6

CDOT Flood Recovery Hydrologic Evaluation



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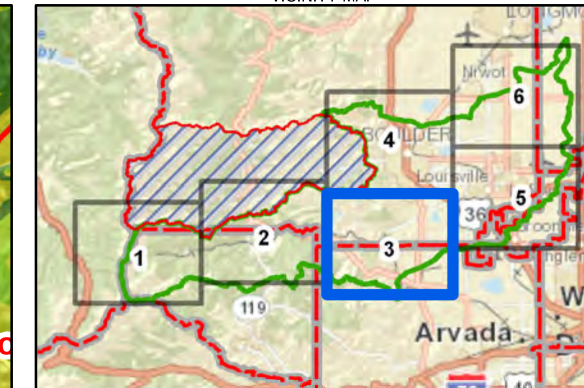

LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Hydrologic Soil Group

- A
- B
- C
- D
- Water
- Counties

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 10c
Phase II Soils Map - Page 3 of 6

CDOT Flood Recovery Hydrologic Evaluation

UNK \\GECKO\GROUPS\TBG\481085-482330 CDOT EMERGENCY RESPONSE SERVICES\390_DESIGN_ELEMENTS\DRAINAGE\GIS_PHASE_II\MAPFILES\REPORT\BOULDERSOIL_DATA_MAP_PHASE_II.MXD BBETTAG 1/21/2015 8:17:17 AM

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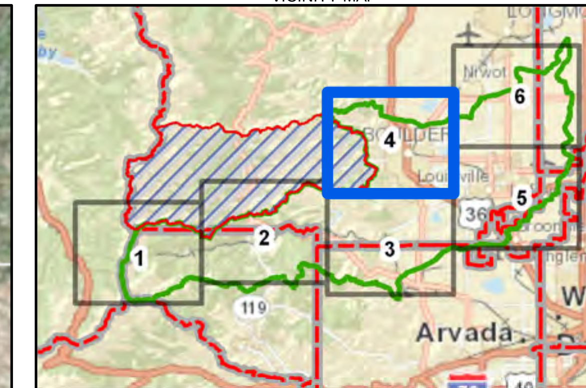
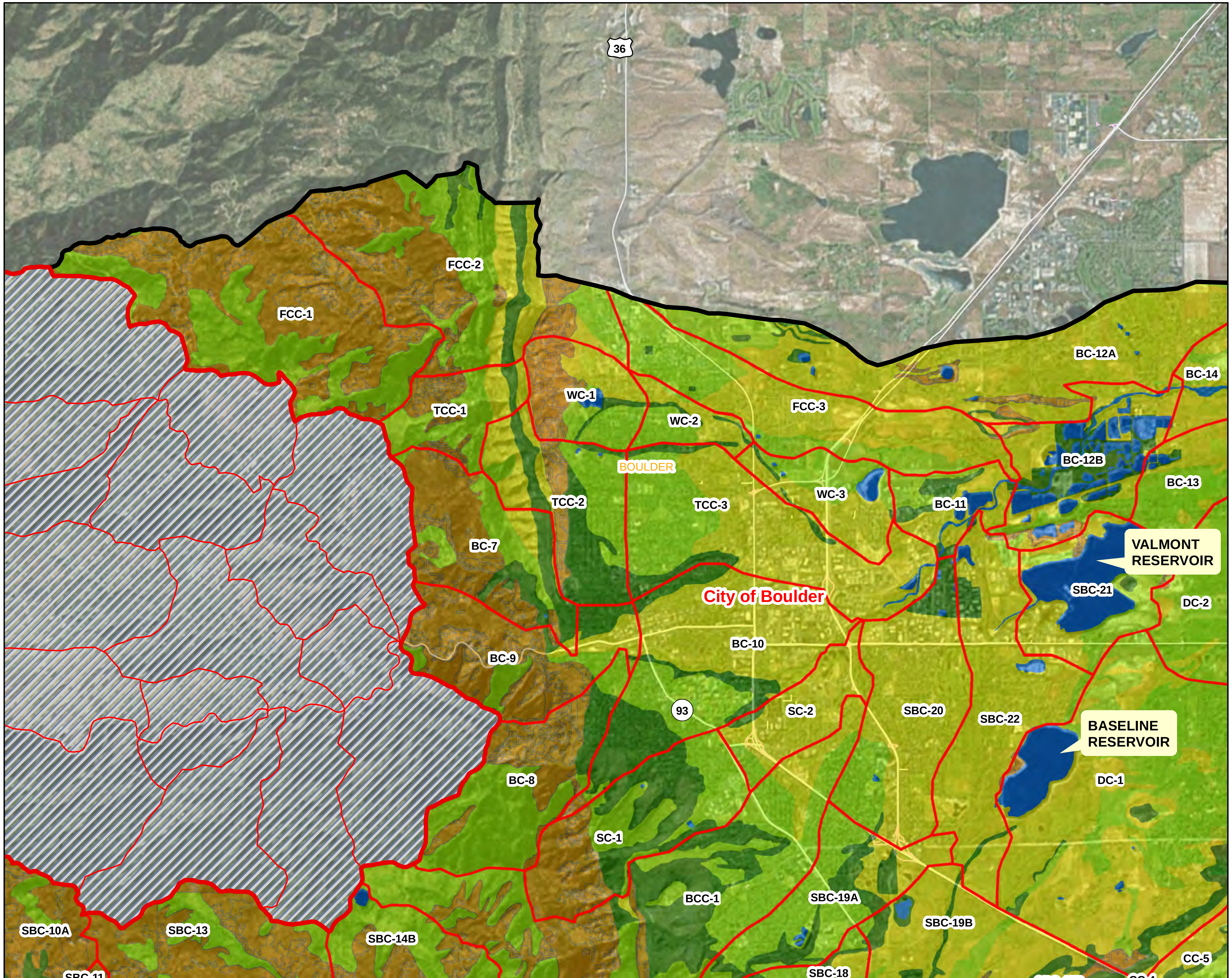
VICINITY MAP





LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Hydrologic Soil Group

- A
- B
- C
- D
- Water
- Counties

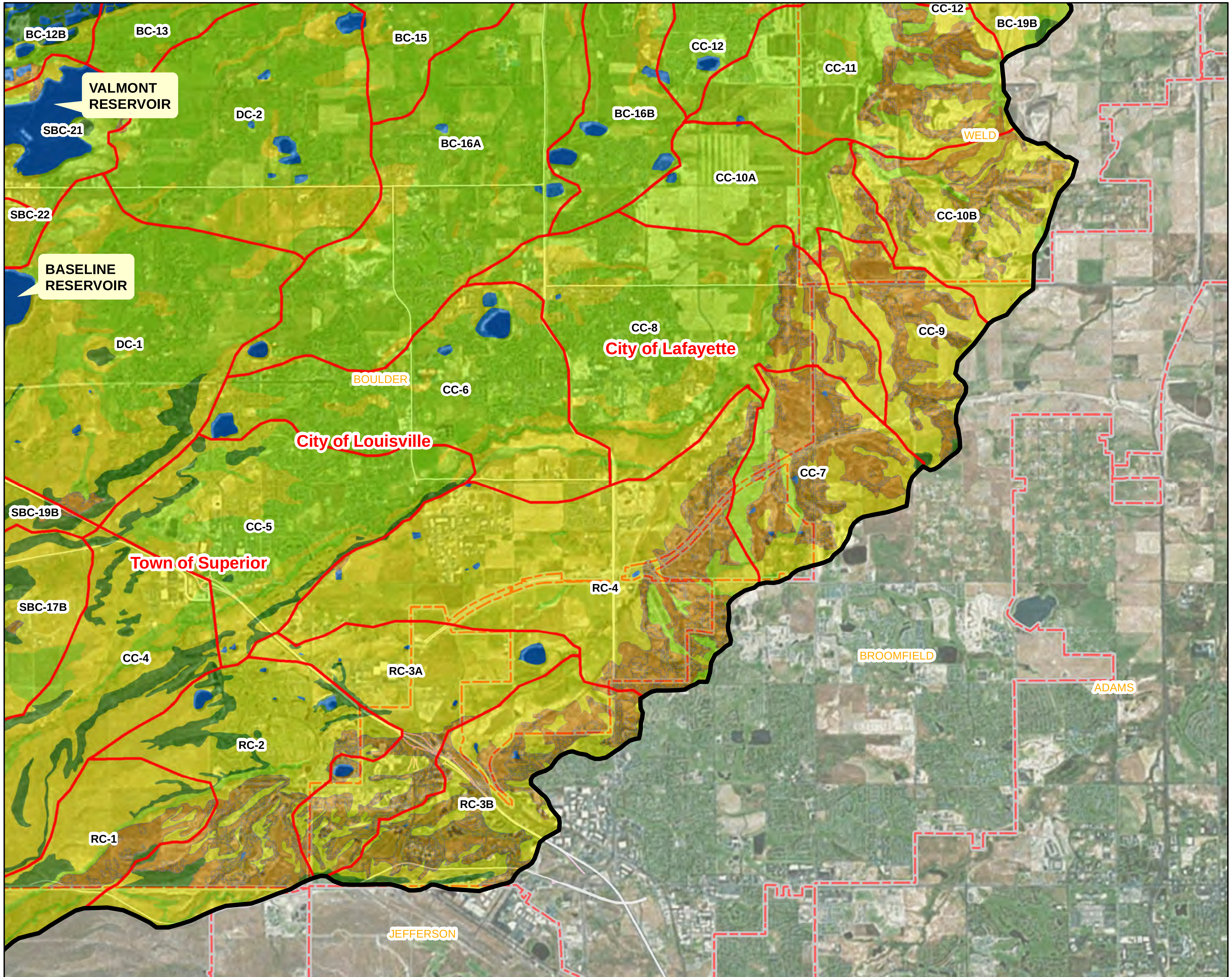
N

0 0.5 1 2 Miles

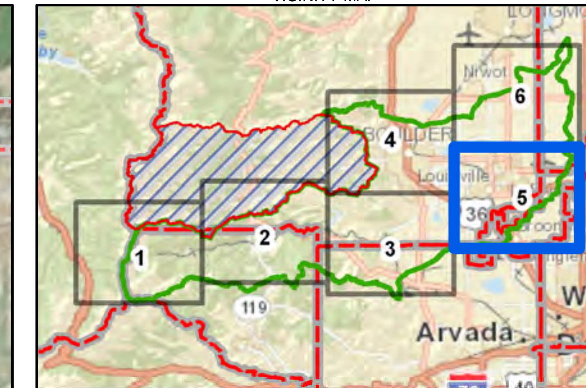
1 inch = 1 miles

FIGURE 10d
Phase II Soils Map - Page 4 of 6

CDOT Flood Recovery Hydrologic Evaluation



VICINITY MAP



LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Hydrologic Soil Group

- A
- B
- C
- D
- Water
- Counties

N

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 10e
Phase II Soils Map - Page 5 of 6

CDOT Flood Recovery Hydrologic Evaluation

UNK \\GECKO\GROUPS\TBG\481085-482330 CDOT EMERGENCY RESPONSE SERVICES\390_DESIGN_ELEMENTS\DRAINAGE\GIS_PHASE_II\MAPFILES\REPORT\BOULDERSOIL_DATA_MAP_PHASE_II.MXD BBETTAG 1/21/2015 8:17:17 AM

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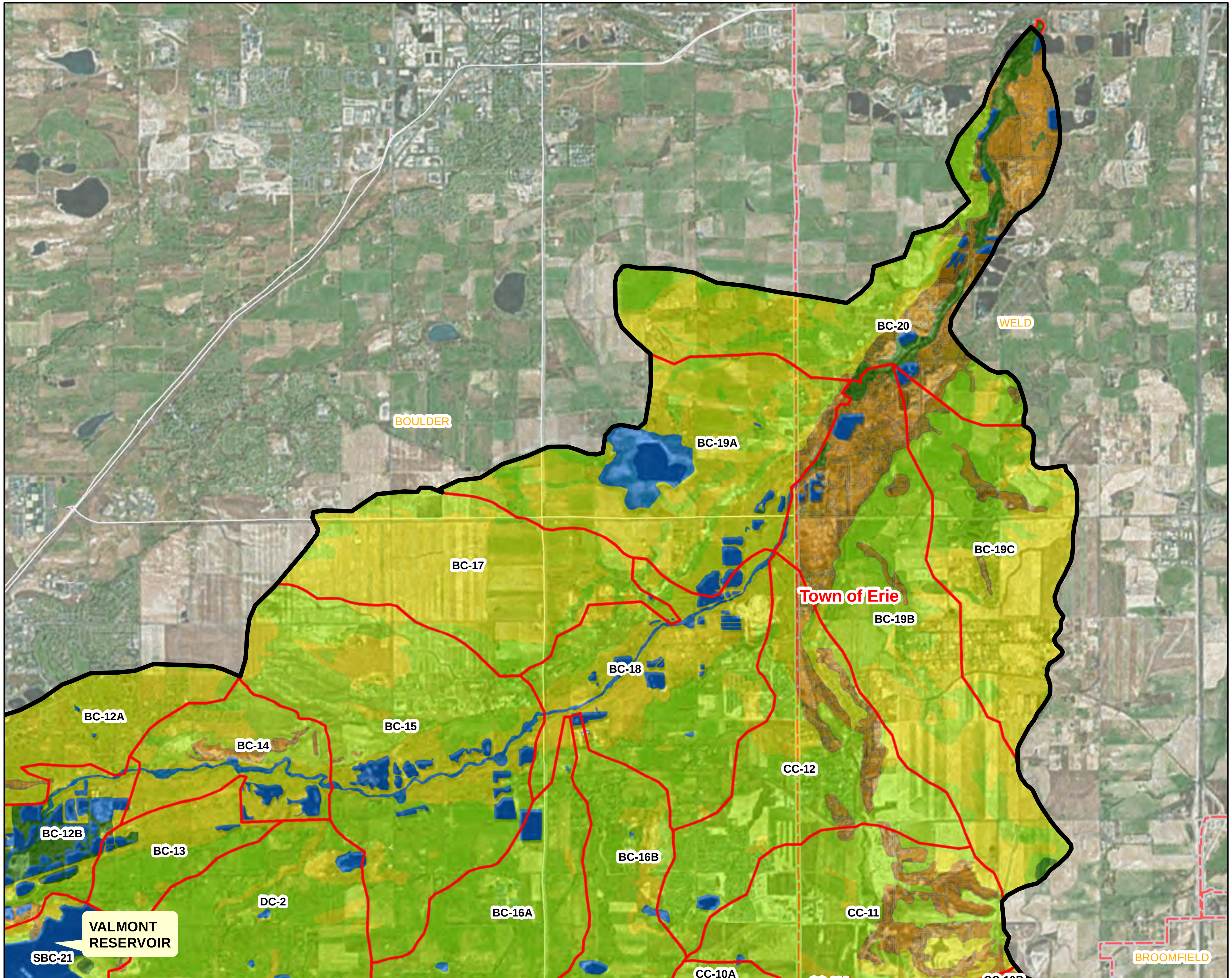
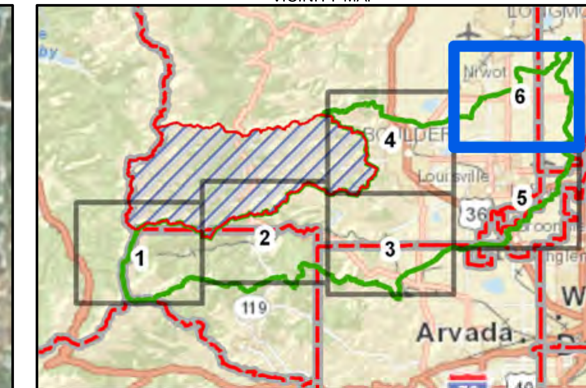


VICINITY MAP



LEGEND

- Phase I Model Subbasins
- Phase II Model Subbasins
- Phase I Model Watershed
- Phase II Model Watershed

Hydrologic Soil Group

- A
- B
- C
- D
- Water
- Counties

0 0.5 1 2 Miles

1 inch = 1 miles

FIGURE 10f
Phase II Soils Map - Page 6 of 6

CDOT Flood Recovery Hydrologic Evaluation

CH2MHILL.

Figure 11a – Muskingum-Cunge Eight-Point Routing Cross Sections

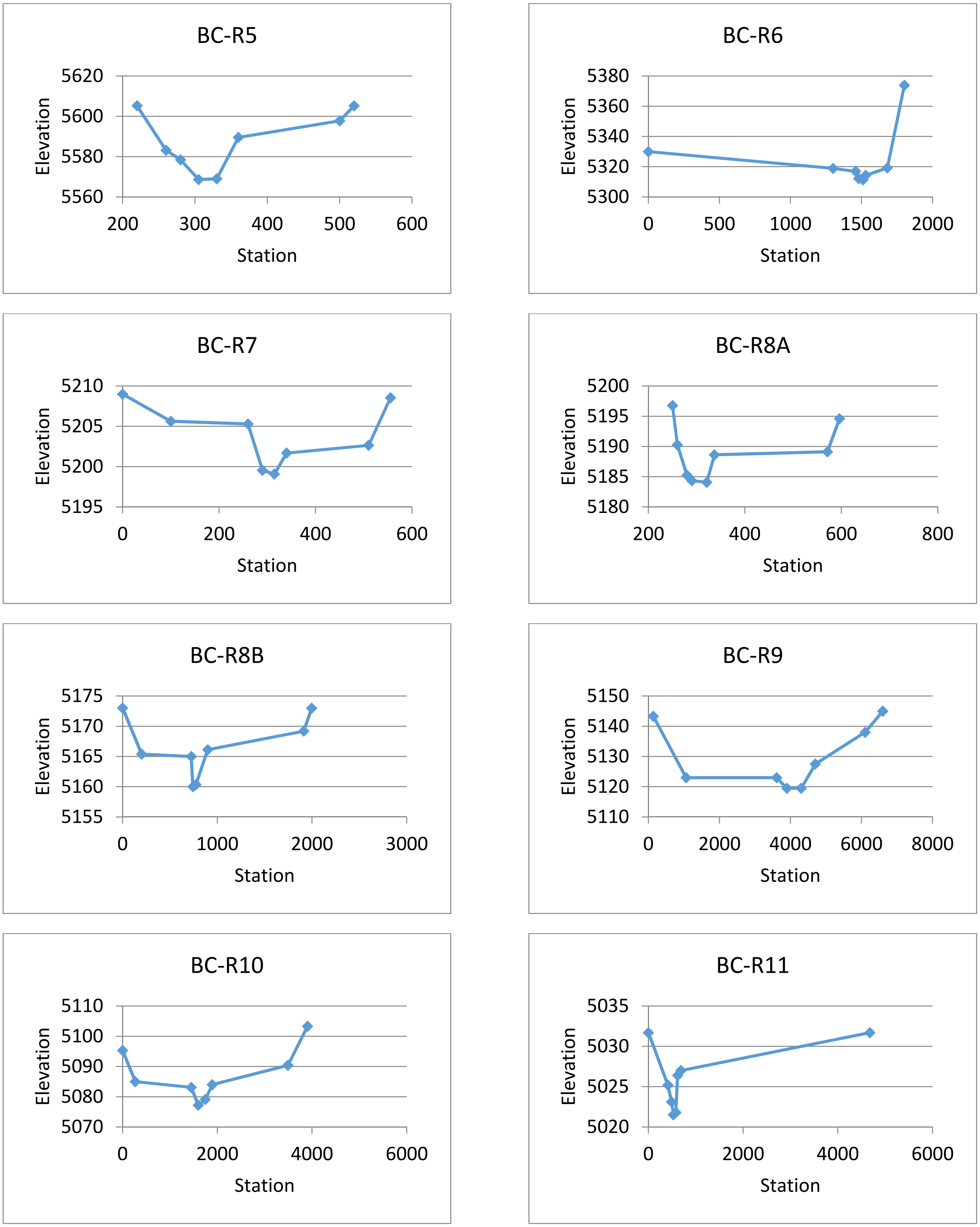
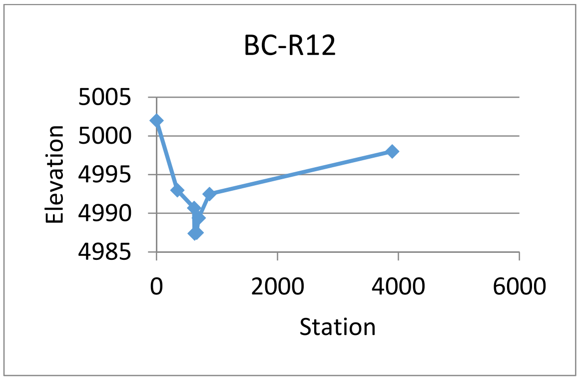
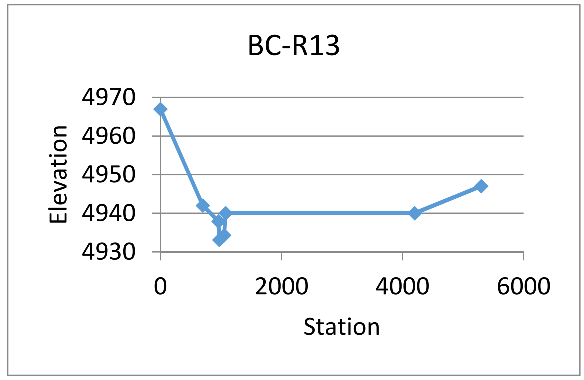


Figure 11b – Muskingum-Cunge Eight-Point Routing Cross Sections (continued)





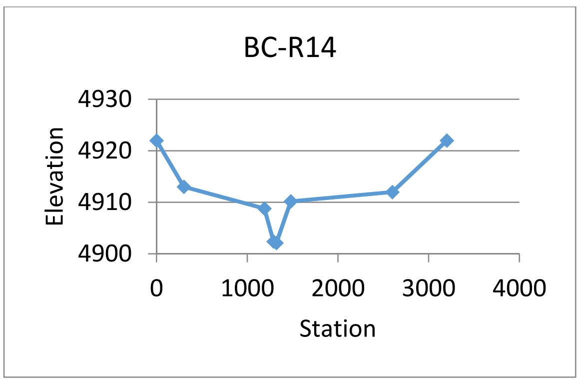


Figure 11c – Muskinguϓ-Cuƴge Eighƚ-Point Routiƴg Cross Sections (continued)

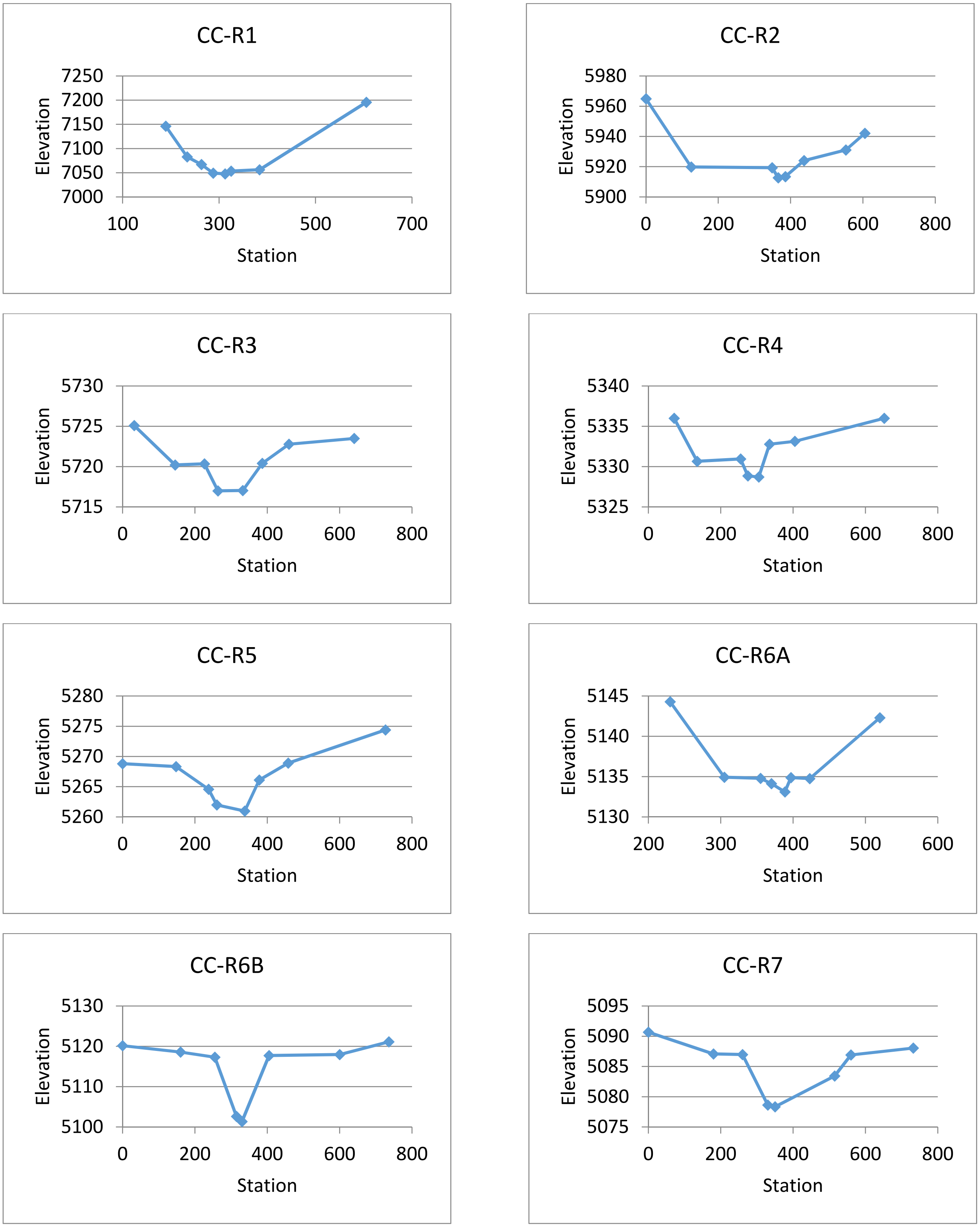


Figure 11d – Muskingum-Cunge Eight-Point Routing Cross Sections (continued)

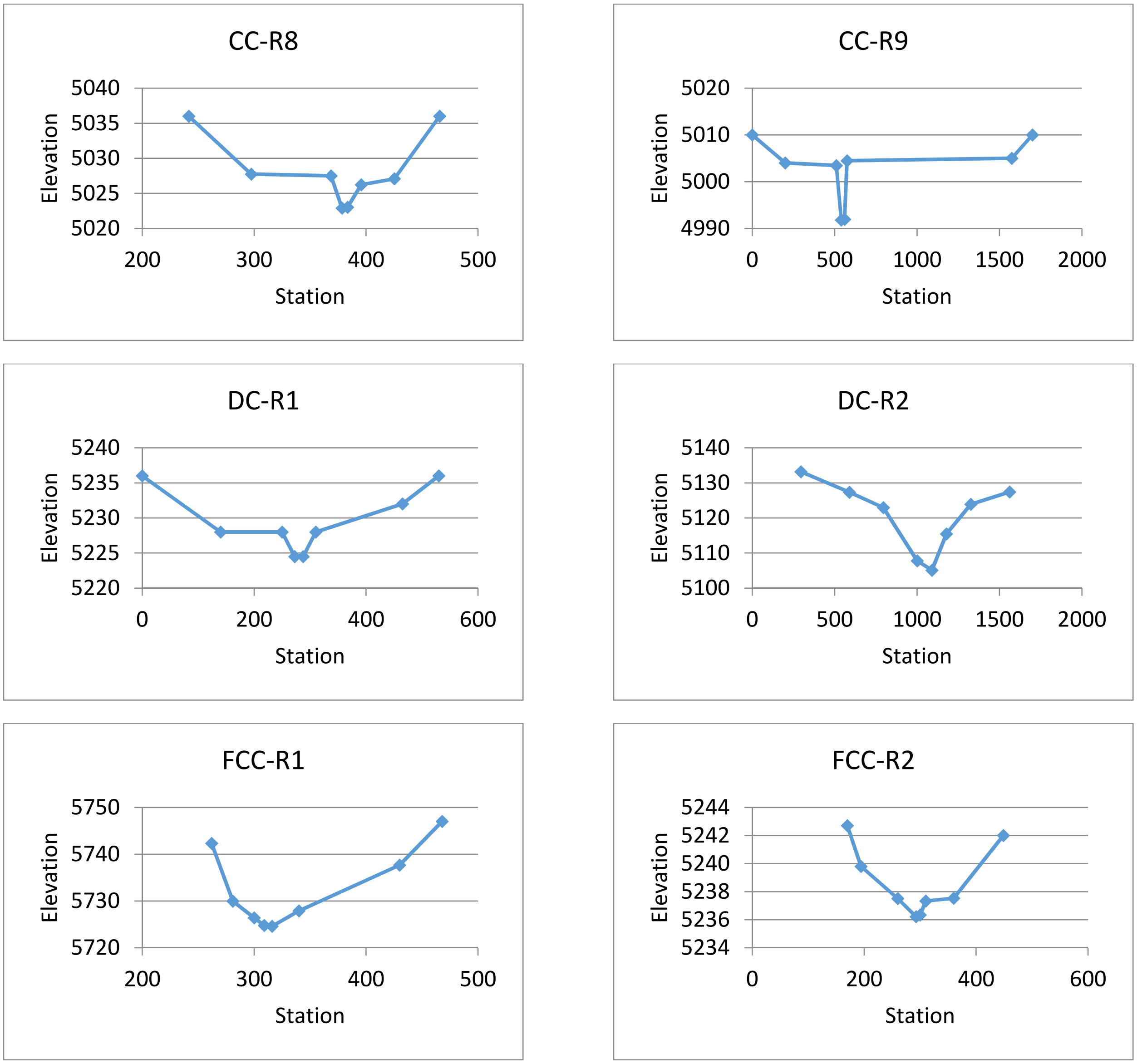
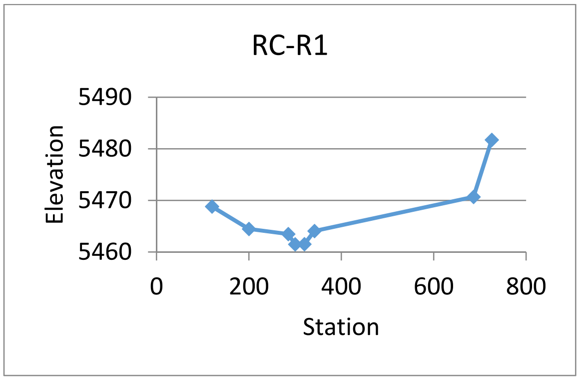
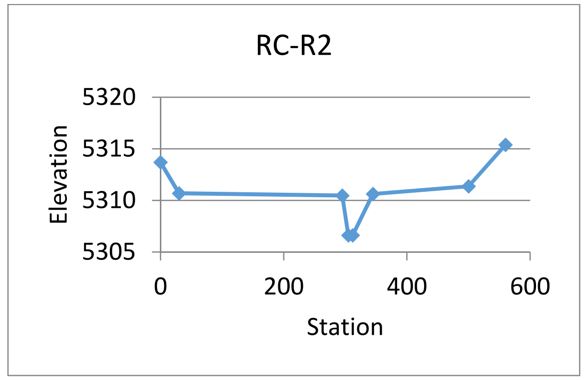


Figure 11e – Muskingum-Cunge Eight-Point Routing Cross Sections (continued)





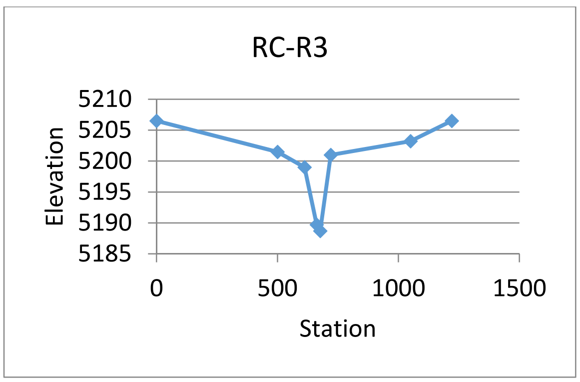
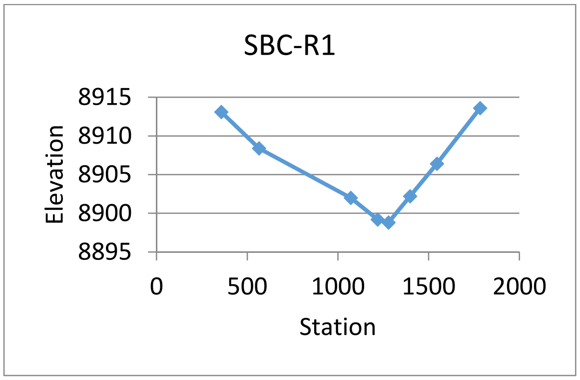
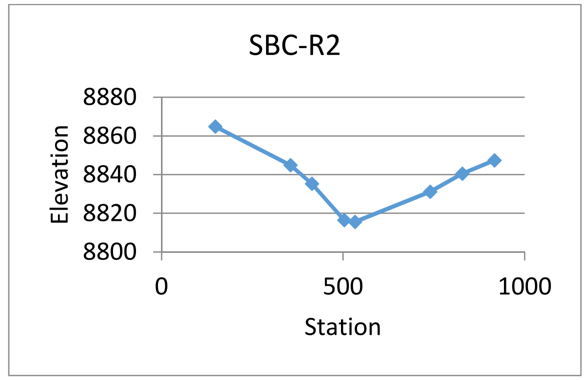
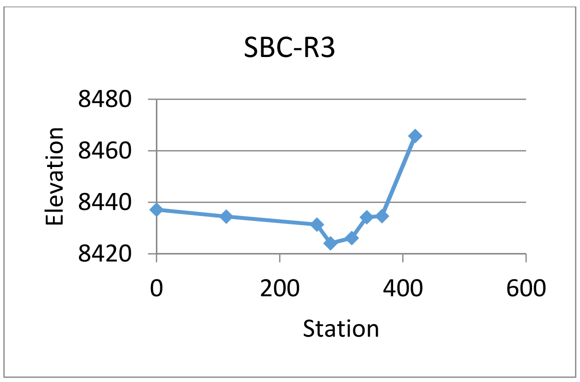
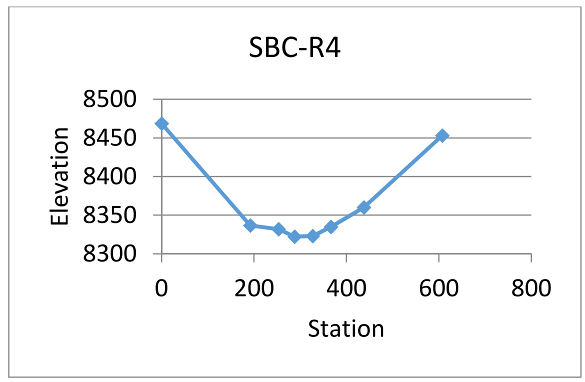


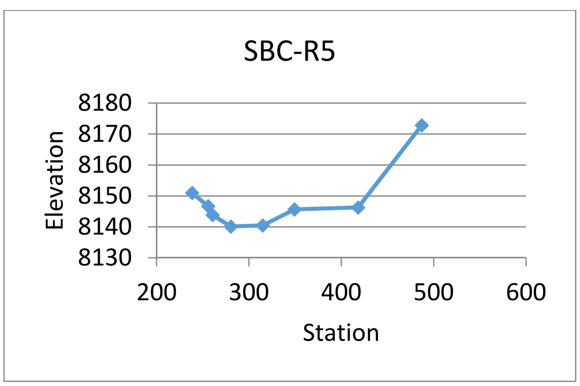
Figure 11f – Muskingum-Cunge Eight-Point Routing Cross Sections (continued)

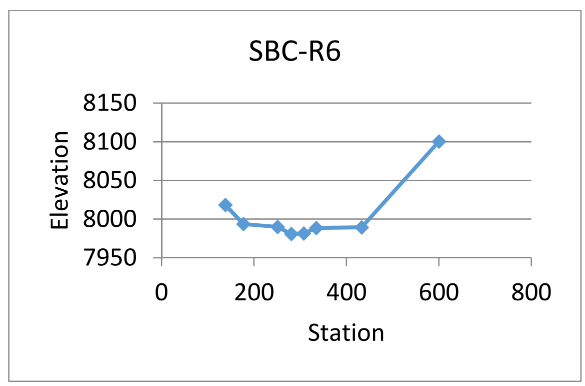


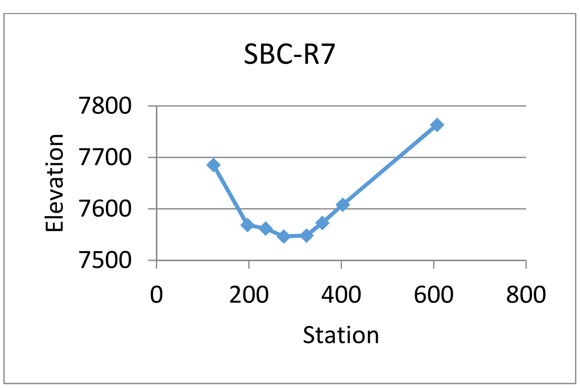












SBC-R8 intentionally omitted; Gross Reservoir modeled with Reservoir element in lieu of routing reach

Figure 11g – Muskingum-Cunge Eight-Point Routing Cross Sections (continued)

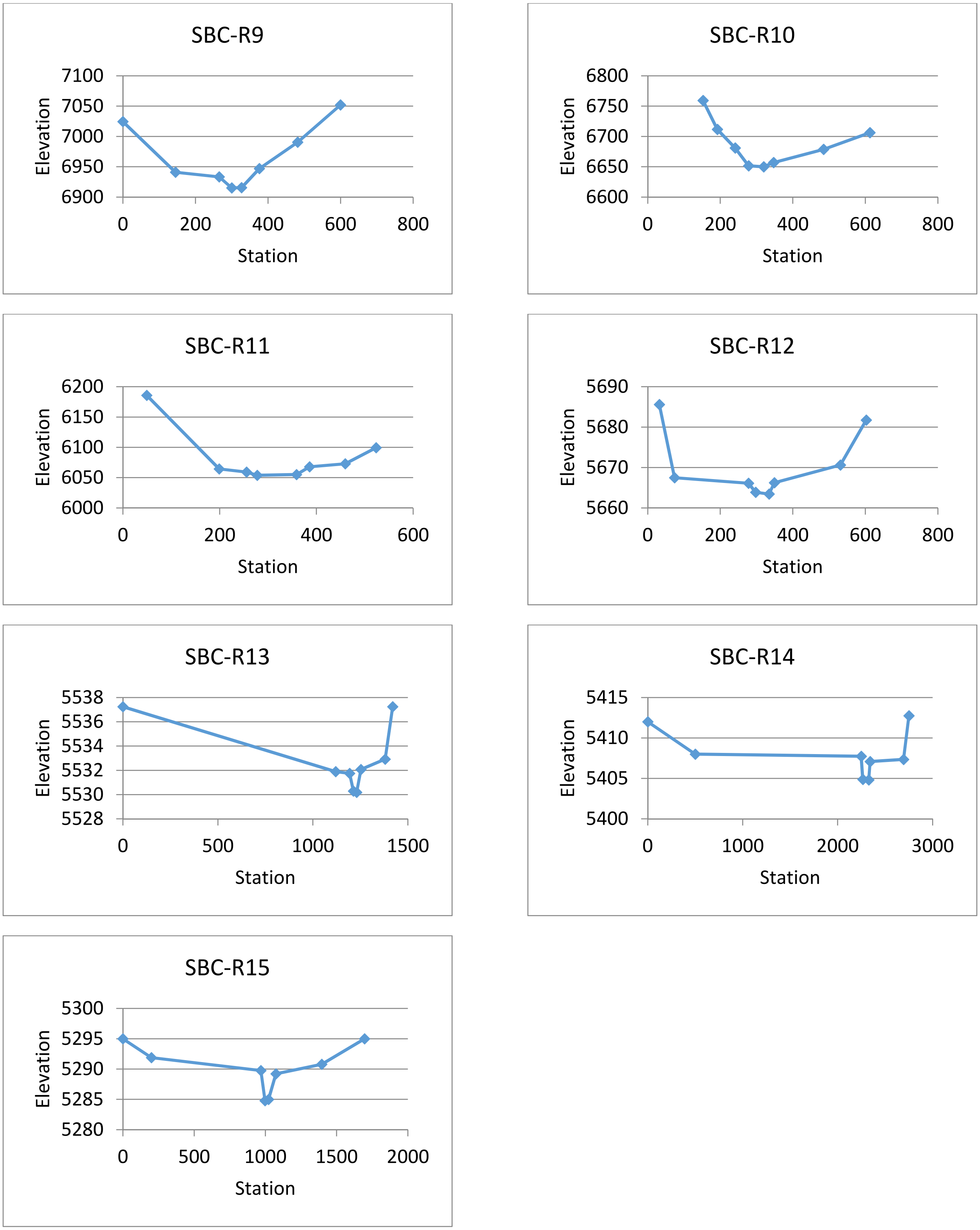
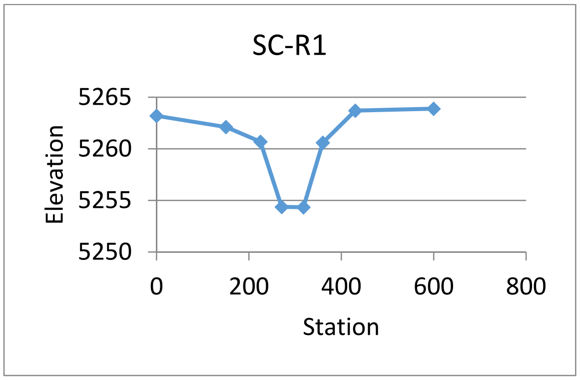
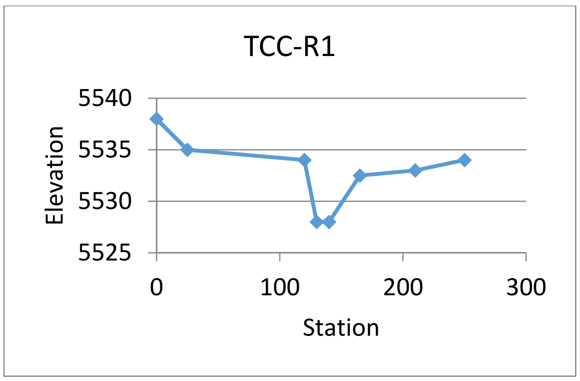
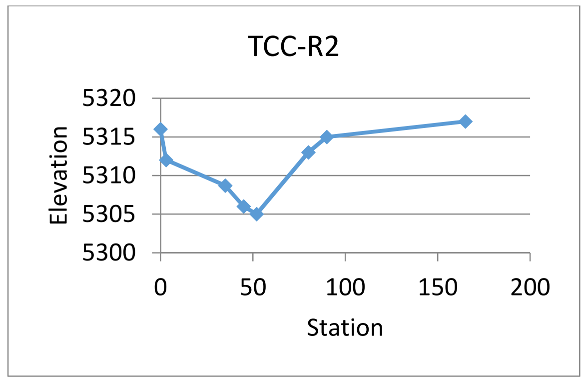
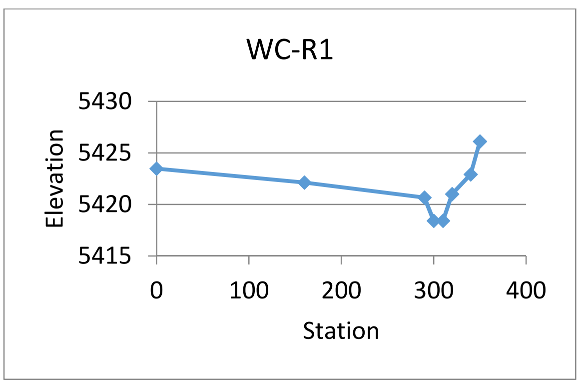


Figure 11h – Muskingum-Cunge Eight-Point Routing Cross Sections (continued)









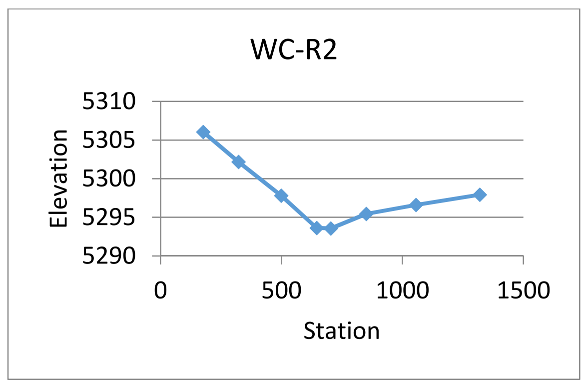


Figure 12 - September 2013 10-day Calibration Results - Time-lag Provided by Barker Reservoir

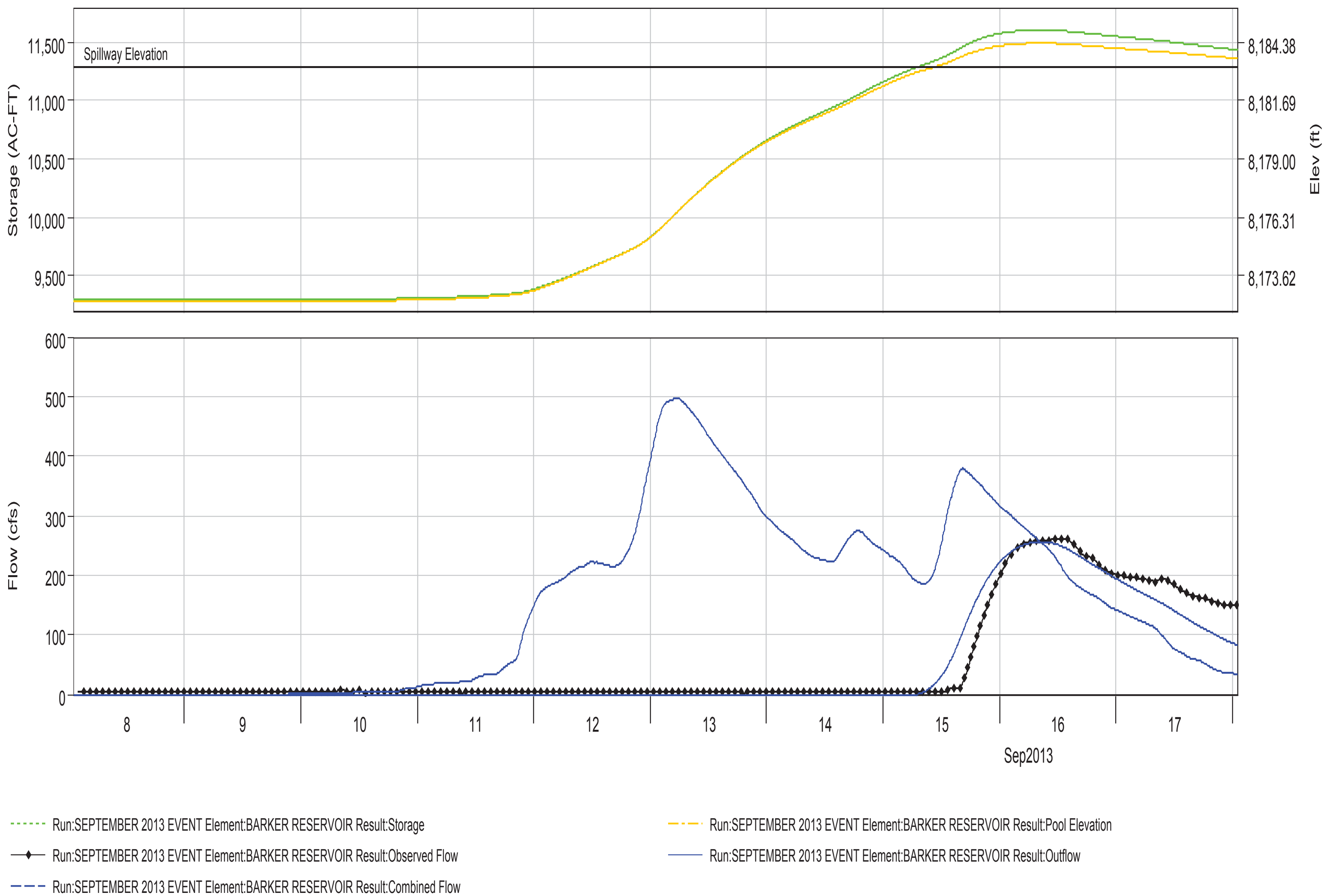


Figure 13 - Hydrograph at CDWR South Boulder Creek below Gross Reservoir Gage

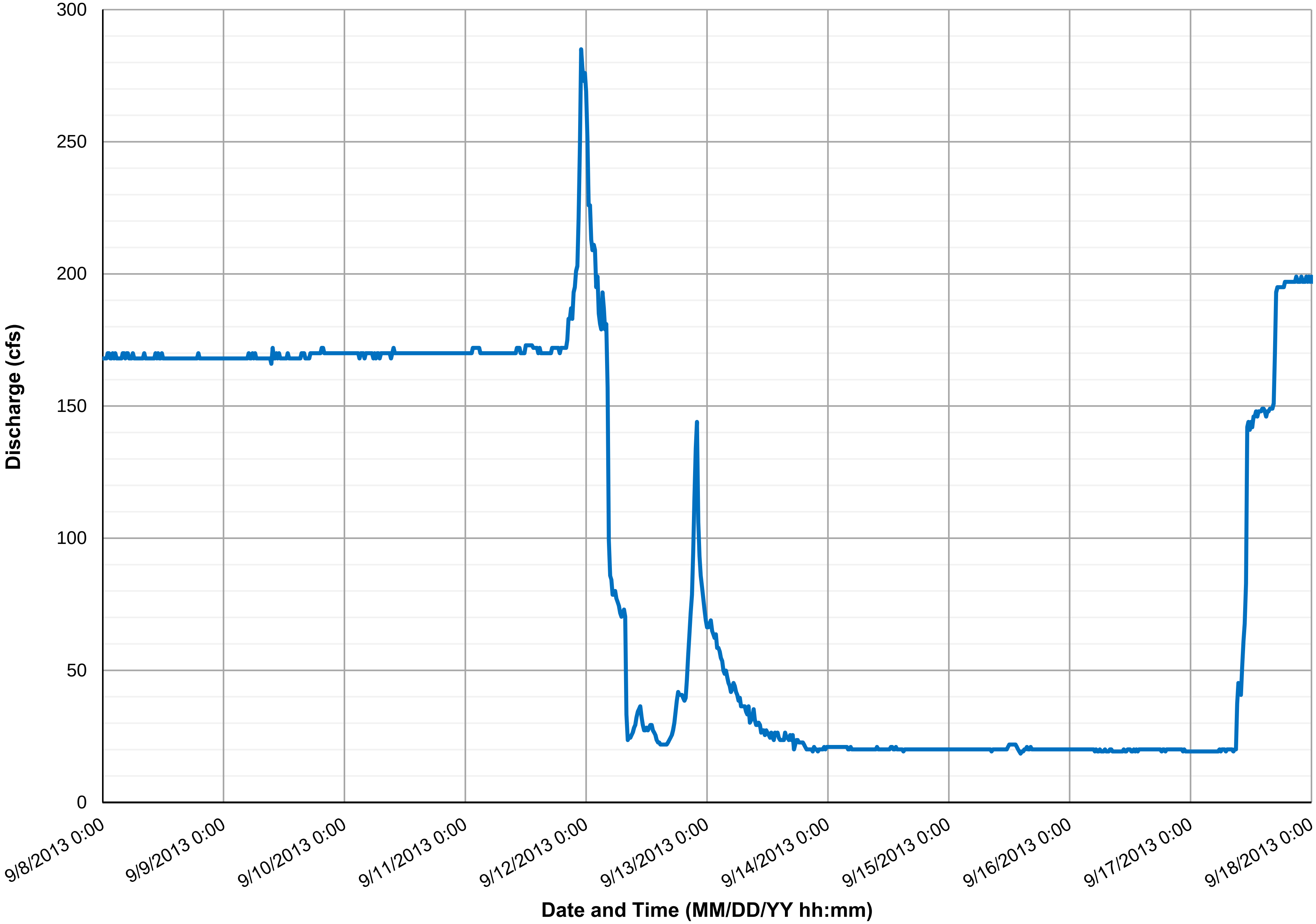


Figure 14a - Hydrographs at Key Design Locations
Junction "BC-J7" - Boulder Creek at Broadway Results for Run "September 2013, 24-hr"

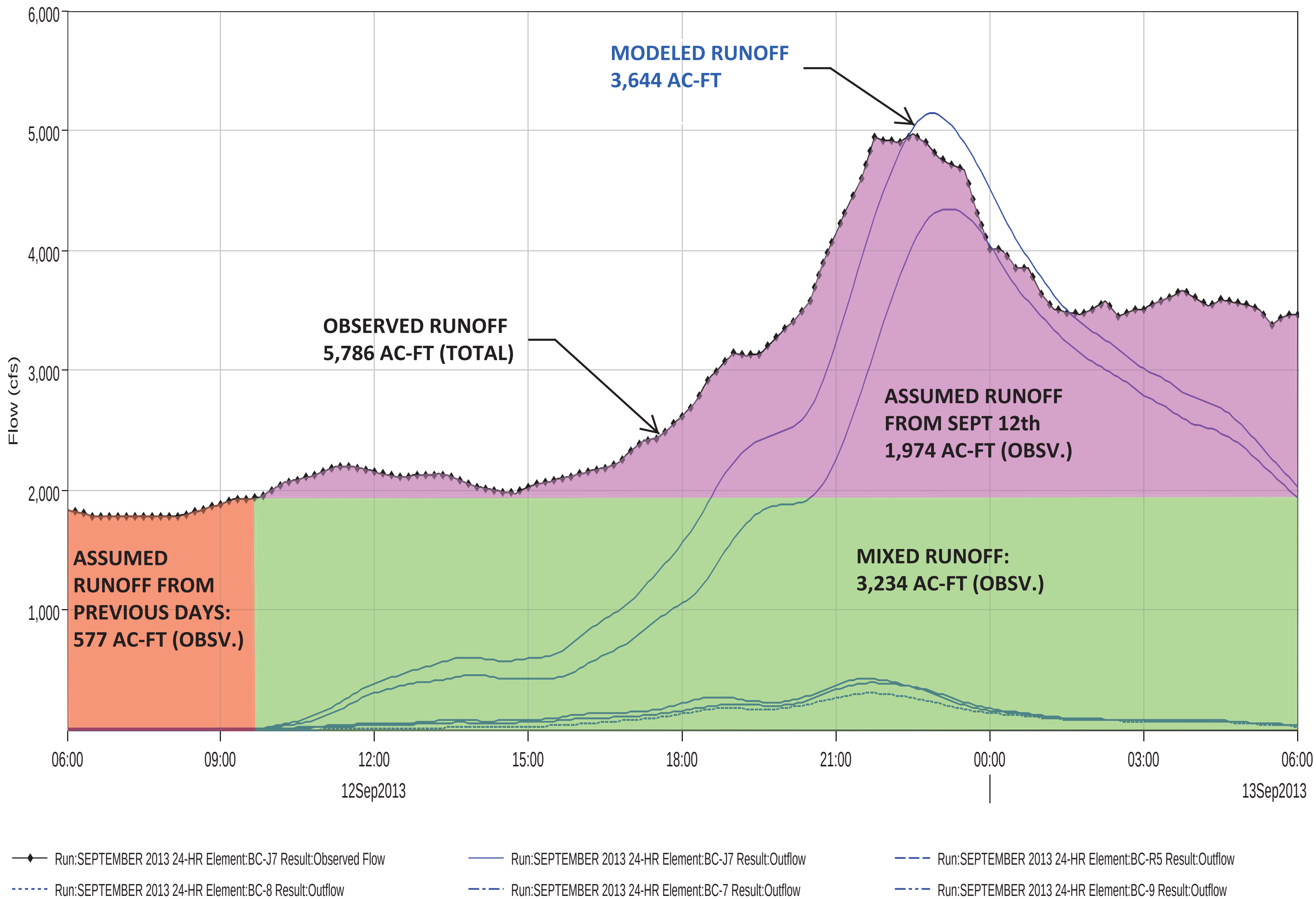


Figure 14b - Hydrographs at Key Design Locations

Junction "BC-J11" - Boulder Creek at N 75th Results for Run "September 2013, 24-hr"

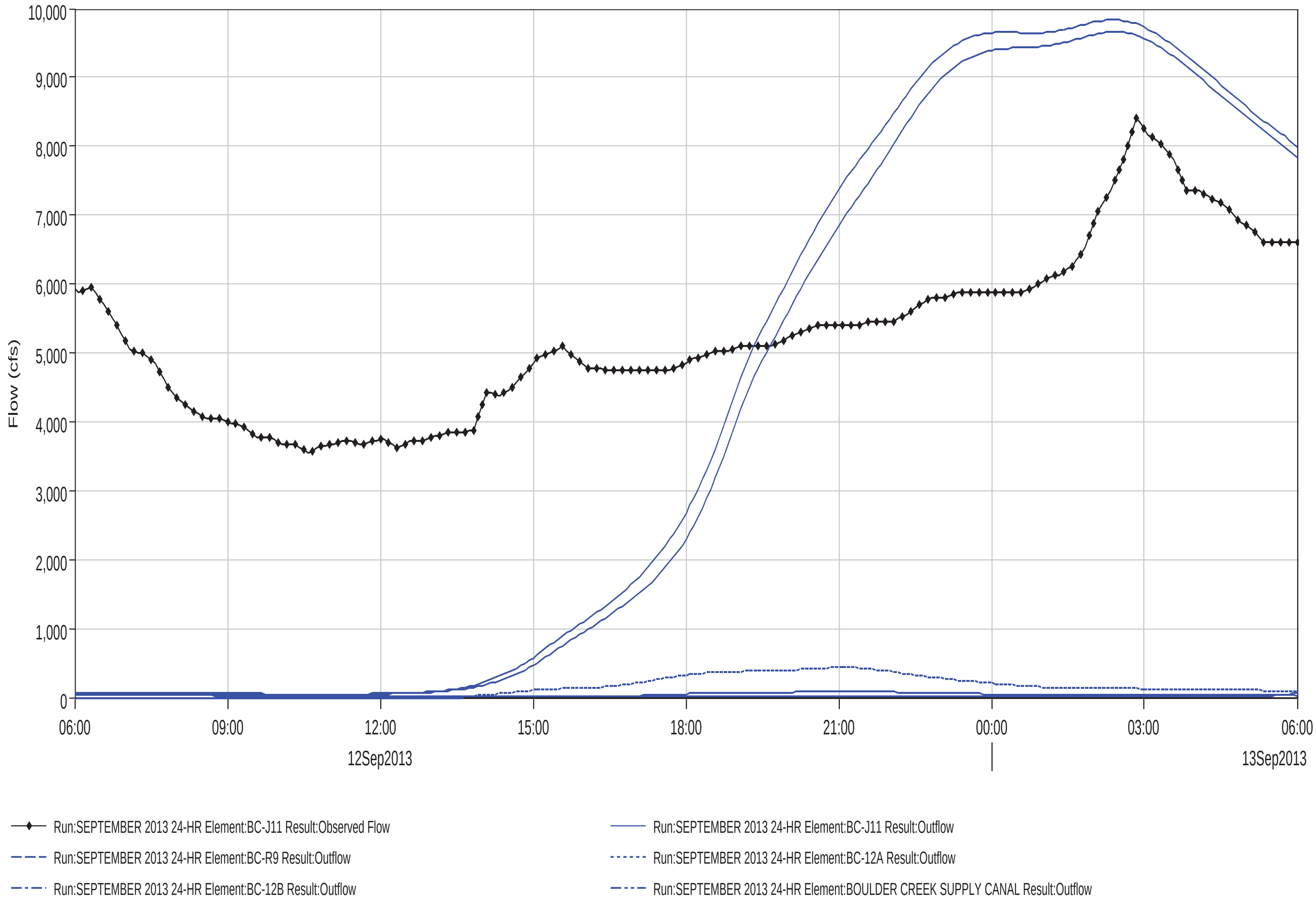


Figure 14c - Hydrographs at Key Design Locations
Junction "SBC-J7" - South Boulder Creek at Pinecliffe Results for Run "September 2013, 24-hr"

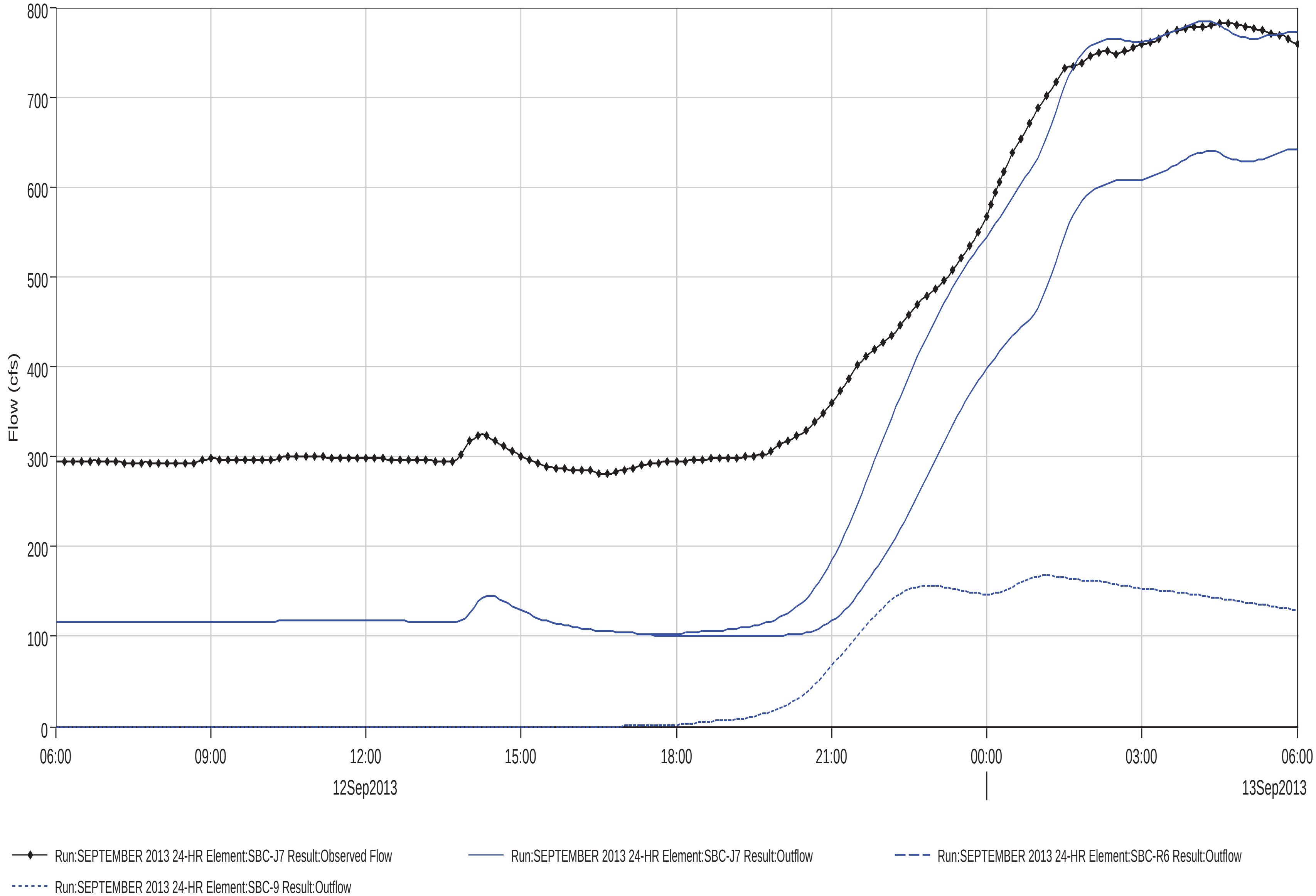


Figure 14d - Hydrographs at Key Design Locations
Junction "SBC-J10A" - South Boulder Creek below Gross Reservoir Results for Run "September 2013, 24-hr"

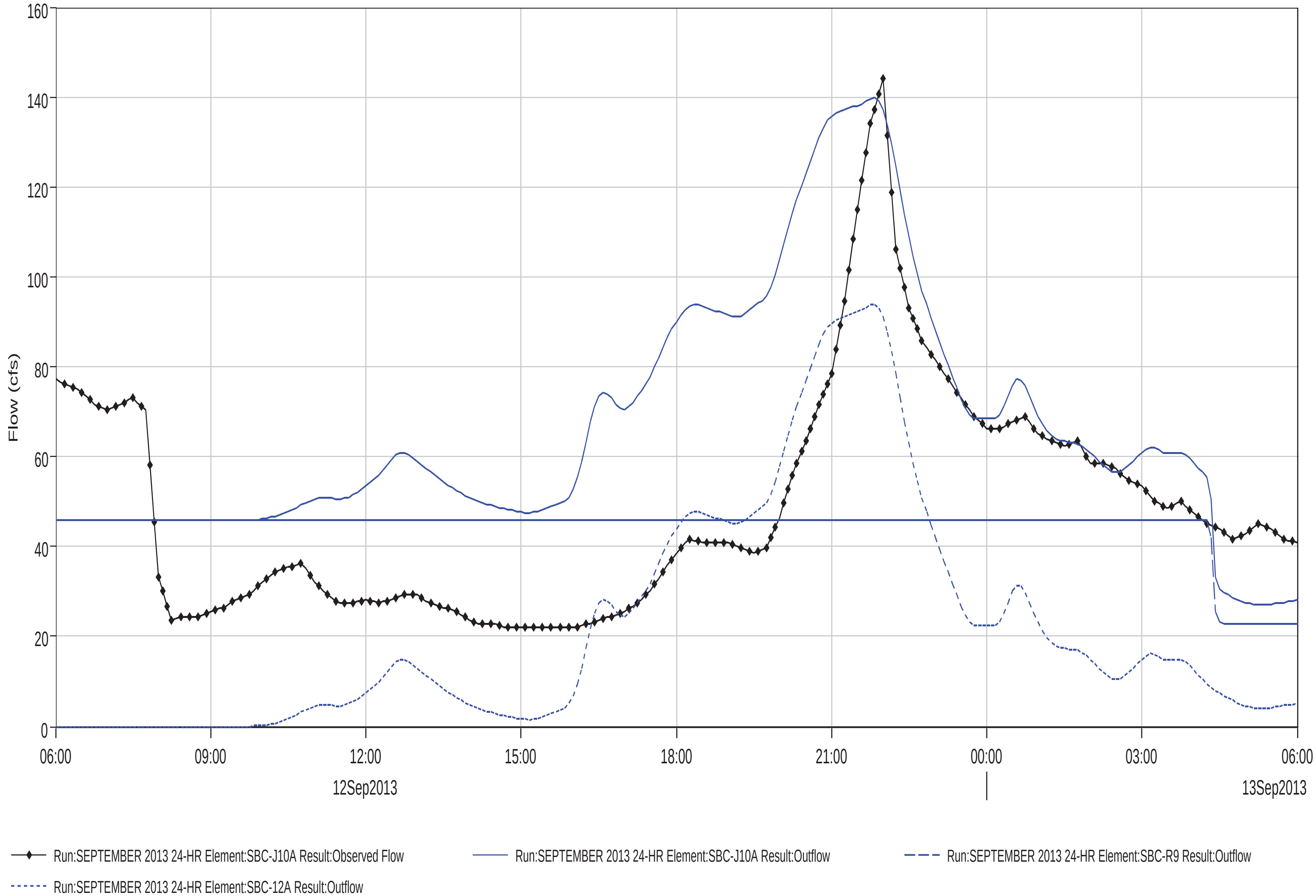


Figure 14e - Hydrographs at Key Design Locations
Junction "BC-J6" - Boulder Creek at Fourmile Creek Results for Run "PREDICTIVE - NRCS 24-hr, DARF = 0.92, 100YR"

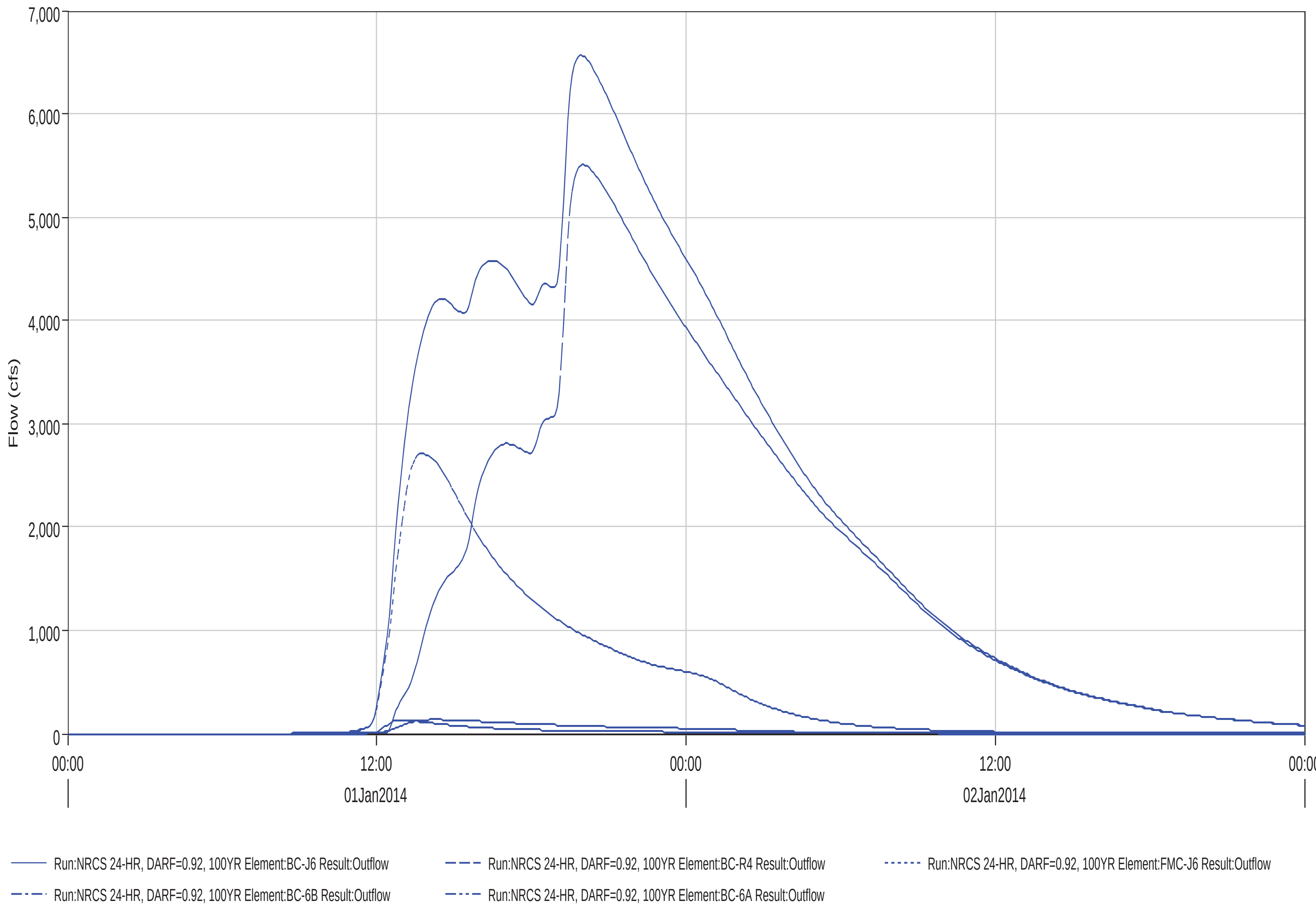


Figure 14f - Hydrographs at Key Design Locations

Junction "BC-J7" - Boulder Creek at Broadway Results for Run "PREDICTIVE - NRCS 24-hr, DARF = 0.92, 100YR"

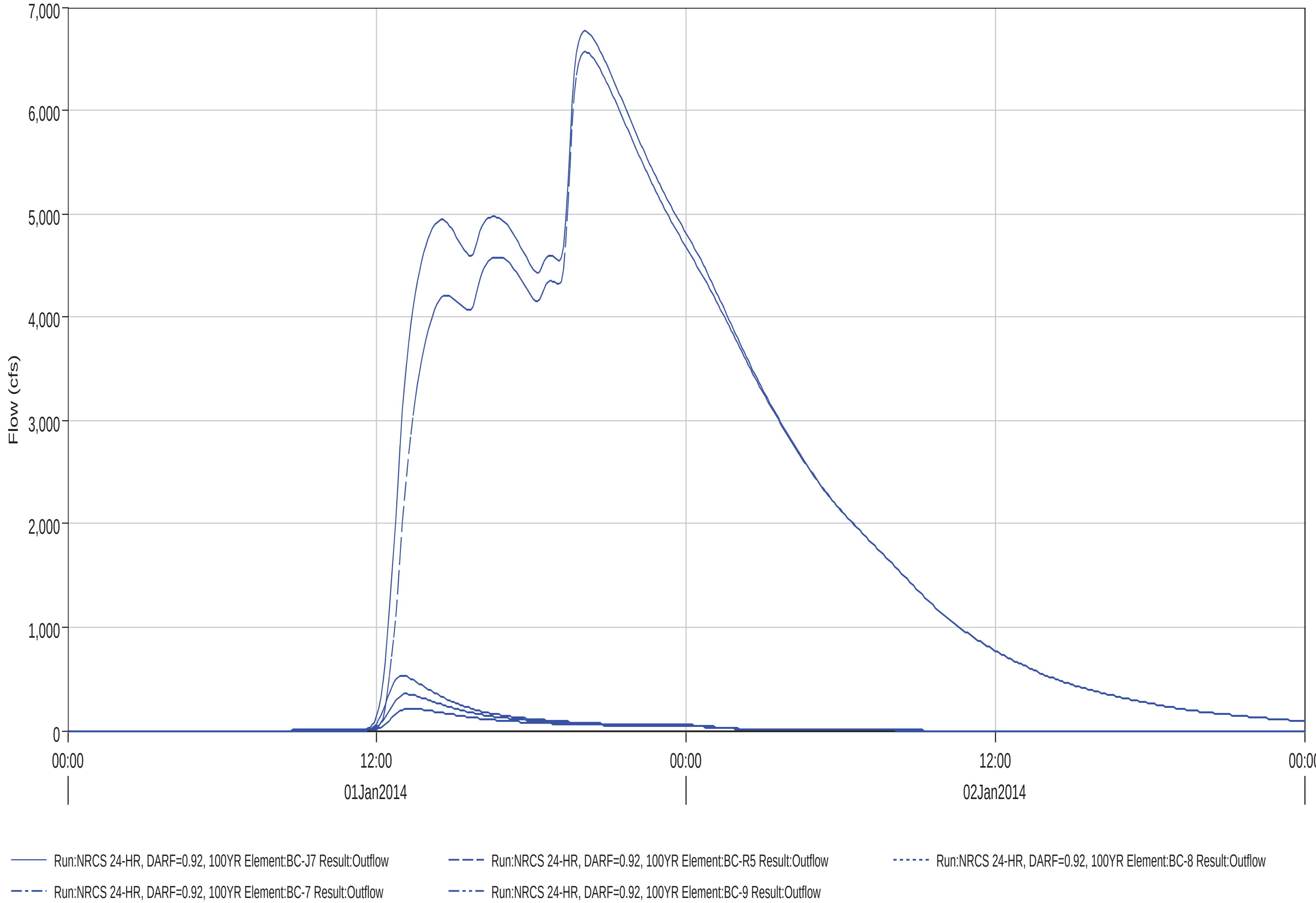


Figure 14g - Hydrographs at Key Design Locations

Junction "BC-J10A" - Boulder Creek at South Boulder Creek Results for Run "PREDICTIVE - NRCS 24-hr, DARF = 0.92, 100YR"

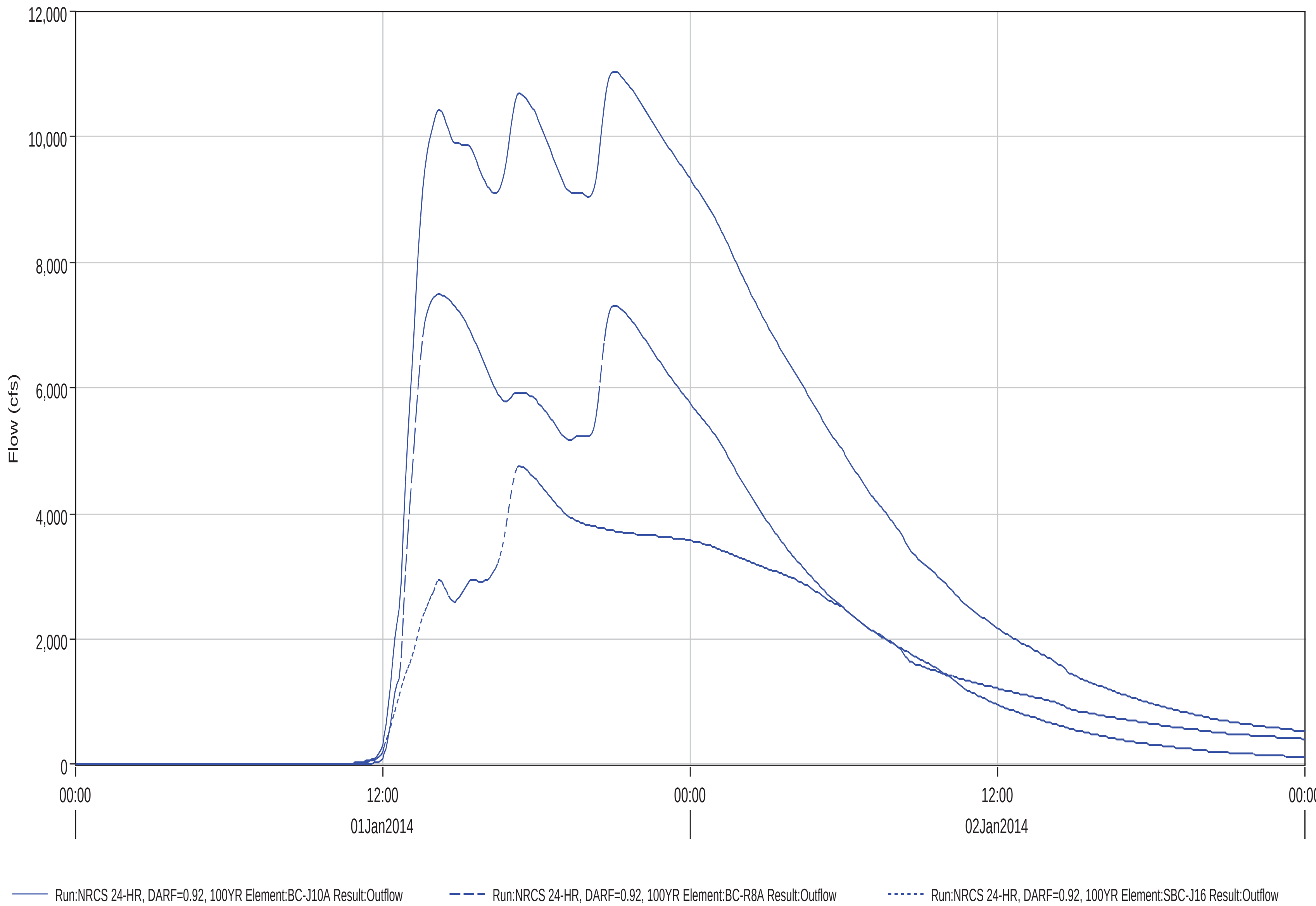


Figure 14h - Hydrographs at Key Design Locations
Junction "BC-J11" - Boulder Creek at N 75th Results for Run "PREDICTIVE - NRCS 24-hr, DARF = 0.92, 100YR"

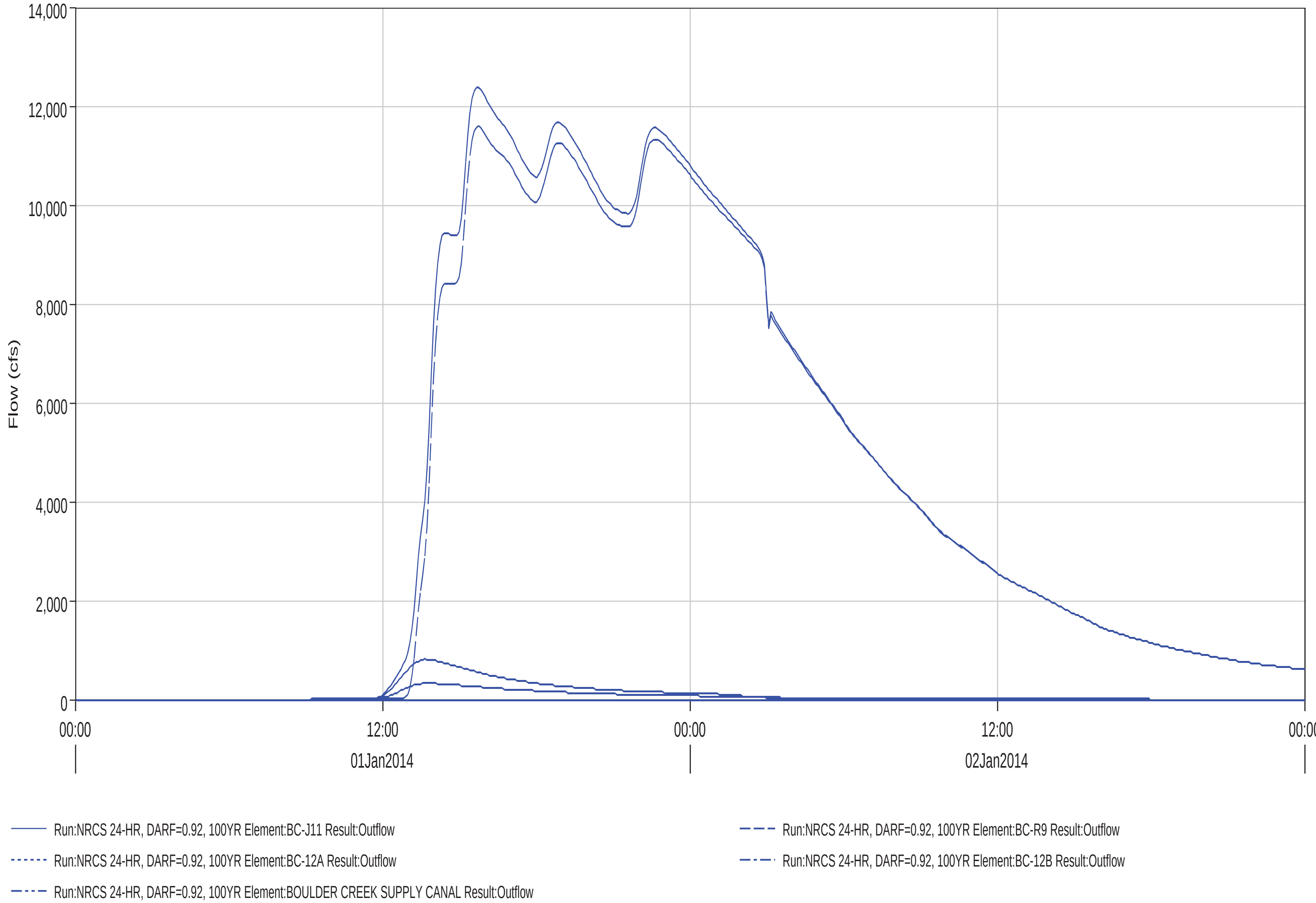


Figure 14i - Hydrographs at Key Design Locations

Junction "BC-J11" - Boulder Creek at Coal Creek Results for Run "PREDICTIVE - NRCS 24-hr, DARF = 0.78, 100YR"

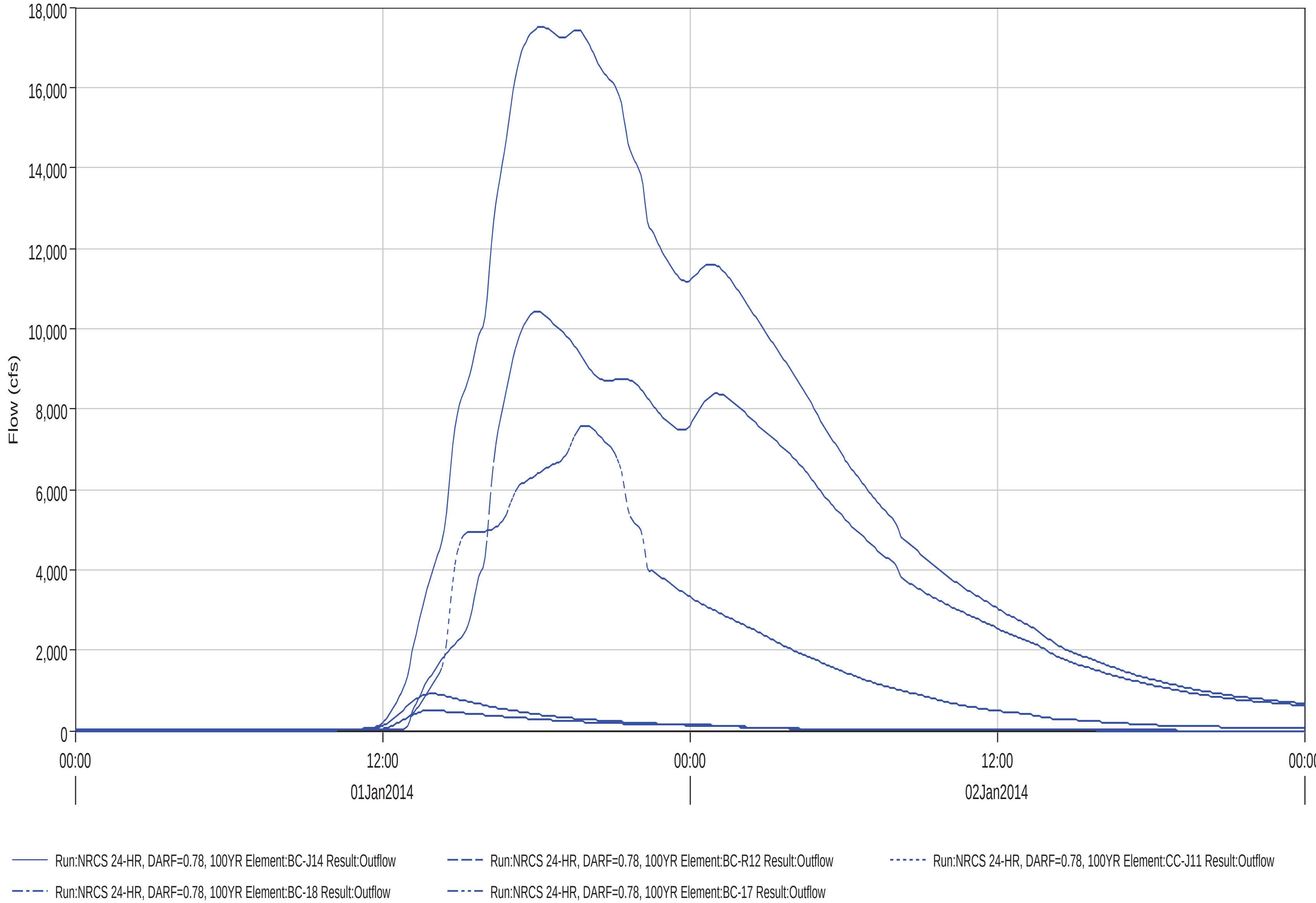


Figure 14j - Hydrographs at Key Design Locations

Junction "BC-J11" - Boulder Creek at St. Vrain Creek Results for Run "PREDICTIVE - NRCS 24-hr, DARF = 0.78, 100YR"

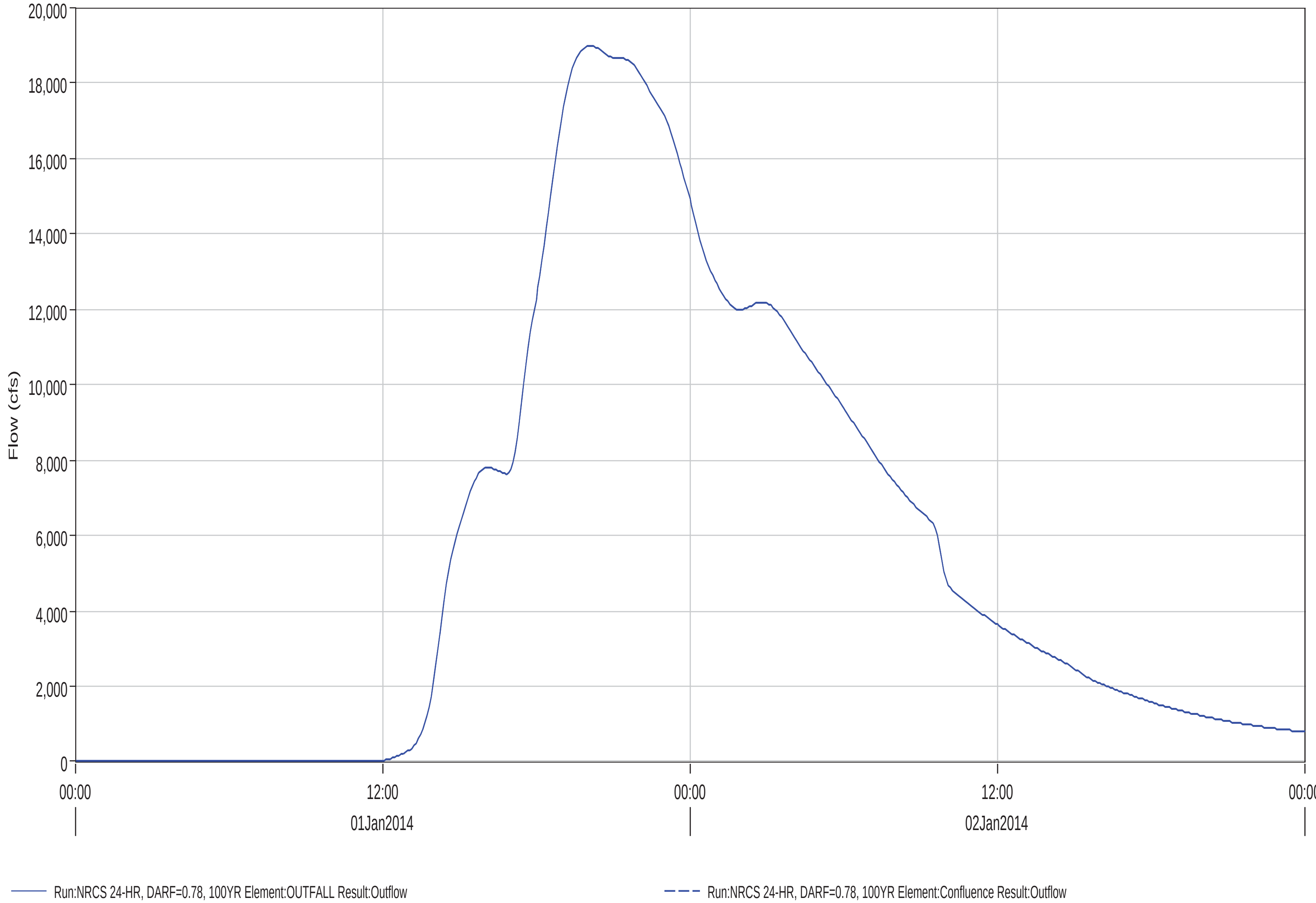


Figure 14k - Hydrographs at Key Design Locations
Junction "BC-J11" - South Boulder Creek at Pinecliffe Results for Run "PREDICTIVE - NRCS 24-hr, DARF = 0.92, 100YR"

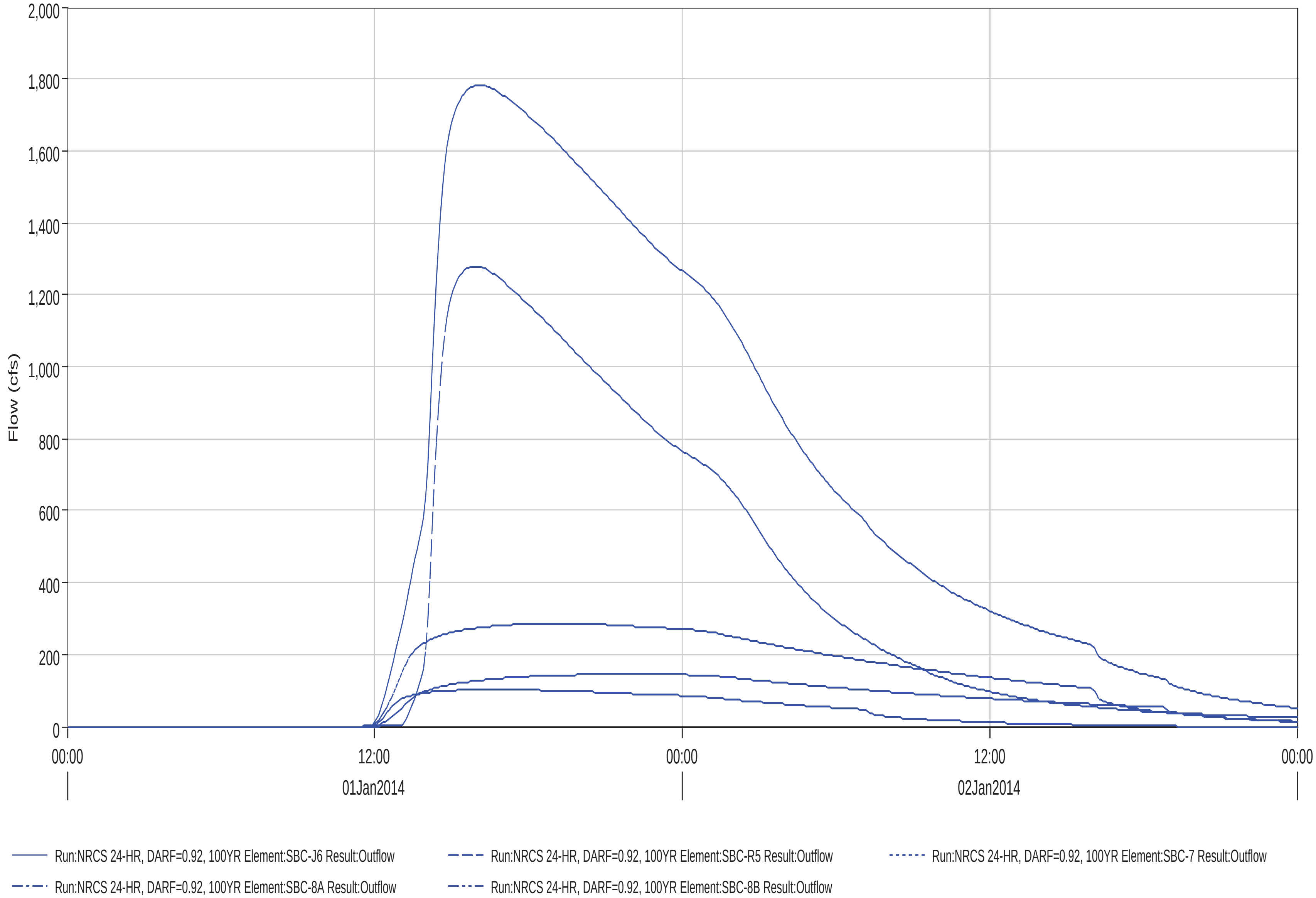


Figure 14l - Hydrographs at Key Design Locations

Junction "Gross Reservoir" - Results for Run "PREDICTIVE - NRCS 24-hr, DARF = 0.92, 100YR"

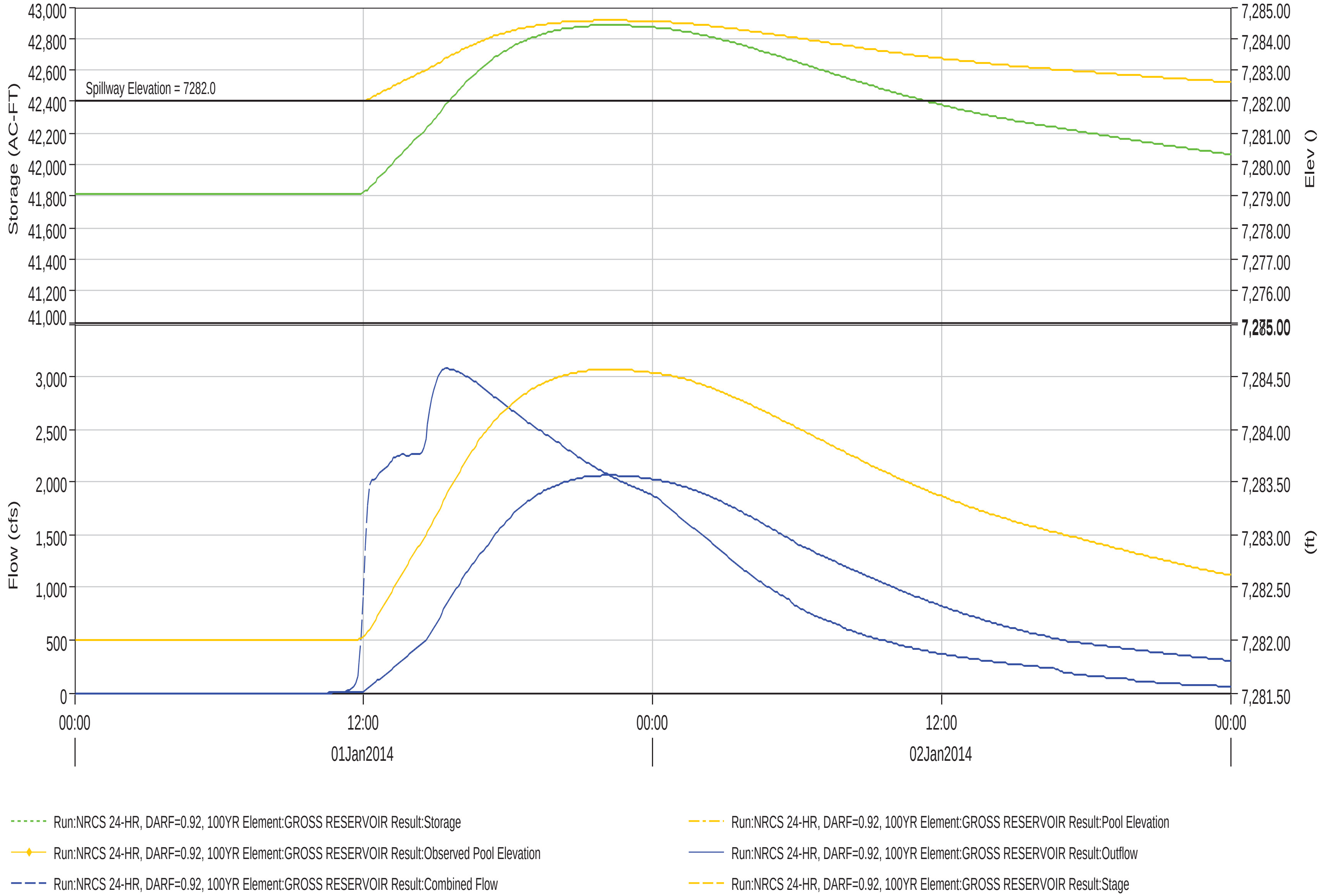


Figure 14m - Hydrographs at Key Design Locations

Junction "CC-7B" - Coal Creek at Rock Creek Results for Run "PREDICTIVE - NRCS 24-hr, DARF = 0.92, 100YR"

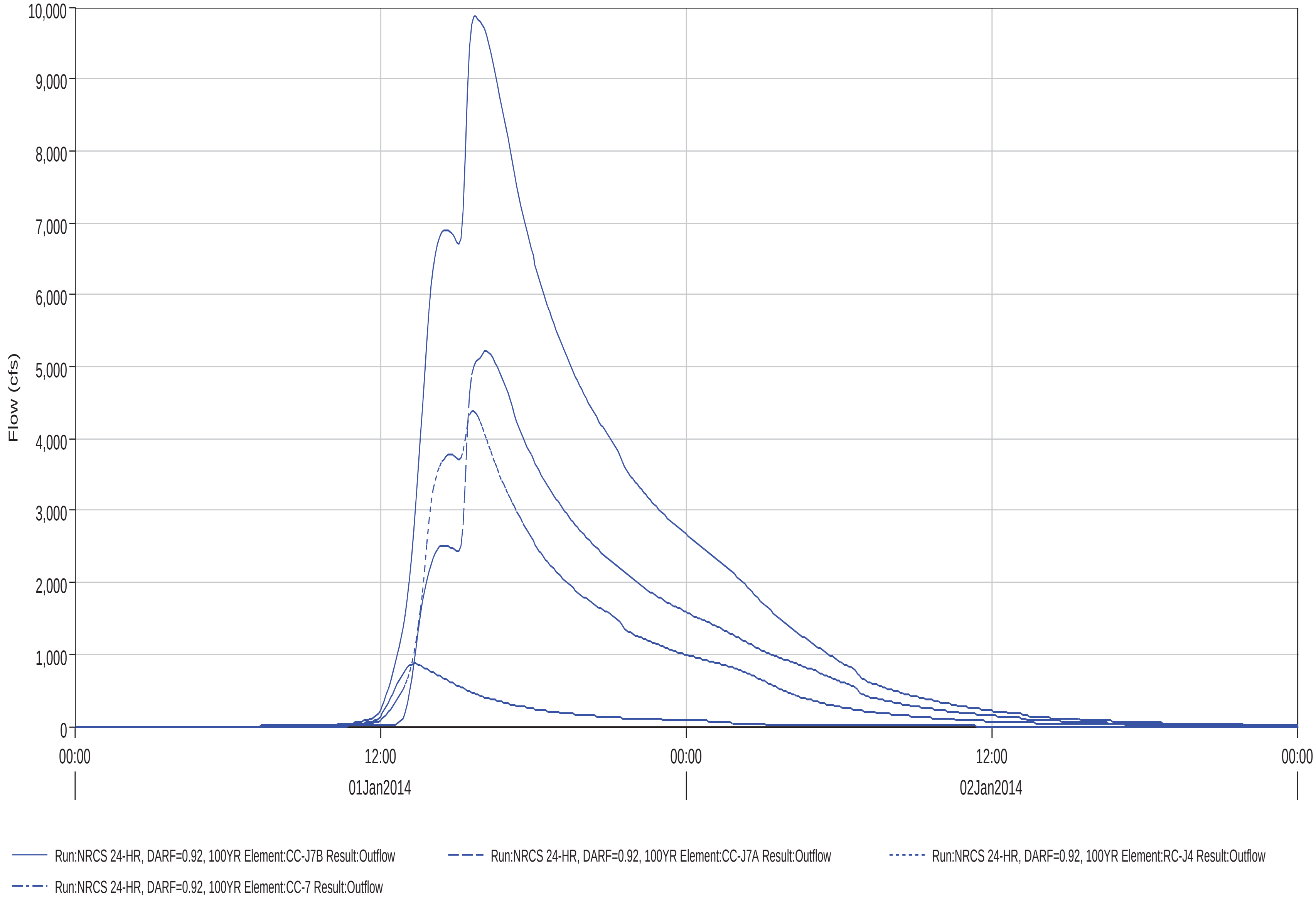
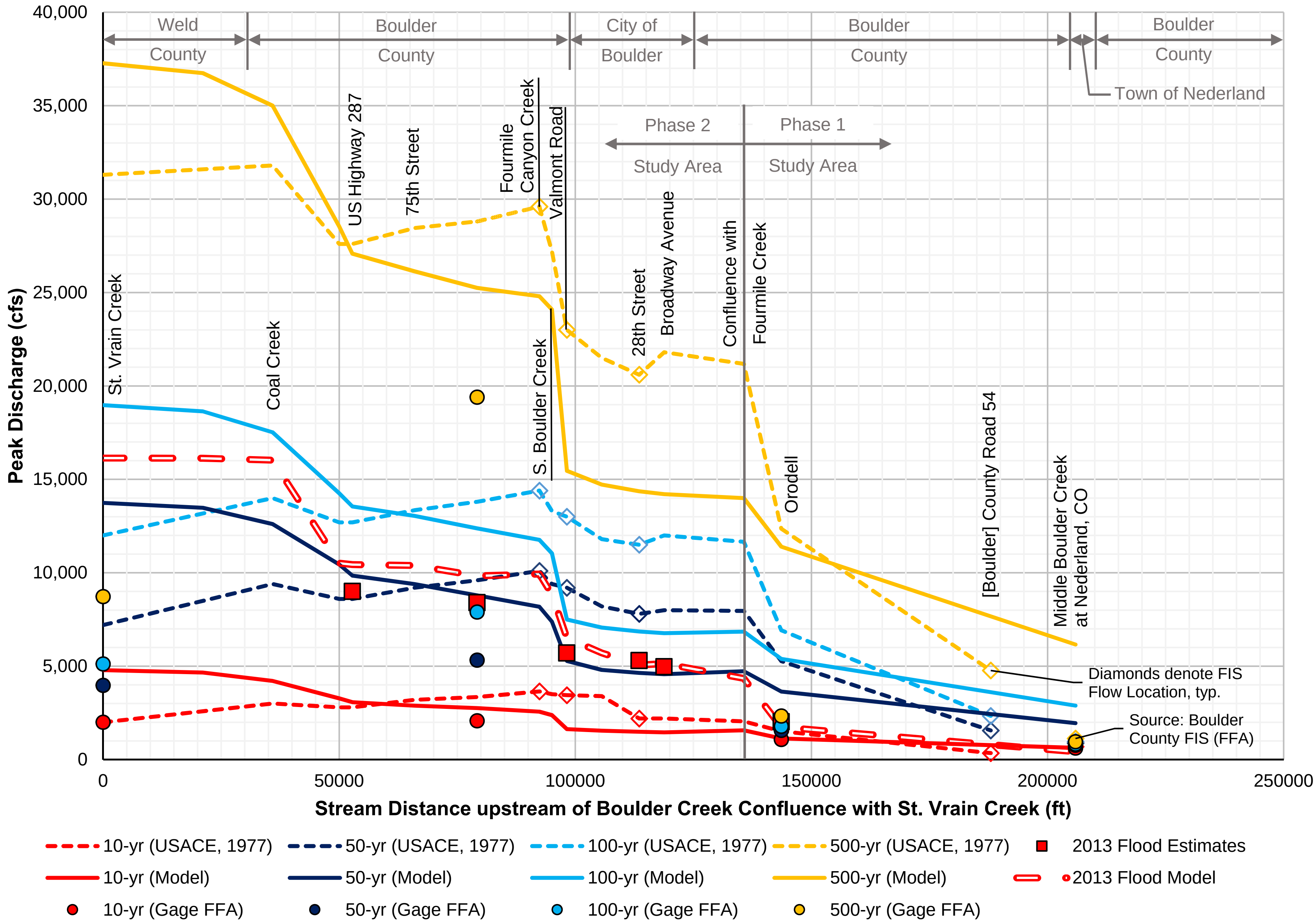
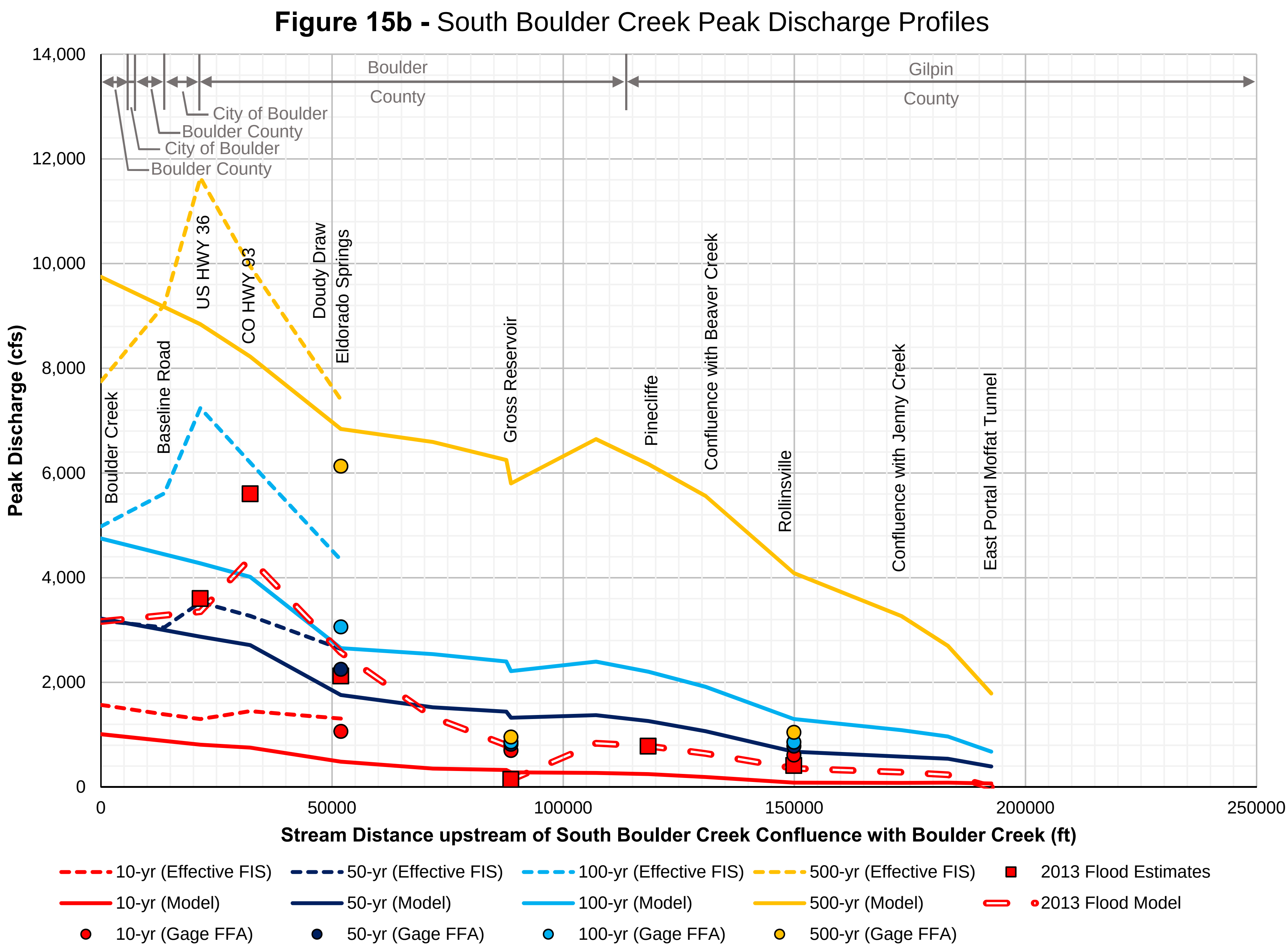


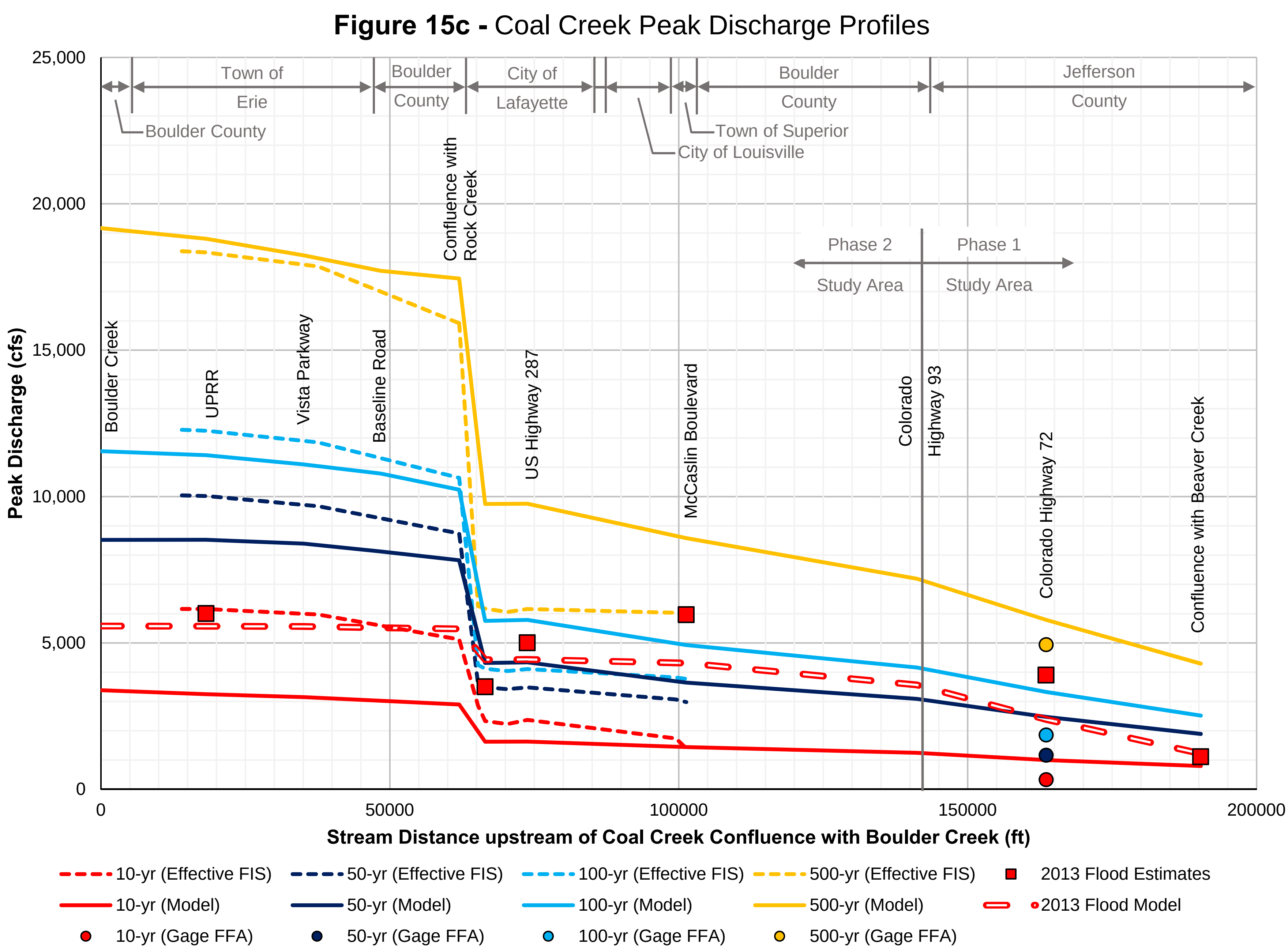
Figure 15a - Boulder Creek Peak Discharge Profiles



Note: FIS values derived from USACE, 1977 study, unless noted otherwise.



Note: Predictive Hydrologic Model results not recommended in place of effective FIS hydrology



Note: Predictive Hydrologic Model results not recommended in place of effective FIS hydrology

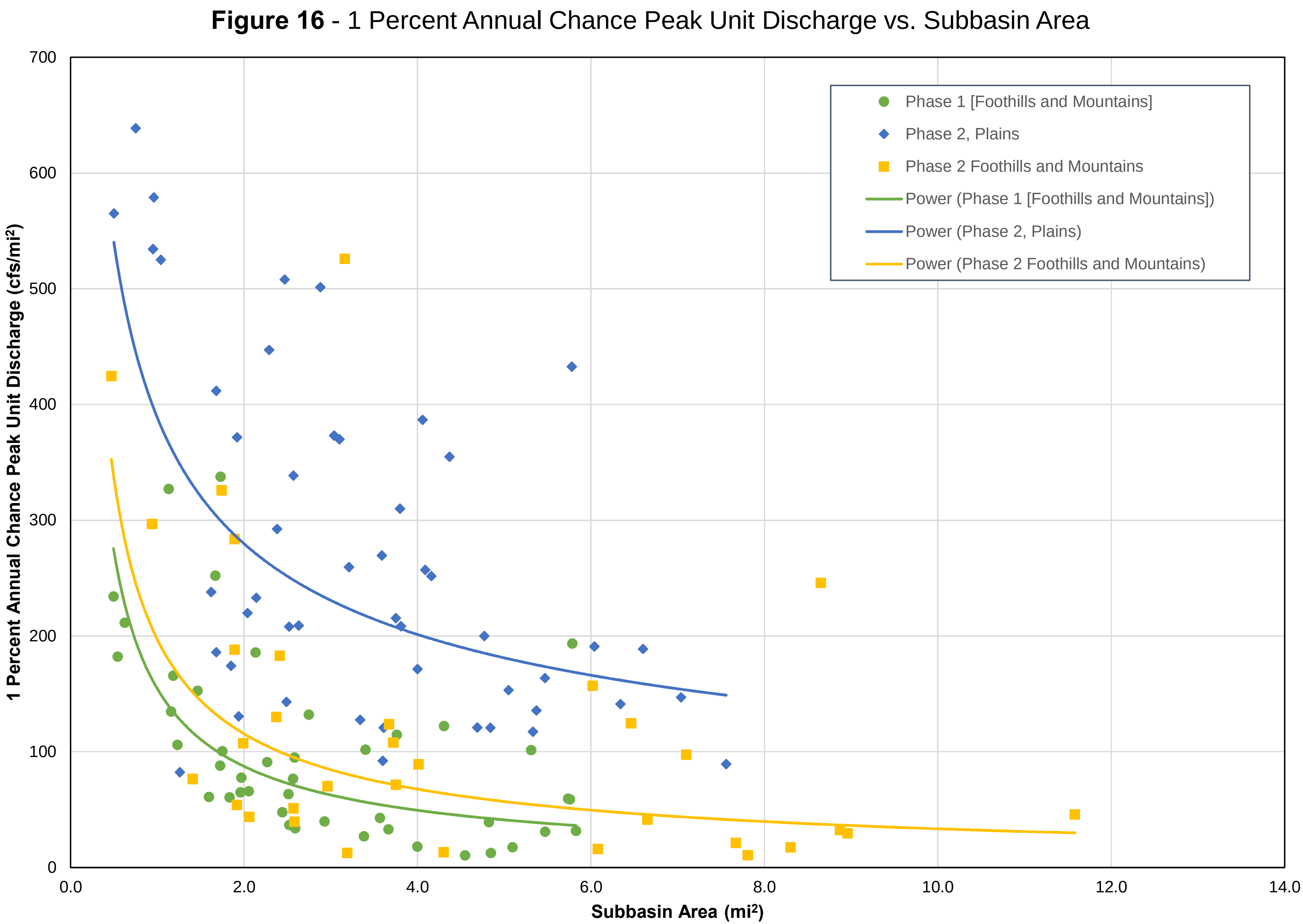
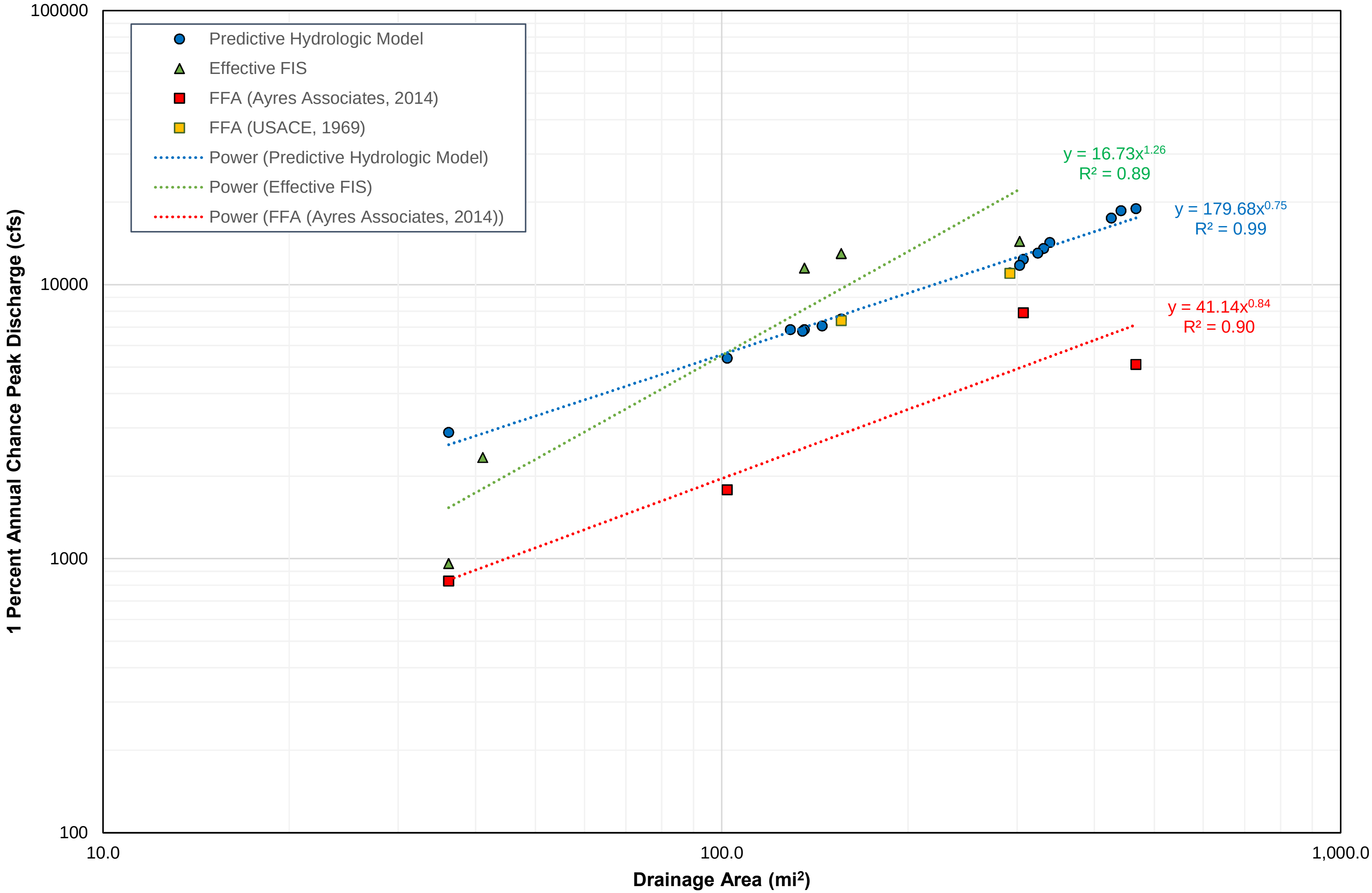


Figure 16 - 1 Percent Annual Chance Peak Unit Discharge vs. Subbasin Area
1 Percent Annual Chance Peak Unit Discharge (cfs/mi²)
Subbasin Area (mi²)
0
100
200
300
400
500
600
700
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
Phase 1 [Foothills and Mountains]
Phase 2, Plains
Phase 2 Foothills and Mountains
Power (Phase 1 [Foothills and Mountains])
Power (Phase 2, Plains)
Power (Phase 2 Foothills and Mountains)

Figure 17 - Comparison of Boulder Creek 1 Percent Annual Chance Peak Discharge Estimates vs. Drainage Area



Appendix A
FEMA Information

Boulder County:

Boulder County FIS Volume I Cover
Summary of Discharges
Community Map History
FIRM Map Number 08013C0390J
FIRM Map Number 08013C0393J
FIRM Map Number 08013C0394J (1)
FIRM Map Number 08013C0394J (2)
FIRM Map Number 08013C0411J
FIRM Map Number 08013C0412J (1)
FIRM Map Number 08013C0412J (2)
FIRM Map Number 08013C0413J (1)
FIRM Map Number 08013C0413J (2)
FIRM Map Number 08013C0416J (1)
FIRM Map Number 08013C0416J (2)
FIRM Map Number 08013C0417J (1)
FIRM Map Number 08013C0417J (2)
FIRM Map Number 08013C0429J (1)
FIRM Map Number 08013C0429J (2)
FIRM Map Number 08013C0429J (3)
FIRM Map Number 08013C0435J
FIRM Map Number 08013C0436J (1)
FIRM Map Number 08013C0436J (2)
FIRM Map Number 08013C0437J
LOMR Letter Number 12-08-0778P-080024
LOMR Letter Number 13-08-0187P-080024
LOMR Letter Number 13-08-0247P-080023
LOMR Letter Number 13-08-0248P-080026
LOMR Letter Number 13-08-0605P-080026

Jefferson County:

Jefferson County FIS Volume I Cover
Community Map History

Weld County:

Weld County FIS Cover
Summary of Discharges
FIRM Map Number 0802660850C (1)
FIRM Map Number 0802660850C (2)
LOMR Letter Number 08-08-0024P-080266
LOMR Letter Number 09-08-0608P-080266
LOMR Letter Number 11-08-1090P-080181
LOMR Letter Number 12-08-1047P-080266

FLOOD INSURANCE STUDY

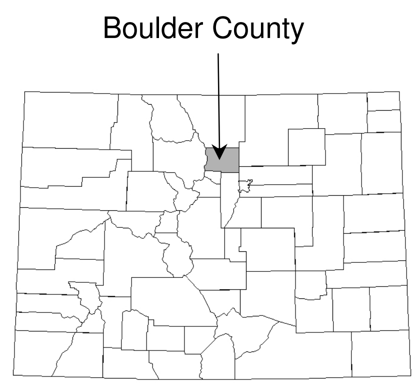
VOLUME 1 OF 4

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

Community Name	*Community Number*
BOULDER, CITY OF	080024
BOULDER COUNTY (UNINCORPORATED AREAS)	080023
ERIE, TOWN OF	080181
JAMESTOWN, TOWN OF	080216
LAFAYETTE, CITY OF	080026
LONGMONT, CITY OF	080027
LOUSIVILLE, CITY OF	085076
LYONS, TOWN OF	080029
NEDERLAND, TOWN OF	080255
SUPERIOR, TOWN OF	080203
*WARD, TOWN OF	080292

* No Special Flood Hazard Areas Identified



Revised: December 18, 2012

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
08013CV001B

Table 4 - Summary of Discharges

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
Arapahoe Avenue Overflow					
At Foothills Parkway (47th Street)	--[1]	--[1]	--[1]	1,500	--[1]
At 30th Street	--[1]	--[1]	--[1]	4,200	--[1]
At 28th Street	--[1]	--[1]	--[1]	3,500	--[1]
Arapahoe Avenue Spill Flow					
Approximately 800 feet downstream of the divergence from Gregory Canyon Creek	--[1]	323	975	1,209	2,149
Balarat Creek					
At Upstream Limit of Detailed Study	0.5	30	150	270	760
Bear Canyon Creek					
At Confluence with Boulder Creek	8.24	2,050	3,762	4,880	7,500
At Confluence of Skunk Creek	5.35	1,170	2,360	3,070	5,100
At Baseline Road	4.96	1,110	2,352	2,930	5,000
At U.S. Highway 36	4.34	820	1,780	2,210	3,850
At Broadway	4.08	680	1,512	1,930	3,400
At Upstream Limit of Detailed Study	3.71	480	1,190	1,600	3,000
Boulder Creek					
At Confluence with Fourmile Canyon Creek	--[1]	3,650	10,100	14,400	29,600
At Valmont Drive	--[1]	3,450	9,200	13,000	23,000
At 28th Street	--[1]	2,200	7,800	8,000	20,600
At County Road 54	--[1]	350	1,560	2,340	4,770
Boulder Creek (Right Bank Overflow)					
Approximately 800 feet Upstream of Foothills Parkway	--[1]	--[1]	1,609	2,523	11,469
Bullhead Gulch					
Just Upstream of Confluence with Boulder Creek	8.85	1,421	1,300	4,532	6,109

[1] Data Not Available

Table 4 – Summary of Discharges (Continued)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
Bullhead Gulch (continued)					
Just Downstream of Confluence of Prince Tributary	8.16	1,474	3,581	4,772	6,275
Just Upstream of Confluence of Prince Tributary	5.61	683	1,935	2,639	3,474
Just Downstream of Confluence of Indian Peaks	2.14	374	970	1,333	1,811
Just Upstream of Confluence of Indian Peaks	1.59	190	532	760	1,251
At Upstream Limit of Detailed Study	0.64	294	575	774	1,041
Clover Basin Tributary					
At 75th Street	--[1]	178	400	495	854
Coal Creek					
Near Erie Municipal Airport	68.61	5,970	9,670	11,850	17,860
At Union Pacific Railroad near Erie	76.86	6,160	10,020	12,250	18,340
At Briggs Street	77.48	6,160	10,040	12,280	18,380
At Confluence of Rock Creek	59.3	5,120	8,740	10,640	15,920
At a Point 65,250 feet above Mouth	37.6	2,860	3,620	4,250	6,260
At Burlington Northern and Santa Fe Railway	36.3	2,330	3,490	4,120	6,170
At U.S. Highway 287	35.6	2,370	3,480	4,110	6,160
At a Point 70,350 feet above Mouth	33.7	2,230	3,420	4,040	6,060
At Denver-Boulder Turnpike	27.9	1,740	3,070	3,820	6,030
At McCaslin Boulevard	26.7	1,400	2,980	3,770	5,990
Dry Creek					
At Confluence with Dry Creek No. 2 Ditch Split Flow	--[1]	--[1]	--[1]	4,030	--[1]
At Downstream Limit of Detailed Study	--[1]	--[1]	--[1]	6,630	--[1]
Dry Creek No. 1					
Just Upstream of Steele Lakes Tributary	--[1]	271	674	987	1,812
Just Upstream of the Confluence of Clover Basin Tributary	--[1]	568	1,268	1,726	3,112
Just Upstream of State Highway 119	--[1]	340	845	1,170	2,127

[1] Data Not Available

Table 4 – Summary of Discharges (Continued)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
Dry Creek No. 1 (Old Channel)					
Just Downstream of State Highway 119	--[1]	260	330	350	415
Just Upstream of the confluence with St. Vrain Creek	--[1]	320	627	802	1,199
Dry Creek No. 2					
At North 107th Street	--[1]	900	1,900	2,600	4,295
Dry Creek No. 2 Ditch Split Flow					
Just Upstream of the Confluence with Dry Creek	--[1]	0	2,680	4,030	8,850
At Upstream Limit of Study	--[1]	0	100	300	800
Dry Creek No. 3					
Just Downstream of Arapahoe Road	13.6	--[1]	--[1]	1,300	--[1]
Elmers Twomile Creek					
At Confluence with Goose Creek	0.54	373	681	883	1,500
At Iris Avenue	0.32	249	508	630	1,010
At Upstream Limit of Detailed Study	0.13	160	315	384	520
Fourmile Canyon Creek					
At Confluence with Boulder Creek	10.03	119	366	500	1,020
At Longmont Diagonal	9.09	913	2,396	3,336	6,800
At 28th Street	8.60	865	2,566	3,468	6,800
At Broadway	7.92	735	2,662	3,581	6,900
At Upstream Limit of Detailed Study	3.93	350	1,170	1,750	4,000
Fourmile Creek Left Bank Overflow					
At Downstream Limit of Detailed Study	--[1]	715	2,071	2,862	5,780
Fourmile Creek Right Bank Overflow					
At Violet Avenue	--[1]	2	1,319	2,054	4,998

[1] Data Not Available

Table 4 – Summary of Discharges (Continued)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
Fourmile Creek					
At Confluence with Boulder Creek	25.0	1,420	4,440	6,230	11,640
Goose Creek					
At Confluence with Boulder Creek	5.46	2,865	5,065	6,315	9,325
At Confluence of Elmers Twomile Creek	3.63	1,050	2,100	2,680	4,300
At Confluence of Twomile Canyon Creek	1.32	670	1,270	1,590	2,400
At 19th Street	1.28	700	1,320	1,600	2,450
At Upstream Limit of Detailed Study	0.48	260	520	620	1,000
Gregory Canyon Creek					
At Marine Street	2.29	673	1,672	2,092	3,700
Downstream of College Avenue	--[1]	600	1,504	1,900	3,300
At Upstream Limit of Detailed Study	1.56	400	1,060	1,450	2,600
Highway 93 Split Flow					
At Downstream Limit	--[1]	0	600	1,660	5,000
At Upstream Limit	--[1]	0	2,580	3,850	7,750
James Creek					
At Cross Section A	14.5	355	2,180	3,930	10,880
At Main Street Bridge	12.2	300	1,785	3,205	8,850
At Confluence of Little James Creek	12.1	300	1,760	3,160	8,725
At Upstream Limit of Detailed Study	8.9	200	1,190	2,140	6,010
Lefthand Creek					
At Confluence with St. Vrain Creek	72.0	520	2,480	4,610	10,320
Lefthand Creek (North Overflow Channel)					
At Divergence from Lefthand Creek	--[1]	--[1]	--[1]	333	--[1]
At Confluence with Lefthand Creek	--[1]	--[1]	--[1]	333	--[1]

[1] Data Not Available

Table 4 – Summary of Discharges (Continued)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
Lefthand Creek (South Overflow Channel)					
At Divergence from Lefthand Creek	--[1]	--[1]	--[1]	472	--[1]
At Confluence with Lefthand Creek (North Overflow Channel)	--[1]	--[1]	--[1]	798	--[1]
Little James Creek					
At Confluence with James Creek	2.8	130	650	1,160	3,220
At Confluence of Balarat Creek	2.25	130	650	1,160	3,220
Little James Creek (continued)					
At Upstream Limit of Detailed Study	1.8	109	544	970	2,690
Little Thompson River					
At Larimer-Weld County Line	--[1]	2,800	5,500	7,200	12,800
Middle Boulder Creek					
At Cross Section A	36.3	693	884	960	1,130
At Cross Section G	29.9	596	760	825	971
Middle St. Vrain Creek					
At Confluence with South St. Vrain Creek	32.4	590	1,430	2,000	4,070
North Beaver Creek					
At Cross Section A	5.3	74	117	135	185
At Cross Section T	5.0	70	112	129	178
North Goose Creek					
At Confluence with Goose Creek	--[1]	3,865	3,865	3,865	6,075
North St. Vrain Creek					
At Confluence with St. Vrain Creek and South St. Vrain Creek	125.0	1,000	2,850	4,310	10,630

[1] Data Not Available

Table 4 – Summary of Discharges (Continued)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
Prince Tributary[1]					
Just Downstream of Confluence with Bullhead Gulch	8.16	--[2]	--[2]	4,772	--[2]
Just Upstream of Confluence with Bullhead Gulch	2.55	--[2]	--[2]	2,130	--[2]
At Upstream Limit of Detailed Study	0.58	--[2]	--[2]	423	--[2]
Rock Creek					
At Confluence with Coal Creek	21.6	2,870	5,350	6,690	10,240
Rock Creek (continued)					
At 2,400 feet Upstream of Confluence with Coal Creek	21.5	2,900	5,400	6,710	10,270
At South 120th Street	21.3	2,910	5,410	6,740	10,310
At 16,450 feet Upstream of Confluence with Coal Creek	18.7	2,900	5,360	6,640	10,050
At Denver-Boulder Turnpike	9.3	1,256	3,229	4,520	9,176
At McCaslin Boulevard	4.9	594	1,800	2,717	7,000
At Upstream Limit of Detailed Study	4.1	504	1,587	2,396	6,182
St. Vrain Creek					
At Boulder-Weld County Line	351.0	5,520	10,950	14,850	28,670
At 85th Street	241.0	3,160	6,890	9,580	19,680
Just Downstream of the Confluence of North St. Vrain Creek and South St. Vrain Creek	211.0	2,040	6,670	8,880	20,260
St. Vrain Creek (Vicinity of Lyons)					
At Second Avenue	219.0	2,040	5,570	8,880	20,260
Skunk Creek					
At Confluence with Bear Canyon Creek	2.83	980	1,830	2,230	3,500
At Madison Avenue	2.43	920	1,580	1,870	2,650
At U.S. Highway 36	2.08	650	1,130	1,350	1,900
At Broadway	1.36	210	520	710	1,320

[1] Separate Data for East and West Branches Not Available
[2] Data Not Available

Table 4 – Summary of Discharges (Continued)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs) 10-Percent Annual Chance	2-Percent Annual Chance	1-Percent Annual Chance	0.2-Percent Annual Chance
Skunk Creek (continued)					
At Upstream Limit of Detailed Study	1.20	180	460	640	1,200
South Boulder Creek					
Near Eldorado Springs	--[1]	1,310	2,640	4,340	7,400
At State Highway 93	--[1]	1,450	3,270	6,200	9,950
At US Highway 36	--[1]	1,300	3,530	7,240	11,640
At Baseline Road	--[1]	1,390	3,050	5,610	9,210
At Confluence with Boulder Creek	--[1]	1,570	3,180	4,980	7,750
Spring Gulch					
At Confluence with St. Vrain Creek	--[1]	1,950	3,150	3,650	4,200
Steele Lakes Tributary					
At 75th Street	--[1]	494	1,165	1,512	2,428
Twomile Canyon Creek					
At Confluence with Goose Creek	2.9	360	840	1,120	2,000
At Broadway	1.68	210	675	890	1,800
At Upstream Limit of Detailed Study	1.40	210	540	710	1,430
Wonderland Creek[2]					
At Confluence with North Goose Creek	1.91	607	1,419	2,107	4,620
At 28th Street	1.35	404	1,032	1,484	3,799
At Broadway	0.85	205	415	531	1,600
At Upstream Limit of Detailed Study	0.38	92	192	253	860

[1] Data Not Available
[2] Includes Flow Diversions From Fourmile Canyon Creek

COMMUNITY NAME	INITIAL IDENTIFICATION	FLOOD HAZARD BOUNDAY MAP REVISION DATE	INITIAL FIRM EFFECTIVE DATE	FIRM REVISION DATE
Boulder, City of	June 14, 1974	March 5, 1976	July 17, 1978	February 24, 1981 August 4, 1988 May 3, 1990
Boulder County (Unincorporated Areas)	February 1, 1979	N/A	February 1, 1979	July 15, 1988 July 3, 1990
Erie, Town of	June 28, 1974	November 28, 1975	October 17, 1978	September 14, 1982 September 28, 1990 December 2, 2004
Jamestown, Town of	July 11, 1975	N/A	July 18, 1983	None
Lafayette, City of	May 24, 1974	January 16, 1976	March 18, 1980	None
Longmont, City of	October 26, 1973	N/A	July 5, 1977	August 1, 1983 September 18, 1987
Louisville, City of	May 4, 1973	N/A	May 4, 1973	July 1, 1974 July 25, 1975 June 23, 1978 December 1, 1978 January 5, 1982

TABLE 7

FEDERAL EMERGENCY MANAGEMENT AGENCY

BOULDER COUNTY, CO.
AND INCORPORATED AREAS

COMMUNITY MAP HISTORY

COMMUNITY NAME	INITIAL IDENTIFICATION	FLOOD HAZARD BOUNDAY MAP REVISION DATE	INITIAL FIRM EFFECTIVE DATE	FIRM REVISION DATE
Lyons, Town of	December 21, 1973	April 2, 1976	August 1, 1980	None
Nederland, Town of	August 22, 1975	N/A	August 1, 1979	None
Superior, Town of	June 4, 1976	N/A	September 28, 1979	None
Ward, Town of *	N/A	N/A	N/A	N/A

TABLE 7

FEDERAL EMERGENCY MANAGEMENT AGENCY

BOULDER COUNTY, CO.
AND INCORPORATED AREAS

COMMUNITY MAP HISTORY

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study Report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study Report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 13. The **horizontal datum** was NAD 83, GRS 1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was provided by the FEMA Map Service Center and the Boulder Area Spatial Data Cooperative (BASIC). Additional input was provided by the Town of Erie and the City of Longmont. These data are current as of 2004.

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables for multiple streams in the Flood Insurance Study Report (which contains authoritative hydraulic data) may reflect stream channel distances that differ from what is shown on this map.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

For information on available products associated with this FIRM visit the **Map Service Center (MSC)** website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the MSC website.

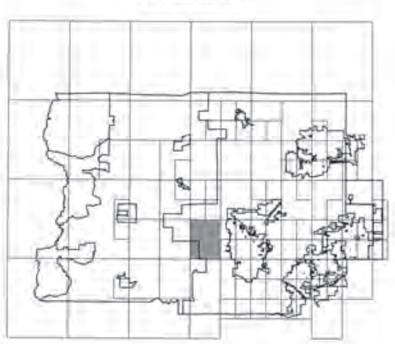
If you have **questions about this map,** how to order products, or the National Flood Insurance Program in general, please call the **FEMA Map Information eXchange (FMIX)** at **1-877-FEMA-MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov/business/nfip.

Boulder County Vertical Datum Offset Table

Flooding Source	Vertical Datum Offset (ft)	Flooding Source	Vertical Datum Offset (ft)
Boulder Creek (East County Line Road to confluence of Fourmile Creek)	3.3	Fourmile Canyon Creek	3.7
Boulder Creek (confluence of Fourmile Creek to 60,000 feet upstream of confluence of Fourmile Creek	3.7	Fourmile Creek (Baseline Road to Confluence with Boulder Creek)	4.0

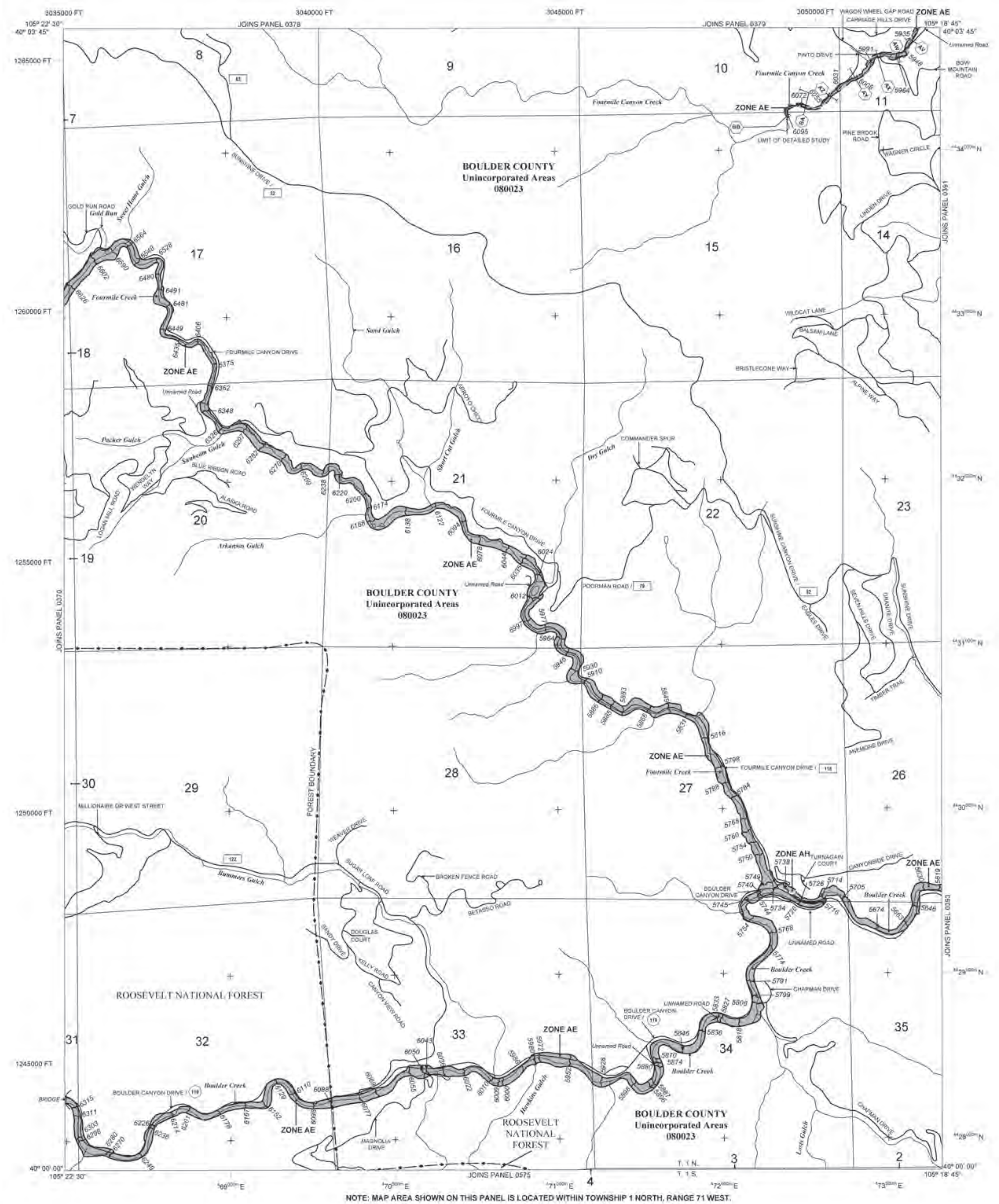
Example: To convert Fourmile Canyon Creek elevations to NAVD 88, 3.7 feet were added to the NGVD 29 elevations

Panel Location Map



The digital Flood Insurance Rate map (FIRM) was produced through a cooperative partnership between the State of Colorado Water Conservation Board, the Urban Drainage and Flood Control District, and the Federal Emergency Management Agency (FEMA). The State of Colorado Water Conservation Board and the Urban Drainage and Flood Control District have implemented a long-term approach of floodplain management to reduce the costs associated with flooding. As part of this effort, both the State of Colorado and the Urban Drainage and Flood Control District have joined in Cooperating Technical Partner agreements with FEMA to produce this digital FIRM.

Additional Flood Hazard information and resources are available from local communities, the Colorado Water Conservation Board, and the Urban Drainage and Flood Control District.



NOTE: MAP AREA SHOWN ON THIS PANEL IS LOCATED WITHIN TOWNSHIP 1 NORTH, RANGE 71 WEST.

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X — Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X — Areas determined to be outside the 0.2% annual chance floodplain.

ZONE D — Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

Floodplain Boundary
Floodway boundary
Zone D boundary
CBRS and OPA boundary
Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
513 — Base Flood Elevation line and value; elevation in feet*
(EL 987) — Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

A — A: Cross section line
23 - - - 23: Transect line
45° 02' 08", 93° 02' 12" — Geographic coordinates referenced to the North American Datum of 1983 (NAD 83) Western Hemisphere
$^{44}89^{000m}$ N — 1000-meter Universal Transverse Mercator grid values, zone 13
3180000 FT — 5000-foot ticks: Colorado State Plane North Zone (FIPS Zone 0501), Lambert Conformal Conic projection
DX5510 × — Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5 — River Mile

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
June 2, 1995

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
May 0, 1990 - to incorporate previously issued Letters of Map Revision, to add roads and road names, and to update corporate limits.
October 4, 2002 - to change base flood elevations, to change special flood hazard areas, to change zone designations, to update roads and road names, to reflect updated topographic information, to incorporate previously issued Letters of Map Revision, and to change floodway.
December 18, 2012 – to update corporate limits, to update roads and road names, to add Special Flood Hazard Areas previously shown on Town of Erie, Colorado Flood Insurance Rate Map dated December 2, 2004, and to incorporate previously issued Letters of Map Revision.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 1000'

500 0 1000 2000 FEET
300 0 300 600 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0390J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 390 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

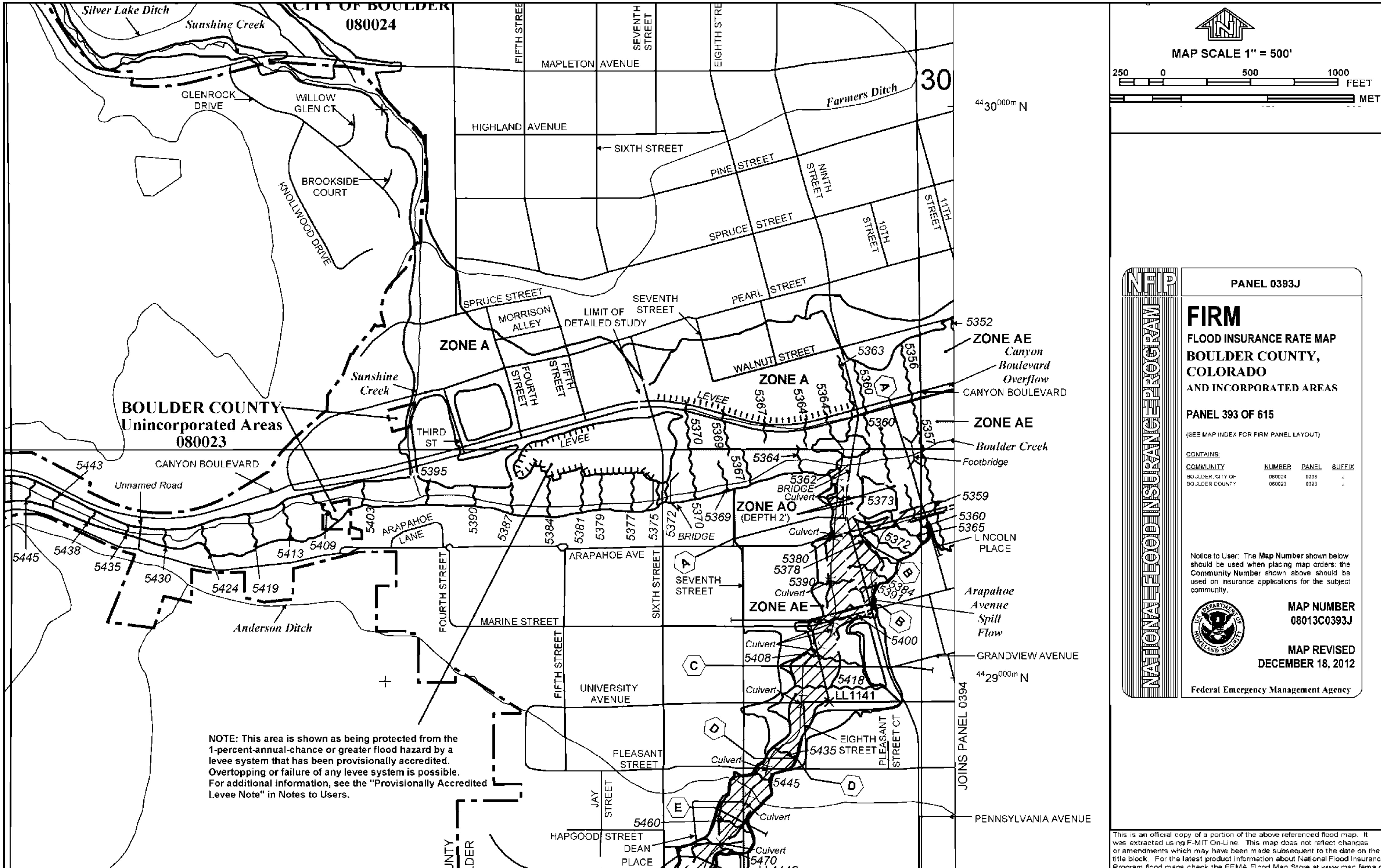
COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0390	J

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

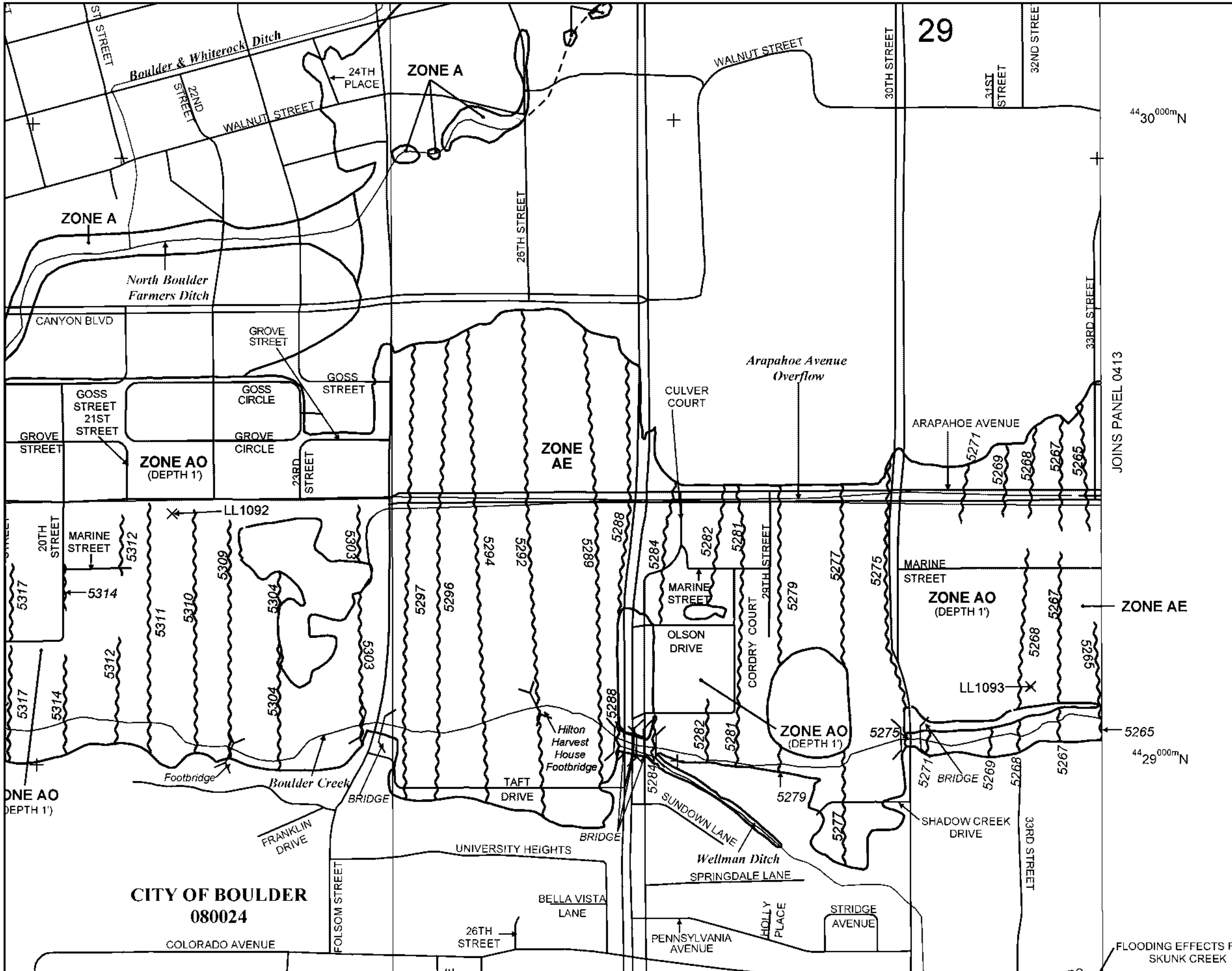
MAP NUMBER
08013C0390J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency



MAP SCALE 1" = 500'
250 0 500 1000
FEET
METER
NFIP
NATIONAL FLOOD INSURANCE PROGRAM
PANEL 0393J
FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS
PANEL 393 OF 615
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)
CONTAINS:
COMMUNITY NUMBER PANEL SUFFIX
BOULDER, CITY OF 080024 0393 J
BOULDER COUNTY 080023 0393 J
Notice to User: The Map Number shown below should be used when placing map orders; the Community Number shown above should be used on insurance applications for the subject community.
MAP NUMBER 08013C0393J
MAP REVISED DECEMBER 18, 2012
Federal Emergency Management Agency
This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov
CITY OF BOULDER 080024
BOULDER COUNTY Unincorporated Areas 080023
Silver Lake Ditch
Sunshine Creek
Farmers Ditch
Anderson Ditch
Boulder Creek
Canyon Boulevard Overflow
Arapahoe Avenue Spill Flow
ZONE A
ZONE AE
ZONE AO (DEPTH 2')
LEVEE
LIMIT OF DETAILED STUDY
MAPLETON AVENUE
HIGHLAND AVENUE
PINE STREET
SPRUCE STREET
PEARL STREET
WALNUT STREET
CANYON BOULEVARD
ARAPAHOE AVE
ARAPAHOE LANE
MARINE STREET
UNIVERSITY AVENUE
PLEASANT STREET
HAPGOOD STREET
DEAN PLACE
GRANDVIEW AVENUE
PENNSYLVANIA AVENUE
LINCOLN PLACE
MORRISON ALLEY
GLENROCK DRIVE
WILLOW GLEN CT
BROOKSIDE COURT
KNOLLWOOD DRIVE
THIRD ST
FOURTH STREET
FIFTH STREET
SIXTH STREET
SEVENTH STREET
EIGHTH STREET
NINTH STREET
10TH STREET
11TH STREET
JAY STREET
PLEASANT STREET CT
Unnamed Road
Footbridge
BRIDGE
Culvert
JOINS PANEL 0394
30
$^{44}30^{000m}$ N
$^{44}29^{000m}$ N
LL1141
LL1142
5352 5356 5357 5359 5360 5362 5363 5364 5365 5367 5369 5370 5372 5373 5375 5377 5378 5379 5380 5381 5384 5387 5390 5391 5395 5400 5403 5408 5409 5413 5418 5419 5424 5430 5435 5438 5443 5445 5460 5470
NOTE: This area is shown as being protected from the 1-percent-annual-chance or greater flood hazard by a levee system that has been provisionally accredited. Overtopping or failure of any levee system is possible. For additional information, see the "Provisionally Accredited Levee Note" in Notes to Users.



MAP SCALE 1" = 500'

250 0 500 1000 FEET

METER

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0394J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 394 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER, CITY OF	080024	0394	J

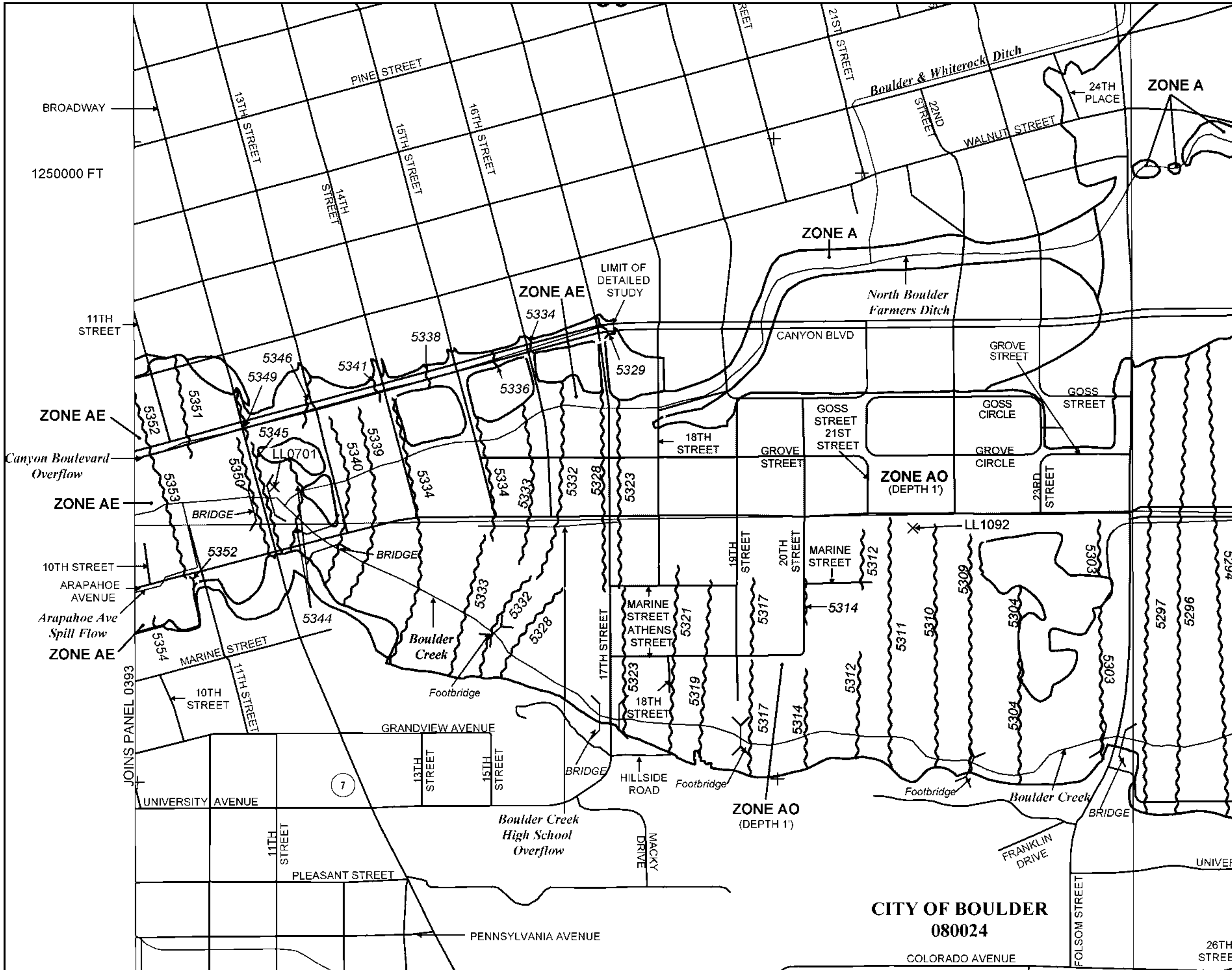
Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER 08013C0394J

MAP REVISED DECEMBER 18, 2012

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov



MAP SCALE 1" = 500'

250 0 500 1000 FEET

METER

NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 0394J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 394 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER CITY OF	080024	0394	J

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08013C0394J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov

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Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study Report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study Report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 13. The **horizontal datum** was NAD 83, GRS 1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242** or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was provided by the FEMA Map Service Centerand the Boulder Area Spatial Data Cooperative (BASIC). Additional input was provided by the Town of Erie and the City of Longmont. These data are current as of 2004.

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables for multiple streams in the Flood Insurance Study Report (which contains authoritative hydraulic data) may reflect stream channel distances that differ from what is shown on this map.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

For information on available products associated with this FIRM visit the **Map Service Center (MSC)** website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the MSC website.

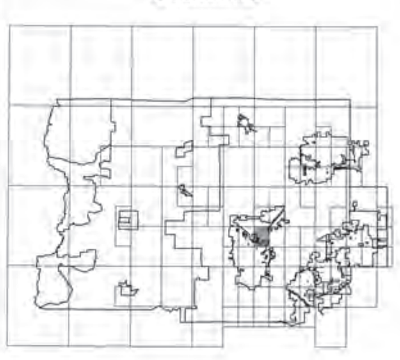
If you have **questions about this map**, how to order products, or the National Flood Insurance Program in general, please call the **FEMA Map Information eXchange (FMIX) at 1-877-FEMA-MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov/business/nfip http://www.fema.gov/business/nfip/.

Boulder County Vertical Datum Offset Table

Flooding Source	Vertical Datum Offset (ft)	Flooding Source	Vertical Datum Offset (ft)
Boulder Creek (East County Line Road to confluence of Fourmile Creek)	3.3	Wonderland Creek	3.3
Fourmile Canyon Creek	3.7		

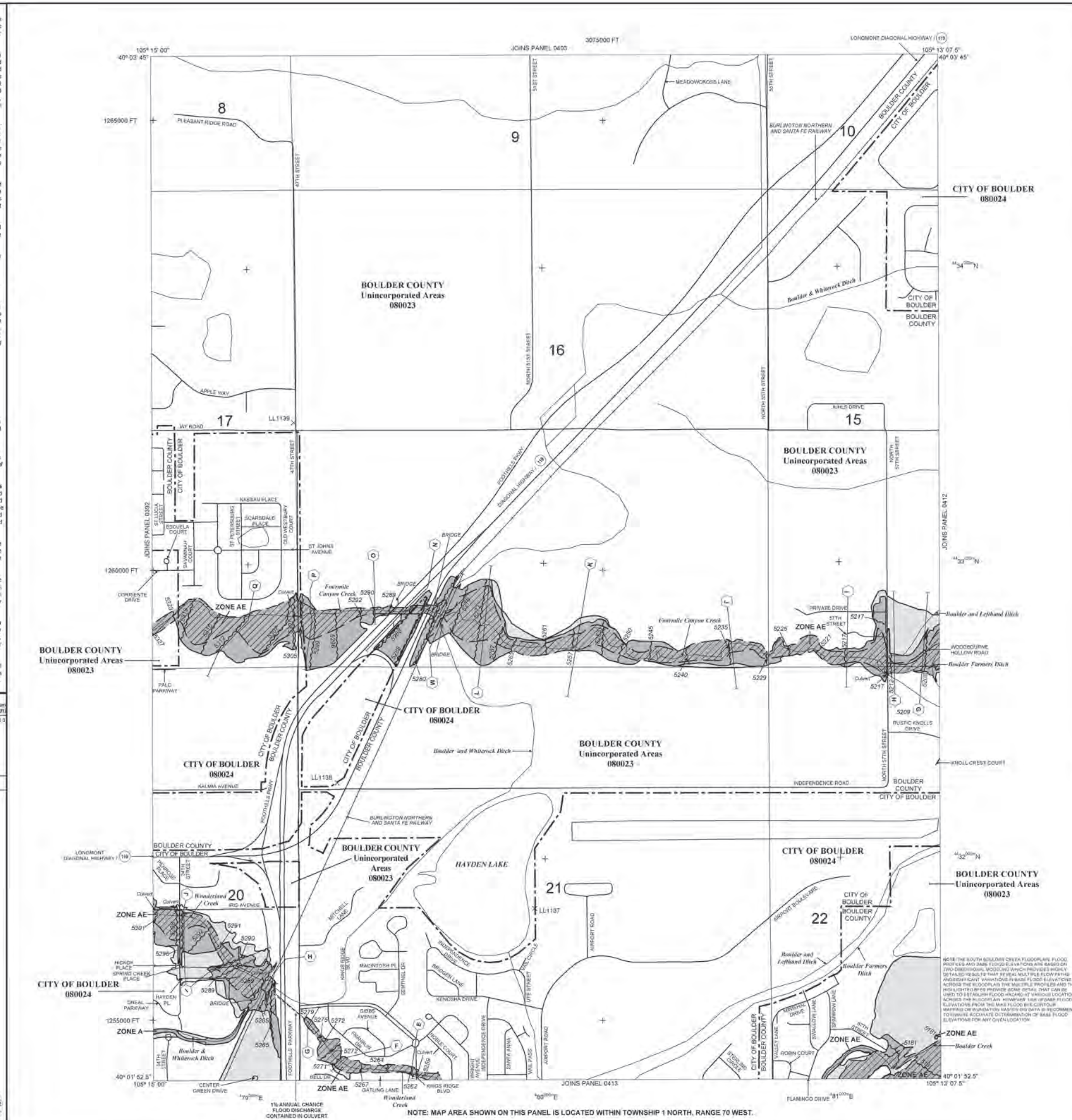
Example: To convert Boulder Creek elevations to NAVD 88, 3.3 feet were added to the NGVD 29 elevations.

Panel Location Map



This digital Flood Insurance Rate map (FIRM) was produced through a cooperative partnership between the State of Colorado Water Conservation Board, the Urban Drainage and Flood Control District, and the Federal Emergency Management Agency (FEMA). The State of Colorado Water Conservation Board and the Urban Drainage and Flood Control District have implemented a long-term approach of floodplain management to reduce the costs associated with flooding. As part of this effort, both the State of Colorado and the Urban Drainage and Flood Control District have joined in Cooperating Technical Partner agreements with FEMA to produce this digital FIRM.

Additional Flood Hazard information and resources are available from local communities, the Colorado Water Conservation Board, and the Urban Drainage and Flood Control District.



LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X — Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X — Areas determined to be outside the 0.2% annual chance floodplain.

ZONE D — Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

	Floodplain Boundary
	Floodway boundary
	Zone D boundary
	CBRS and OPA boundary
	Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
~~ 513 ~~~	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

(A)———(A)	Cross section line
(23) - - - - (23)	Transect line
45° 02' 08", 93° 02' 12"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83) Western Hemisphere
4989000 N	1000-meter Universal Transverse Mercator grid values, zone 13
3160000 FT	5000-foot ticks: Colorado State Plane North Zone (FIPS Zone 0501), Lambert Conformal Conic projection
DX5510 ×	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
June 2, 1995

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
May 6, 1996 - to incorporate previously issued Letters of Map Revision, to add roads and road names, and to update corporate limits.
October 4, 2002 - to change base flood elevations, to change special flood hazard areas, to change zone designations, to update roads and road names, to reflect updated topographic information, to incorporate previously issued Letters of Map Revision, and to change floodway.
December 18, 2012 - to update corporate limits, to update roads and road names, to add Special Flood Hazard Areas previously shown on Town of Erie, Colorado Flood Insurance Rate Map dated December 2, 2004, and to incorporate previously issued Letters of Map Revision.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET
150 0 150 300 METERS

NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 0411J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 411 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

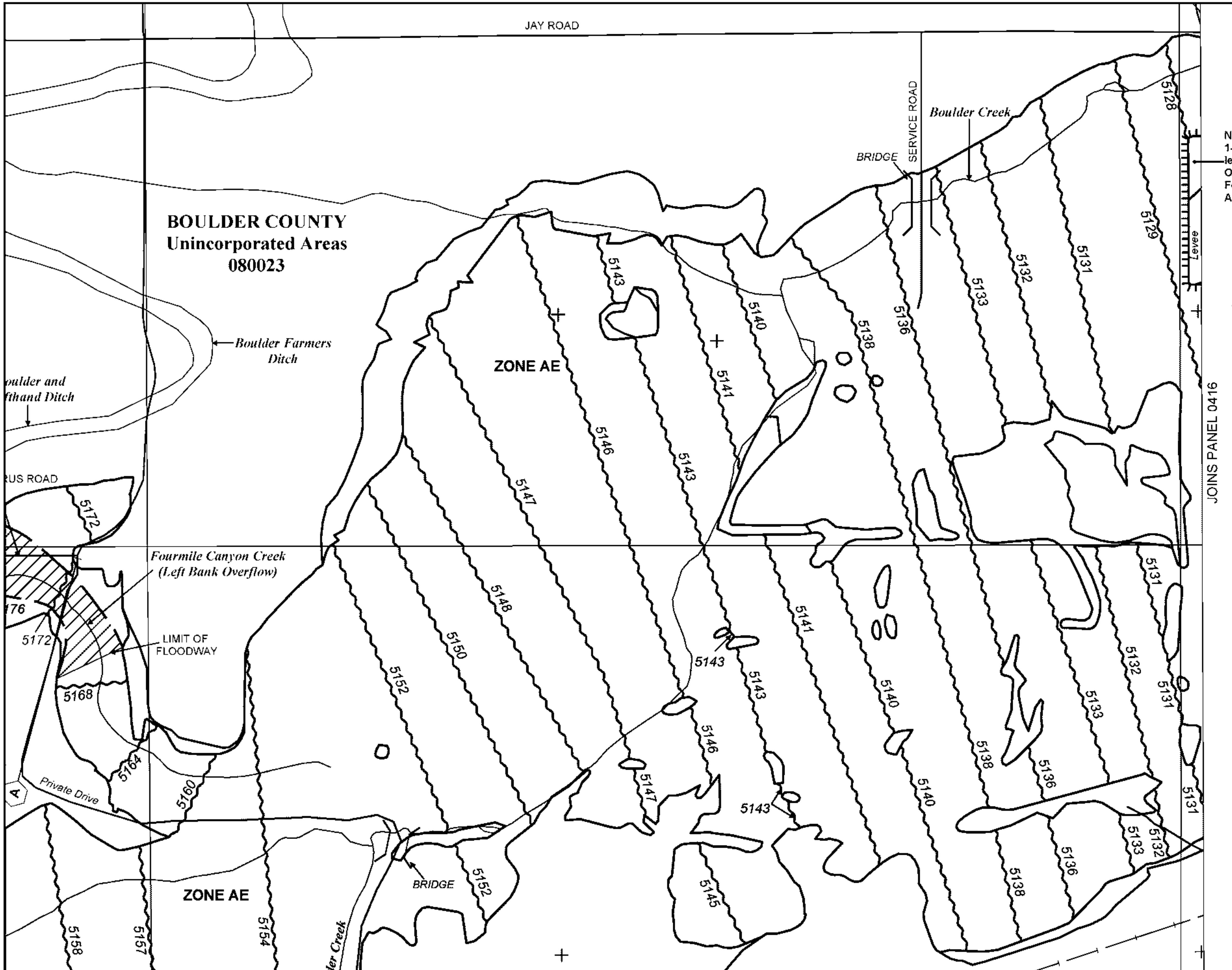
COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER, CITY OF	080024	0411	J
BOULDER COUNTY	080023	0411	J

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08013C0411J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency



MAP SCALE 1" = 500'

250 0 500 1000 FEET

METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0412J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 412 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER, CITY OF	080024	0412	J
BOULDER COUNTY	080023	0412	J

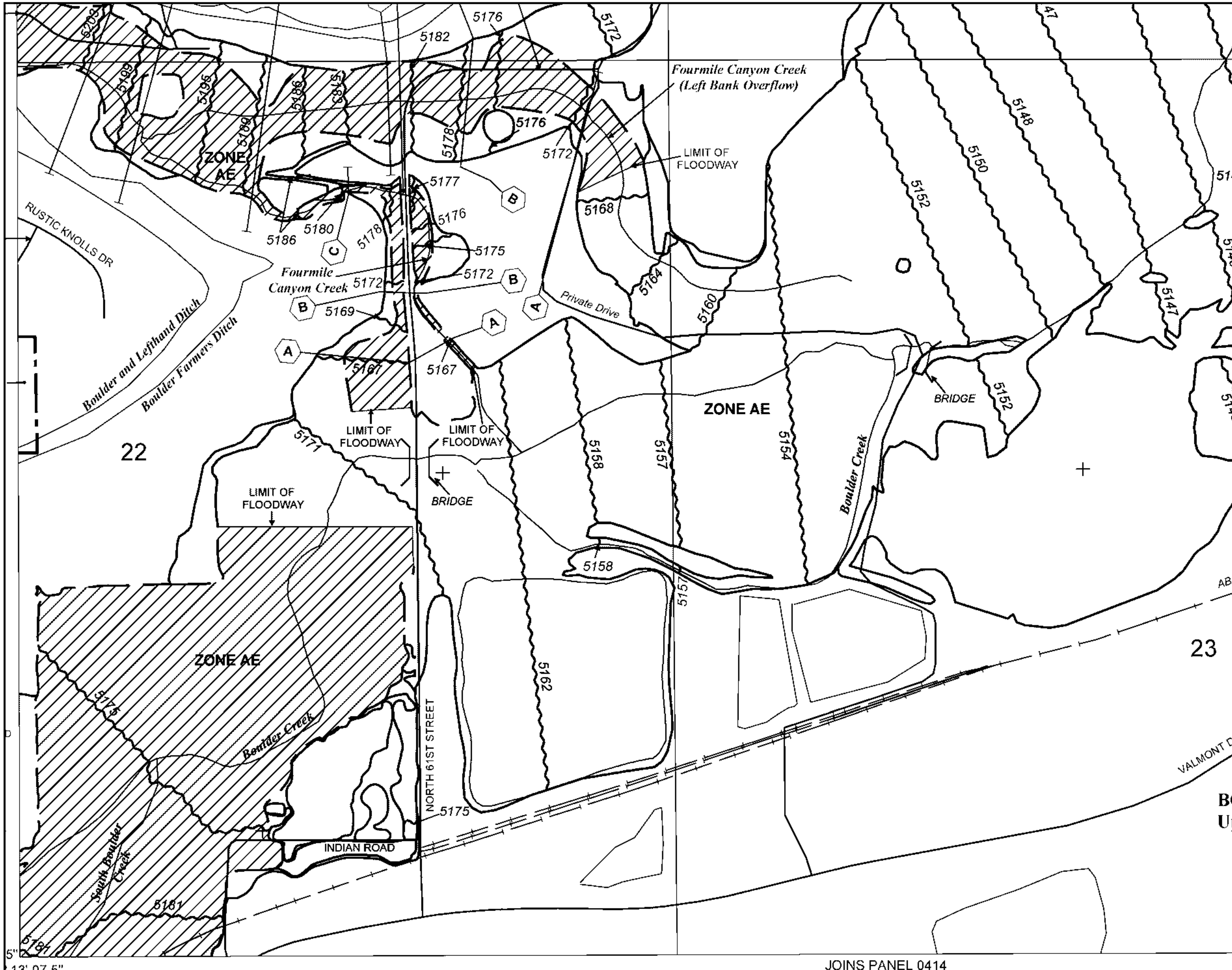
Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08013C0412J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov



MAP SCALE 1" = 500'

250 0 500 1000 FEET

METER

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0412J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 412 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

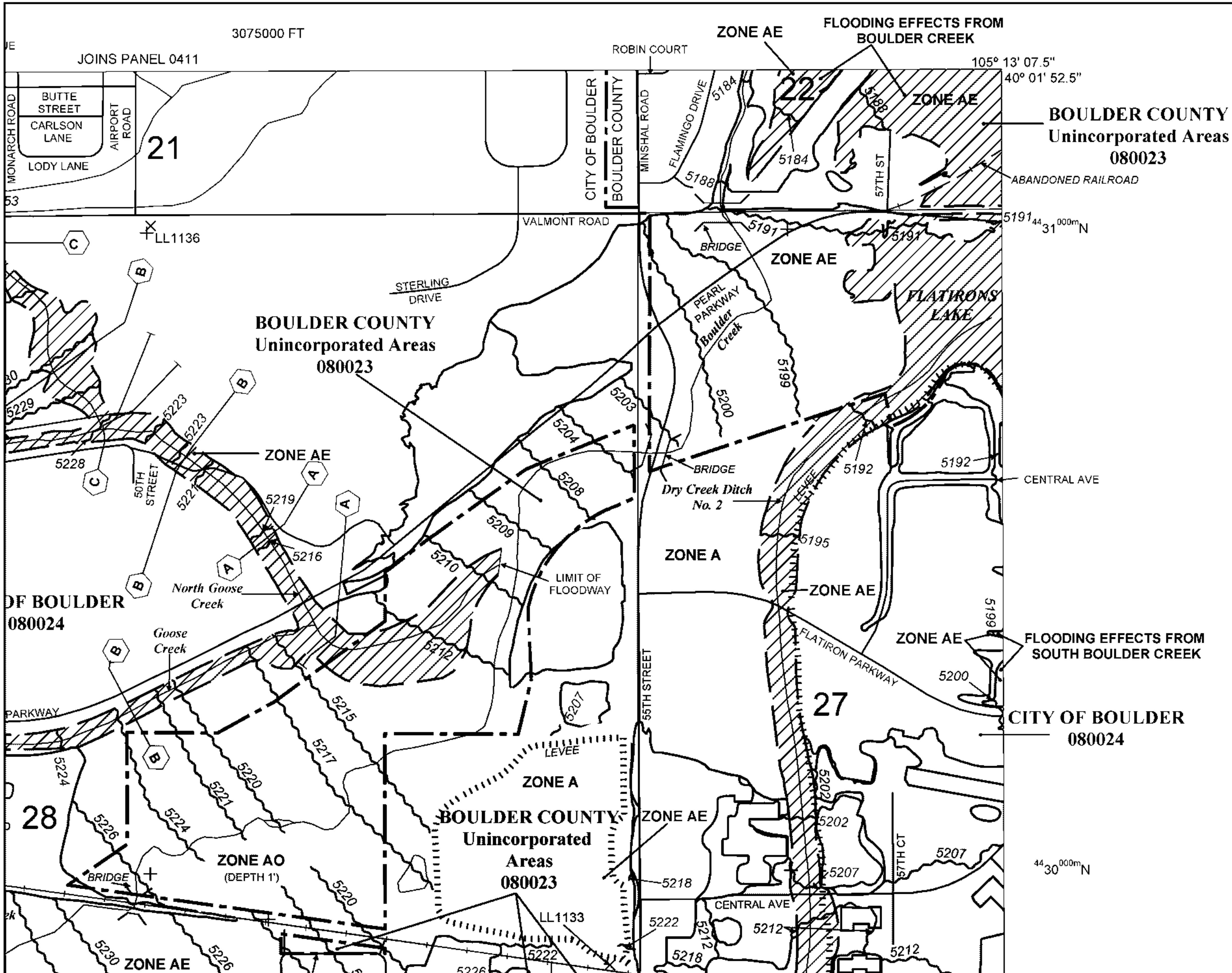
COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER, CITY OF	080024	0412	J
BOULDER COUNTY	080023	0412	J

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08013C0412J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency



MAP SCALE 1" = 500'

250 0 500 1000 FEET

METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0413J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 413 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER, CITY OF	080024	0413	J
BOULDER COUNTY	080023	0413	J

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MAP NUMBER
08013C0413J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

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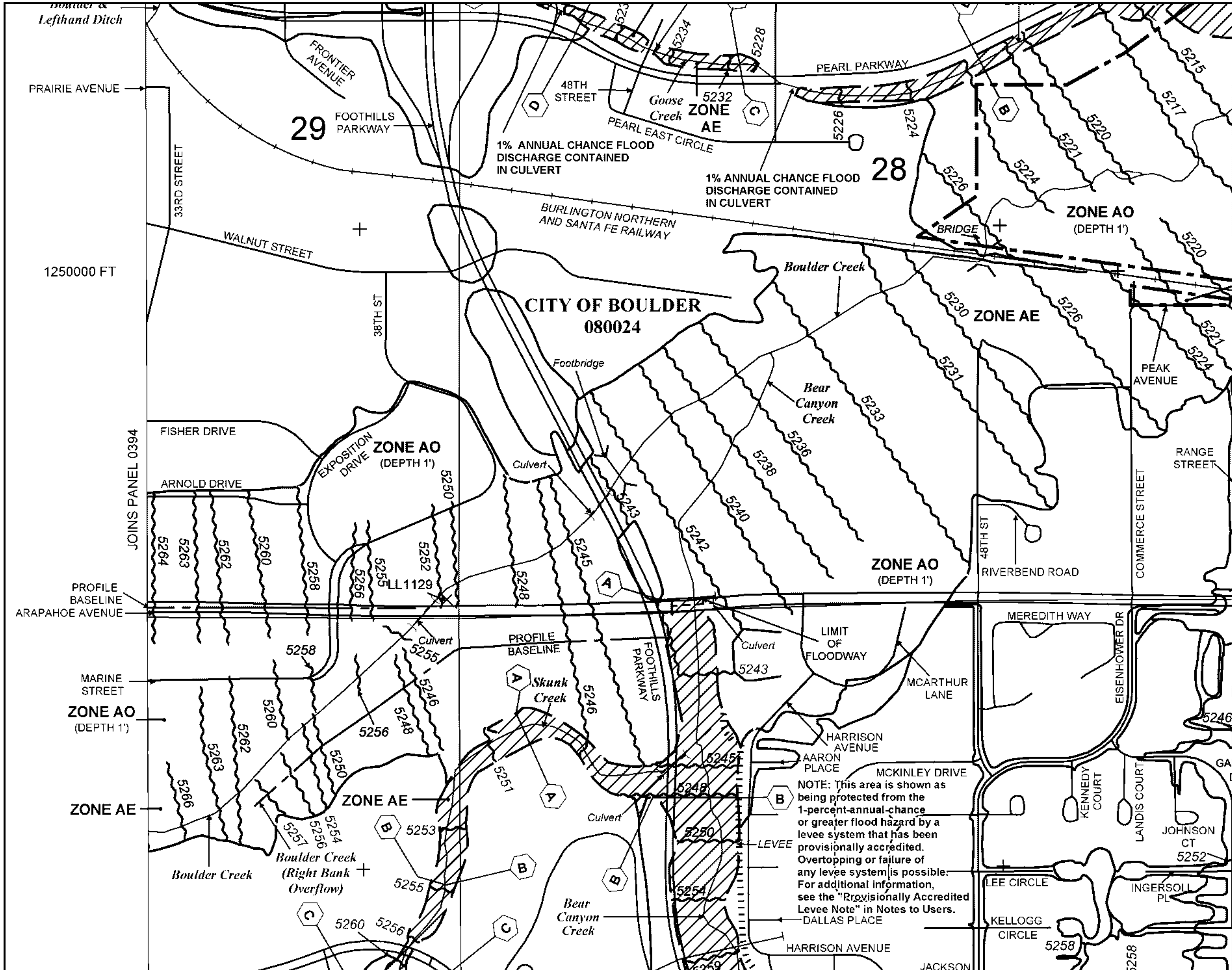

MAP SCALE 1" = 500'

250 0 500 1000 FEET

METER

NFIP

PANEL 0413J

NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 413 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER, CITY OF	080024	0413	J
BOULDER COUNTY	080023	0413	J

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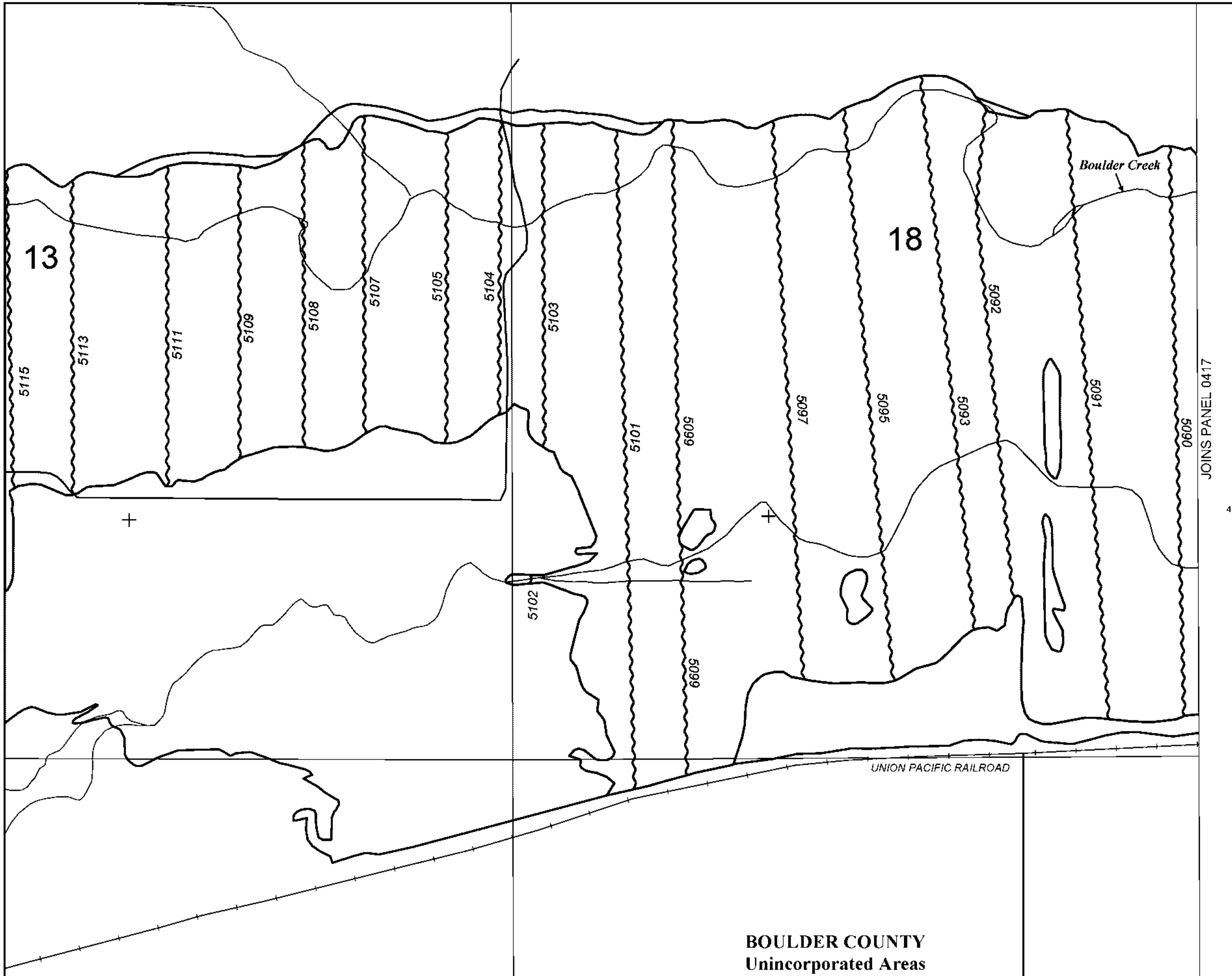
MAP NUMBER
08013C0413J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency



NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 0416J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 416 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0416	J

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08013C0416J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov

MAP SCALE 1" = 500'

250 0 500 1000 FEET

METER

NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 0416J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 416 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0416	J

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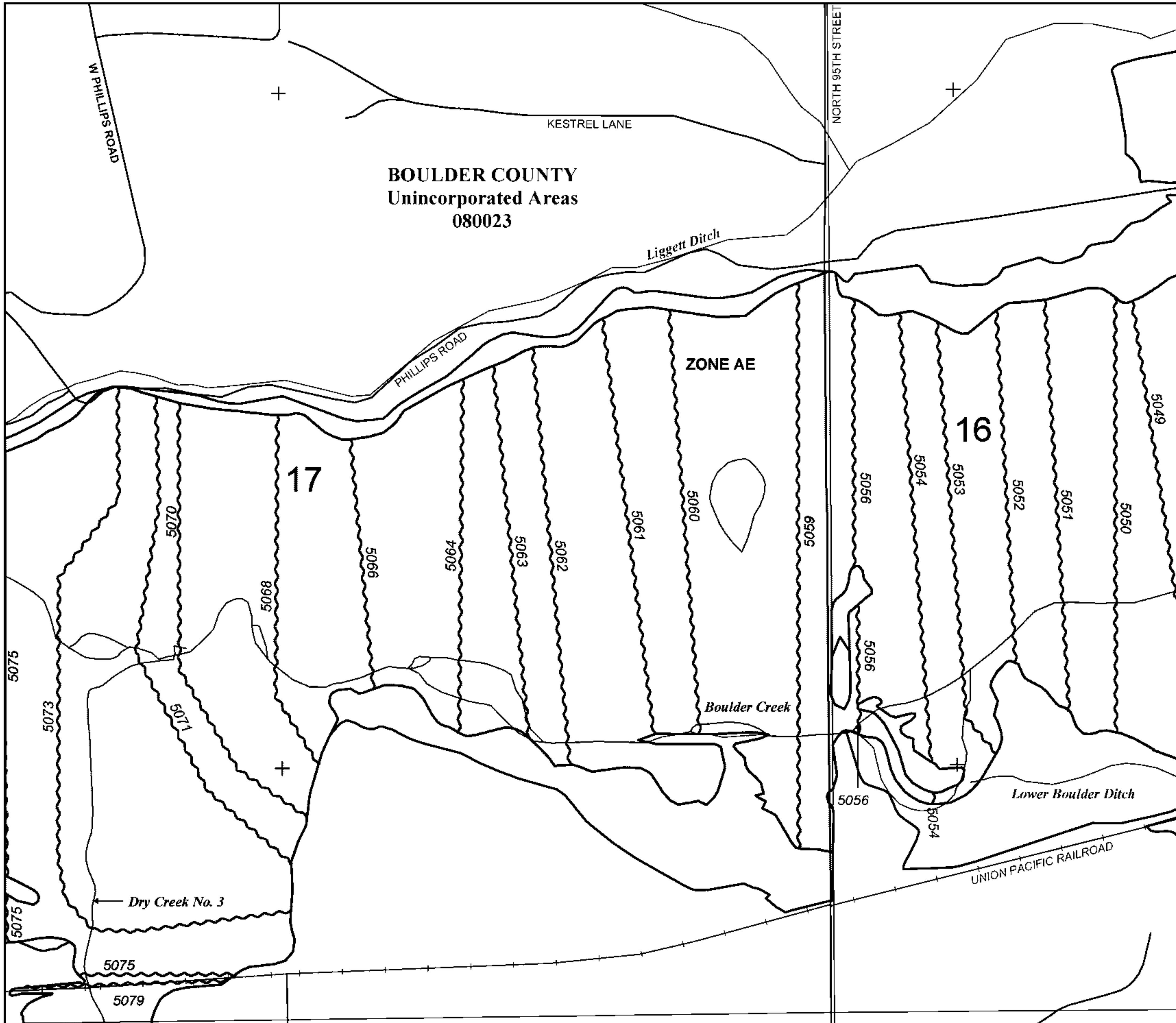
MAP NUMBER
08013C0416J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency



MAP SCALE 1" = 500'

250 0 500 1000 FEET

METER

NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 0417J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 417 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0417	J

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MAP NUMBER
08013C0417J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0417J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 417 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0417	J

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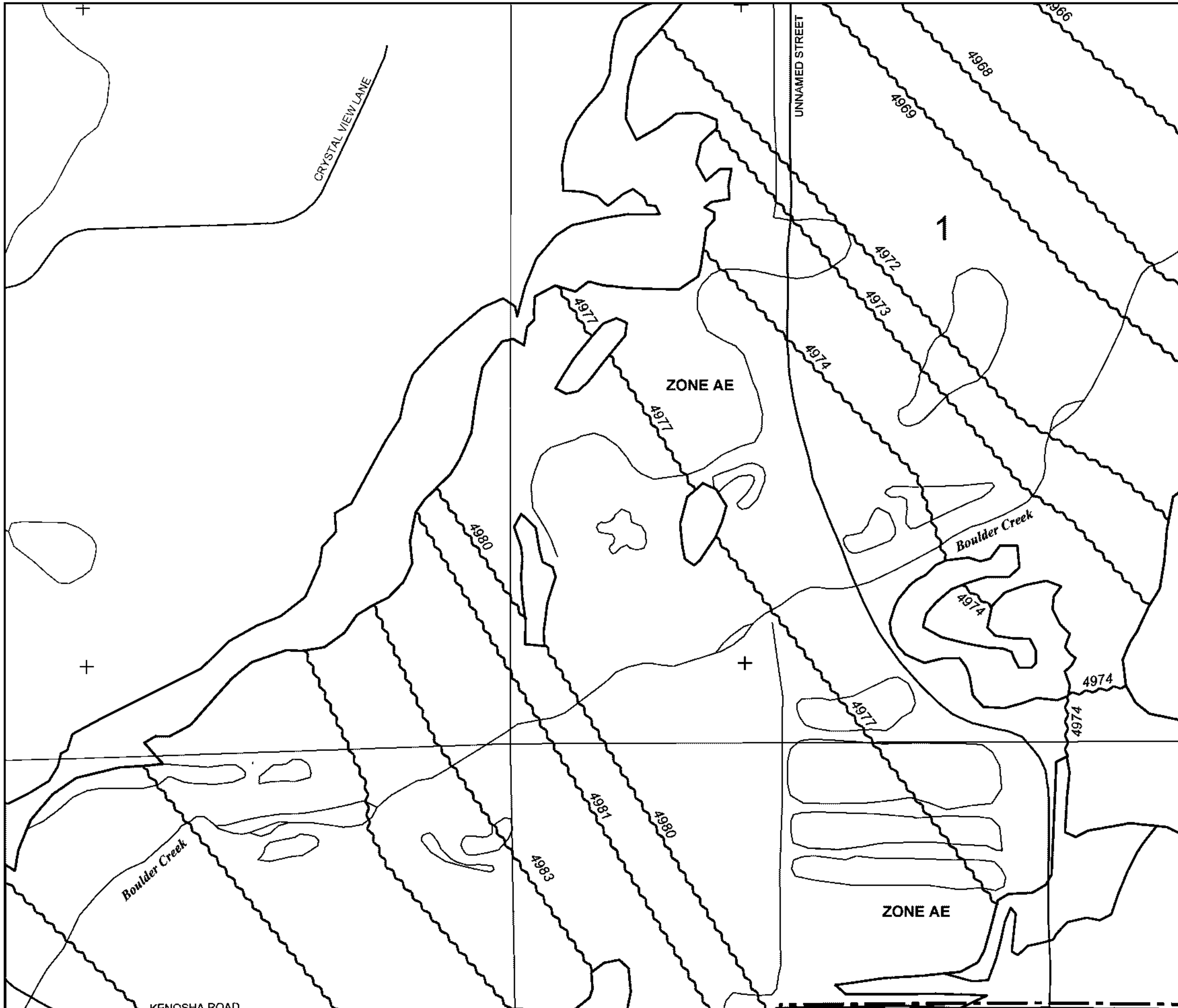
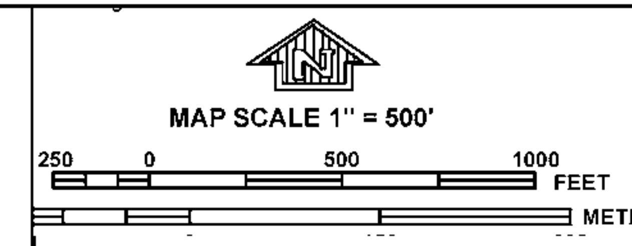
MAP NUMBER
08013C0417J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency





NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 0429J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 429 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0429	J
ERIE TOWN OF	080181	0429	J

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08013C0429J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

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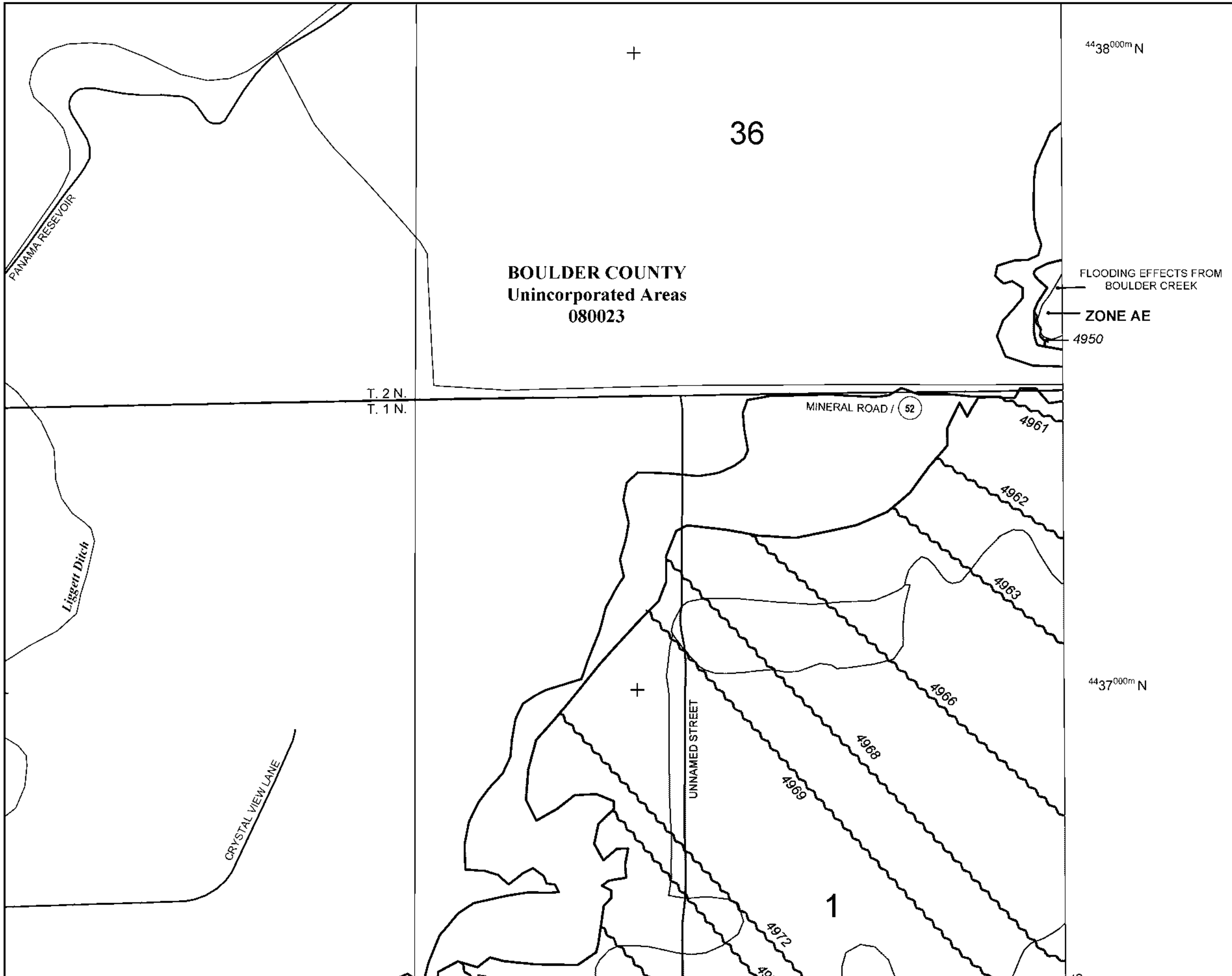

MAP SCALE 1" = 500'

250 0 500 1000 FEET

METER

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0429J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 429 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0429	J
ERIE, TOWN OF	080181	0429	J

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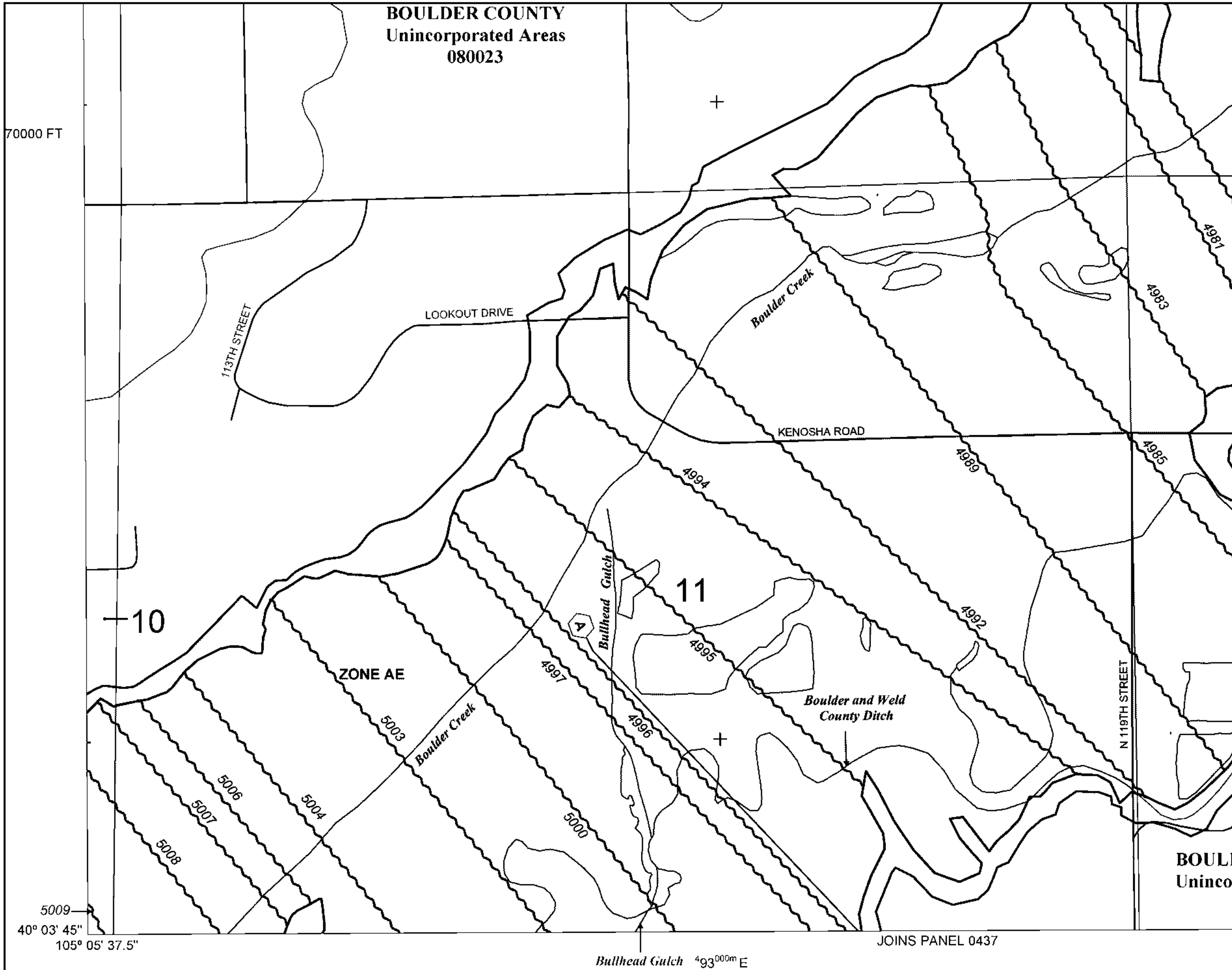
MAP NUMBER
08013C0429J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency



MAP SCALE 1" = 500'

250 0 500 1000 FEET

METER

NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 0429J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 429 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0429	J
ERIE, TOWN OF	080181	0429	J

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MAP NUMBER
08013C0429J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

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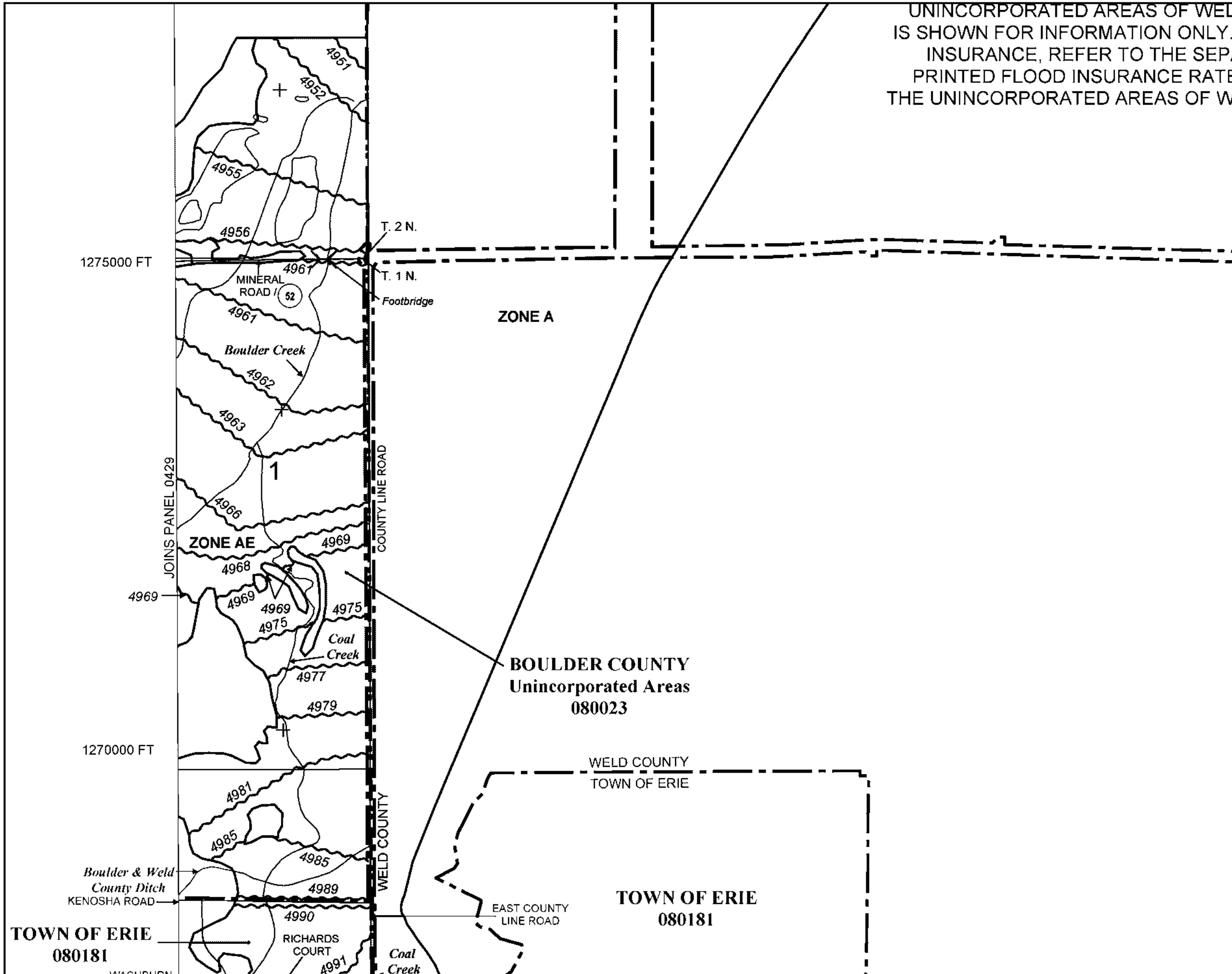

MAP SCALE 1" = 1000'

500 0 1000 2000 FEET

METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0435J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 435 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0435	J
ERIE, TOWN OF	080181	0435	J

Notice to User: The **Map Number** shown below should be used when placing map orders: the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08013C0435J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

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NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

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NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242** or visit its website at http://www.ngs.noaa.gov.

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This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables for multiple streams in the Flood Insurance Study Report (which contains authoritative hydraulic data) may reflect stream channel distances that differ from what is shown on this map.

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Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

For information on available products associated with this FIRM visit the **Map Service Center (MSC)** website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the MSC website.

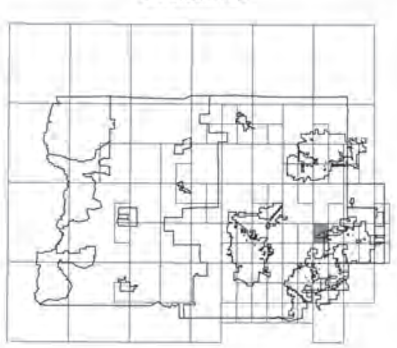
If you have **questions about this map,** how to order products, or the National Flood Insurance Program in general, please call the **FEMA Map Information eXchange (FMIX)** at **1-877-FEMA-MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov/business/nfip.

Boulder County Vertical Datum Offset Table

Flooding Source	Vertical Datum Offset (ft)	Flooding Source	Vertical Datum Offset (ft)
Boulder Creek (Confluence of Fourmile Creek to approximately 160,000 feet upstream of confluence)	3.7	Prince Tributary West Branch	3.1
		Prince Tributary East Branch	3.1
Bullhead Gulch	3.1		

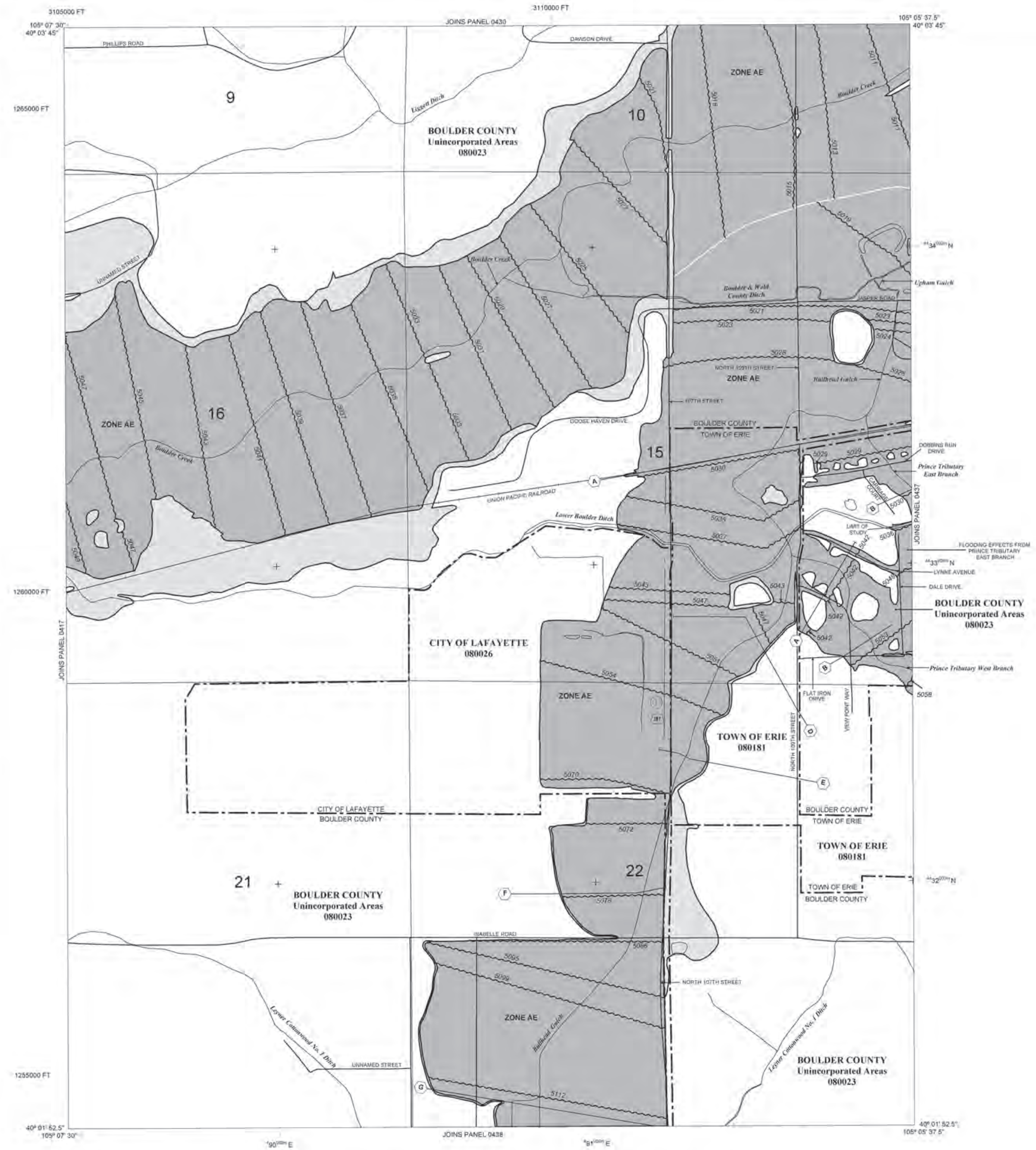
Example: To convert Boulder Creek elevations to NAVD 88, 3.7 feet were added to the NGVD 29 elevations.

Panel Location Map



This digital Flood Insurance Rate Map (FIRM) was produced through a cooperative partnership between the State of Colorado Water Conservation Board, the Urban Drainage and Flood Control District, and the Federal Emergency Management Agency (FEMA). The State of Colorado Water Conservation Board and the Urban Drainage and Flood Control District have implemented a long-term approach of floodplain management to reduce the costs associated with flooding. As part of this effort, both the State of Colorado and the Urban Drainage and Flood Control District have joined in Cooperating Technical Partner agreements with FEMA to produce this digital FIRM.

Additional Flood Hazard information and resources are available from local communities, the Colorado Water Conservation Board, and the Urban Drainage and Flood Control District.



NOTE: MAP AREA SHOWN ON THIS PANEL IS LOCATED WITHIN TOWNSHIP 1 NORTH, RANGE 69 WEST.

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X — Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X — Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D — Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

Floodplain Boundary
Floodway boundary
Zone D boundary
CBRS and OPA boundary
Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
513 — Base Flood Elevation line and value; elevation in feet*
(EL 987) — Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

(A)—(A) Cross section line
(23) - - - (23) Transect line
45° 02' 08", 93° 02' 12" — Geographic coordinates referenced to the North American Datum of 1983 (NAD 83) Western Hemisphere
^{47}89^{000m} N — 1000-meter Universal Transverse Mercator grid values, zone 13
3180000 FT — 5000-foot ticks: Colorado State Plane North Zone (FIPS Zone 0501), Lambert Conformal Conic projection
DX5510 × — Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5 — River Mile

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
June 2, 1995

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
May 6, 1996 - to incorporate previously issued Letters of Map Revision, to add roads and road names, and to update corporate limits.
October 4, 2002 - to change base flood elevations, to change special flood hazard areas, to change zone designations, to update roads and road names, to reflect updated topographic information, to incorporate previously issued Letters of Map Revision, and to change floodway.
December 18, 2012 - to update corporate limits, to update roads and road names, to add Special Flood Hazard Areas previously shown on Town of Erie, Colorado Flood Insurance Rate Map dated December 2, 2004, and to incorporate previously issued Letters of Map Revision.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET
150 0 150 300 METERS

NFIP
NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0436J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 436 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

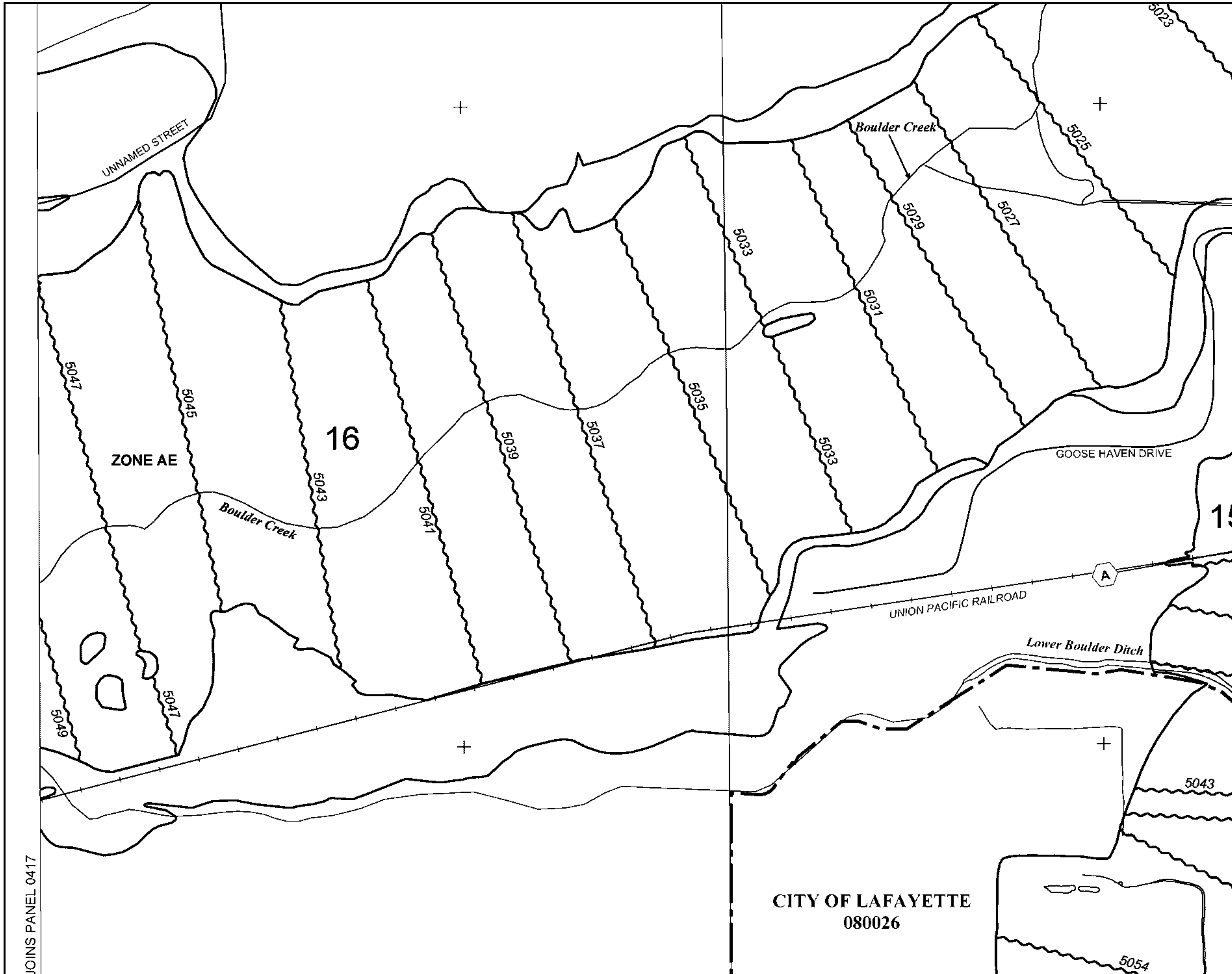
COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0436	J
ERIE, TOWN OF	080181	0436	J
LAFAYETTE, CITY OF	080026	0436	J

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08013C0436J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency



MAP SCALE 1" = 500'

250 0 500 1000 FEET

METER

NATIONAL FLOOD INSURANCE PROGRAM

NFIP

PANEL 0436J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 436 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

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MAP NUMBER
08013C0436J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study Report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study Report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 13. The **horizontal datum** was NAD 83, GRS 1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was provided by the FEMA Map Service Centerand the Boulder Area Spatial Data Cooperative (BASIC). Additional input was provided by the Town of Erie and the City of Longmont. These data are current as of 2004

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables for multiple streams in the Flood Insurance Study Report (which contains authoritative hydraulic data) may reflect stream channel distances that differ from what is shown on this map.

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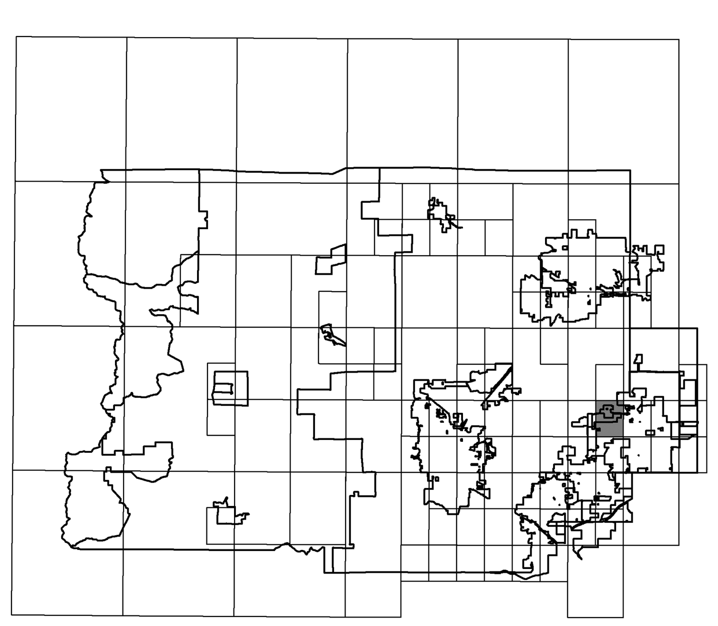
Boulder County Vertical Datum Offset Table

Flooding Source	Vertical Datum Offset (ft)	Flooding Source	Vertical Datum Offset (ft)
Bullhead Gulch	3.1	Prince Tributary West Branch	3.1
Prince Tributary East Branch	3.1	Boulder Creek (Confluence of Fourmile Creek to East County Line Road)	3.3

Example: To convert Bullhead Gulch elevations to NAVD 88, 3.1 feet were added to the NGVD 29 elevations.

Panel Location Map



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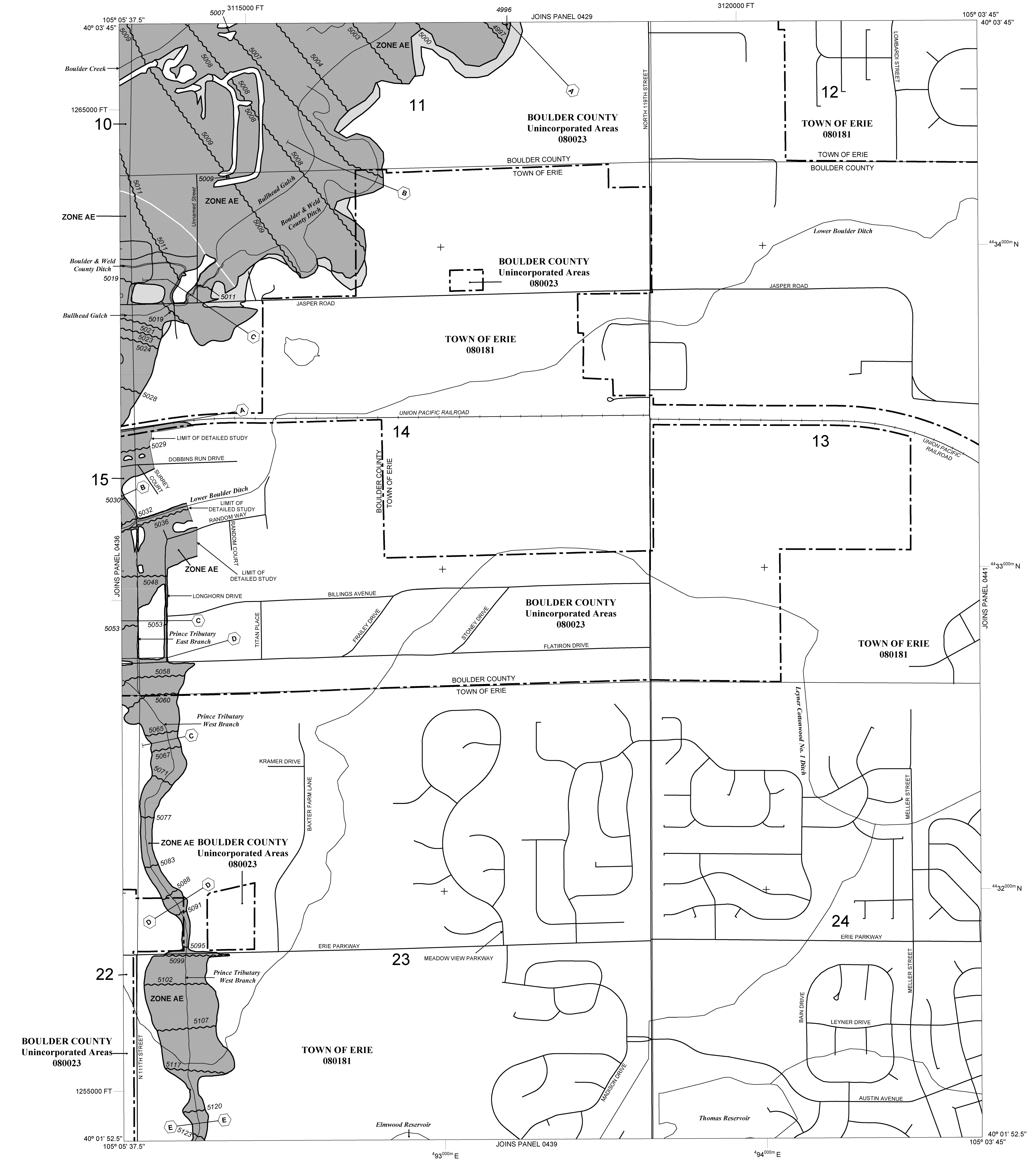

NOTE: MAP AREA SHOWN ON THIS PANEL IS LOCATED WITHIN TOWNSHIP 1 NORTH, RANGE 69 WEST.

LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

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ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
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COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

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CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

Floodplain boundary
Floodway boundary
Zone D boundary
CBRS and OPA boundary
Boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
513 — Base Flood Elevation line and value; elevation in feet*
(EL 987) — Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

A — A Cross section line
23 — 23 Transect line
45° 02' 08", 93° 02' 12" — Geographic coordinates referenced to the North American Datum of 1983 (NAD 83) Western Hemisphere
4989000m N — 1000-meter Universal Transverse Mercator grid values, zone 13
3180000 FT — 5000-foot ticks: Colorado State Plane North Zone (FIPS Zone 0501), Lambert Conformal Conic projection
DX5510 × — Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5 — River Mile

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
June 2, 1995

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
May 6, 1996 - to incorporate previously issued Letters of Map Revision; to add roads and road names; and to update corporate limits.
October 4, 2002 - to change base flood elevations; to change special flood hazard areas; to change zone designations; to update roads and road names; to reflect updated topographic information; to incorporate previously issued Letters of Map Revision; and to change floodway.
December 18, 2012 - to update corporate limits; to update roads and road names; to add Special Flood Hazard Areas previously shown on Town of Erie, Colorado Flood Insurance Rate Map dated December 2, 2004; and to incorporate previously issued Letters of Map Revision.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'
250 0 500 1000 FEET
150 0 150 300 METERS

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0437J

FIRM
FLOOD INSURANCE RATE MAP
BOULDER COUNTY, COLORADO
AND INCORPORATED AREAS

PANEL 437 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0437	J
ERIE, TOWN OF	080181	0437	J

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MAP NUMBER
08013C0437J

MAP REVISED
DECEMBER 18, 2012

Federal Emergency Management Agency

The following LOMRs have been uploaded to the FEMA Map Server as secured PDF, and can be accessed using the link https://msc.fema.gov/portal/search?AddressQuery=boulder%20county%2C%20co

LOMR Letter Number 12-08-0778P-080024

LOMR Letter Number 13-08-0187P-080024

LOMR Letter Number 13-08-0247P-080023

LOMR Letter Number 13-08-0248P-080026

 | **Issue Date: September 10, 2013** | **Effective Date: January 24, 2014** | **Case No.: 13-08-0605P** | LOMR-APP

Follows Conditional Case No.: 07-08-0928R

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT

COMMUNITY AND REVISION INFORMATION		PROJECT DESCRIPTION	BASIS OF REQUEST
COMMUNITY	**City of Lafayette Boulder County Colorado** **COMMUNITY NO.: 080026**	**CULVERT**	**HYDRAULIC ANALYSIS NEW TOPOGRAPHIC DATA**
IDENTIFIER	Indian Peaks Filing No. 17	**APPROXIMATE LATITUDE & LONGITUDE: 39.996, -105.130** **SOURCE:** USGS QUADRANGLE **DATUM:** NAD 83	

ANNOTATED MAPPING ENCLOSURES	ANNOTATED STUDY ENCLOSURES
TYPE: FIRM* NO.: 08013C0582J DATE: December 18, 2012	DATE OF EFFECTIVE FLOOD INSURANCE STUDY: December 18, 2012 PROFILE(S): 79P

Enclosures reflect changes to flooding sources affected by this revision.
* FIRM - Flood Insurance Rate Map; ** FBFM - Flood Boundary and Floodway Map; *** FHBM - Flood Hazard Boundary Map

FLOODING SOURCE(S) & REVISED REACH(ES)

Bullhead Gulch - from approximately 260 feet downstream to approximately 2,000 feet upstream of State Highway 42

SUMMARY OF REVISIONS

Flooding Source	Effective Flooding	Revised Flooding	Increases	Decreases
Bullhead Gulch	BFEs	BFEs	YES	YES
	Zone AE	Zone AE	YES	YES

* BFEs - Base Flood Elevations

DETERMINATION

This document provides the determination from the Department of Homeland Security's Federal Emergency Management Agency (FEMA) regarding a request for a Letter of Map Revision (LOMR) for the area described above. Using the information submitted, we have determined that a revision to the flood hazards depicted in the Flood Insurance Study (FIS) report and/or National Flood Insurance Program (NFIP) map is warranted. This document revises the effective NFIP map, as indicated in the attached documentation. Please use the enclosed annotated map panels revised by this LOMR for floodplain management purposes and for all flood insurance policies and renewals in your community.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Erin E. Cobb, CFM, Program Specialist
Engineering Management Branch
Federal Insurance and Mitigation Administration

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT (CONTINUED)

OTHER COMMUNITIES AFFECTED BY THIS REVISION

CID Number: 085076 **Name:** City of Louisville, Colorado

AFFECTED MAP PANELS	AFFECTED PORTIONS OF THE FLOOD INSURANCE STUDY REPORT
TYPE: FIRM* NO.: 08013C0582J DATE: December 18, 2012	DATE OF EFFECTIVE FLOOD INSURANCE STUDY: December 18, 2012 PROFILE: 79P

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Erin E. Cobb

Erin E. Cobb, CFM, Program Specialist
Engineering Management Branch
Federal Insurance and Mitigation Administration

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT (CONTINUED)

COMMUNITY INFORMATION

APPLICABLE NFIP REGULATIONS/COMMUNITY OBLIGATION

We have made this determination pursuant to Section 206 of the Flood Disaster Protection Act of 1973 (P.L. 93-234) and in accordance with the National Flood Insurance Act of 1968, as amended (Title XIII of the Housing and Urban Development Act of 1968, P.L. 90-448), 42 U.S.C. 4001-4128, and 44 CFR Part 65. Pursuant to Section 1361 of the National Flood Insurance Act of 1968, as amended, communities participating in the NFIP are required to adopt and enforce floodplain management regulations that meet or exceed NFIP criteria. These criteria, including adoption of the FIS report and FIRM, and the modifications made by this LOMR, are the minimum requirements for continued NFIP participation and do not supersede more stringent State/Commonwealth or local requirements to which the regulations apply.

NFIP regulations Subparagraph 60.3(b)(7) requires communities to ensure that the flood-carrying capacity within the altered or relocated portion of any watercourse is maintained. This provision is incorporated into your community's existing floodplain management ordinances; therefore, responsibility for maintenance of the altered or relocated watercourse, including any related appurtenances such as bridges, culverts, and other drainage structures, rests with your community. We may request that your community submit a description and schedule of maintenance activities necessary to ensure this requirement.

COMMUNITY REMINDERS

We based this determination on the base (1-percent-annual-chance) flood discharges computed in the FIS for your community without considering subsequent changes in watershed characteristics that could increase flood discharges. Future development of projects upstream could cause increased flood discharges, which could cause increased flood hazards. A comprehensive restudy of your community's flood hazards would consider the cumulative effects of development on flood discharges subsequent to the publication of the FIS report for your community and could, therefore, establish greater flood hazards in this area.

Your community must regulate all proposed floodplain development and ensure that permits required by Federal and/or State/Commonwealth law have been obtained. State/Commonwealth or community officials, based on knowledge of local conditions and in the interest of safety, may set higher standards for construction or may limit development in floodplain areas. If your State/Commonwealth or community has adopted more restrictive or comprehensive floodplain management criteria, those criteria take precedence over the minimum NFIP requirements.

We will not print and distribute this LOMR to primary users, such as local insurance agents or mortgage lenders; instead, the community will serve as a repository for the new data. We encourage you to disseminate the information in this LOMR by preparing a news release for publication in your community's newspaper that describes the revision and explains how your community will provide the data and help interpret the NFIP maps. In that way, interested persons, such as property owners, insurance agents, and mortgage lenders, can benefit from the information.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Erin E. Cobb

Erin E. Cobb, CFM, Program Specialist
Engineering Management Branch
Federal Insurance and Mitigation Administration

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

We have designated a Consultation Coordination Officer (CCO) to assist your community. The CCO will be the primary liaison between your community and FEMA. For information regarding your CCO, please contact:

Ms. Jeanine D. Petterson
Director, Mitigation Division
Federal Emergency Management Agency, Region VIII
Denver Federal Center, Building 710
P.O. Box 25267
Denver, CO 80225-0267
(303) 235-4830

STATUS OF THE COMMUNITY NFIP MAPS

We will not physically revise and republish the FIRM and FIS report for your community to reflect the modifications made by this LOMR at this time. When changes to the previously cited FIRM panel(s) and FIS report warrant physical revision and republication in the future, we will incorporate the modifications made by this LOMR at that time.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

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Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

PUBLIC NOTIFICATION OF REVISION

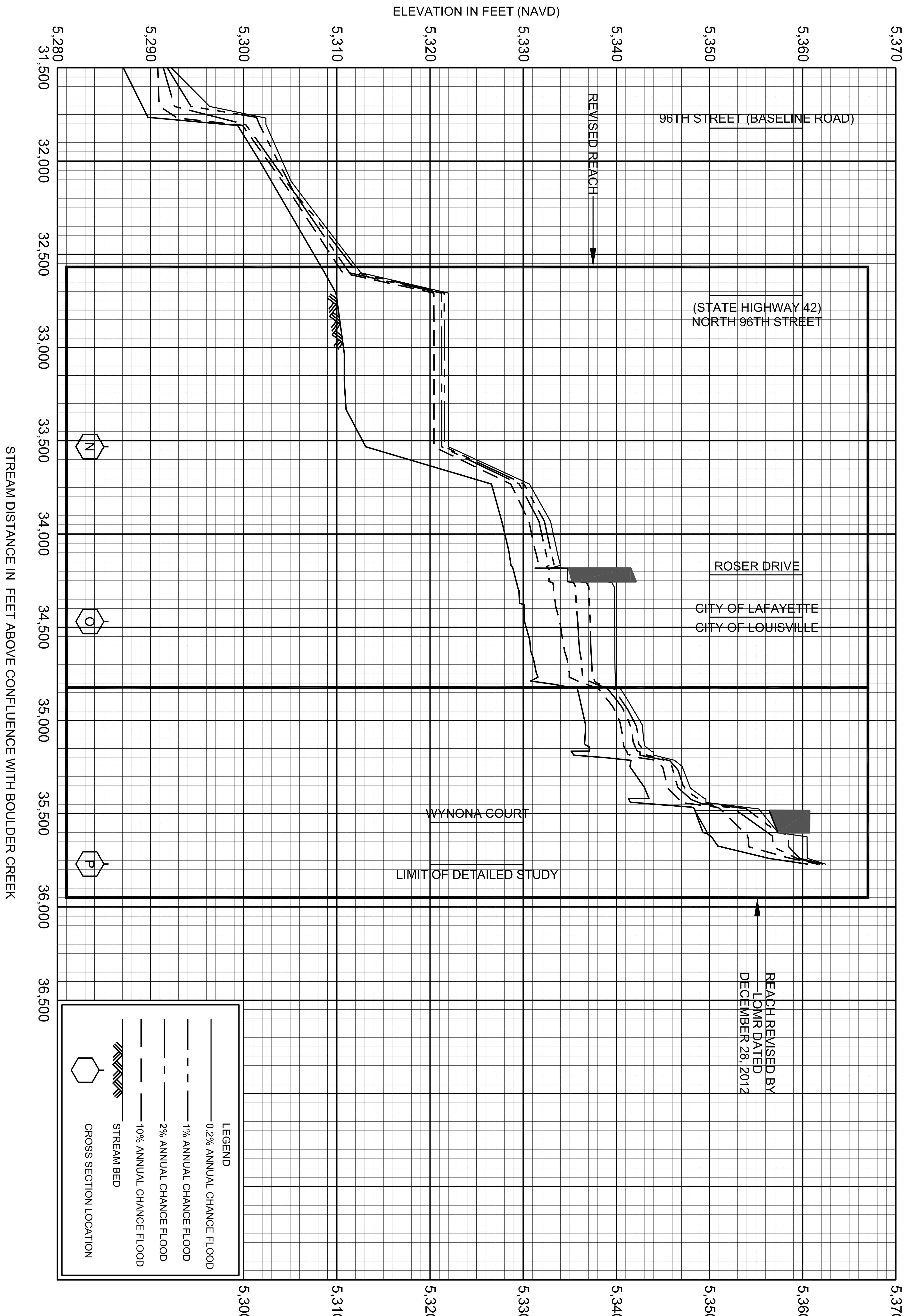
A notice of changes will be published in the *Federal Register*. This information also will be published in your local newspaper on or about the dates listed below and through FEMA's Flood Hazard Mapping website at https://www.floodmaps.fema.gov/fhm/Scripts/bfe_main.asp.

LOCAL NEWSPAPER Name: *The Daily Camera*
Dates: September 19, 2013 and September 26, 2013

Within 90 days of the second publication in the local newspaper, a citizen may request that we reconsider this determination. Any request for reconsideration must be based on scientific or technical data. Therefore, this letter will be effective only after the 90-day appeal period has elapsed and we have resolved any appeals that we receive during this appeal period. Until this LOMR is effective, the revised flood hazard determination information presented in this LOMR may be changed.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Erin E. Cobb, CFM, Program Specialist
Engineering Management Branch
Federal Insurance and Mitigation Administration



FEDERAL EMERGENCY MANAGEMENT AGENCY

BOULDER COUNTY, CO

AND INCORPORATED AREAS

FLOOD PROFILES

REVISED TO REFLECT LOMR EFFECTIVE: January 24, 2014

BULLHEAD GULCH

Legend

- 1% annual chance (100-Year) Floodplain
- 1% annual chance (100-Year) Floodway
- 0.2% annual chance (500-Year) Floodplain

N

MAP SCALE 1" = 500'

250 0 500 FEET

150 0 150 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0582J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO AND INCORPORATED AREAS

PANEL 582 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER COUNTY	080023	0582	J
LAFAYETTE, CITY OF	080026	0582	J
LOUISVILLE, CITY OF	085076	0582	J

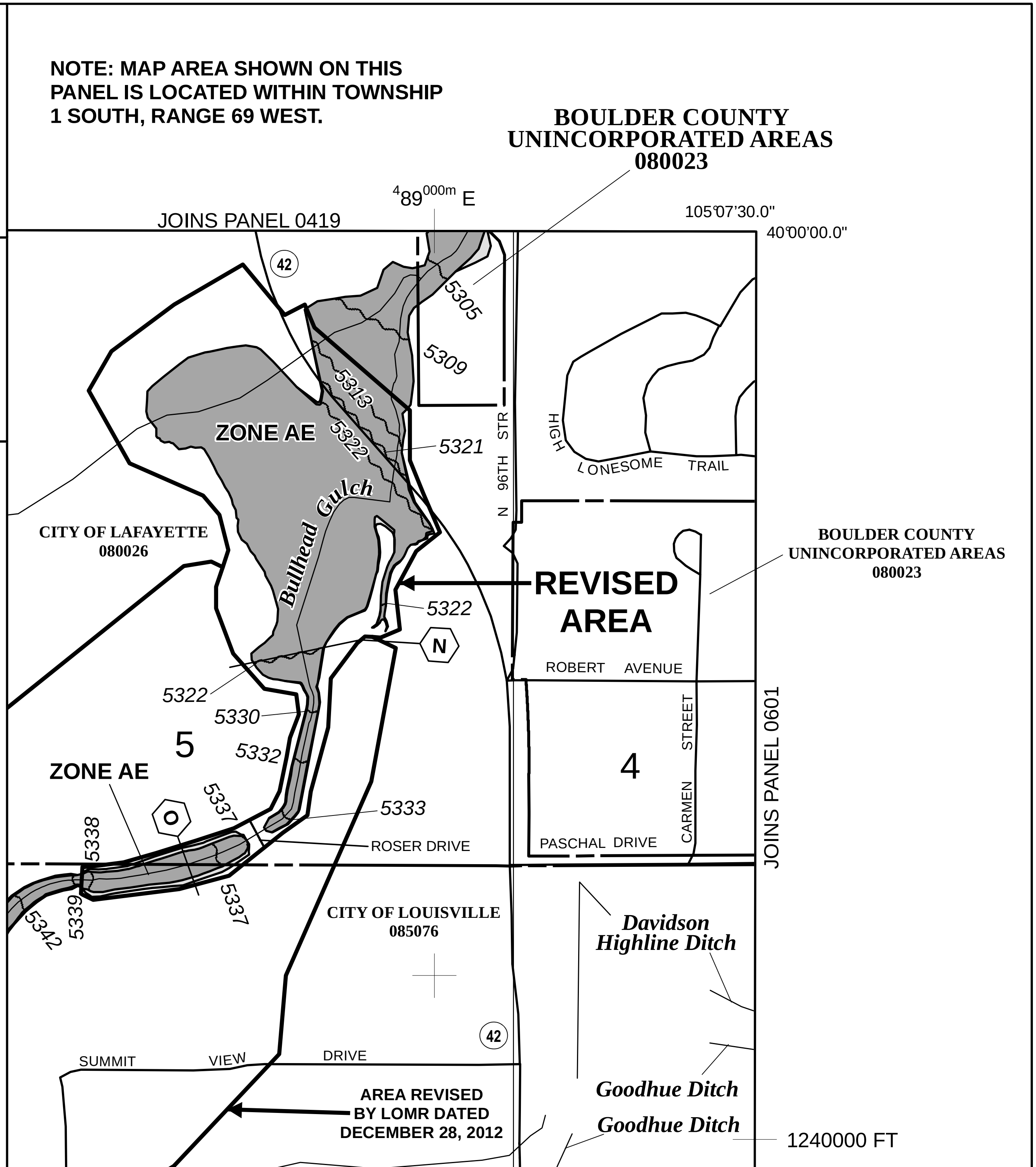
REVISED TO REFLECT LOMR EFFECTIVE: January 24, 2014

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER 08013C0582J

MAP REVISED DECEMBER 18, 2012

Federal Emergency Management Agency

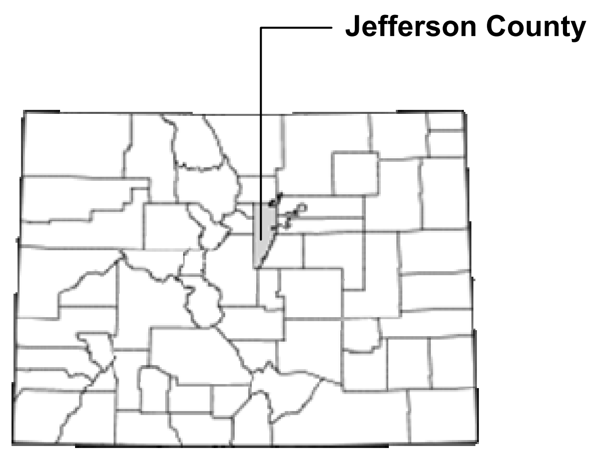


FLOOD INSURANCE STUDY

VOLUME 1 OF 7

JEFFERSON COUNTY, COLORADO

AND INCORPORATED AREAS



Community Name	Community Number
ARVADA, CITY OF	085072
BOW MAR, TOWN OF*	080232
EDGEWATER, CITY OF	080089
GOLDEN, CITY OF	080090
JEFFERSON COUNTY (UNINCORPORATED AREAS)	080087
LAKESIDE, TOWN OF*	080311
LAKEWOOD, CITY OF	085075
MORRISON, TOWN OF	080092
MOUNTAIN VIEW, TOWN OF*	080254
WESTMINSTER, CITY OF	080008
WHEAT RIDGE, CITY OF	085079

*NO SPECIAL FLOOD HAZARD AREAS IDENTIFIED

PRELIMINARY

Notice

This preliminary FIS report includes only revised Flood Profiles and Floodway Data Tables. See “Notice to Flood Insurance Study Users” page for additional details.

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
08059CV001C

COMMUNITY NAME	INITIAL IDENTIFICATION	FLOOD HAZARD BOUNDARY MAP REVISIONS DATE	FIRM EFFECTIVE DATE	FIRM REVISIONS DATE
Arvada, City of	July 13, 1972	---	July 1, 1974 August 16, 1995	April 23, 1976 February 19, 1992 June 17, 2003 February 2, 2014 TBD
*Bow Mar, Town of	---	---	---	---
Edgewater, City of	June 14, 1974	December 19, 1975 November 14, 1978	August 15, 1989	June 17, 2003 February 2, 2014 TBD
Golden, City of	November 5, 1976	---	May 15, 1985	June 17, 2003 February 2, 2014 TBD

* No Special Flood Hazard Areas Identified

TABLE 8

FEDERAL EMERGENCY MANAGEMENT AGENCY

JEFFERSON COUNTY, CO
AND INCORPORATED AREAS

COMMUNITY MAP HISTORY

COMMUNITY NAME	INITIAL IDENTIFICATION	FLOOD HAZARD BOUNDARY MAP REVISIONS DATE	FIRM EFFECTIVE DATE	FIRM REVISIONS DATE
Jefferson County (Unincorporated Areas)	November 22, 1974	July 5, 1977	August 5, 1986	July 4, 1989 June 17, 2003 February 2, 2014 TBD
*Lakeside, Town of	---	---	---	---
Lakewood, City of	July 21, 1972	---	December 31, 1974	January 4, 1974 July 1, 1974 July 1, 1977 March 23, 1979 January 3, 1983 June 17, 2003 February 2, 2014 TBD
Morrison, Town of	September 13, 1974	March 26, 1976	December 1, 1982	June 17, 2003 February 2, 2014 TBD
*Mountain View, Town of	---	---	---	---

* No Special Flood Hazard Areas Identified

TABLE 8

FEDERAL EMERGENCY MANAGEMENT AGENCY

JEFFERSON COUNTY, CO
AND INCORPORATED AREAS

COMMUNITY MAP HISTORY

COMMUNITY NAME	INITIAL IDENTIFICATION	FLOOD HAZARD BOUNDARY MAP REVISIONS DATE	FIRM EFFECTIVE DATE	FIRM REVISIONS DATE
Westminster, City of	June 7, 1974	April 23, 1976	September 30, 1988	April 2, 1991 May 17, 1993 April 2, 1997 June 17, 2003 February 2, 2014 TBD
Wheat Ridge, City of	May 26, 1972	---	May 26,1972	July 1, 1974 July 22, 1977 January 3, 1983 February 4, 1988 June 17, 2003 February 2, 2014 TBD

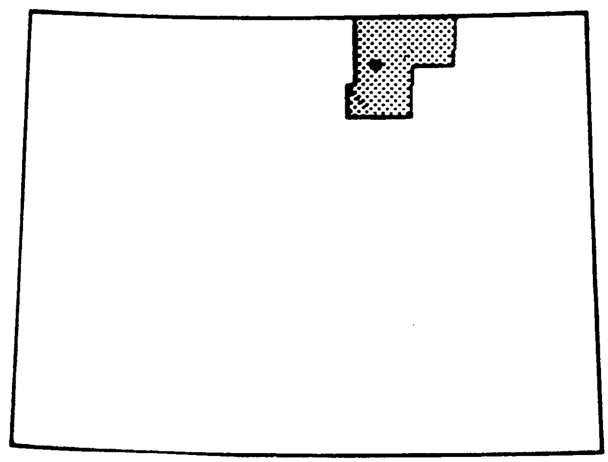
TABLE 8

FEDERAL EMERGENCY MANAGEMENT AGENCY

JEFFERSON COUNTY, CO
AND INCORPORATED AREAS

COMMUNITY MAP HISTORY

FLOOD INSURANCE STUDY



WELD COUNTY, COLORADO
UNINCORPORATED AREAS
AND
TOWN OF EATON, COLORADO
WELD COUNTY

REVISED: SEPTEMBER 22,1999

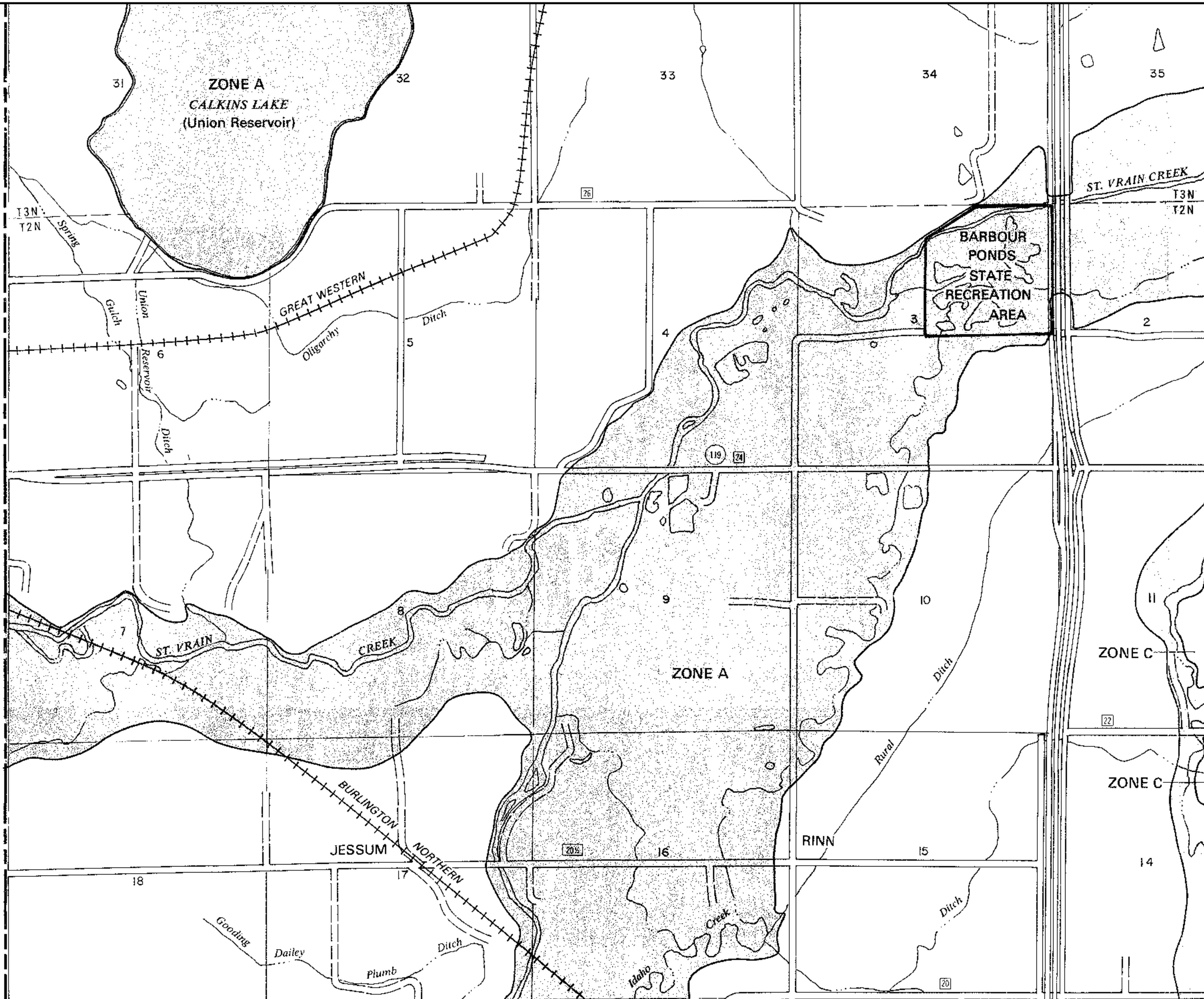
Federal Emergency Management Agency

COMMUNITY NUMBER - 080266

Table 1. Summary of Discharges (Cont'd)

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cubic feet per second) 10-Year	50-Year	100-Year	500-Year
Tri-Area Drainageway					
At Firestone	3.6	540	1,720	1,910	2,550
At Frederick	1.7	440	1,600	1,810	2,190
At Dacono	1.4	310	580	740	1,180
Big Thompson River					
Larimer-Weld County Line	595	3,600	7,600	10,000	18,500
Upstream from Little Thompson River	613	2,200	4,700	6,500	12,000
Downstream from Little Thompson River	813	3,200	7,300	9,900	20,000
Confluence with South Platte River	819	2,500	5,900	8,000	15,000
Coal Creek					
Near Tri-County Airport	68.61	5,970	9,670	11,850	17,860
At Briggs Street	77.48	6,160	10,040	12,280	18,380
The Slough	--[1]	275	1,350	2,150	4,800

[1]Data not available



APPROXIMATE SCALE

2000 0 2000 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP

WELD COUNTY, COLORADO
UNINCORPORATED AREA

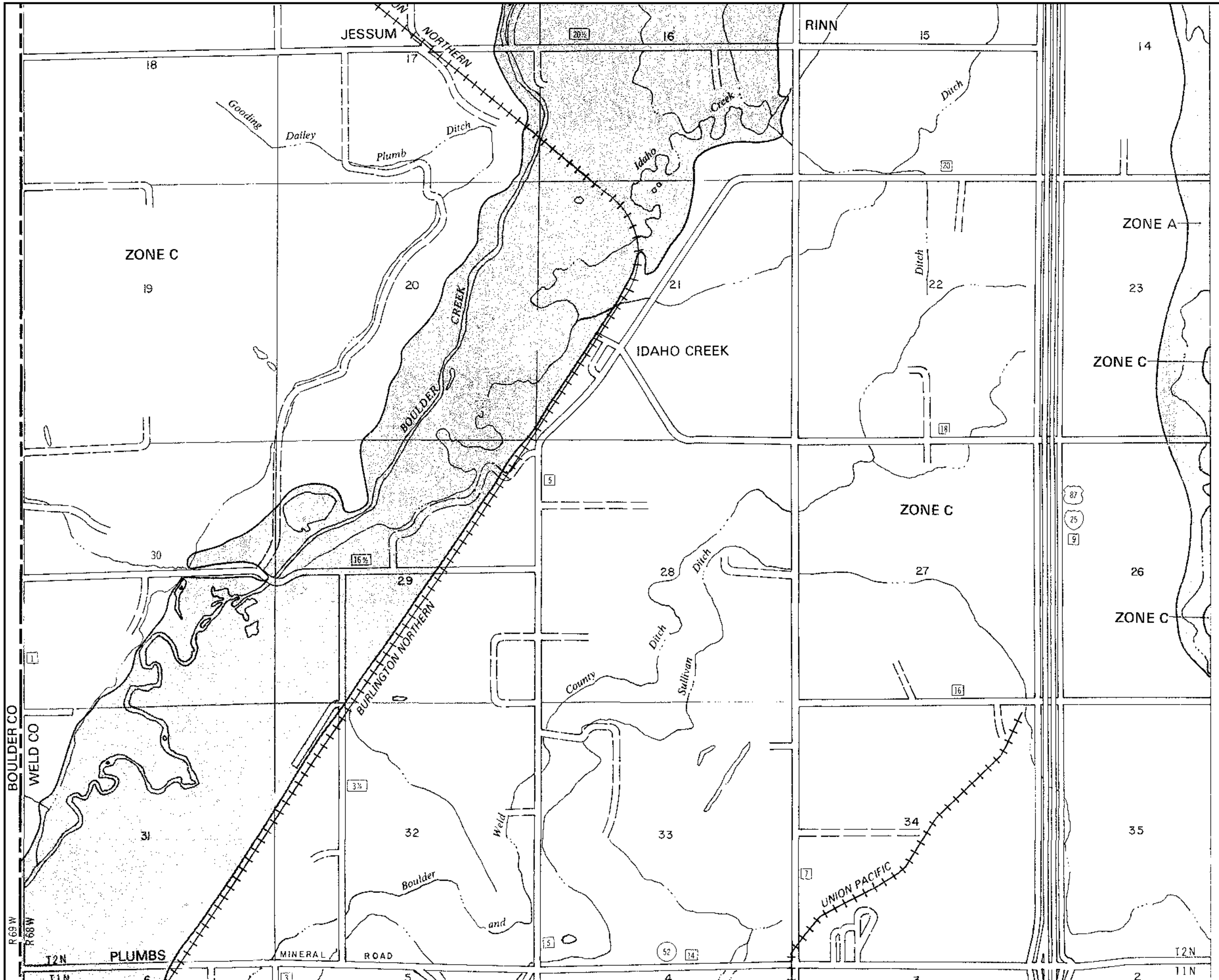
PANEL 850 OF 1075
(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER
080266 0850 C

MAP REVISED:
SEPTEMBER 28. 1982

federal emergency management agency

JR. INC. "A" FRAME



APPROXIMATE SCALE

2000 0 2000 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

WELD COUNTY, COLORADO

UNINCORPORATED AREA

PANEL 850 OF 1075

(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER
080266 0850 C

MAP REVISED:
SEPTEMBER 28, 1982

federal emergency management agency

JR. INC.

"A" FRAME

The following LOMRs have been uploaded to the FEMA Map Server as secured PDF, and can be accessed using the link https://msc.fema.gov/portal/search?AddressQuery=boulder%20county%2C%20co

LOMR Letter Number 11-08-1090P-080181

 | Issue Date: MAY 19 2008 | Effective Date: JUN 18 2008 | Case No.: 08-08-0024P | LOMR-APP

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT

COMMUNITY AND REVISION INFORMATION		PROJECT DESCRIPTION	BASIS OF REQUEST
COMMUNITY	Weld County Colorado (Unincorporated Areas) COMMUNITY NO.: 080266	NO PROJECT	HYDRAULIC ANALYSIS NEW TOPOGRAPHIC DATA
IDENTIFIER	Avocet Subdivision	APPROXIMATE LATITUDE & LONGITUDE: 40.124, -105.022 SOURCE: Precision Mapping Streets DATUM: NAD 83	

ANNOTATED MAPPING ENCLOSURES	ANNOTATED STUDY ENCLOSURES
TYPE: FIRM* NO.: 080266 0850 C DATE: September 28, 1982	NO REVISION TO THE FLOOD INSURANCE STUDY REPORT

Enclosures reflect changes to flooding sources affected by this revision.
* FIRM - Flood Insurance Rate Map; ** FBFM - Flood Boundary and Floodway Map; *** FHBM - Flood Hazard Boundary Map

FLOODING SOURCE(S) & REVISED REACH(ES)

Boulder Creek - from approximately 1,340 feet upstream of the Burlington Northern Railroad to approximately 6,180 feet upstream

SUMMARY OF REVISIONS

Flooding Source	Effective Flooding	Revised Flooding	Increases	Decreases
Boulder Creek	Zone A	Zone A	YES	YES

* BFEs - Base Flood Elevations

DETERMINATION

This document provides the determination from the Department of Homeland Security's Federal Emergency Management Agency (FEMA) regarding a request for a Letter of Map Revision (LOMR) for the area described above. Using the information submitted, we have determined that a revision to the flood hazards depicted in the Flood Insurance Study (FIS) report and/or National Flood Insurance Program (NFIP) map is warranted. This document revises the effective NFIP map, as indicated in the attached documentation. Please use the enclosed annotated map panels revised by this LOMR for floodplain management purposes and for all flood insurance policies and renewals in your community.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMR Depot, 3601 Eisenhower Avenue, Alexandria, VA 22304. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Beth A. Norton

Beth A. Norton, CFM, Program Specialist
Engineering Management Branch
Mitigation Directorate

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

COMMUNITY INFORMATION

APPLICABLE NFIP REGULATIONS/COMMUNITY OBLIGATION

We have made this determination pursuant to Section 206 of the Flood Disaster Protection Act of 1973 (P.L. 93-234) and in accordance with the National Flood Insurance Act of 1968, as amended (Title XIII of the Housing and Urban Development Act of 1968, P.L. 90-448), 42 U.S.C. 4001-4128, and 44 CFR Part 65. Pursuant to Section 1361 of the National Flood Insurance Act of 1968, as amended, communities participating in the NFIP are required to adopt and enforce floodplain management regulations that meet or exceed NFIP criteria. These criteria, including adoption of the FIS report and FIRM, and the modifications made by this LOMR, are the minimum requirements for continued NFIP participation and do not supersede more stringent State/Commonwealth or local requirements to which the regulations apply.

COMMUNITY REMINDERS

We based this determination on the 1-percent-annual-chance flood discharges computed in the FIS for your community without considering subsequent changes in watershed characteristics that could increase flood discharges. Future development of projects upstream could cause increased flood discharges, which could cause increased flood hazards. A comprehensive restudy of your community's flood hazards would consider the cumulative effects of development on flood discharges subsequent to the publication of the FIS report for your community and could, therefore, establish greater flood hazards in this area.

Your community must regulate all proposed floodplain development and ensure that permits required by Federal and/or State/Commonwealth law have been obtained. State/Commonwealth or community officials, based on knowledge of local conditions and in the interest of safety, may set higher standards for construction or may limit development in floodplain areas. If your State/Commonwealth or community has adopted more restrictive or comprehensive floodplain management criteria, those criteria take precedence over the minimum NFIP requirements.

We will not print and distribute this LOMR to primary users, such as local insurance agents or mortgage lenders; instead, the community will serve as a repository for the new data. We encourage you to disseminate the information in this LOMR by preparing a news release for publication in your community's newspaper that describes the revision and explains how your community will provide the data and help interpret the NFIP maps. In that way, interested persons, such as property owners, insurance agents, and mortgage lenders, can benefit from the information.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMR Depot, 3601 Eisenhower Avenue, Alexandria, VA 22304. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Beth A. Norton

Beth A. Norton, CFM, Program Specialist
Engineering Management Branch
Mitigation Directorate

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

We have designated a Consultation Coordination Officer (CCO) to assist your community. The CCO will be the primary liaison between your community and FEMA. For information regarding your CCO, please contact:

Ms. Jeanine D. Petterson
Director, Mitigation Division
Federal Emergency Management Agency, Region VIII
Denver Federal Center, Building 710
P.O. Box 25267
Denver, CO 80225-0267
(303) 235-4830

STATUS OF THE COMMUNITY NFIP MAPS

We will not physically revise and republish the FIRM for your community to reflect the modifications made by this LOMR at this time. When changes to the previously cited FIRM panel(s) warrant physical revision and republication in the future, we will incorporate the modifications made by this LOMR at that time.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMR Depot, 3601 Eisenhower Avenue, Alexandria, VA 22304. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Beth A. Norton

Beth A. Norton, CFM, Program Specialist
Engineering Management Branch
Mitigation Directorate

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT (CONTINUED)

PUBLIC NOTIFICATION OF REVISION

This revision will become effective 30 days from the date of this letter. Any requests to review or alter this determination should be made within 30 days and must be based on scientific or technical data.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMR Depot, 3601 Eisenhower Avenue, Alexandria, VA 22304. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

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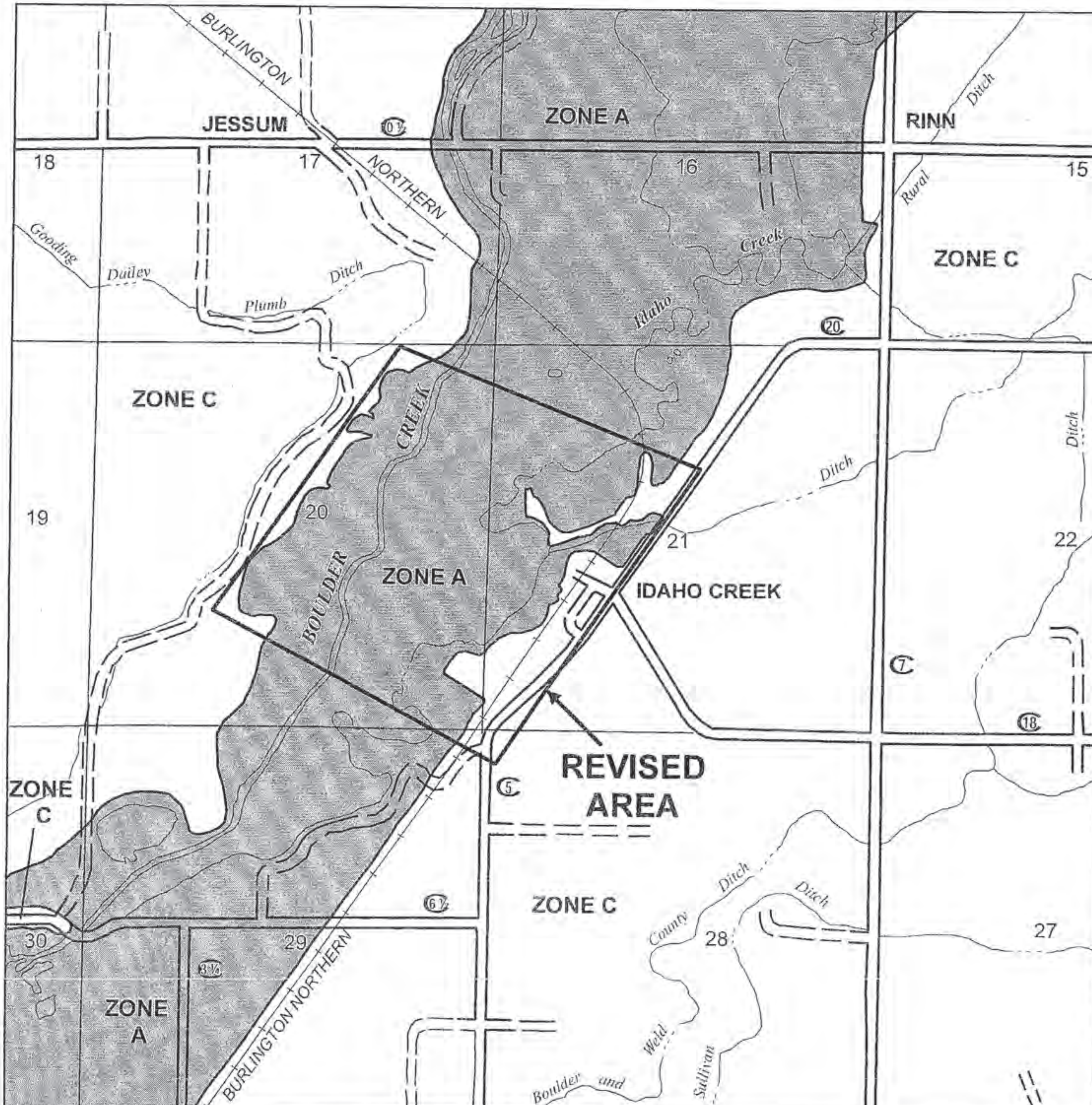
Engineering Management Branch
Mitigation Directorate



Legend

1% annual chance (100-Year) Floodplain

1% annual chance (100-Year) Floodway

0.2% annual chance (500-Year) Floodplain

APPROXIMATE SCALE IN FEET

2,000 0 2,000

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP

WELD COUNTY, COLORADO
UNINCORPORATED AREA

PANEL 850 OF 1075
(SEE MAP INDEX FOR PANELS NOT PRINTED)

REVISED TO REFLECT LOMR EFFECTIVE JUN 1 8 2008

COMMUNITY - PANEL NUMBER
080266 0850 C

MAP REVISED:
SEPTEMBER 28, 1982

Federal Emergency Management Agency

Federal Emergency Management Agency
Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT

COMMUNITY AND REVISION INFORMATION		PROJECT DESCRIPTION	BASIS OF REQUEST
COMMUNITY	**Weld County Colorado (Unincorporated Areas)** **COMMUNITY NO.: 080266**	**BRIDGE CHANNELIZATION**	**HYDRAULIC ANALYSIS NEW TOPOGRAPHIC DATA**
IDENTIFIER	Coal Creek LOMR	**APPROXIMATE LATITUDE & LONGITUDE: 40.055, -105.048** **SOURCE:** Other **DATUM:** NAD 83	

ANNOTATED MAPPING ENCLOSURES	ANNOTATED STUDY ENCLOSURES
TYPE: FIRM* NO.: 080266 0960 D DATE: September 28, 1990	NO REVISION TO THE FLOOD INSURANCE STUDY REPORT

Enclosures reflect changes to flooding sources affected by this revision.
* FIRM - Flood Insurance Rate Map; ** FBFM - Flood Boundary and Floodway Map; *** FHBM - Flood Hazard Boundary Map

FLOODING SOURCE(S) & REVISED REACH(ES)

Coal Creek - from approximately 3,280 feet downstream to just downstream of Cheeseman Street

SUMMARY OF REVISIONS

Flooding Source	Effective Flooding	Revised Flooding	Increases	Decreases
Coal Creek	Zone A	Zone AE	YES	YES
	No BFEs*	BFEs	YES	NONE
	No Floodway	Floodway	YES	NONE

* BFEs - Base Flood Elevations

DETERMINATION

This document provides the determination from the Department of Homeland Security's Federal Emergency Management Agency (FEMA) regarding a request for a Letter of Map Revision (LOMR) for the area described above. Using the information submitted, we have determined that a revision to the flood hazards depicted in the Flood Insurance Study (FIS) report and/or National Flood Insurance Program (NFIP) map is warranted. This document revises the effective NFIP map, as indicated in the attached documentation. Please use the enclosed annotated map panels revised by this LOMR for floodplain management purposes and for all flood insurance policies and renewals in your community.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 6730 Santa Barbara Court, Elkridge, MD 21075. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

David N. Bascom, CFM, Program Specialist
Engineering Management Branch
Mitigation Directorate

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

OTHER COMMUNITIES AFFECTED BY THIS REVISION

CID Number: 080181 **Name:** Town of Erie, Colorado

AFFECTED MAP PANELS	AFFECTED PORTIONS OF THE FLOOD INSURANCE STUDY REPORT
TYPE: FIRM* NO.: 080181 0016 E DATE: December 2, 2004	DATE OF EFFECTIVE FLOOD INSURANCE STUDY: December 2, 2002 PROFILE(S): 02P FLOODWAY DATA TABLE: 2

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 6730 Santa Barbara Court, Elkridge, MD 21075. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

David N. Bascom, CFM, Program Specialist
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Mitigation Directorate

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

COMMUNITY INFORMATION

APPLICABLE NFIP REGULATIONS/COMMUNITY OBLIGATION

We have made this determination pursuant to Section 206 of the Flood Disaster Protection Act of 1973 (P.L. 93-234) and in accordance with the National Flood Insurance Act of 1968, as amended (Title XIII of the Housing and Urban Development Act of 1968, P.L. 90-448), 42 U.S.C. 4001-4128, and 44 CFR Part 65. Pursuant to Section 1361 of the National Flood Insurance Act of 1968, as amended, communities participating in the NFIP are required to adopt and enforce floodplain management regulations that meet or exceed NFIP criteria. These criteria, including adoption of the FIS report and FIRM, and the modifications made by this LOMR, are the minimum requirements for continued NFIP participation and do not supersede more stringent State/Commonwealth or local requirements to which the regulations apply.

We provide the floodway designation to your community as a tool to regulate floodplain development. Therefore, the floodway revision we have described in this letter, while acceptable to us, must also be acceptable to your community and adopted by appropriate community action, as specified in Paragraph 60.3(d) of the NFIP regulations.

NFIP regulations Subparagraph 60.3(b)(7) requires communities to ensure that the flood-carrying capacity within the altered or relocated portion of any watercourse is maintained. This provision is incorporated into your community's existing floodplain management ordinances; therefore, responsibility for maintenance of the altered or relocated watercourse, including any related appurtenances such as bridges, culverts, and other drainage structures, rests with your community. We may request that your community submit a description and schedule of maintenance activities necessary to ensure this requirement.

COMMUNITY REMINDERS

We based this determination on the 1-percent-annual-chance flood discharges computed in the FIS for your community without considering subsequent changes in watershed characteristics that could increase flood discharges. Future development of projects upstream could cause increased flood discharges, which could cause increased flood hazards. A comprehensive restudy of your community's flood hazards would consider the cumulative effects of development on flood discharges subsequent to the publication of the FIS report for your community and could, therefore, establish greater flood hazards in this area.

Your community must regulate all proposed floodplain development and ensure that permits required by Federal and/or State/Commonwealth law have been obtained. State/Commonwealth or community officials, based on knowledge of local conditions and in the interest of safety, may set higher standards for construction or may limit development in floodplain areas. If your State/Commonwealth or community has adopted more restrictive or comprehensive floodplain management criteria, those criteria take precedence over the minimum NFIP requirements.

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This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 6730 Santa Barbara Court, Elkridge, MD 21075. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

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Mitigation Directorate

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

We have designated a Consultation Coordination Officer (CCO) to assist your community. The CCO will be the primary liaison between your community and FEMA. For information regarding your CCO, please contact:

Ms. Jeanine D. Petterson
Director, Mitigation Division
Federal Emergency Management Agency, Region VIII
Denver Federal Center, Building 710
P.O. Box 25267
Denver, CO 80225-0267
(303) 235-4830

STATUS OF THE COMMUNITY NFIP MAPS

We will not physically revise and republish the FIRM for your community to reflect the modifications made by this LOMR at this time. When changes to the previously cited FIRM panel(s) warrant physical revision and republication in the future, we will incorporate the modifications made by this LOMR at that time.

Although the project area is shown on the above-referenced FIRM panel as within Weld County, the Town of Erie has annexed portions of this area. We have not reflected these corporate limits changes in this LOMR. Please see the Town of Erie FIRM for updated corporate limits.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 6730 Santa Barbara Court, Elkridge, MD 21075. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

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Engineering Management Branch
Mitigation Directorate

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

PUBLIC NOTIFICATION OF REVISION

PUBLIC NOTIFICATION

FLOODING SOURCE	LOCATION OF REFERENCED ELEVATION	BFE (FEET NAVD 88)		MAP PANEL NUMBER(S)
		EFFECTIVE	REVISED	
Coal Creek	Just upstream of Briggs Street	None	5,014	080266 0960 D

Within 90 days of the second publication in the local newspaper, a citizen may request that we reconsider this determination. Any request for reconsideration must be based on scientific or technical data. Therefore, this letter will be effective only after the 90-day appeal period has elapsed and we have resolved any appeals that we receive during this appeal period. Until this LOMR is effective, the revised BFEs presented in this LOMR may be changed.

A notice of changes will be published in the *Federal Register*. This information also will be published in your local newspaper on or about the dates listed below.

LOCAL NEWSPAPER Name: *The Greeley Tribune*
Dates: 10/30/2009 11/06/2009

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 6730 Santa Barbara Court, Elkridge, MD 21075. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

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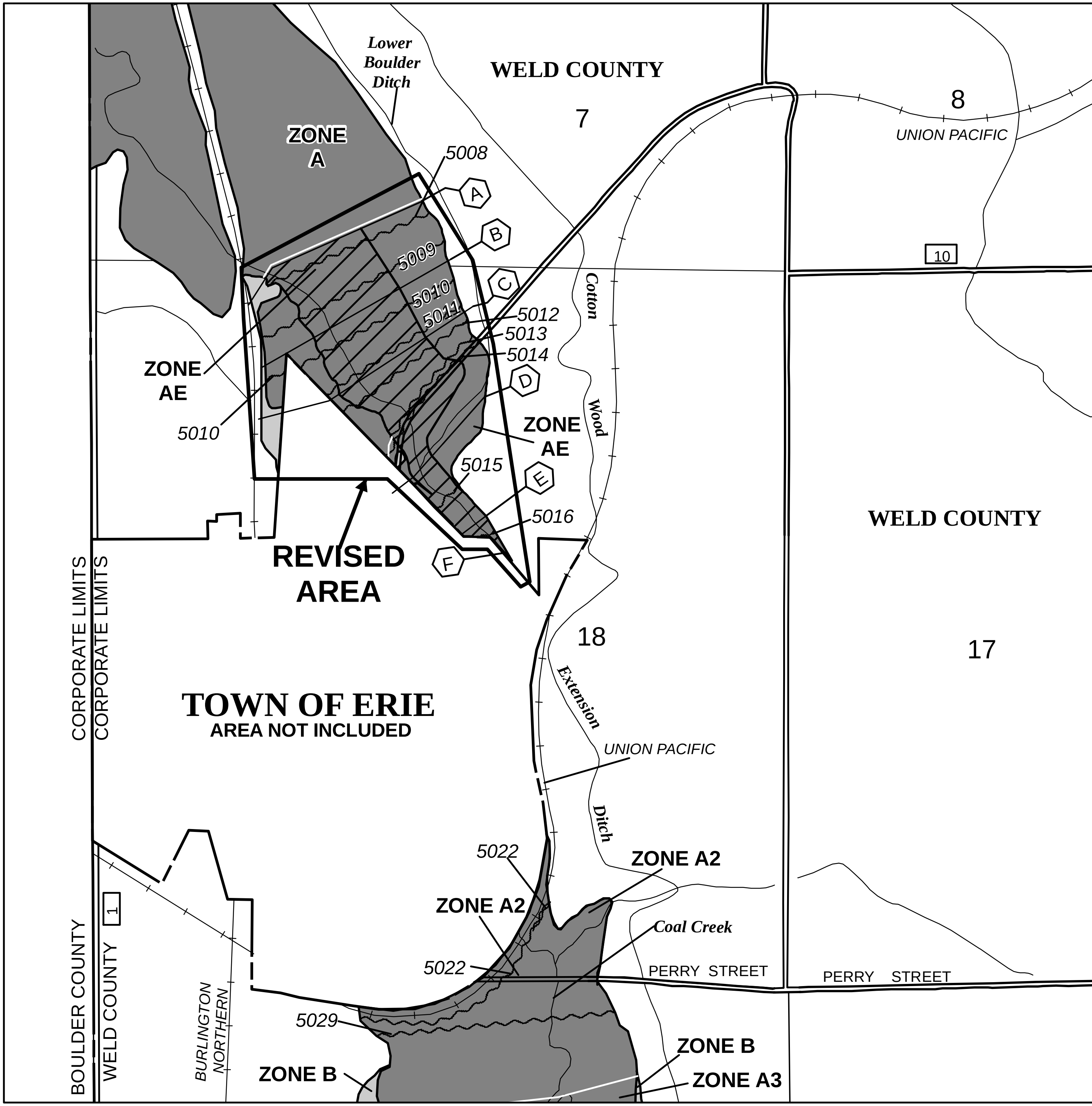
Engineering Management Branch
Mitigation Directorate



Legend

	1% annual chance (100-Year) Floodplain
	1% annual chance (100-Year) Floodway
	0.2% annual chance (500-Year) Floodplain

APPROXIMATE SCALE IN FEET

1,000 0 1,000

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP

WELD COUNTY, COLORADO
(UNINCORPORATED AREAS)

PANEL 960 OF 1075
(SEE MAP INDEX FOR PANELS NOT PRINTED)

REVISED TO
REFLECT LOMR
EFFECTIVE: **March 6, 2010**

COMMUNITY-PANEL NUMBER
080266 0960D

MAP REVISED:
SEPTEMBER 28, 1990

Federal Emergency Management Agency

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT

COMMUNITY AND REVISION INFORMATION		PROJECT DESCRIPTION	BASIS OF REQUEST
COMMUNITY	**Weld County Colorado (Unincorporated Areas)** **COMMUNITY NO.: 080266**	**EXCAVATION**	**FLOODWAY** **HYDRAULIC ANALYSIS** **NEW TOPOGRAPHIC DATA**
IDENTIFIER	Boulder Creek- McCully/ Schell Properties	**APPROXIMATE LATITUDE & LONGITUDE: 40.136, -105.013** **SOURCE:** USGS QUADRANGLE **DATUM:** NAD 83	

ANNOTATED MAPPING ENCLOSURES	ANNOTATED STUDY ENCLOSURES
TYPE: FIRM* NO.: 0802660850C DATE: September 28, 1982	DATE OF EFFECTIVE FLOOD INSURANCE STUDY: September 22, 1999 PROFILE(S): 85P(e) AND 85P(f) FLOODWAY DATA TABLE: 2

Enclosures reflect changes to flooding sources affected by this revision.
* FIRM - Flood Insurance Rate Map; ** FBFM - Flood Boundary and Floodway Map; *** FHBM - Flood Hazard Boundary Map

FLOODING SOURCE(S) & REVISED REACH(ES)

Boulder Creek - from approximately 1,000 feet downstream to approximately 4,200 feet upstream of County Road 20 1/2

SUMMARY OF REVISIONS

Flooding Source	Effective Flooding	Revised Flooding	Increases	Decreases
Boulder Creek	Zone A	Zone AE	YES	YES
	No BFEs*	BFEs	YES	NONE
	No Floodway	Floodway	YES	NONE

* BFEs - Base Flood Elevations

DETERMINATION

This document provides the determination from the Department of Homeland Security's Federal Emergency Management Agency (FEMA) regarding a request for a Letter of Map Revision (LOMR) for the area described above. Using the information submitted, we have determined that a revision to the flood hazards depicted in the Flood Insurance Study (FIS) report and/or National Flood Insurance Program (NFIP) map is warranted. This document revises the effective NFIP map, as indicated in the attached documentation. Please use the enclosed annotated map panels revised by this LOMR for floodplain management purposes and for all flood insurance policies and renewals in your community.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Erin E. Cobb, CFM, Program Specialist
Engineering Management Branch
Federal Insurance and Mitigation Administration

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT (CONTINUED)

OTHER COMMUNITIES AFFECTED BY THIS REVISION

CID Number: 080244 **Name:** Town of Frederick, Colorado

AFFECTED MAP PANELS	AFFECTED PORTIONS OF THE FLOOD INSURANCE STUDY REPORT
TYPE: FIRM* NO.: 0802660850C DATE: September 28, 1982	DATE OF EFFECTIVE FLOOD INSURANCE STUDY: September 22, 1999 PROFILE(S): 85P(e) AND 85P(f) FLOODWAY DATA TABLE: 2

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Erin E. Cobb, CFM, Program Specialist
Engineering Management Branch
Federal Insurance and Mitigation Administration

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT (CONTINUED)

COMMUNITY INFORMATION

APPLICABLE NFIP REGULATIONS/COMMUNITY OBLIGATION

We have made this determination pursuant to Section 206 of the Flood Disaster Protection Act of 1973 (P.L. 93-234) and in accordance with the National Flood Insurance Act of 1968, as amended (Title XIII of the Housing and Urban Development Act of 1968, P.L. 90-448), 42 U.S.C. 4001-4128, and 44 CFR Part 65. Pursuant to Section 1361 of the National Flood Insurance Act of 1968, as amended, communities participating in the NFIP are required to adopt and enforce floodplain management regulations that meet or exceed NFIP criteria. These criteria, including adoption of the FIS report and FIRM, and the modifications made by this LOMR, are the minimum requirements for continued NFIP participation and do not supersede more stringent State/Commonwealth or local requirements to which the regulations apply.

We provide the floodway designation to your community as a tool to regulate floodplain development. Therefore, the floodway revision we have described in this letter, while acceptable to us, must also be acceptable to your community and adopted by appropriate community action, as specified in Paragraph 60.3(d) of the NFIP regulations.

COMMUNITY REMINDERS

We based this determination on the 1-percent-annual-chance flood discharges computed in the FIS for your community without considering subsequent changes in watershed characteristics that could increase flood discharges. Future development of projects upstream could cause increased flood discharges, which could cause increased flood hazards. A comprehensive restudy of your community's flood hazards would consider the cumulative effects of development on flood discharges subsequent to the publication of the FIS report for your community and could, therefore, establish greater flood hazards in this area.

Your community must regulate all proposed floodplain development and ensure that permits required by Federal and/or State/Commonwealth law have been obtained. State/Commonwealth or community officials, based on knowledge of local conditions and in the interest of safety, may set higher standards for construction or may limit development in floodplain areas. If your State/Commonwealth or community has adopted more restrictive or comprehensive floodplain management criteria, those criteria take precedence over the minimum NFIP requirements.

We will not print and distribute this LOMR to primary users, such as local insurance agents or mortgage lenders; instead, the community will serve as a repository for the new data. We encourage you to disseminate the information in this LOMR by preparing a news release for publication in your community's newspaper that describes the revision and explains how your community will provide the data and help interpret the NFIP maps. In that way, interested persons, such as property owners, insurance agents, and mortgage lenders, can benefit from the information.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

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Engineering Management Branch
Federal Insurance and Mitigation Administration

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

We have designated a Consultation Coordination Officer (CCO) to assist your community. The CCO will be the primary liaison between your community and FEMA. For information regarding your CCO, please contact:

Ms. Jeanine D. Petterson
Director, Mitigation Division
Federal Emergency Management Agency, Region VIII
Denver Federal Center, Building 710
P.O. Box 25267
Denver, CO 80225-0267
(303) 235-4830

STATUS OF THE COMMUNITY NFIP MAPS

We will not physically revise and republish the FIRM and FIS report for your community to reflect the modifications made by this LOMR at this time. When changes to the previously cited FIRM panel(s) and FIS report warrant physical revision and republication in the future, we will incorporate the modifications made by this LOMR at that time.

As part of this revision, the format of the map panels has changed. Previously, flood hazard information was shown on both the FIRM and the Flood Boundary and Floodway Map (FBFM). In the new format, all BFEs, cross sections, zone designations, and floodplain and floodway boundary delineations are shown on the FIRM, and the FBFM has been eliminated. Some of the flood insurance zone designations were changed to reflect the new format. Areas previously shown as numbered Zone A were changed to Zone AE. Areas previously shown as Zone B were changed to Zone X (shaded). Areas previously shown as Zone C were changed to Zone X (unshaded).

Portions of the revision area have been annexed by the Town of Frederick; however, these corporate limits changes are not reflected in this LOMR.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Erin E. Cobb

Erin E. Cobb, CFM, Program Specialist
Engineering Management Branch
Federal Insurance and Mitigation Administration

Federal Emergency Management Agency

Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

PUBLIC NOTIFICATION OF REVISION

A notice of changes will be published in the *Federal Register*. This information also will be published in your local newspaper on or about the dates listed below and through FEMA's Flood Hazard Mapping website at https://www.floodmaps.fema.gov/fhm/Scripts/bfe_main.asp.

LOCAL NEWSPAPER Name: *The Greeley Tribune*
Dates: August 22, 2013 and August 29, 2013

Within 90 days of the second publication in the local newspaper, a citizen may request that we reconsider this determination. Any request for reconsideration must be based on scientific or technical data. Therefore, this letter will be effective only after the 90-day appeal period has elapsed and we have resolved any appeals that we receive during this appeal period. Until this LOMR is effective, the revised flood hazard determination information presented in this LOMR may be changed.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Information eXchange (FMIX) toll free at 1-877-336-2627 (1-877-FEMA MAP) or by letter addressed to the LOMC Clearinghouse, 847 South Pickett Street, Alexandria, VA 22304-4605. Additional Information about the NFIP is available on our website at http://www.fema.gov/nfip.

Erin E. Cobb

Erin E. Cobb, CFM, Program Specialist
Engineering Management Branch
Federal Insurance and Mitigation Administration

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	**DISTANCE**	**WIDTH (FEET)**	**SECTION AREA (SQUARE FEET)**	**MEAN VELOCITY (FEET PER SECOND)**	**REGULATORY**	**WITHOUT FLOODWAY (FEET NGVD)**	**WITH FLOODWAY (FEET NGVD)**	**INCREASE**
Boulder Creek				REVISED DATA				
N	8,704[1]	3,481	9,683	2.2	4,876.5	4,876.5	4,876.9	0.4
O	10,054[1]	2,242	14,810	5.1	4,880.7	4,880.7	4,881.2	0.5
P	12,330[1]	1,279	5,025	3.8	4,887.5	4,887.5	4,887.6	0.1
		DATA REVISED BY LOMR DATED April 15, 2013						
R	16,900[1]	2,953	10,558	1.3	4,900.9	4,900.9	4,901.2	0.3
S	18,095[1]	1,232	2,519	3.4	4,904.6	4,904.6	4,904.6	0.0
T	19,435[1]	529	1,463	5.9	4,905.7	4,905.7	4,905.7	0.0
U	21,750[1]	1,246	10,393	2.2	4,913.0	4,913.0	4,913.1	0.1
V	24,030[1]	1,138	3,084	4.5	4,921.1	4,921.1	4,921.3	0.2
W	26,020[1]	1,971	4,223	3.3	4,925.7	4,925.7	4,926.0	0.3
X	28,145[1]	96	253	9.1	4,929.8	4,929.8	4,930.2	0.4
Y	30,070[1]	72	364	6.3	4,938.2	4,938.2	4,938.4	0.2
Z	32,275[1]	1,483	3,210	4.3	4,944.5	4,944.5	4,944.6	0.1
Boulder Creek Turnpike								
A	2,135[2]	830	17,672	3.0	4,929.0	4,929.0	4,929.5	0.5
B	3,560[2]	653	10,719	3.6	4,929.5	4,929.5	4,929.8	0.3
		DATA REVISED BY LOMR DATED MARCH 25, 2013						
Boulder Creek Diversion								
A	710[2]	1,460	7,625	1.7	4,902.0	4,902.0	4,902.0	0.0
B	2,225[2]	1,384	3,854	2.1	4,902.4	4,902.4	4,902.4	0.0
		DATA REVISED BY LOMR DATED April 15, 2013						

[1] Stream distance in feet above mouth

[2] Stream distance in feet above confluence with Boulder Creek

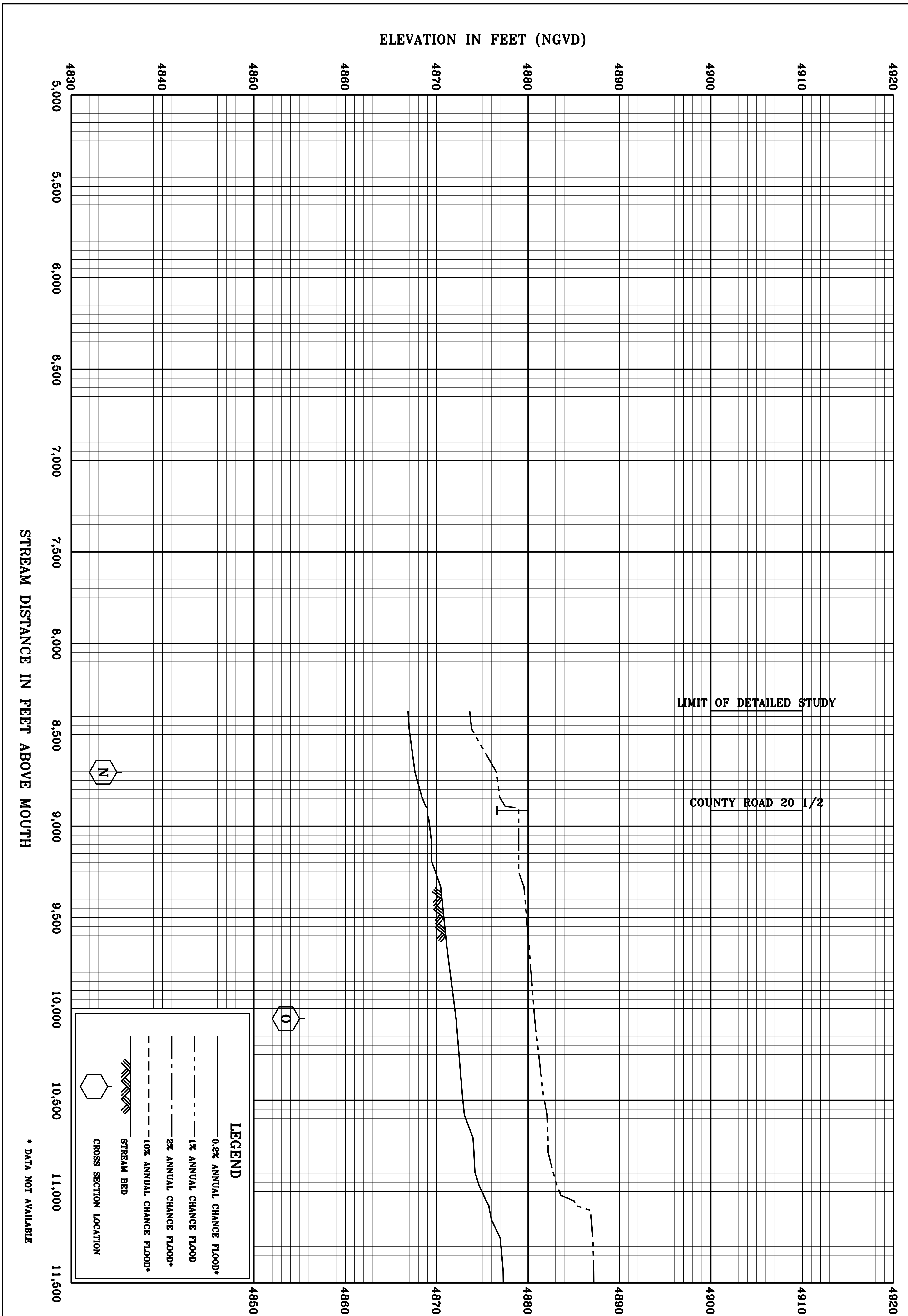
TABLE 2

FEDERAL EMERGENCY MANAGEMENT AGENCY
WELD COUNTY, CO
(UNINCORPORATED AREAS)

FLOODWAY DATA

BOULDER CREEK - BOULDER CREEK TURNPIKE
BOULDER CREEK DIVERSION

REVISED TO
REFLECT LOMR
EFFECTIVE: December 27, 2013



85P(e)

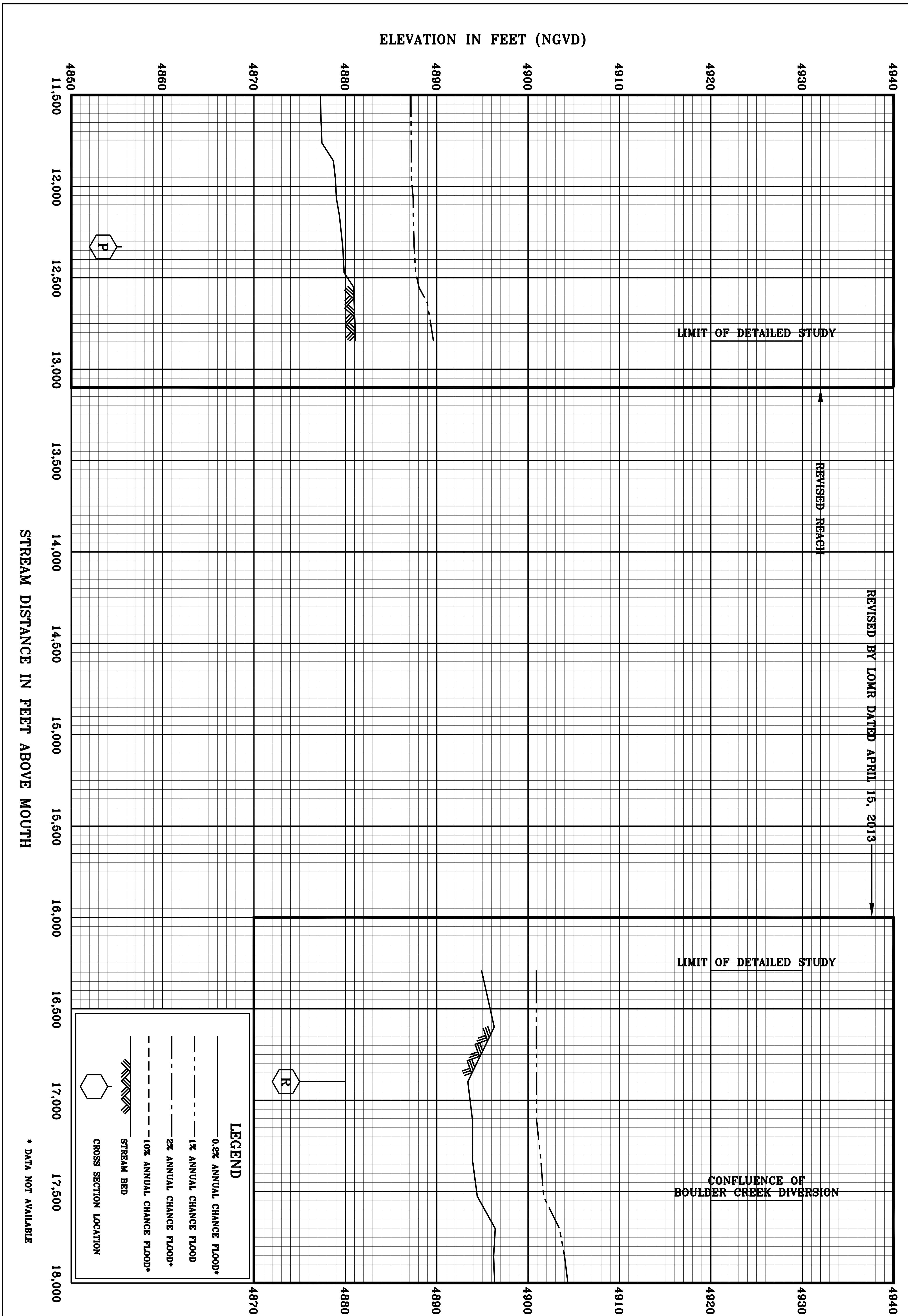
FEDERAL EMERGENCY MANAGEMENT AGENCY

WELD COUNTY, CO
(UNINCORPORATED AREAS)

FLOOD PROFILES

BOULDER CREEK

REVISED TO
REFLECT LOMR
EFFECTIVE: December 27, 2013



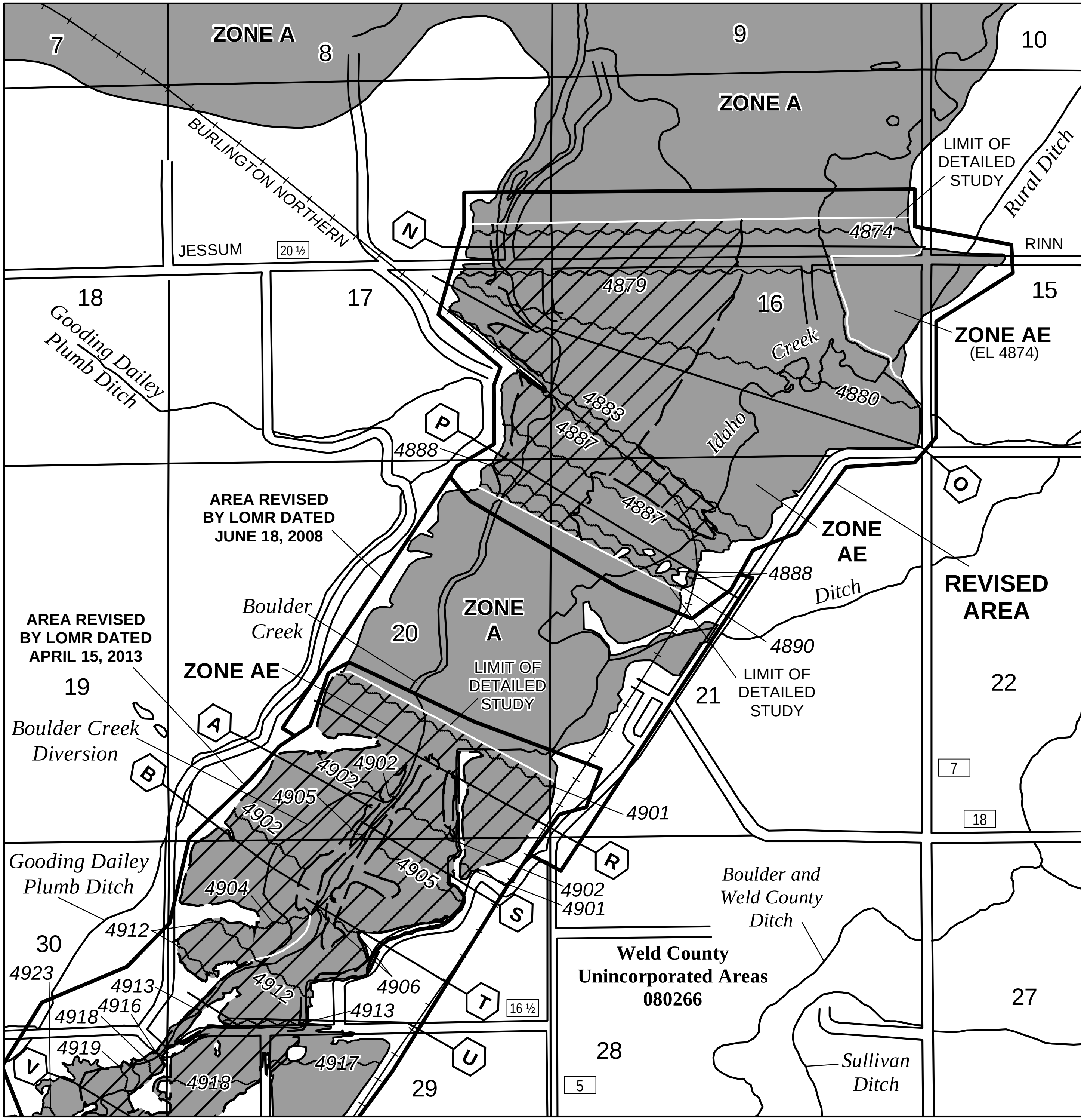
FEDERAL EMERGENCY MANAGEMENT AGENCY

WELD COUNTY, CO
(UNINCORPORATED AREAS)

FLOOD PROFILES

BOULDER CREEK

REVISED TO
REFLECT LOMR
EFFECTIVE: December 27, 2013



Legend

1% annual chance (100-Year) Floodplain

1% annual chance (100-Year) Floodway

0.2% annual chance (500-Year) Floodplain

APPROXIMATE SCALE IN FEET

2,000 0 2,000

NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

WELD COUNTY, COLORADO

UNINCORPORATED AREA

PANEL 850 OF 1075

(SEE MAP INDEX FOR PANELS NOT PRINTED)

REVISED TO REFLECT LOMR EFFECTIVE: December 27, 2013

COMMUNITY - PANEL NUMBER
080266 0850 C

MAP REVISED:
SEPTEMBER 28, 1982

Federal Emergency Management Agency

Appendix B
Hydrologic Analysis and Parameters

Table B-1

24-hour Boulder Creek Models: Hydrologic Zone, Subbasin Area, and Curve Number (CN)

Basin ID	Hydrologic Zone	Calibrated		Predictive	
		Area mi^2	CN	Area mi^2	CN
BC-2A	Phase 1, Boulder Canyon	1.23	77.9	1.23	61.6
BC-2B	Phase 1, Boulder Canyon	2.51	73.8	2.51	55.5
BC-3A	Phase 1, Boulder Canyon	0.54	75.4	0.54	57.8
BC-3B	Phase 1, Boulder Canyon	0.50	78.4	0.50	61.5
BC-3C	Phase 1, Boulder Canyon	1.96	74.1	1.96	55.9
BC-4	Phase 1, Boulder Canyon	2.57	79.7	2.57	64.1
BC-5A	Phase 1, Boulder Canyon	1.72	77.7	1.72	60.9
BC-5B	Phase 1, Boulder Canyon	1.60	72.6	1.60	53.9
BC-6A	Phase 1, Boulder Canyon	0.63	80.1	0.63	64.0
BC-6B	Phase 1, Boulder Canyon	2.05	72.1	2.05	53.4
BC-7	Phase 2, Foothills	1.89	76.5	1.89	60.5
BC-8	Phase 2, Foothills	1.99	70.8	1.99	52.9
BC-9	Phase 2, Foothills	1.89	80.9	1.89	66.1
BC-10	Phase 2, Plains	3.04	80.9	3.04	66.5
BC-11	Phase 2, Plains	0.65	76.4	0.75	65.7
BC-12A	Phase 2, Plains	3.75	83.6	3.75	70.5
BC-12B	Phase 2, Plains	1.23	72.0	1.85	71.0
BC-13	Phase 2, Plains	1.22	72.8	1.26	58.2
BC-14	Phase 2, Plains	1.72	78.5	1.94	67.2
BC-15	Phase 2, Plains	5.61	83.8	6.04	73.0
BC-16A	Phase 2, Plains	6.22	80.7	6.34	67.0
BC-16B	Phase 2, Plains	2.63	82.6	2.63	69.8
BC-17	Phase 2, Plains	3.80	91.6	3.80	83.4
BC-18	Phase 2, Plains	3.68	83.0	4.00	72.6
BC-19A	Phase 2, Plains	4.09	88.7	4.77	81.8
BC-19B	Phase 2, Plains	5.32	89.2	5.47	79.9
BC-19C	Phase 2, Plains	3.59	89.4	3.59	80.1
BC-20	Phase 2, Plains	4.65	87.7	5.05	79.4
BCC-1	Phase 2, Plains	4.84	70.2	4.84	53.0
CC-1	Phase 2, Foothills	8.65	81.7	8.65	68.3
CC-2	Phase 2, Foothills	6.46	80.0	6.46	64.5
CC-3	Phase 2, Plains	5.31	80.9	5.37	66.2
CC-4	Phase 2, Plains	7.56	78.6	7.56	62.9
CC-5	Phase 2, Plains	4.16	81.2	4.16	66.4
CC-6	Phase 2, Plains	4.37	83.2	4.37	69.9
CC-7	Phase 2, Plains	2.57	90.2	2.57	80.4
CC-8	Phase 2, Plains	5.78	84.4	5.78	71.6
CC-9	Phase 2, Plains	1.92	90.4	1.92	80.7
CC-10A	Phase 2, Plains	2.14	87.3	2.14	75.9
CC-10B	Phase 2, Plains	2.47	90.1	2.47	80.0
CC-11	Phase 2, Plains	3.81	86.9	3.81	75.1
CC-12	Phase 2, Plains	4.09	85.7	4.09	73.6

Basin ID	Hydrologic Zone	Calibrated		Predictive	
		Area mi^2	CN	Area mi^2	CN
DC-1	Phase 2, Plains	7.04	78.1	7.04	63.4
DC-2	Phase 2, Plains	5.33	81.8	5.33	69.1
FCC-1	Phase 2, Foothills	4.01	74.3	4.01	57.2
FCC-2	Phase 2, Foothills	3.67	74.3	3.67	57.8
FCC-3	Phase 2, Plains	2.38	81.8	2.38	67.2
FMC-1	Phase 1, Fourmile Creek	2.59	69.1	2.59	50.8
FMC-2A	Phase 1, Fourmile Creek	2.44	72.4	2.44	54.7
FMC-2B	Phase 1, Fourmile Creek	1.83	75.4	1.83	57.9
FMC-3A	Phase 1, Fourmile Creek	3.76	75.1	3.76	58.7
FMC-3B	Phase 1, Fourmile Creek	2.58	76.2	2.58	59.2
FMC-4A	Phase 1, Fourmile Creek	2.75	81.2	2.75	66.9
FMC-4B	Phase 1, Fourmile Creek	1.67	81.4	1.67	67.5
FMC-4C	Phase 1, Fourmile Creek	1.19	76.6	1.19	59.2
FMC-5A	Phase 1, Fourmile Creek	1.16	83.5	1.16	70.7
FMC-5B	Phase 1, Fourmile Creek	1.47	83.7	1.47	69.9
FMC-6A	Phase 1, Fourmile Creek	1.73	86.4	1.73	74.5
FMC-6B	Phase 1, Fourmile Creek	1.13	83.2	1.13	69.7
MBC-1A	Phase 1, Middle Boulder Creek	4.31	72.0	4.31	72.0
MBC-1B	Phase 1, Middle Boulder Creek	1.75	66.6	1.75	66.6
MBC-2	Phase 1, Middle Boulder Creek	5.79	77.7	5.79	77.7
MBC-3A	Phase 1, Middle Boulder Creek	5.74	76.9	5.74	60.6
MBC-3B	Phase 1, Middle Boulder Creek	5.76	78.8	5.76	63.7
MBC-4	Phase 1, Middle Boulder Creek	4.82	74.1	4.82	56.5
MBC-5A	Phase 1, Middle Boulder Creek	5.47	73.9	5.47	56.0
MBC-5B	Phase 1, Middle Boulder Creek	2.93	75.9	2.93	59.0
MBC-6	Phase 1, Middle Boulder Creek	2.13	83.8	2.13	71.1
MBC-7A	Phase 1, Middle Boulder Creek	1.97	78.4	1.97	62.2
MBC-7B	Phase 1, Middle Boulder Creek	3.67	71.7	3.67	52.9
NBC-1A	Phase 1, North Boulder Creek	3.40	81.8	3.40	70.1
NBC-1B	Phase 1, North Boulder Creek	5.31	80.9	5.31	69.0
NBC-2	Phase 1, North Boulder Creek	5.10	66.7	5.10	47.8
NBC-3	Phase 1, North Boulder Creek	4.85	64.9	4.85	45.8
NBC-4	Phase 1, North Boulder Creek	4.55	64.8	4.55	45.3
NBC-5A	Phase 1, North Boulder Creek	3.38	71.4	3.38	53.7
NBC-5B	Phase 1, North Boulder Creek	4.00	68.9	4.00	50.7
NBC-5C	Phase 1, North Boulder Creek	2.52	74.3	2.52	56.8
NBC-6A	Phase 1, North Boulder Creek	5.83	74.8	5.83	57.4
NBC-6B	Phase 1, North Boulder Creek	3.57	77.1	3.57	60.3
NBC-7	Phase 1, North Boulder Creek	2.27	80.5	2.27	65.4
RC-1	Phase 2, Plains	4.69	83.9	4.69	70.2
RC-2	Phase 2, Plains	4.06	85.4	4.06	73.1
RC-3A	Phase 2, Plains	3.21	87.3	3.21	76.1
RC-3B	Phase 2, Plains	3.10	88.3	3.10	77.5

Basin ID	Hydrologic Zone	Calibrated		Predictive	
		Area mi^2	CN	Area mi^2	CN
RC-4	Phase 2, Plains	6.60	88.9	6.60	78.5
SBC-1A	Phase 2, Mountains	11.58	59.0	11.58	59.0
SBC-1B	Phase 2, Mountains	8.96	54.4	8.96	54.4
SBC-2A	Phase 2, Mountains	7.81	64.8	7.81	45.9
SBC-2B	Phase 2, Mountains	2.06	70.2	2.06	53.5
SBC-3	Phase 2, Mountains	6.08	65.1	6.08	46.0
SBC-4	Phase 2, Mountains	3.19	64.0	3.19	44.5
SBC-5	Phase 2, Mountains	4.30	71.5	4.30	53.7
SBC-6	Phase 2, Mountains	7.67	67.4	7.67	49.0
SBC-7	Phase 2, Foothills	8.87	75.2	8.87	60.3
SBC-8A	Phase 2, Mountains	8.30	72.8	8.30	55.3
SBC-8B	Phase 2, Mountains	2.58	77.3	2.58	60.5
SBC-9	Phase 2, Mountains	6.65	75.0	6.65	58.0
SBC-10A	Phase 2, Mountains	7.10	77.2	7.10	60.6
SBC-10B	Phase 2, Foothills	2.57	68.3	2.57	50.2
SBC-10C	Phase 2, Foothills	2.41	76.1	2.41	61.5
SBC-11	Phase 2, Foothills	3.16	79.3	3.16	65.8
SBC-12A	Phase 2, Foothills	0.47	82.4	0.47	67.4
SBC-12B	Phase 2, Foothills	2.37	73.6	2.37	56.8
SBC-13	Phase 2, Foothills	3.72	74.8	3.72	57.9
SBC-14A	Phase 2, Foothills	1.41	71.0	1.41	52.8
SBC-14B	Phase 2, Foothills	3.75	69.1	3.75	50.7
SBC-15A	Phase 2, Foothills	6.02	76.7	6.02	60.4
SBC-15B	Phase 2, Foothills	1.74	78.6	1.74	62.9
SBC-16A	Phase 2, Foothills	2.96	66.7	2.96	49.0
SBC-16B	Phase 2, Plains	3.34	77.2	3.34	60.7
SBC-17A	Phase 2, Plains	3.60	70.9	3.60	52.9
SBC-17B	Phase 2, Plains	3.61	80.9	3.61	66.9
SBC-18	Phase 2, Foothills	1.92	66.0	1.92	48.0
SBC-19A	Phase 2, Plains	1.62	74.8	1.62	57.9
SBC-19B	Phase 2, Plains	2.49	74.1	2.49	57.9
SBC-20	Phase 2, Plains	2.29	85.4	2.29	72.6
SBC-21	Phase 2, Plains	1.68	91.2	1.68	84.6
SBC-22	Phase 2, Plains	2.52	76.4	2.52	61.0
SC-1	Phase 2, Plains	2.04	71.9	2.04	54.5
SC-2	Phase 2, Plains	0.95	85.5	0.95	72.8
TCC-1	Phase 2, Foothills	0.94	76.7	0.94	62.3
TCC-2	Phase 2, Plains	1.68	73.9	1.68	56.4
TCC-3	Phase 2, Plains	2.88	83.8	2.88	70.3
WC-1	Phase 2, Plains	1.04	84.5	1.04	71.8
WC-2	Phase 2, Plains	0.50	81.6	0.50	66.7
WC-3	Phase 2, Plains	0.96	84.1	0.96	71.1

Table B-2

Boulder Creek Rainfall Depths at Subbasin Centroids

Subbasin	24-hour Sept. 2013 Total Precip.	24-hour Sept. 2013 Precip. Recurrence	Antecedent Rainfall [a]	Antecedent Moisture Condition	24-hour Rainfall Total Precipitation (in) NOAA Atlas 14				
					10-year	25-year	50-year	100-year	500-year
BC-10	4.66	50 to 100 yr	10.58	AMC III	3.27	4.10	4.78	5.50	7.34
BC-11	3.52	25 to 50 yr	7.77	AMC III	3.11	3.92	4.59	5.30	7.13
BC-12A	3.04	25 to 50 yr	7.28	AMC III	3.04	3.86	4.54	5.26	7.13
BC-12B	3.25	25 to 50 yr	7.62	AMC III	3.03	3.83	4.49	5.20	7.03
BC-13	2.75	< 10-year	6.69	AMC III	2.98	3.78	4.44	5.14	6.96
BC-14	2.28	< 10-year	6.08	AMC III	2.98	3.78	4.45	5.16	6.99
BC-15	1.08	< 10-year	4.42	AMC III	2.98	3.79	4.45	5.16	6.99
BC-16A	1.26	< 10-year	4.75	AMC III	2.99	3.78	4.44	5.13	6.92
BC-16B	0.76	< 10-year	4.46	AMC III	2.96	3.74	4.39	5.07	6.84
BC-17	0.93	< 10-year	4.45	AMC III	2.98	3.79	4.46	5.17	7.00
BC-18	0.75	< 10-year	4.74	AMC III	2.95	3.73	4.38	5.07	6.84
BC-19A	0.73	< 10-year	5.01	AMC III	2.94	3.73	4.38	5.07	6.85
BC-19B	0.83	< 10-year	5.89	AMC III	2.90	3.66	4.29	4.96	6.69
BC-19C	0.87	< 10-year	6.04	AMC III	2.88	3.63	4.26	4.92	6.66
BC-20	0.75	< 10-year	4.74	AMC III	2.89	3.65	4.30	4.98	6.79
BC-2A	3.34	25 to 50 yr	7.97	AMC III	2.99	3.75	4.40	5.10	6.95
BC-2B	3.45	25 to 50 yr	7.67	AMC III	3.04	3.80	4.45	5.15	7.01
BC-3A	4.24	50 to 100 yr	10.35	AMC III	3.13	3.92	4.59	5.31	7.20
BC-3B	4.15	50 to 100 yr	9.98	AMC III	3.15	3.95	4.62	5.34	7.22
BC-3C	3.86	25 to 50 yr	9.00	AMC III	3.20	4.00	4.67	5.39	7.28
BC-4	3.41	25 to 50 yr	8.35	AMC III	2.96	3.72	4.37	5.07	6.93
BC-5A	3.83	25 to 50 yr	9.60	AMC III	3.11	3.90	4.57	5.29	7.18
BC-5B	3.93	25 to 50 yr	9.53	AMC III	3.24	4.05	4.73	5.45	7.34
BC-6A	3.90	25 to 50 yr	9.90	AMC III	3.20	4.01	4.70	5.43	7.34
BC-6B	3.94	25 to 50 yr	9.83	AMC III	3.27	4.09	4.78	5.51	7.40
BC-7	4.51	50 to 100 yr	9.32	AMC III	3.24	4.07	4.77	5.51	7.43
BC-8	4.25	50 to 100 yr	8.89	AMC III	3.34	4.18	4.87	5.60	7.48
BC-9	4.38	50 to 100 yr	9.26	AMC III	3.27	4.11	4.80	5.54	7.45
BCC-1	4.92	50 to 100 yr	8.70	AMC III	3.41	4.24	4.93	5.65	7.49
CC-1	2.99	< 10-year	6.37	AMC III	3.29	4.06	4.71	5.41	7.21
CC-10A	0.74	< 10-year	4.07	AMC III	2.96	3.73	4.35	5.02	6.71
CC-10B	1.07	< 10-year	5.25	AMC III	2.91	3.65	4.27	4.91	6.56
CC-11	0.96	< 10-year	5.22	AMC III	2.93	3.68	4.31	4.97	6.66
CC-12	0.84	< 10-year	4.86	AMC III	2.95	3.72	4.35	5.02	6.75
CC-2	4.74	100 to 500 yr	8.38	AMC III	3.26	4.03	4.67	5.36	7.13
CC-3	6.22	> 500 yr	8.96	AMC III	3.31	4.10	4.75	5.45	7.25
CC-4	4.22	50 to 100 yr	6.70	AMC III	3.15	3.93	4.58	5.26	7.01
CC-5	2.31	< 10-year	5.36	AMC III	3.07	3.85	4.50	5.19	6.95
CC-6	1.52	< 10-year	4.89	AMC III	3.03	3.82	4.47	5.15	6.91
CC-7	0.95	< 10-year	4.63	AMC III	2.95	3.70	4.32	4.97	6.62
CC-8	0.85	< 10-year	4.46	AMC III	2.97	3.74	4.38	5.05	6.77
CC-9	1.01	< 10-year	5.13	AMC III	2.93	3.67	4.28	4.92	6.56
DC-1	3.56	25 to 50 yr	8.01	AMC III	3.09	3.89	4.55	5.24	7.03
DC-2	2.45	< 10-year	6.07	AMC III	2.98	3.77	4.42	5.12	6.91
FCC-1	5.16	100 to 500 yr	8.45	AMC III	3.04	3.83	4.51	5.24	7.17
FCC-2	4.73	100 to 500 yr	8.62	AMC III	3.11	3.92	4.62	5.36	7.34
FCC-3	3.57	25 to 50 yr	8.52	AMC III	3.14	3.96	4.65	5.39	7.29
FMC-1	2.04	< 10-year	5.60	AMC III	2.70	3.38	3.97	4.63	6.44
FMC-2A	2.24	< 10-year	5.50	AMC III	2.68	3.36	3.95	4.61	6.40
FMC-2B	2.14	< 10-year	5.56	AMC III	2.64	3.31	3.89	4.54	6.30
FMC-3A	2.91	25 to 50 yr	6.76	AMC III	2.78	3.50	4.12	4.79	6.62
FMC-3B	2.04	< 10-year	5.60	AMC III	2.74	3.45	4.05	4.72	6.51
FMC-4A	4.36	100 to 500 yr	9.52	AMC III	2.92	3.68	4.33	5.04	6.93
FMC-4B	3.71	50 to 100 yr	8.73	AMC III	2.91	3.66	4.31	5.00	6.87
FMC-4C	3.45	25 to 50 yr	8.48	AMC III	2.92	3.67	4.31	5.01	6.86
FMC-5A	4.60	100 to 500 yr	10.19	AMC III	3.03	3.82	4.49	5.21	7.13
FMC-5B	3.67	25 to 50 yr	9.04	AMC III	3.04	3.82	4.48	5.20	7.09
FMC-6A	4.45	50 to 100 yr	11.14	AMC III	3.15	3.96	4.65	5.38	7.31
FMC-6B	3.91	25 to 50 yr	10.06	AMC III	3.15	3.95	4.63	5.36	7.27
MBC-1A	0.98	< 10-year	1.90	AMC II	2.64	3.35	4.00	4.76	6.93
MBC-1B	1.22	< 10-year	2.41	AMC III	2.58	3.28	3.93	4.67	6.81
MBC-2	1.12	< 10-year	2.44	AMC III	2.73	3.45	4.12	4.88	7.06
MBC-3A	1.77	< 10-year	3.91	AMC III	2.65	3.34	3.98	4.71	6.77
MBC-3B	1.36	< 10-year	2.72	AMC III	2.55	3.24	3.89	4.62	6.74
MBC-4	1.81	< 10-year	3.80	AMC III	2.50	3.16	3.77	4.46	6.42
MBC-5A	1.86	< 10-year	4.45	AMC III	2.55	3.22	3.83	4.51	6.51
MBC-5B	1.84	< 10-year	4.49	AMC III	2.55	3.23	3.83	4.51	6.41
MBC-6	1.84	< 10-year	5.15	AMC III	2.58	3.25	3.84	4.50	6.32
MBC-7A	2.29	< 10-year	6.04	AMC III	2.73	3.42	4.01	4.67	6.43
MBC-7B	2.24	< 10-year	5.86	AMC III	2.74	3.43	4.03	4.69	6.47

Subbasin	24-hour Sept. 2013 Total Precip.	24-hour Sept. 2013 Precip. Recurrence	Antecedent Rainfall [a]	Antecedent Moisture Condition	24-hour Rainfall Total Precipitation (in) NOAA Atlas 14				
					10-year	25-year	50-year	100-year	500-year
NBC-1A	1.46	< 10-year	3.47	AMC III	2.81	3.54	4.20	4.95	7.06
NBC-1B	1.45	< 10-year	3.48	AMC III	2.80	3.52	4.19	4.94	7.07
NBC-2	1.80	< 10-year	4.20	AMC III	2.69	3.38	4.01	4.72	6.73
NBC-3	1.90	< 10-year	4.39	AMC III	2.71	3.39	4.01	4.71	6.66
NBC-4	1.99	< 10-year	5.23	AMC III	2.71	3.38	3.97	4.63	6.46
NBC-5A	1.96	< 10-year	5.48	AMC III	2.61	3.26	3.84	4.48	6.23
NBC-5B	1.95	< 10-year	5.09	AMC III	2.59	3.25	3.84	4.50	6.32
NBC-5C	1.85	< 10-year	5.14	AMC III	2.55	3.21	3.80	4.46	6.28
NBC-6A	2.03	< 10-year	5.65	AMC III	2.63	3.29	3.88	4.51	6.25
NBC-6B	2.01	< 10-year	5.82	AMC III	2.64	3.31	3.89	4.53	6.27
NBC-7	2.94	25 to 50 yr	6.87	AMC III	2.83	3.56	4.18	4.85	6.66
RC-1	4.46	50 to 100 yr	6.70	AMC III	3.09	3.85	4.47	5.13	6.84
RC-2	2.64	< 10-year	4.50	AMC III	3.02	3.78	4.40	5.06	6.75
RC-3A	1.72	< 10-year	3.97	AMC III	3.01	3.78	4.41	5.07	6.77
RC-3B	1.12	< 10-year	3.30	AMC III	2.95	3.70	4.31	4.95	6.60
RC-4	1.07	< 10-year	3.86	AMC III	2.99	3.75	4.38	5.05	6.75
SBC-10A	2.82	< 10-year	5.41	AMC III	2.99	3.73	4.37	5.06	6.92
SBC-10B	2.78	< 10-year	5.60	AMC III	3.11	3.87	4.52	5.23	7.13
SBC-10C	2.78	< 10-year	6.06	AMC III	3.21	3.99	4.65	5.37	7.27
SBC-11	3.54	25 to 50 yr	7.16	AMC III	3.28	4.07	4.73	5.45	7.34
SBC-12A	3.44	25 to 50 yr	7.87	AMC III	3.31	4.11	4.77	5.49	7.35
SBC-12B	3.19	< 10-year	8.05	AMC III	3.32	4.11	4.76	5.46	7.29
SBC-13	3.42	25 to 50 yr	6.11	AMC III	3.26	4.06	4.73	5.45	7.34
SBC-14A	3.64	25 to 50 yr	7.45	AMC III	3.38	4.19	4.87	5.58	7.43
SBC-14B	3.81	25 to 50 yr	7.09	AMC III	3.42	4.25	4.94	5.67	7.54
SBC-15A	4.33	50 to 100 yr	8.35	AMC III	3.42	4.23	4.90	5.62	7.45
SBC-15B	5.02	50 to 100 yr	7.98	AMC III	3.52	4.37	5.06	5.79	7.67
SBC-16A	5.34	100 to 500 yr	7.53	AMC III	3.51	4.36	5.06	5.79	7.70
SBC-16B	5.48	100 to 500 yr	8.04	AMC III	3.43	4.25	4.93	5.65	7.52
SBC-17A	5.15	100 to 500 yr	7.35	AMC III	3.42	4.25	4.93	5.65	7.50
SBC-17B	4.54	50 to 100 yr	7.26	AMC III	3.17	3.96	4.62	5.31	7.08
SBC-18	5.21	100 to 500 yr	7.86	AMC III	3.39	4.22	4.90	5.61	7.44
SBC-19A	5.52	> 500 yr	9.25	AMC III	3.27	4.08	4.75	5.45	7.24
SBC-19B	5.31	100 to 500 yr	8.44	AMC III	3.20	4.00	4.66	5.35	7.14
SBC-1A	0.75	< 10-year	1.26	AMC II	2.39	3.05	3.67	4.38	6.44
SBC-1B	1.16	< 10-year	1.81	AMC II	2.41	3.07	3.69	4.39	6.43
SBC-20	4.71	100 to 500 yr	10.55	AMC III	3.19	4.00	4.66	5.37	7.17
SBC-21	3.70	25 to 50 yr	8.95	AMC III	3.03	3.83	4.48	5.18	6.98
SBC-22	4.43	50 to 100 yr	9.91	AMC III	3.14	3.94	4.61	5.31	7.10
SBC-2A	1.66	< 10-year	2.98	AMC III	2.49	3.16	3.79	4.50	6.55
SBC-2B	1.87	< 10-year	3.36	AMC III	2.48	3.15	3.77	4.47	6.48
SBC-3	1.80	< 10-year	3.18	AMC III	2.53	3.21	3.83	4.53	6.51
SBC-4	1.70	< 10-year	2.88	AMC III	2.65	3.35	3.97	4.67	6.61
SBC-5	1.82	< 10-year	3.36	AMC III	2.59	3.28	3.89	4.58	6.50
SBC-6	1.68	< 10-year	2.95	AMC III	2.71	3.41	4.04	4.73	6.63
SBC-7	2.05	< 10-year	3.74	AMC III	2.93	3.66	4.29	4.98	6.85
SBC-8A	1.93	< 10-year	4.04	AMC III	2.61	3.30	3.90	4.58	6.47
SBC-8B	2.06	< 10-year	3.79	AMC III	2.81	3.52	4.15	4.83	6.70
SBC-9	2.26	< 10-year	4.85	AMC III	3.01	3.76	4.40	5.10	6.98
SC-1	4.80	50 to 100 yr	9.03	AMC III	3.34	4.18	4.86	5.59	7.44
SC-2	4.80	100 to 500 yr	10.10	AMC III	3.23	4.05	4.72	5.43	7.24
TCC-1	4.69	100 to 500 yr	8.99	AMC III	3.15	3.98	4.67	5.42	7.37
TCC-2	4.26	50 to 100 yr	9.47	AMC III	3.23	4.07	4.77	5.51	7.44
TCC-3	3.94	25 to 50 yr	10.13	AMC III	3.20	4.03	4.71	5.44	7.32
WC-1	3.66	25 to 50 yr	9.24	AMC III	3.18	4.02	4.72	5.47	7.42
WC-2	3.81	25 to 50 yr	9.73	AMC III	3.18	4.01	4.71	5.46	7.39
WC-3	3.95	25 to 50 yr	8.96	AMC III	3.15	3.97	4.65	5.37	7.22

[a] Total Rainfall over 5 Days Preceding 24-hour Analysis Window

Table B-3

5-minute Dimensionless 24-hr NRCS Type II Cumulative Rainfall Distribution

Time (Hours) \ Minutes	0	5	10	15	20	25	30	35	40	45	50	55
0	0.000	0.001	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010
1	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021	0.022
2	0.023	0.024	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032	0.033	0.034
3	0.035	0.036	0.037	0.038	0.039	0.040	0.041	0.042	0.043	0.044	0.045	0.047
4	0.048	0.049	0.051	0.052	0.053	0.055	0.056	0.057	0.059	0.060	0.061	0.063
5	0.064	0.065	0.067	0.068	0.069	0.071	0.072	0.073	0.075	0.076	0.077	0.079
6	0.080	0.082	0.083	0.085	0.087	0.088	0.090	0.092	0.093	0.095	0.097	0.098
7	0.100	0.102	0.103	0.105	0.107	0.108	0.110	0.112	0.113	0.115	0.117	0.118
8	0.120	0.122	0.124	0.126	0.128	0.131	0.133	0.135	0.138	0.140	0.142	0.145
9	0.147	0.150	0.152	0.155	0.158	0.160	0.163	0.166	0.169	0.172	0.175	0.178
10	0.181	0.184	0.188	0.191	0.195	0.199	0.203	0.208	0.213	0.218	0.224	0.230
11	0.236	0.243	0.250	0.257	0.266	0.274	0.283	0.318	0.352	0.387	0.479	0.571
12	0.663	0.678	0.692	0.707	0.716	0.726	0.735	0.743	0.750	0.758	0.764	0.770
13	0.776	0.781	0.786	0.791	0.795	0.800	0.804	0.808	0.811	0.815	0.818	0.822
14	0.825	0.828	0.831	0.834	0.837	0.839	0.842	0.844	0.847	0.849	0.851	0.854
15	0.856	0.858	0.861	0.863	0.865	0.867	0.869	0.871	0.873	0.875	0.877	0.879
16	0.881	0.883	0.885	0.887	0.889	0.891	0.893	0.895	0.896	0.898	0.900	0.901
17	0.903	0.905	0.906	0.908	0.910	0.911	0.913	0.915	0.916	0.918	0.919	0.921
18	0.922	0.923	0.925	0.926	0.927	0.929	0.930	0.931	0.933	0.934	0.935	0.937
19	0.938	0.939	0.941	0.942	0.943	0.945	0.946	0.947	0.949	0.950	0.951	0.952
20	0.953	0.954	0.955	0.956	0.957	0.958	0.959	0.960	0.961	0.962	0.963	0.964
21	0.965	0.966	0.967	0.968	0.969	0.970	0.971	0.972	0.973	0.974	0.975	0.976
22	0.977	0.978	0.979	0.980	0.981	0.982	0.983	0.984	0.985	0.986	0.987	0.988
23	0.989	0.990	0.991	0.992	0.993	0.994	0.995	0.996	0.997	0.998	0.999	0.999
24	1.000											

Table B-4

24-hour Boulder Creek Models: Unit Hydrograph Parameters

Basin ID	K_n	L *mi*	L_c *mi*	S *ft/mile*	T_{LAG} *hours*	C_p
BC-2A	0.15	2.23	1.26	790.4	1.55	0.40
BC-2B	0.15	2.84	1.59	911.1	1.77	0.40
BC-3A	0.15	1.66	0.99	482.7	0.59	0.40
BC-3B	0.15	1.81	1.11	474.8	0.63	0.40
BC-3C	0.15	3.45	2.04	690.6	2.14	0.40
BC-4	0.15	3.10	1.51	48.5	2.91	0.40
BC-5A	0.15	3.04	1.95	515.3	2.13	0.40
BC-5B	0.15	3.12	1.80	666.6	2.00	0.40
BC-6A	0.15	1.92	1.26	379.2	0.93	0.40
BC-6B	0.15	2.73	1.53	802.9	1.76	0.40
BC-7	0.08	3.23	1.57	373.7	1.14	0.50
BC-8	0.08	3.66	1.98	626.4	1.17	0.50
BC-9	0.08	3.01	1.24	350.9	1.04	0.50
BC-10	0.07	4.78	1.75	144.4	1.37	0.80
BC-11	0.05	1.58	0.81	130.4	0.54	0.80
BC-12A	0.07	5.81	2.00	68.0	1.73	0.50
BC-12B	0.08	2.88	1.53	23.8	1.71	0.40
BC-13	0.08	2.86	1.40	27.0	1.62	0.40
BC-14	0.08	3.34	1.57	17.6	1.90	0.40
BC-15	0.08	3.67	1.73	52.3	1.69	0.40
BC-16A	0.07	7.17	3.50	70.1	2.22	0.50
BC-16B	0.08	3.60	1.69	77.5	1.57	0.50
BC-17	0.08	4.25	2.32	83.0	1.82	0.40
BC-18	0.08	3.75	1.95	22.7	2.04	0.50
BC-19A	0.08	5.44	3.20	45.5	2.42	0.40
BC-19B	0.08	6.79	3.53	42.8	2.71	0.40
BC-19C	0.08	4.30	2.19	59.6	1.89	0.50
BC-20	0.08	7.12	3.57	31.6	2.91	0.40
BCC-1	0.08	8.00	4.43	396.6	2.14	0.80
CC-1	0.08	4.55	2.02	405.1	1.36	0.50
CC-2	0.08	5.91	3.32	291.3	1.85	0.40
CC-3	0.08	6.02	3.12	187.5	1.96	0.40
CC-4	0.08	7.01	3.52	94.8	2.40	0.40
CC-5	0.07	5.11	3.05	60.4	1.95	0.80
CC-6	0.07	4.68	2.00	94.6	1.53	0.80
CC-7	0.08	3.00	1.59	74.5	1.46	0.50
CC-8	0.07	3.19	1.39	77.5	1.24	0.80
CC-9	0.07	3.31	1.67	93.4	1.29	0.50
CC-10A	0.08	3.08	1.48	71.8	1.44	0.40
CC-10B	0.08	2.72	1.71	61.3	1.49	0.80
CC-11	0.08	4.10	2.26	34.3	2.06	0.50
CC-12	0.07	6.78	4.54	29.9	2.74	0.80
DC-1	0.08	3.79	2.26	91.7	1.70	0.50
DC-2	0.08	5.13	3.74	51.9	2.44	0.40
FCC-1	0.08	4.85	2.01	368.3	1.41	0.40
FCC-2	0.08	4.49	2.33	423.4	1.41	0.50
FCC-3	0.07	5.33	2.77	66.6	1.88	0.80
FMC-1	0.10	3.19	1.73	853.1	1.27	0.40
FMC-2A	0.10	3.22	1.99	617.4	1.41	0.40
FMC-2B	0.10	2.95	2.03	493.4	1.43	0.40
FMC-3A	0.10	4.06	2.14	340.3	0.80	0.40
FMC-3B	0.12	3.81	2.09	313.1	1.04	0.40
FMC-4A	0.10	3.57	1.83	564.0	1.44	0.35
FMC-4B	0.10	3.76	2.29	372.0	0.64	0.35
FMC-4C	0.10	3.37	2.03	274.2	0.52	0.35
FMC-5A	0.12	2.33	1.37	57.1	2.00	0.35
FMC-5B	0.12	2.38	1.66	310.0	1.62	0.35
FMC-6A	0.10	3.15	2.39	314.5	0.83	0.35
FMC-6B	0.10	2.51	1.51	358.3	0.64	0.35
MBC-1A	0.10	3.95	2.24	516.3	1.62	0.30
MBC-1B	0.10	2.87	1.75	525.1	1.34	0.30
MBC-2	0.10	3.73	1.40	592.5	1.33	0.30
MBC-3A	0.10	4.87	2.48	841.2	1.65	0.30
MBC-3B	0.10	5.96	2.79	410.3	2.07	0.30
MBC-4	0.10	3.46	1.57	324.7	1.49	0.30
MBC-5A	0.10	5.59	3.16	451.7	2.08	0.30
MBC-5B	0.10	4.06	1.97	98.3	2.06	0.30
MBC-6	0.10	0.92	0.66	239.0	0.76	0.30
MBC-7A	0.07	6.33	3.45	168.6	1.84	0.40
MBC-7B	0.07	7.08	4.24	150.1	2.08	0.40

Basin ID	K_n	L *mi*	L_c *mi*	S *ft/mile*	T_{LAG} *hours*	C_p
NBC-1A	0.15	5.10	2.53	429.2	2.83	0.40
NBC-1B	0.15	4.50	2.46	477.8	2.65	0.40
NBC-2	0.15	4.48	2.19	693.7	2.39	0.40
NBC-3	0.15	3.88	2.62	398.8	2.65	0.40
NBC-4	0.15	5.73	2.90	571.6	2.94	0.40
NBC-5A	0.15	4.53	2.36	564.5	2.55	0.40
NBC-5B	0.15	4.50	2.95	370.5	2.93	0.40
NBC-5C	0.15	3.96	1.62	302.5	2.39	0.40
NBC-6A	0.15	5.07	3.46	281.7	3.36	0.40
NBC-6B	0.15	4.38	2.15	137.2	3.08	0.40
NBC-7	0.15	2.70	1.81	271.6	2.22	0.40
RC-1	0.08	7.58	4.26	121.0	2.52	0.40
RC-2	0.07	5.13	2.09	99.1	1.59	0.80
RC-3A	0.08	3.80	2.05	71.7	1.72	0.50
RC-3B	0.08	4.69	2.70	68.8	2.03	0.80
RC-4	0.08	7.15	4.07	42.3	2.90	0.50
SBC-1A	0.07	6.75	2.96	504.9	1.49	0.30
SBC-1B	0.07	6.43	2.88	366.3	1.53	0.30
SBC-2A	0.07	6.86	3.87	333.2	1.75	0.30
SBC-2B	0.07	2.63	1.13	538.6	0.79	0.30
SBC-3	0.07	3.42	1.00	578.3	0.81	0.30
SBC-4	0.07	3.97	2.00	557.5	1.08	0.30
SBC-5	0.12	4.31	2.08	106.7	2.53	0.12
SBC-6	0.07	5.72	3.62	387.7	1.57	0.30
SBC-7	0.08	5.48	2.69	226.7	1.76	0.12
SBC-8A	0.08	6.57	2.96	224.2	1.93	0.12
SBC-8B	0.08	3.25	1.57	295.3	1.19	0.12
SBC-9	0.08	4.56	0.71	208.3	1.08	0.12
SBC-10A	0.08	4.67	2.09	227.4	1.53	0.40
SBC-10B	0.08	3.58	1.70	306.2	1.25	0.40
SBC-10C	0.07	3.53	1.04	404.3	0.88	0.40
SBC-11	0.09	0.71	0.24	2106.4	0.32	0.40
SBC-12A	0.08	1.24	0.51	882.8	0.49	0.40
SBC-12B	0.08	3.31	1.24	759.6	0.94	0.40
SBC-13	0.08	4.06	2.06	348.4	1.36	0.40
SBC-14A	0.08	3.34	1.67	139.9	1.38	0.40
SBC-14B	0.08	3.43	1.85	328.5	1.25	0.40
SBC-15A	0.06	5.58	2.69	541.9	1.15	0.40
SBC-15B	0.04	3.07	2.04	455.7	0.59	0.40
SBC-16A	0.08	3.67	1.41	470.6	1.10	0.40
SBC-16B	0.08	5.28	3.18	543.3	1.59	0.40
SBC-17A	0.08	3.69	1.34	363.1	1.13	0.40
SBC-17B	0.08	4.78	3.34	61.2	2.24	0.40
SBC-18	0.08	3.84	1.67	454.5	1.19	0.40
SBC-19A	0.07	3.38	1.68	143.6	1.21	0.80
SBC-19B	0.08	2.22	0.66	169.5	0.86	0.40
SBC-20	0.07	3.20	1.78	45.0	1.47	0.80
SBC-21	0.15	1.39	0.46	70.6	1.41	0.20
SBC-22	0.07	4.40	2.26	43.9	1.77	0.80
SC-1	0.08	3.19	1.51	630.8	1.03	0.80
SC-2	0.07	2.54	1.51	68.4	1.20	0.80
TCC-1	0.08	1.67	0.79	566.8	0.68	0.50
TCC-2	0.07	1.89	0.27	350.8	0.47	0.80
TCC-3	0.05	3.62	2.17	52.5	1.14	0.80
WC-1	0.08	1.29	0.68	406.0	0.63	0.50
WC-2	0.07	1.60	0.69	92.4	0.76	0.80
WC-3	0.07	1.98	0.90	62.5	0.94	0.80

	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	17-Sep	18-Sep
Gage Elevation (ft above reference)	121.7	123.18	125.96	128.72	130.61	132.27	132.27	132.27
Reservoir Elevation (ft)	8172.45	8173.93	8176.71	8179.47	8181.36	8183.02	8183.02	8183.02
Reservoir Volume Stored (AF)	9298.65	9562.85	10073.6	10595.1	10962.58	11288.56	11288.56	11288.56
Average Inflows (cfs)	80.4	153	320	188	205	172	132	124
Average Flow (cfs) to river incl. spillway	4.01	4.34	3.93	3.74	113.62	225.91	163.36	145.60

	19-Sep	20-Sep	21-Sep	22-Sep	23-Sep	24-Sep	25-Sep
Gage Elevation (ft above reference)	132.24	132.21	132.17	132.06	132.06	132.03	132.03
Reservoir Elevation (ft)	8182.99	8182.96	8182.92	8182.81	8182.81	8182.78	8182.78
Reservoir Volume Stored (AF)	11282.67	11276.77	11268.92	11247.32	11247.32	11241.43	11241.43
Average Inflows (cfs)	111	94.9	83.6	81.4	94.9	82.4	77.9
Average Flow (cfs) to river incl. spillway	110.57	77.19	60.63	62.03	74.82	53.07	49.50

TABLE B-5
Barker Reservoir Elevation-Storage Data During September 2013 High-flow Event
(Source: City of Boulder)
CDOT Flood Recovery Hydrologic Evaluation

Table B-6

Gross Reservoir Daily Outflow, August 1, 2013 to October 31, 2013

Date	Reservoir Elevation (ft)	Reservoir Volume Storage (AF)	Average Outflow (cfs)
8/1/2013	7279.61	40831	183
8/2/2013	7279.3	40705	183
8/3/2013	7278.99	40579	183
8/4/2013	7278.68	40454	183
8/5/2013	7278.28	40292	183
8/6/2013	7277.9	40139	184
8/7/2013	7277.49	39975	184
8/8/2013	7277.1	39819	185
8/9/2013	7276.7	39659	180
8/10/2013	7276.39	39535	154
8/11/2013	7276.03	39392	152
8/12/2013	7275.85	39321	133
8/13/2013	7275.65	39242	139
8/14/2013	7275.48	39174	139
8/15/2013	7275.2	39064	139
8/16/2013	7274.83	38918	139
8/17/2013	7274.49	38784	134
8/18/2013	7274.12	38639	134
8/19/2013	7273.61	38440	159
8/20/2013	7273.07	38229	160
8/21/2013	7272.6	38047	160
8/22/2013	7272.14	37869	160
8/23/2013	7271.61	37664	190
8/24/2013	7271.04	37445	195
8/25/2013	7270.44	37215	194
8/26/2013	7270.03	37059	194
8/27/2013	7269.51	36861	194
8/28/2013	7268.89	36626	194
8/29/2013	7268.34	36419	193
8/30/2013	7267.76	36200	193
8/31/2013	7267.13	35965	193
9/1/2013	7266.58	35760	193
9/2/2013	7265.98	35537	193
9/3/2013	7265.33	35297	193
9/4/2013	7264.71	35068	193
9/5/2013	7264.11	34848	193
9/6/2013	7263.75	34717	169
9/7/2013	7263.35	34571	168
9/8/2013	7262.91	34411	168
9/9/2013	7262.76	34357	169
9/10/2013	7262.86	34393	170
9/11/2013	7264.21	34885	171
9/12/2013	7268.78	36584	46
9/13/2013	7272.63	38058	23
9/14/2013	7274.93	38957	20
9/15/2013	7278.05	40200	20
9/16/2013	7280.54	41210	20
9/17/2013	7281.62	41654	164
9/18/2013	7282.2	41894	201
9/19/2013	7282.35	41956	255
9/20/2013	7282.25	41914	248
9/21/2013	7282.15	41873	227
9/22/2013	7282.11	41856	218
9/23/2013	7281.91	41774	221
9/24/2013	7281.76	41712	201
9/25/2013	7281.62	41654	180
9/26/2013	7281.57	41633	150
9/27/2013	7281.72	41695	117
9/28/2013	7281.79	41724	117
9/29/2013	7281.8	41728	116
9/30/2013	7281.76	41712	115
10/1/2013	7281.76	41712	101
10/2/2013	7281.75	41708	95
10/3/2013	7281.76	41712	92
10/4/2013	7281.81	41732	91
10/5/2013	7281.76	41712	91
10/6/2013	7281.74	41703	90
10/7/2013	7281.67	41675	90
10/8/2013	7281.57	41633	90
10/9/2013	7281.48	41596	90
10/10/2013	7281.42	41572	92
10/11/2013	7281.28	41514	93
10/12/2013	7281.18	41473	89
10/13/2013	7281.08	41432	89
10/14/2013	7280.93	41370	89
10/15/2013	7280.79	41313	88
10/16/2013	7280.64	41251	87
10/17/2013	7280.45	41173	87
10/18/2013	7280.25	41092	91
10/19/2013	7280.06	41014	91
10/20/2013	7279.86	40933	90
10/21/2013	7279.71	40871	90
10/22/2013	7279.52	40794	89
10/23/2013	7279.32	40713	89
10/24/2013	7279.13	40636	88
10/25/2013	7278.83	40514	104
10/26/2013	7278.74	40478	70
10/27/2013	7278.64	40438	66
10/28/2013	7278.63	40433	44
10/29/2013	7278.64	40438	43
10/30/2013	7278.69	40458	43
10/31/2013	7278.64	40438	43

Data provided by Denver Water

Table B-7

Baseline Reservoir Accounting, September 2013

Date	Reservoir Elevation* (ft)	Reservoir Volume Storage* (AF)	Average Inflow (cfs)	Average Outflow (cfs)
9/1/2013			9.82	14.37
9/2/2013			9.43	14.69
9/3/2013			7.07	14.40
9/4/2013			2.85	10.89
9/5/2013			3.33	9.43
9/6/2013	30.93	4436	2.21	8.47
9/7/2013			1.85	10.23
9/8/2013			1.74	10.57
9/9/2013	30.90	4436	0.73	9.14
9/10/2013	31.09	4463	0.80	3.89
9/11/2013	32.30	4826	0.00	3.65
9/12/2013			0.00	77.40
9/13/2013	34.00	5326	0.00	75.00
9/14/2013			0.00	75.00
9/15/2013			0.00	75.00
9/16/2013			0.00	75.00
9/17/2013			0.00	75.00
9/18/2013			0.00	74.00
9/19/2013			0.00	74.00
9/20/2013			0.00	74.00
9/21/2013	32.00	4740	0.00	74.00
9/22/2013			0.00	74.00
9/23/2013			0.00	74.00
9/24/2013			0.00	74.00
9/25/2013			0.00	41.00
9/26/2013	29.42	4038	0.00	41.00
9/27/2013			0.00	0.00
9/28/2013			0.00	0.00
9/29/2013			0.00	0.00
9/30/2013	29.00	3933	0.00	0.00

Provided by Baseline Reservoir Company via City of Lafeyette

Table B-8

24-hour Boulder Creek Models: Routing Reach Parameters

Reach ID	Stream Name	L	Slope	Calibrated Model			Predictive Model			Invert
		ft	*ft/ft*	Method	$n_{channel}$	$n_{overbank}$	Method	$n_{channel}$	$n_{overbank}$	*ft (NAVD88)*
BC-R1	Boulder Creek	11445	0.0524	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	6388.3
BC-R2	Boulder Creek	8193	0.0342	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	6123.0
BC-R3	Boulder Creek	4632	0.0173	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	6005.0
BC-R3A	Bummer's Gulch	13492	0.0563	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	6757.9
BC-R4	Boulder Creek	7796	0.0257	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	5785.5
BC-R5	Boulder Creek	16010	0.0235	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	5568.6
BC-R6	Boulder Creek	13215	0.0084	Modified Puls	0.080	0.100	Muskingum-Cunge	0.045	0.060	5311.4
BC-R7	Boulder Creek	6391	0.0057	Modified Puls	0.100	0.150	Muskingum-Cunge	0.045	0.060	5199.1
BC-R8A	Boulder Creek	4265	0.0050	Modified Puls	0.070	0.100	Muskingum-Cunge	0.045	0.060	5184.1
BC-R8B	Boulder Creek	3467	0.0041	Modified Puls	0.070	0.150	Muskingum-Cunge	0.045	0.060	5158.2
BC-R9	Boulder Creek	11716	0.0038	Modified Puls	0.070	0.150	Muskingum-Cunge	0.045	0.060	5119.5
BC-R10	Boulder Creek	15421	0.0032	Muskingum-Cunge	0.040	0.045	Muskingum-Cunge	0.040	0.045	5083.3
BC-R11	Boulder Creek	15423	0.0037	Muskingum-Cunge	0.030	0.035	Muskingum-Cunge	0.030	0.035	5021.5
BC-R12	Boulder Creek	14757	0.0033	Muskingum-Cunge	0.030	0.035	Muskingum-Cunge	0.030	0.035	4987.4
BC-R13	Boulder Creek	13902	0.0028	Muskingum-Cunge	0.030	0.035	Muskingum-Cunge	0.030	0.035	4933.1
BC-R14	Boulder Creek	21653	0.0030	Muskingum-Cunge	0.030	0.030	Muskingum-Cunge	0.030	0.030	4902.1
CC-R1	Coal Creek	26763	0.0415	Muskingum-Cunge	0.050	0.055	Muskingum-Cunge	0.050	0.055	7047.7
CC-R2	Coal Creek	22350	0.0272	Muskingum-Cunge	0.035	0.060	Muskingum-Cunge	0.035	0.060	5912.7
CC-R3	Coal Creek	30661	0.0142	Muskingum-Cunge	0.035	0.060	Muskingum-Cunge	0.035	0.060	5717.0
CC-R4	Coal Creek	19621	0.0102	Muskingum-Cunge	0.035	0.050	Muskingum-Cunge	0.035	0.050	5328.7
CC-R5	Coal Creek	8792	0.0081	Muskingum-Cunge	0.035	0.070	Muskingum-Cunge	0.035	0.070	5261.0
CC-R6A	Coal Creek	13656	0.0061	Muskingum-Cunge	0.035	0.070	Muskingum-Cunge	0.035	0.070	5133.1
CC-R6B	Coal Creek	18238	0.0022	Muskingum-Cunge	0.035	0.060	Muskingum-Cunge	0.035	0.060	5101.3
CC-R7	Coal Creek	11064	0.0021	Muskingum-Cunge	0.035	0.050	Muskingum-Cunge	0.035	0.050	5078.3
CC-R8	Coal Creek	19260	0.0021	Muskingum-Cunge	0.035	0.050	Muskingum-Cunge	0.035	0.050	5022.9
CC-R9	Coal Creek	19946	0.0029	Muskingum-Cunge	0.033	0.045	Muskingum-Cunge	0.033	0.045	4991.8
DC-R1	Dry Creek No. 3	8643	0.0052	Muskingum-Cunge	0.035	0.035	Muskingum-Cunge	0.035	0.035	5224.5
DC-R2	Dry Creek No. 3	25561	0.0069	Muskingum-Cunge	0.035	0.040	Muskingum-Cunge	0.035	0.040	5105.1
FCC-R1	Fourmile Canyon Creek	12642	0.0374	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	5724.6
FCC-R2	Fourmile Canyon Creek	25796	0.0141	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	5236.2
FMC-R1	Fourmile Creek	14925	0.0911	Muskingum-Cunge	0.040	0.050	Muskingum-Cunge	0.040	0.050	8581.6
FMC-R2	Fourmile Creek	14384	0.0250	Muskingum-Cunge	0.040	0.050	Muskingum-Cunge	0.040	0.050	7503.7
FMC-R3	Fourmile Creek	15676	0.0408	Muskingum-Cunge	0.040	0.050	Muskingum-Cunge	0.040	0.050	6704.8
FMC-R4	Fourmile Creek	10089	0.0436	Muskingum-Cunge	0.040	0.050	Muskingum-Cunge	0.040	0.050	6283.9
FMC-R5	Fourmile Creek	12495	0.0288	Muskingum-Cunge	0.040	0.050	Muskingum-Cunge	0.040	0.050	5889.2
MBC-R1	Jasper Creek	11643	0.0653	Muskingum-Cunge	0.050	0.060	Muskingum-Cunge	0.050	0.060	9260.5
MBC-R2	N. Fk. Middle Boulder Creek	21143	0.0530	Muskingum-Cunge	0.050	0.060	Muskingum-Cunge	0.050	0.060	9575.8
MBC-R3	Middle Boulder Creek	14376	0.0278	Muskingum-Cunge	0.050	0.060	Muskingum-Cunge	0.050	0.060	8638.9
MBC-R4	Middle Boulder Creek	18676	0.0223	Muskingum-Cunge	0.050	0.060	Muskingum-Cunge	0.050	0.060	8437.0

Reach ID	Stream Name	L	Slope	Calibrated Model			Predictive Model			Invert
		ft	*ft/ft*	Method	$n_{channel}$	$n_{overbank}$	Method	$n_{channel}$	$n_{overbank}$	*ft (NAVD88)*
MBC-R5	Barker Reservoir	N/A	N/A	N/A	N/A	N/A	Lag (270 mins)	N/A	N/A	N/A
MBC-R6	Middle Boulder Creek	31544	0.0413	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	8187.5
NBC-R1	North Boulder Creek	13643	0.0645	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	9817.8
NBC-R2	Caribou Creek	3983	0.0854	Muskingum-Cunge	0.050	0.060	Muskingum-Cunge	0.050	0.060	9624.6
NBC-R3	North Boulder Creek	20694	0.0599	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	8557.2
NBC-R3A	Trib. to North Boulder Creek	12188	0.0328	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	8327.9
NBC-R4	North Boulder Creek	20713	0.0280	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	7791.5
NBC-R5	North Boulder Creek	12008	0.0533	Muskingum-Cunge	0.070	0.080	Muskingum-Cunge	0.070	0.080	7348.7
RC-R1	Rock Creek	14315	0.0118	Muskingum-Cunge	0.035	0.050	Muskingum-Cunge	0.035	0.050	5461.5
RC-R2	Rock Creek	17124	0.0051	Muskingum-Cunge	0.035	0.060	Muskingum-Cunge	0.035	0.060	5306.6
RC-R3	Rock Creek	29049	0.0046	Muskingum-Cunge	0.035	0.080	Muskingum-Cunge	0.035	0.080	5198.2
SBC-R1	South Boulder Creek	10007	0.0162	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	8898.8
SBC-R2	South Boulder Creek	4074	0.0168	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	8815.5
SBC-R3	South Boulder Creek	20472	0.0192	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	8424.1
SBC-R4	South Boulder Creek	4883	0.0130	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	8322.2
SBC-R5	South Boulder Creek	12963	0.0167	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	8140.1
SBC-R6	South Boulder Creek	12430	0.0161	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	7980.8
SBC-R7	South Boulder Creek	11344	0.0510	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	7546.1
SBC-R9	South Boulder Creek	5061	0.0363	Muskingum-Cunge	0.045	0.050	Muskingum-Cunge	0.045	0.050	6915.2
SBC-R10	South Boulder Creek	15864	0.0234	Muskingum-Cunge	0.045	0.050	Muskingum-Cunge	0.045	0.050	6649.8
SBC-R11	South Boulder Creek	19914	0.0335	Muskingum-Cunge	0.045	0.050	Muskingum-Cunge	0.045	0.050	6053.8
SBC-R12	South Boulder Creek	8588	0.0194	Muskingum-Cunge	0.080	0.100	Muskingum-Cunge	0.045	0.060	5663.4
SBC-R13	South Boulder Creek	11061	0.0122	Muskingum-Cunge	0.080	0.150	Muskingum-Cunge	0.045	0.060	5530.2
SBC-R14	South Boulder Creek	10760	0.0107	Muskingum-Cunge	0.080	0.150	Muskingum-Cunge	0.045	0.060	5404.8
SBC-R15	South Boulder Creek	21496	0.0081	Muskingum-Cunge	0.080	0.150	Muskingum-Cunge	0.045	0.060	5284.8
SC-R1	Skunk Canyon Creek	12399	0.0124	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	5254.3
TCC-R1	Twomile Canyon Creek	8747	0.0592	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	5528.0
TCC-R2	Twomile Canyon Creek	17950	0.0136	Muskingum-Cunge	0.030	0.035	Muskingum-Cunge	0.030	0.035	5305.0
WC-R1	Wonderland Creek	6752	0.0154	Muskingum-Cunge	0.040	0.055	Muskingum-Cunge	0.040	0.055	5418.4
WC-R2	Wonderland Creek	11960	0.0123	Muskingum-Cunge	0.030	0.035	Muskingum-Cunge	0.030	0.035	5293.6

Table B-9

TR-55 Cover Descriptions for NLCD Land Covers

NLCD Land Cover Description	Assigned TR-55 Cover Description [a]		
	Mountains	Foothills	Plains
11 - Open Water	Water	Water	Water
12 - Perennial Snow / Ice	Bare soil	Bare soil	Bare soil
21 - Developed Open Space	Streets and road: paved open ditches	Streets and road: paved open ditches	Open space, good condition
22 - Developed, Low Intensity	Streets and road: paved open ditches	Residential lots, 12 percent impervious	Residential lots, 12 percent impervious
23 - Developed, Medium Intensity	Residential lots, 30 percent impervious	Residential lots, 12 percent impervious	Residential lots, 12 percent impervious
24 - Developed, High Intensity	Residential lots, 38 percent impervious	Residential lots, 30 percent impervious	Residential lots, 30 percent impervious
31 - Barren Land (Rock / Sand / Clay)	Bare soil	Bare soil	Bare soil
41 - Deciduous Forest	Oak-aspen, fair condition	Oak-aspen, good condition	Oak-aspen, good condition
42 - Evergreen Forest	Oak-aspen, fair condition	Pinyon-juniper, good condition	Pinyon-juniper, good condition
43 - Mixed Forest	Oak-aspen, fair condition	Pinyon-juniper, good condition	Pinyon-juniper, good condition
52 – Shrub/Scrub	Brush, fair condition	Sagebrush, good condition	Sagebrush, fair condition
71 - Grassland/Herbaceous	Herbaceous, poor condition	Sagebrush, good condition	Herbaceous, good condition
81 - Pasture/Hay	Pasture, poor condition	Pasture, good condition	Pasture, good condition
82 - Cultivated Crops	Straight row, poor condition	Straight row, poor condition	Straight row, poor condition
90 - Woody Wetlands	Herbaceous, poor condition	Oak-aspen, good condition	Oak-aspen, good condition
95 - Emergent Herbaceous Wetlands	Herbaceous, poor condition	Herbaceous, good condition	Herbaceous, fair condition

[a] Aerial imagery was used to visually assess accuracy of NLCD Land Cover Descriptions. Generally, each NLCD Land Cover description represented a single land use type. However, land use condition based on assessment of aerial photography may not have agreed with the NLCD description (e.g., developed, low intensity in the Mountain Hydrologic Zone represented rural highways and county roads based on aerial photography). Also, land use conditions based on aerial photography did vary between, but not within, Hydrologic Zones.

Table B-10

1 Percent Annual Chance Peak Discharge at Key Locations [a]

HMS Junction	Feature	Location	DARF	Drainage Area *mi²*	Modeled Peak Discharge [a] *cfs*	FIS Discharge *cfs*
BCC-1	Bear Canyon Creek	at Baseline Road	1.00	5.35	748	3,070
BCC-J1	Bear Canyon Creek	at Confluence with Boulder Creek	1.00	8.24	1,643	4,880
DC-J1	Dry Creek No. 3 [b]	just Downstream of Arapahoe Road	0.98	13.6	1,202	1,300
FCC-J1	Fourmile Canyon Creek	at Upstream Limit of Detailed Study	1.00	3.93	451	1,750
FCC-J2	Fourmile Canyon Creek	at Broadway Street	1.00	7.92	1,006	3,581
FCC-J3	Fourmile Canyon Creek	at Boulder Creek Confluence [c]	0.98	10.0	1,558	3,362
TCC-J3	Goose Creek	at Confluence with Boulder Creek	1.00	5.46	3,956	6,315
BC-8	Gregory Canyon Creek	at Marine Street	1.00	2.29	277	2,092
RC-J1	Rock Creek	at McCaslin Boulevard	1.00	4.90	668	2,717
RC-J2	Rock Creek	at Denver-Boulder Turnpike	1.00	9.30	2,158	4,520
RC-J4	Rock Creek	at Confluence with Coal Creek	0.98	21.6	5,001	6,690
SC-J1	Skunk Creek	at Broadway Street	1.00	1.36	575	1,320
BC-7	Sunshine Creek	at Confluence with Boulder Creek	1.00	1.89	437	N/E
TCC-J2	Twomile Canyon Creek	at Broadway Street	1.00	1.68	1,080	890
WC-J1	Wonderland Creek	at Broadway Street	1.00	0.85	637	531 [d]
WC-J2	Wonderland Creek	at 28th Street	1.00	1.35	934	1,484 [d]
WC-J3	Wonderland Creek	at Confluence with North Goose Creek	1.00	1.91	1,405	2,107 [d]

N/E = No estimate provided

[a] Predictive hydrologic model peak discharges not recommended in place of effective FIS hydrology for provided tributaries

[b] Downstream of Baseline Reservoir

[c] Reported value is summation of Fourmile Canyon Creek at Confluence with Boulder Creek and Fourmile Creek Left Bank Overflow

[d] Includes flow diversions from Fourmile Canyon Creek (FEMA, 2012)

Table B-11

Boulder Creek Hydrologic Modeling Detailed Results Summary, by Subbasin (DARF = 0.92) [a]

Hydrologic Element	Drainage Area (mi^2)	Calibrated 24-hour			10 Percent Annual Chance			4 Percent Annual Chance			2 Percent Annual Chance			1 Percent Annual Chance			0.2 Percent Annual Chance		
		Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)
BC-2A	1.232	147	119	1.25	24	20	0.29	54	44	0.58	88	71	0.87	131	106	1.23	270	219	2.33
BC-2B	2.512	254	101	1.04	20	8	0.15	56	22	0.36	100	40	0.59	159	63	0.88	367	146	1.83
BC-3A	0.543	131	242	1.86	13	23	0.23	35	64	0.49	62	115	0.76	99	182	1.09	221	406	2.14
BC-3B	0.495	124	250	2.01	20	41	0.34	48	96	0.66	78	157	0.97	116	234	1.35	235	475	2.50
BC-3C	1.96	214	109	1.26	20	10	0.20	49	25	0.44	83	42	0.70	127	65	1.01	277	141	2.01
BC-4	2.565	224	87	1.15	44	17	0.36	89	35	0.67	137	53	0.99	196	77	1.37	385	150	2.54
BC-5A	1.724	212	123	1.49	30	17	0.31	65	38	0.61	103	60	0.91	152	88	1.28	306	178	2.41
BC-5B	1.597	176	110	1.25	13	8	0.16	35	22	0.39	62	39	0.62	97	61	0.92	218	136	1.87
BC-6A	0.625	123	196	1.92	29	46	0.44	59	95	0.80	92	148	1.16	132	212	1.58	253	405	2.81
BC-6B	2.054	231	112	1.27	17	8	0.16	48	23	0.38	85	41	0.62	135	66	0.92	305	148	1.86
BC-7	1.89	390	206	2.13	64	34	0.34	148	78	0.66	240	127	0.99	356	188	1.38	714	378	2.53
BC-8	1.99	303	152	1.52	23	12	0.16	71	36	0.39	131	66	0.63	214	107	0.93	493	248	1.86
BC-9	1.89	424	224	2.39	133	70	0.55	260	138	0.96	386	204	1.35	536	284	1.80	972	514	3.10
BC-10	3.04	761	250	2.67	300	99	0.57	570	188	0.98	831	273	1.37	1134	373	1.81	1991	655	3.07
BC-11	0.75	141	187	1.40	108	143	0.47	225	301	0.84	341	454	1.20	479	639	1.62	876	1168	2.83
BC-12A	3.75	431	115	1.46	223	59	0.63	412	110	1.07	595	159	1.48	808	215	1.96	1419	378	3.31
BC-12B	1.85	86	46	0.86	92	50	0.64	167	90	1.08	238	129	1.48	322	174	1.95	564	305	3.28
BC-13	1.26	57	45	0.62	15	12	0.20	39	31	0.45	67	53	0.71	104	82	1.03	224	178	2.03
BC-14	1.94	68	35	0.58	61	31	0.47	120	62	0.85	181	93	1.21	253	130	1.64	468	241	2.88
BC-15	6.04	52	9	0.15	343	57	0.70	611	101	1.17	861	142	1.60	1153	191	2.09	1975	327	3.45
BC-16A	6.34	66	10	0.15	218	34	0.47	429	68	0.84	643	101	1.20	895	141	1.61	1641	259	2.81
BC-16B	2.63	15	6	0.04	146	56	0.56	276	105	0.96	403	153	1.34	550	209	1.78	977	371	3.02
BC-17	3.8	64	17	0.29	479	126	1.27	727	191	1.88	943	248	2.41	1178	310	2.99	1800	474	4.55
BC-18	4	16	4	0.03	203	51	0.67	360	90	1.11	511	128	1.52	685	171	1.99	1177	294	3.29
BC-19A	4.77	30	6	0.08	372	78	1.14	576	121	1.71	755	158	2.21	953	200	2.76	1486	311	4.24
BC-19B	5.47	49	9	0.12	335	61	1.00	528	97	1.52	701	128	1.99	895	164	2.51	1422	260	3.91
BC-19C	3.59	50	14	0.17	364	101	1.00	572	159	1.52	761	212	1.98	967	269	2.49	1540	429	3.90
BC-20	5.05	26	5	0.07	282	56	0.96	448	89	1.48	603	119	1.96	774	153	2.48	1255	249	3.94
BCC-1	4.84	873	180	1.96	73	15	0.18	211	44	0.41	374	77	0.65	584	121	0.95	1268	262	1.87
CC-1	8.65	1222	141	1.31	629	73	0.65	1107	128	1.06	1575	182	1.44	2127	246	1.89	3704	428	3.15
CC-2	6.46	1171	181	2.46	210	33	0.49	394	61	0.84	579	90	1.17	805	125	1.57	1475	228	2.71
CC-3	5.37	1303	243	3.79	206	38	0.57	372	69	0.96	534	99	1.32	729	136	1.75	1297	241	2.96
CC-4	7.56	941	124	1.77	157	21	0.39	315	42	0.71	478	63	1.03	674	89	1.40	1269	168	2.48
CC-5	4.16	214	52	0.77	261	63	0.48	508	122	0.84	754	181	1.19	1047	252	1.60	1887	454	2.77
CC-6	4.37	128	29	0.39	435	100	0.60	802	184	1.01	1153	264	1.40	1550	355	1.84	2678	613	3.08
CC-7	2.57	47	18	0.26	340	132	1.06	526	205	1.59	690	269	2.05	870	339	2.55	1346	524	3.90
CC-8	5.78	69	12	0.10	734	127	0.64	1321	228	1.06	1875	324	1.45	2502	433	1.90	4241	734	3.14
CC-9	1.92	42	22	0.31	283	147	1.07	434	226	1.59	568	296	2.05	714	372	2.55	1103	574	3.89
CC-10A	2.14	20	9	0.08	168	78	0.83	281	131	1.31	382	179	1.73	499	233	2.21	814	380	3.52
CC-10B	2.47	72	29	0.36	492	199	1.02	760	308	1.53	999	405	1.98	1255	508	2.48	1937	784	3.82
CC-11	3.81	48	13	0.15	262	69	0.77	440	115	1.23	607	159	1.65	794	208	2.11	1311	344	3.40
CC-12	4.09	36	9	0.10	339	83	0.71	579	142	1.16	800	196	1.57	1051	257	2.03	1751	428	3.32

Hydrologic Element	Drainage Area (mi^2)	Calibrated 24-hour			10 Percent Annual Chance			4 Percent Annual Chance			2 Percent Annual Chance			1 Percent Annual Chance			0.2 Percent Annual Chance		
		Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)
DC-1	7.04	812	115	1.45	219	31	0.38	466	66	0.72	725	103	1.04	1035	147	1.42	1982	281	2.54
DC-2	5.33	265	50	0.77	168	32	0.54	314	59	0.94	455	85	1.32	625	117	1.76	1116	209	3.01
FCC-1	4.01	728	182	2.39	48	12	0.19	128	32	0.43	226	56	0.69	357	89	1.02	805	201	2.07
FCC-2	3.67	647	176	2.10	63	17	0.23	166	45	0.49	291	79	0.77	454	124	1.12	1005	274	2.22
FCC-3	2.38	419	176	1.79	178	75	0.54	341	143	0.94	504	212	1.33	696	292	1.79	1248	524	3.10
FMC-1	2.5895	62	24	0.21	5	2	0.03	19	7	0.13	44	17	0.26	88	34	0.45	276	107	1.17
FMC-2A	2.441	100	41	0.36	9	4	0.07	32	13	0.21	65	27	0.38	117	48	0.61	316	130	1.43
FMC-2B	1.833	81	44	0.41	12	6	0.11	35	19	0.28	66	36	0.48	111	60	0.74	277	151	1.62
FMC-3A	3.762	396	105	0.89	48	13	0.16	141	38	0.37	263	70	0.60	431	115	0.89	1042	277	1.87
FMC-3B	2.583	132	51	0.42	29	11	0.16	83	32	0.37	150	58	0.59	245	95	0.89	581	225	1.84
FMC-4A	2.746	437	159	2.28	84	31	0.43	167	61	0.78	254	92	1.13	363	132	1.54	700	255	2.80
FMC-4B	1.67	297	178	1.89	93	56	0.45	191	114	0.80	295	177	1.15	421	252	1.56	814	488	2.82
FMC-4C	1.185	188	159	1.35	24	20	0.21	67	57	0.45	122	103	0.71	196	166	1.03	451	380	2.06
FMC-5A	1.16	186	161	2.50	45	39	0.63	80	69	1.06	115	99	1.47	156	135	1.94	280	241	3.33
FMC-5B	1.465	204	139	1.86	62	43	0.60	113	77	1.01	163	111	1.41	224	153	1.87	403	275	3.22
FMC-6A	1.73	435	252	2.94	191	110	0.87	321	185	1.37	444	257	1.84	584	338	2.37	982	567	3.86
FMC-6B	1.131	272	241	2.20	100	89	0.64	186	164	1.07	270	239	1.48	370	327	1.96	659	583	3.33
MBC-1A	4.306	4	1	0.01	129	30	0.49	242	56	0.86	365	85	1.24	527	122	1.73	1057	245	3.30
MBC-1B	1.75	2	1	0.01	32	18	0.29	69	40	0.58	115	65	0.89	176	101	1.30	393	224	2.69
MBC-2	5.786	39	7	0.07	349	60	0.78	581	100	1.24	824	142	1.70	1120	194	2.26	2042	353	3.99
MBC-3A	5.737	119	21	0.24	46	8	0.17	117	20	0.38	209	36	0.63	341	59	0.96	824	144	2.12
MBC-3B	5.756	62	11	0.12	53	9	0.21	125	22	0.45	215	37	0.73	339	59	1.10	792	138	2.38
MBC-4	4.824	85	18	0.20	16	3	0.07	50	10	0.21	105	22	0.39	189	39	0.64	530	110	1.58
MBC-5A	5.473	83	15	0.17	16	3	0.07	49	9	0.21	96	18	0.39	168	31	0.64	469	86	1.59
MBC-5B	2.928	52	18	0.21	14	5	0.12	38	13	0.29	70	24	0.50	116	40	0.79	288	98	1.77
MBC-6	2.133	136	64	0.58	92	43	0.43	181	85	0.76	276	129	1.09	396	186	1.50	780	366	2.76
MBC-7A	1.969	103	52	0.56	26	13	0.23	61	31	0.47	100	51	0.72	153	78	1.04	329	167	2.05
MBC-7B	3.666	101	28	0.30	10	3	0.06	33	9	0.18	68	18	0.34	121	33	0.56	327	89	1.33
NBC-1A	3.399	68	20	0.22	88	26	0.50	163	48	0.86	243	72	1.24	346	102	1.72	677	199	3.21
NBC-1B	5.311	97	18	0.20	130	24	0.45	245	46	0.80	375	71	1.17	539	101	1.63	1081	203	3.11
NBC-2	5.096	38	8	0.08	3	1	0.01	18	3	0.07	43	8	0.18	89	17	0.36	316	62	1.08
NBC-3	4.845	34	7	0.07	1	0	0.00	11	2	0.04	29	6	0.13	61	13	0.28	227	47	0.91
NBC-4	4.548	36	8	0.08	0	0	0.00	9	2	0.04	22	5	0.11	47	10	0.24	171	38	0.80
NBC-5A	3.383	54	16	0.17	8	2	0.05	25	7	0.16	51	15	0.31	91	27	0.52	249	74	1.27
NBC-5B	3.999	45	11	0.12	4	1	0.02	17	4	0.10	38	9	0.22	72	18	0.40	223	56	1.10
NBC-5C	2.522	43	17	0.20	9	4	0.08	27	11	0.23	54	21	0.41	93	37	0.65	242	96	1.52
NBC-6A	5.828	113	19	0.22	24	4	0.10	63	11	0.26	114	20	0.46	185	32	0.70	444	76	1.55
NBC-6B	3.566	83	23	0.28	24	7	0.16	57	16	0.36	98	27	0.58	152	43	0.86	343	96	1.79
NBC-7	2.267	192	85	0.99	45	20	0.35	93	41	0.66	143	63	0.96	206	91	1.33	409	180	2.48
RC-1	4.69	716	153	2.37	174	37	0.64	303	65	1.04	425	91	1.42	566	121	1.84	976	208	3.06
RC-2	4.06	649	160	1.31	513	126	0.73	873	215	1.17	1200	296	1.57	1571	387	2.02	2595	639	3.28
RC-3A	3.21	171	53	0.67	291	91	0.87	478	149	1.35	646	201	1.79	833	260	2.27	1347	420	3.59
RC-3B	3.1	95	31	0.33	426	137	0.90	679	219	1.39	902	291	1.82	1147	370	2.30	1811	584	3.59
RC-4	6.6	83	13	0.25	467	71	0.98	735	111	1.49	976	148	1.95	1246	189	2.46	1968	298	3.82

Hydrologic Element	Drainage Area (mi^2)	Calibrated 24-hour			10 Percent Annual Chance			4 Percent Annual Chance			2 Percent Annual Chance			1 Percent Annual Chance			0.2 Percent Annual Chance		
		Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)	Peak Discharge (cfs)	Unit Peak Discharge (cfs/mi^2)	Runoff Volume (in)
SBC-1A	11.58	0	0	0.00	47	4	0.08	145	13	0.24	298	26	0.44	530	46	0.73	1477	128	1.79
SBC-1B	8.96	0	0	0.00	16	2	0.03	59	7	0.14	135	15	0.29	265	30	0.52	844	94	1.42
SBC-2A	7.81	30	4	0.03	0	0	0.00	11	1	0.02	35	5	0.10	83	11	0.23	364	47	0.87
SBC-2B	2.06	40	19	0.18	4	2	0.03	17	8	0.14	44	21	0.29	90	44	0.51	302	147	1.38
SBC-3	6.08	44	7	0.07	0	0	0.00	12	2	0.03	37	6	0.11	96	16	0.24	462	76	0.86
SBC-4	3.19	12	4	0.04	0	0	0.00	6	2	0.03	17	5	0.10	40	13	0.23	184	58	0.80
SBC-5	4.3	24	6	0.05	5	1	0.04	18	4	0.15	33	8	0.29	56	13	0.50	139	32	1.28
SBC-6	7.67	44	6	0.06	8	1	0.02	35	5	0.10	82	11	0.22	162	21	0.41	524	68	1.12
SBC-7	8.87	122	14	0.16	63	7	0.24	127	14	0.49	197	22	0.75	286	32	1.08	581	66	2.14
SBC-8A	8.3	74	9	0.10	18	2	0.07	51	6	0.21	90	11	0.38	145	17	0.62	352	42	1.50
SBC-8B	2.58	57	22	0.27	20	8	0.21	43	17	0.44	69	27	0.70	102	40	1.02	218	84	2.07
SBC-9	6.65	167	25	0.32	53	8	0.20	114	17	0.44	184	28	0.69	274	41	1.00	583	88	2.02
SBC-10A	7.1	653	92	0.86	122	17	0.26	279	39	0.52	459	65	0.80	692	97	1.14	1474	208	2.22
SBC-10B	2.57	154	60	0.49	10	4	0.07	35	14	0.22	74	29	0.39	131	51	0.63	358	139	1.45
SBC-10C	2.41	257	107	0.84	86	36	0.36	187	78	0.67	298	124	0.98	441	183	1.37	892	370	2.52
SBC-11	3.16	676	214	1.60	404	128	0.54	797	252	0.92	1189	376	1.29	1662	526	1.72	3051	965	2.99
SBC-12A	0.47	94	200	1.74	54	115	0.63	100	214	1.04	146	310	1.42	200	425	1.87	355	754	3.16
SBC-12B	2.37	263	111	0.97	50	21	0.26	121	51	0.52	202	85	0.78	308	130	1.10	658	278	2.10
SBC-13	3.72	417	112	1.15	69	19	0.27	162	44	0.54	266	72	0.83	401	108	1.17	844	227	2.23
SBC-14A	1.41	148	105	1.08	14	10	0.17	38	27	0.39	68	48	0.62	108	76	0.91	243	172	1.82
SBC-14B	3.75	395	105	1.10	28	8	0.13	88	23	0.33	164	44	0.55	268	72	0.83	632	169	1.70
SBC-15A	6.02	1024	170	1.98	206	34	0.40	426	71	0.73	656	109	1.05	945	157	1.43	1818	302	2.54
SBC-15B	1.74	477	274	2.77	135	77	0.53	272	156	0.92	407	234	1.29	567	326	1.71	1038	597	2.93
SBC-16A	2.96	493	166	1.97	19	7	0.11	64	22	0.30	125	42	0.51	208	70	0.77	512	173	1.62
SBC-16B	3.34	688	206	2.89	98	29	0.42	197	59	0.75	300	90	1.08	426	128	1.47	814	244	2.62
SBC-17A	3.6	704	195	2.16	43	12	0.18	119	33	0.41	210	58	0.65	332	92	0.95	743	206	1.87
SBC-17B	3.61	590	163	2.25	119	33	0.54	219	61	0.93	319	88	1.30	435	121	1.72	775	215	2.92
SBC-18	1.92	326	170	1.81	8	4	0.08	29	15	0.24	60	31	0.42	104	54	0.65	265	138	1.41
SBC-19A	1.62	530	327	2.85	61	37	0.27	154	95	0.55	257	159	0.83	386	238	1.17	784	484	2.17
SBC-19B	2.49	629	253	2.57	55	22	0.25	138	55	0.52	234	94	0.79	356	143	1.12	753	302	2.11
SBC-20	2.29	737	322	3.13	337	147	0.80	570	249	1.27	782	342	1.70	1024	447	2.20	1682	734	3.54
SBC-21	1.68	0	0	0.00	133	79	1.38	197	117	2.00	252	150	2.53	312	186	3.11	473	281	4.66
SBC-22	2.52	535	212	2.08	99	39	0.32	225	89	0.63	360	143	0.94	525	208	1.30	1022	406	2.37
SC-1	2.04	428	210	2.03	50	24	0.20	157	77	0.45	283	139	0.71	448	220	1.02	983	482	1.98
SC-2	0.95	283	297	3.23	170	179	0.83	286	301	1.32	390	410	1.77	508	534	2.26	827	871	3.63
TCC-1	0.94	238	253	2.33	49	52	0.37	116	124	0.71	188	200	1.04	279	297	1.45	557	593	2.67
TCC-2	1.68	431	257	1.78	67	40	0.22	232	138	0.48	434	258	0.76	692	412	1.10	1508	898	2.15
TCC-3	2.88	698	242	2.30	428	148	0.70	766	266	1.15	1081	375	1.58	1444	501	2.06	2457	853	3.43
WC-1	1.04	236	227	2.11	162	156	0.75	290	279	1.24	409	393	1.69	546	525	2.20	934	898	3.66
WC-2	0.5	125	250	2.00	68	136	0.54	136	271	0.94	203	406	1.33	283	565	1.79	508	1016	3.11
WC-3	0.96	247	257	2.32	166	173	0.71	296	308	1.17	417	435	1.59	556	579	2.08	939	978	3.43

[a] DARF = 0.92 not appropriate for estimation of high-flow hydrology of subbasins in this table. Therefore, reported modeled peak discharges should be considered for reference only.

Appendix C
Ayres Associates Flood Frequency Analyses

HEC-SSP Output for USGS Gage 06730200, Boulder Creek at North 75th Street near Boulder, CO
HEC-SSP Output for USGS Gage 06730500, Boulder Creek at Mouth, near Longmont, CO
HEC-SSP Output for CDWR Gage COCREPCO / USGS Gage 06730300, Coal Creek near Plainview, CO
HEC-SSP Output for USGS Gage 06729000, South Boulder Creek near Rollinsville, CO
HEC-SSP Output for CDWR Gage BOCBGRCO, South Boulder Creek below Gross Reservoir
HEC-SSP Output for CDWR Gage BOCELSCO / USGS Gage 06729500, South Boulder Creek near Eldorado Springs, CO

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Bulletin 17B Frequency Analysis
    10 Jun 2014   06:19 PM
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--- Input Data ---

Analysis Name: BLDR CK-NTH 75TH 2013 ST
Description:

Data Set Name: BLDR CK-NTH 75TH ST. N 2013
DSS File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\CH2M_F.dss
DSS Pathname: /BOULDER CREEK/NORTH 75TH ST. NEAR BOULDER, CO/FLOW-ANNUAL
PEAK/01jan1900/IR-CENTURY/Save Data As: BLDR CK-NTH 75TH ST. N 2013/

Report File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\BLDR_CK-NTH_75TH_2013_ST\BLDR_CK-
NTH_75TH_2013_ST.rpt
XML File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\BLDR_CK-NTH_75TH_2013_ST\BLDR_CK-
NTH_75TH_2013_ST.xml

Start Date:
End Date:

Skew Option: Use Station Skew
Regional Skew: -Infinity
Regional Skew MSE: -Infinity

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95
Use High Outlier Threshold
High Outlier Threshold: 4519.9

Use Historic Data
Historic Period Start Year: ---
Historic Period End Year: ---

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---
```

--- Preliminary Results ---

<< Plotting Positions >>
BLDR CK-NTH 75TH ST. N 2013

Events Analyzed			Ordered Events			
Day Mon Year	FLOW CFS		Rank	Water Year	FLOW CFS	Median Plot Pos
09 Jun 1987	1,080		1	2013	8,400*	2.55
18 May 1988	663		2	2003	2,050	6.20
03 Jun 1989	542		3	1995	1,950	9.85
29 Apr 1990	542		4	1997	1,500	13.50
01 Jun 1991	1,090		5	1999	1,330	17.15
24 Aug 1992	371		6	2011	1,220	20.80
18 Jun 1993	957		7	2000	1,180	24.45
11 Aug 1994	769		8	1991	1,090	28.10
17 May 1995	1,950		9	1987	1,080	31.75
26 May 1996	1,000		10	2010	1,020	35.40
13 Jun 1997	1,500		11	1996	1,000	39.05
30 Jul 1998	554		12	1993	957	42.70
04 Aug 1999	1,330		13	2005	901	46.35
16 Jul 2000	1,180		14	2012	863	50.00
09 Aug 2001	548		15	1994	769	53.65
23 May 2002	443		16	2009	667	57.30
30 May 2003	2,050		17	1988	663	60.95
23 Jul 2004	532		18	2006	648	64.60
24 May 2005	901		19	1998	554	68.25
09 Jul 2006	648		20	2001	548	71.90
07 Jun 2007	343		21	1990	542	75.55
05 Jun 2008	493		22	1989	542	79.20
26 Jun 2009	667		23	2004	532	82.85
13 Jun 2010	1,020		24	2008	493	86.50
13 Jul 2011	1,220		25	2002	443	90.15
07 Jul 2012	863		26	1992	371	93.80
12 Sep 2013	8,400		27	2007	343	97.45

* Outlier

<< Skew Weighting >>

Based on 27 events, mean-square error of station skew = 0.519
Mean-square error of regional skew = -?

<< Frequency Curve >>

BLDR CK-NTH 75TH ST. N 2013

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
19,399	36,083	0.2	49,972	10,586
11,654	17,878	0.5	25,966	6,952
7,895	10,750	1.0	15,770	5,034
5,326	6,594	2.0	9,546	3,624
3,136	3,512	5.0	4,890	2,314
2,079	2,219	10.0	2,938	1,619
1,359	1,399	20.0	1,767	1,098
741	741	50.0	911	591
511	507	80.0	636	387
454	449	90.0	570	336
424	419	95.0	537	310
395	391	99.0	503	285

<< Systematic Statistics >>

BLDR CK-NTH 75TH ST. N 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	2.941	Historic Events	0
Standard Dev	0.284	High Outliers	0
Station Skew	1.574	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	1.574	Systematic Events	27

--- End of Preliminary Results ---

<< High Outlier Test >>

Based on 27 events, 10 percent outlier test deviate K(N) = 2.519
Computed high outlier test value = 4,519.9

1 high outlier(s) identified above input threshold of 4,519.9

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* Note - Collection of historical information and           *
*        comparison with similar data should be explored,   *
*        if not incorporated in this analysis.              *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Statistics and frequency curve adjusted for 1 high outlier(s)

<< Systematic Statistics >>
BLDR CK-NTH 75TH ST. N 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	2.941	Historic Events	0
Standard Dev	0.284	High Outliers	1
Station Skew	1.574	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	1.574	Systematic Events	27

<< Low Outlier Test >>

Based on 27 events, 10 percent outlier test deviate K(N) = 2.519
Computed low outlier test value = 168.4

0 low outlier(s) identified below test value of 168.4

--- Final Results ---

<< Plotting Positions >>
BLDR CK-NTH 75TH ST. N 2013

Events Analyzed		Ordered Events			
Day Mon Year	FLOW CFS	Rank	Water Year	FLOW CFS	Median Plot Pos
09 Jun 1987	1,080	1	2013	8,400*	2.55
18 May 1988	663	2	2003	2,050	6.20
03 Jun 1989	542	3	1995	1,950	9.85
29 Apr 1990	542	4	1997	1,500	13.50
01 Jun 1991	1,090	5	1999	1,330	17.15
24 Aug 1992	371	6	2011	1,220	20.80
18 Jun 1993	957	7	2000	1,180	24.45
11 Aug 1994	769	8	1991	1,090	28.10
17 May 1995	1,950	9	1987	1,080	31.75
26 May 1996	1,000	10	2010	1,020	35.40
13 Jun 1997	1,500	11	1996	1,000	39.05
30 Jul 1998	554	12	1993	957	42.70
04 Aug 1999	1,330	13	2005	901	46.35
16 Jul 2000	1,180	14	2012	863	50.00
09 Aug 2001	548	15	1994	769	53.65
23 May 2002	443	16	2009	667	57.30
30 May 2003	2,050	17	1988	663	60.95
23 Jul 2004	532	18	2006	648	64.60
24 May 2005	901	19	1998	554	68.25
09 Jul 2006	648	20	2001	548	71.90
07 Jun 2007	343	21	1990	542	75.55
05 Jun 2008	493	22	1989	542	79.20

26 Jun 2009	667	23	2004	532	82.85
13 Jun 2010	1,020	24	2008	493	86.50
13 Jul 2011	1,220	25	2002	443	90.15
07 Jul 2012	863	26	1992	371	93.80
12 Sep 2013	8,400	27	2007	343	97.45

* Outlier

<< Skew Weighting >>

Based on 27 events, mean-square error of station skew = 0.519
Mean-square error of regional skew = -?

<< Frequency Curve >>
BLDR CK-NTH 75TH ST. N 2013

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
19,399	36,083	0.2	49,972	10,586
11,654	17,878	0.5	25,966	6,952
7,895	10,750	1.0	15,770	5,034
5,326	6,594	2.0	9,546	3,624
3,136	3,512	5.0	4,890	2,314
2,079	2,219	10.0	2,938	1,619
1,359	1,399	20.0	1,767	1,098
741	741	50.0	911	591
511	507	80.0	636	387
454	449	90.0	570	336
424	419	95.0	537	310
395	391	99.0	503	285

<< Adjusted Statistics >>
BLDR CK-NTH 75TH ST. N 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	2.941	Historic Events	0
Standard Dev	0.284	High Outliers	1
Station Skew	1.574	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	1.574	Systematic Events	27

--- End of Analytical Frequency Curve ---

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Bulletin 17B Frequency Analysis
    03 Sep 2014   05:43 PM
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--- Input Data ---

Analysis Name: BLDR CK-MO NR LMT 2013 ST
Description: Bouder Creek FFA with the USGS 2013 Q of 8,910 cfs
1 -- Discharge is a Maximum Daily Average
2 -- Discharge is an Estimate

Data Set Name: BOULDER CREEK-MOUTH NEAR LONGMONT, WITH 2013 ANNUAL PEAK
DSS File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\CH2M_F.dss
DSS Pathname: /BOULDER CREEK/MOUTH NEAR LONGMONT, CO/FLOW-ANNUAL
PEAK/01jan1900/IR-CENTURY/USGS/

Report File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\BLDR_CK-MO_NR_LMT_2013_ST\BLDR_CK-
MO_NR_LMT_2013_ST.rpt
XML File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\BLDR_CK-MO_NR_LMT_2013_ST\BLDR_CK-
MO_NR_LMT_2013_ST.xml

Start Date:
End Date:

Skew Option: Use Station Skew
Regional Skew: -Infinity
Regional Skew MSE: -Infinity

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95
Use High Outlier Threshold
High Outlier Threshold: 6943.0

Use Historic Data
Historic Period Start Year: ---
Historic Period End Year: ---

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---
```

--- Preliminary Results ---

<< Plotting Positions >>

BOULDER CREEK-MOUTH NEAR LONGMONT, WITH 2013 ANNUAL PEAK

Events Analyzed				Ordered Events			
			FLOW		Water	FLOW	Median
Day	Mon	Year	CFS	Rank	Year	CFS	Plot Pos
28	Jul	1927	407	1	2013	8,910*	1.12
04	Jun	1928	694	2	1938	4,410	2.72
23	Jul	1929	530	3	1995	2,300	4.33
17	Aug	1930	353	4	1983	2,090	5.93
29	May	1931	369	5	1947	2,040	7.53
13	Jul	1932	128	6	1949	2,020	9.13
04	May	1933	670	7	1980	1,990	10.74
10	May	1934	388	8	1952	1,990	12.34
28	May	1935	1,110	9	1942	1,790	13.94
17	Jun	1936	366	10	1997	1,760	15.54
26	Jun	1937	680	11	1951	1,540	17.15
03	Sep	1938	4,410	12	1999	1,470	18.75
24	Apr	1939	390	13	2010	1,420	20.35
03	Jul	1940	174	14	1993	1,420	21.96
22	Jun	1941	738	15	1996	1,400	23.56
24	Apr	1942	1,790	16	2003	1,240	25.16
19	May	1943	553	17	2000	1,230	26.76
14	Apr	1944	970	18	2006	1,210	28.37
30	May	1945	702	19	2011	1,140	29.97
19	Jul	1946	178	20	1935	1,110	31.57
23	Jun	1947	2,040	21	1979	1,040	33.17
15	Oct	1947	721	22	1987	981	34.78
07	Jun	1949	2,020	23	1944	970	36.38
03	Aug	1951	1,540	24	2009	843	37.98
24	May	1952	1,990	25	2004	775	39.58
29	May	1953	247	26	1982	770	41.19
14	Jan	1954	26	27	2005	755	42.79
19	Aug	1955	336	28	1941	738	44.39
10	Jun	1979	1,040	29	2012	725	45.99
01	May	1980	1,990	30	1948	721	47.60
29	May	1981	387	31	1945	702	49.20
13	May	1982	770	32	1928	694	50.80
19	May	1983	2,090	33	2008	680	52.40
24	Apr	1984	560	34	1937	680	54.01
10	Jun	1985	448	35	1933	670	55.61
09	Jun	1986	508	36	2007	633	57.21
09	Jun	1987	981	37	1989	623	58.81
20	May	1988	540	38	1992	609	60.42
04	Jun	1989	623	39	1998	566	62.02
12	Jun	1990	392	40	1984	560	63.62
24	Aug	1992	609	41	1943	553	65.22
18	Jun	1993	1,420	42	1988	540	66.83
18	Oct	1993	497	43	1929	530	68.43
17	May	1995	2,300	44	1986	508	70.03
26	May	1996	1,400	45	1994	497	71.63

07 Jun 1997	1,760	46	1985	448	73.24
26 Apr 1998	566	47	1927	407	74.84
30 Apr 1999	1,470	48	1990	392	76.44
17 Jul 2000	1,230	49	1939	390	78.04
05 May 2001	377	50	1934	388	79.65
24 May 2002	238	51	1981	387	81.25
31 May 2003	1,240	52	2001	377	82.85
23 Jul 2004	775	53	1931	369	84.46
24 May 2005	755	54	1936	366	86.06
09 Jul 2006	1,210	55	1930	353	87.66
25 Apr 2007	633	56	1955	336	89.26
16 Aug 2008	680	57	1953	247	90.87
02 Jun 2009	843	58	2002	238	92.47
14 Jun 2010	1,420	59	1946	178	94.07
13 Jul 2011	1,140	60	1940	174	95.67
08 Jul 2012	725	61	1932	128	97.28
13 Sep 2013	8,910	62	1954	26*	98.88

* Outlier

<< Skew Weighting >>

Based on 62 events, mean-square error of station skew = 0.117
Mean-square error of regional skew = -?

<< Frequency Curve >>
BOULDER CREEK-MOUTH NEAR LONGMONT, WITH 2013 ANNUAL PEAK

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
5,416	5,787	0.2	8,121	3,958
4,639	4,894	0.5	6,796	3,446
4,050	4,235	1.0	5,814	3,051
3,462	3,587	2.0	4,858	2,649
2,688	2,755	5.0	3,642	2,106
2,108	2,143	10.0	2,768	1,686
1,534	1,549	20.0	1,943	1,254
775	775	50.0	936	644
353	348	80.0	431	280
224	218	90.0	282	169
150	144	95.0	197	107
67	61	99.0	96	43

<< Systematic Statistics >>
BOULDER CREEK-MOUTH NEAR LONGMONT, WITH 2013 ANNUAL PEAK

Log Transform: FLOW, CFS		Number of Events	
Mean	2.858	Historic Events	0
Standard Dev	0.383	High Outliers	0
Station Skew	-0.498	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	-0.498	Systematic Events	62

--- End of Preliminary Results ---

<< Low Outlier Test >>

Based on 62 events, 10 percent outlier test deviate K(N) = 2.849
Computed low outlier test value = 58.3

1 low outlier(s) identified below test value of 58.3

Statistics and frequency curve adjusted for 1 low outlier(s)

```
<< Systematic Statistics >>
BOULDER CREEK-MOUTH NEAR LONGMONT, WITH 2013 ANNUAL PEAK
----------------------------------------------------------------
|        Log Transform:         |                               |
|          FLOW, CFS            |       Number of Events        |
|-------------------------------|-------------------------------|
|  Mean                  2.881  |  Historic Events          0   |
|  Standard Dev          0.338  |  High Outliers         0      |
|  Station Skew          0.383  |  Low Outliers          1      |
|  Regional Skew           ---  |  Zero Events           0      |
|  Weighted Skew           ---  |  Missing Events        0      |
|  Adopted Skew         -0.498  |  Systematic Events       62   |
|                               |  Historic Period         87   |
|-------------------------------|-------------------------------|


-----------------------
<< High Outlier Test >>
-----------------------
 Based on 61 events, 10 percent outlier test deviate K(N) = 2.842
                         Computed high outlier test value = 6,943

      1 high outlier(s) identified above input threshold of 6,943

   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
   * Note - Collection of historical information and          *
   *        comparison with similar data should be explored, *
   *        if not incorporated in this analysis.            *
   * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

    Statistics and frequency curve adjusted for 1 high outlier(s)


<< Systematic Statistics >>
BOULDER CREEK-MOUTH NEAR LONGMONT, WITH 2013 ANNUAL PEAK
----------------------------------------------------------------
|        Log Transform:         |                               |
|          FLOW, CFS            |       Number of Events        |
|-------------------------------|-------------------------------|
|  Mean                  2.876  |  Historic Events          0   |
|  Standard Dev          0.330  |  High Outliers         1      |
|  Station Skew          0.287  |  Low Outliers          1      |
|  Regional Skew           ---  |  Zero Events           0      |
|  Weighted Skew           ---  |  Missing Events        0      |
|  Adopted Skew         -0.498  |  Systematic Events       62   |
|                               |  Historic Period         87   |
|-------------------------------|-------------------------------|


Note: Statistics and frequency curve were modified
using conditional probability adjustment.
```

--- Final Results ---

<< Plotting Positions >>
BOULDER CREEK-MOUTH NEAR LONGMONT, WITH 2013 ANNUAL PEAK

Events Analyzed				Ordered Events			
Day	Mon	Year	FLOW CFS	Rank	Water Year	FLOW CFS	Median Plot Pos
28	Jul	1927	407	1	2013	8,910*	0.80
04	Jun	1928	694	2	1938	4,410	2.18
23	Jul	1929	530	3	1995	2,300	3.79
17	Aug	1930	353	4	1983	2,090	5.41
29	May	1931	369	5	1947	2,040	7.02
13	Jul	1932	128	6	1949	2,020	8.63
04	May	1933	670	7	1980	1,990	10.24
10	May	1934	388	8	1952	1,990	11.86
28	May	1935	1,110	9	1942	1,790	13.47
17	Jun	1936	366	10	1997	1,760	15.08
26	Jun	1937	680	11	1951	1,540	16.70
03	Sep	1938	4,410	12	1999	1,470	18.31
24	Apr	1939	390	13	2010	1,420	19.92
03	Jul	1940	174	14	1993	1,420	21.54
22	Jun	1941	738	15	1996	1,400	23.15
24	Apr	1942	1,790	16	2003	1,240	24.76
19	May	1943	553	17	2000	1,230	26.38
14	Apr	1944	970	18	2006	1,210	27.99
30	May	1945	702	19	2011	1,140	29.60
19	Jul	1946	178	20	1935	1,110	31.22
23	Jun	1947	2,040	21	1979	1,040	32.83
15	Oct	1947	721	22	1987	981	34.44
07	Jun	1949	2,020	23	1944	970	36.05
03	Aug	1951	1,540	24	2009	843	37.67
24	May	1952	1,990	25	2004	775	39.28
29	May	1953	247	26	1982	770	40.89
14	Jan	1954	26	27	2005	755	42.51
19	Aug	1955	336	28	1941	738	44.12
10	Jun	1979	1,040	29	2012	725	45.73
01	May	1980	1,990	30	1948	721	47.35
29	May	1981	387	31	1945	702	48.96
13	May	1982	770	32	1928	694	50.57
19	May	1983	2,090	33	2008	680	52.19
24	Apr	1984	560	34	1937	680	53.80
10	Jun	1985	448	35	1933	670	55.41
09	Jun	1986	508	36	2007	633	57.02
09	Jun	1987	981	37	1989	623	58.64
20	May	1988	540	38	1992	609	60.25
04	Jun	1989	623	39	1998	566	61.86
12	Jun	1990	392	40	1984	560	63.48
24	Aug	1992	609	41	1943	553	65.09
18	Jun	1993	1,420	42	1988	540	66.70
18	Oct	1993	497	43	1929	530	68.32

17 May 1995	2,300	44	1986	508	69.93
26 May 1996	1,400	45	1994	497	71.54
07 Jun 1997	1,760	46	1985	448	73.16
26 Apr 1998	566	47	1927	407	74.77
30 Apr 1999	1,470	48	1990	392	76.38
17 Jul 2000	1,230	49	1939	390	77.99
05 May 2001	377	50	1934	388	79.61
24 May 2002	238	51	1981	387	81.22
31 May 2003	1,240	52	2001	377	82.83
23 Jul 2004	775	53	1931	369	84.45
24 May 2005	755	54	1936	366	86.06
09 Jul 2006	1,210	55	1930	353	87.67
25 Apr 2007	633	56	1955	336	89.29
16 Aug 2008	680	57	1953	247	90.90
02 Jun 2009	843	58	2002	238	92.51
14 Jun 2010	1,420	59	1946	178	94.13
13 Jul 2011	1,140	60	1940	174	95.74
08 Jul 2012	725	61	1932	128	97.35
13 Sep 2013	8,910	62	1954	26*	98.96

Note: Plotting positions based on historic period (H) = 87
Number of historic events plus high outliers (Z) = 1
Weighting factor for systematic events (W) = 1.4098

* Outlier

<< Skew Weighting >>

Based on 87 events, mean-square error of station skew =	0.077
Mean-square error of regional skew =	-?

<< Frequency Curve >>

BOULDER CREEK-MOUTH NEAR LONGMONT, WITH 2013 ANNUAL PEAK

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
8,722	10,005	0.2	13,869	6,134
6,493	7,189	0.5	9,844	4,725
5,119	5,534	1.0	7,475	3,827
3,972	4,207	2.0	5,577	3,052
2,746	2,843	5.0	3,653	2,191
2,001	2,044	10.0	2,551	1,643
1,384	1,399	20.0	1,691	1,166
714	714	50.0	837	608
389	386	80.0	463	318
289	285	90.0	351	228
229	223	95.0	283	175
152	145	99.0	195	109

<< Synthetic Statistics >>

BOULDER CREEK-MOUTH NEAR LONGMONT, WITH 2013 ANNUAL PEAK

Log Transform: FLOW, CFS		Number of Events	
Mean	2.870	Historic Events	0
Standard Dev	0.329	High Outliers	1
Station Skew	0.308	Low Outliers	1
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	0.308	Systematic Events	62
		Historic Period	87

--- End of Analytical Frequency Curve ---

```
------------------------------
Bulletin 17B Frequency Analysis
    10 Jun 2014   06:19 PM
------------------------------


--- Input Data ---

Analysis Name: COAL CK-PLAINVIEW 2013 ST
Description:

Data Set Name: COAL CK-PLAINVIEW 2013
DSS File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\CH2M_F.dss
DSS Pathname: /COAL CREEK/PLAINVIEW, CO./FLOW-ANNUAL PEAK/01jan1900/IR-
CENTURY/USGS/

Report File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\COAL_CK-PLAINVIEW_2013_ST\COAL_CK-
PLAINVIEW_2013_ST.rpt
XML File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\COAL_CK-PLAINVIEW_2013_ST\COAL_CK-
PLAINVIEW_2013_ST.xml

Start Date:
End Date:

Skew Option: Use Station Skew
Regional Skew: -Infinity
Regional Skew MSE: -Infinity

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95
Use High Outlier Threshold
High Outlier Threshold: 2574.0

Use Historic Data
Historic Period Start Year: ---
Historic Period End Year: ---

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---









--- Preliminary Results --
```

<< Plotting Positions >>
COAL CK-PLAINVIEW 2013

Events Analyzed				Ordered Events			
Day	Mon	Year	FLOW CFS	Rank	Water Year	FLOW CFS	Median Plot Pos
02	Aug	1959	2	1	2013	3,900*	1.54
07	May	1960	164	2	1969	2,060	3.74
17	May	1961	60	3	1973	338	5.95
19	Apr	1962	34	4	1999	227	8.15
16	Jun	1963	195	5	1995	221	10.35
14	Mar	1964	17	6	1980	205	12.56
24	Jul	1965	101	7	1963	195	14.76
04	Mar	1966	4	8	1971	167	16.96
21	Jun	1967	46	9	1960	164	19.16
24	May	1968	37	10	2009	105	21.37
07	May	1969	2,060	11	1965	101	23.57
11	Jun	1970	76	12	1998	100	25.77
25	Apr	1971	167	13	1979	96	27.97
06	May	1972	30	14	2007	94	30.18
06	May	1973	338	15	2003	85	32.38
04	May	1974	28	16	2010	78	34.58
03	Jun	1975	76	17	1997	76	36.78
25	May	1976	28	18	1975	76	38.99
24	Jul	1977	41	19	1970	76	41.19
10	May	1978	46	20	1981	64	43.39
09	Jun	1979	96	21	1961	60	45.59
30	Apr	1980	205	22	2005	56	47.80
30	May	1981	64	23	2004	47	50.00
20	May	1982	43	24	1978	46	52.20
16	Apr	1993	43	25	1967	46	54.41
06	May	1994	20	26	2001	46	56.61
26	May	1995	221	27	1993	43	58.81
26	May	1996	41	28	1982	43	61.01
29	Apr	1997	76	29	1996	41	63.22
04	May	1998	100	30	1977	41	65.42
04	Aug	1999	227	31	2008	40	67.62
04	Apr	2000	12	32	1968	37	69.82
08	May	2001	46	33	1962	34	72.03
25	May	2002	9	34	2011	30	74.23
15	May	2003	85	35	1972	30	76.43
27	Jun	2004	47	36	1976	28	78.63
06	May	2005	56	37	1974	28	80.84
13	Oct	2005	3	38	1994	20	83.04
28	Apr	2007	94	39	1964	17	85.24
05	Aug	2008	40	40	2000	12	87.44
21	Apr	2009	105	41	2002	9	89.65
29	Apr	2010	78	42	2012	6	91.85
20	May	2011	30	43	1966	4	94.05
04	Apr	2012	6	44	2006	3	96.26
14	Sep	2013	3,900	45	1959	2	98.46

* Outlier

<< Skew Weighting >>

Based on 45 events, mean-square error of station skew = 0.142
Mean-square error of regional skew = -?

<< Frequency Curve >>
COAL CK-PLAINVIEW 2013

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
6,183	---	0.2	18,056	2,855
3,458	---	0.5	9,005	1,726
2,171	---	1.0	5,165	1,151
1,324	---	2.0	2,869	747
648	---	5.0	1,235	398
353	---	10.0	608	231
175	---	20.0	273	121
51	---	50.0	72	36
17	---	80.0	24	11
10	---	90.0	15	6
6	---	95.0	10	4
3	---	99.0	5	2

<< Systematic Statistics >>
COAL CK-PLAINVIEW 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	1.744	Historic Events	0
Standard Dev	0.611	High Outliers	0
Station Skew	0.387	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	0.387	Systematic Events	45

--- End of Preliminary Results ---

<< Low Outlier Test >>

Based on 45 events, 10 percent outlier test deviate K(N) = 2.727
Computed low outlier test value = 1.2

0 low outlier(s) identified below test value of 1.2

<< High Outlier Test >>

Based on 45 events, 10 percent outlier test deviate K(N) = 2.727
Computed high outlier test value = 2,574

1 high outlier(s) identified above input threshold of 2,574

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* Note - Collection of historical information and          *
*        comparison with similar data should be explored,  *
*        if not incorporated in this analysis.             *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Statistics and frequency curve adjusted for 1 high outlier(s)

<< Systematic Statistics >>

COAL CK-PLAINVIEW 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	1.736	Historic Events	0
Standard Dev	0.599	High Outliers	1
Station Skew	0.319	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	0.387	Systematic Events	45
		Historic Period	55

--- Final Results ---

<< Plotting Positions >>

COAL CK-PLAINVIEW 2013

Events Analyzed		Ordered Events			
Day Mon Year	FLOW CFS	Rank	Water Year	FLOW CFS	Median Plot Pos
02 Aug 1959	2	1	2013	3,900*	1.26
07 May 1960	164	2	1969	2,060	3.27
17 May 1961	60	3	1973	338	5.49
19 Apr 1962	34	4	1999	227	7.70
16 Jun 1963	195	5	1995	221	9.92
14 Mar 1964	17	6	1980	205	12.13
24 Jul 1965	101	7	1963	195	14.35
04 Mar 1966	4	8	1971	167	16.57
21 Jun 1967	46	9	1960	164	18.78

24 May 1968	37	10	2009	105	21.00
07 May 1969	2,060	11	1965	101	23.21
11 Jun 1970	76	12	1998	100	25.43
25 Apr 1971	167	13	1979	96	27.64
06 May 1972	30	14	2007	94	29.86
06 May 1973	338	15	2003	85	32.07
04 May 1974	28	16	2010	78	34.29
03 Jun 1975	76	17	1997	76	36.50
25 May 1976	28	18	1975	76	38.72
24 Jul 1977	41	19	1970	76	40.93
10 May 1978	46	20	1981	64	43.15
09 Jun 1979	96	21	1961	60	45.36
30 Apr 1980	205	22	2005	56	47.58
30 May 1981	64	23	2004	47	49.79
20 May 1982	43	24	1978	46	52.01
16 Apr 1993	43	25	1967	46	54.23
06 May 1994	20	26	2001	46	56.44
26 May 1995	221	27	1993	43	58.66
26 May 1996	41	28	1982	43	60.87
29 Apr 1997	76	29	1996	41	63.09
04 May 1998	100	30	1977	41	65.30
04 Aug 1999	227	31	2008	40	67.52
04 Apr 2000	12	32	1968	37	69.73
08 May 2001	46	33	1962	34	71.95
25 May 2002	9	34	2011	30	74.16
15 May 2003	85	35	1972	30	76.38
27 Jun 2004	47	36	1976	28	78.59
06 May 2005	56	37	1974	28	80.81
13 Oct 2005	3	38	1994	20	83.02
28 Apr 2007	94	39	1964	17	85.24
05 Aug 2008	40	40	2000	12	87.45
21 Apr 2009	105	41	2002	9	89.67
29 Apr 2010	78	42	2012	6	91.89
20 May 2011	30	43	1966	4	94.10
04 Apr 2012	6	44	2006	3	96.32
14 Sep 2013	3,900	45	1959	2	98.53

Note: Plotting positions based on historic period (H) = 55
Number of historic events plus high outliers (Z) = 1
Weighting factor for systematic events (W) = 1.2273

* Outlier

<< Skew Weighting >>

Based on 55 events, mean-square error of station skew = 0.115
Mean-square error of regional skew = -?

<< Frequency Curve >>
COAL CK-PLAINVIEW 2013

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
4,941	---	0.2	13,813	2,353
2,873	---	0.5	7,220	1,471
1,857	---	1.0	4,290	1,006
1,166	---	2.0	2,467	669
593	---	5.0	1,111	368
332	---	10.0	566	219
169	---	20.0	262	118
51	---	50.0	71	36
17	---	80.0	24	11
10	---	90.0	15	6
6	---	95.0	10	4
3	---	99.0	5	1

<< Adjusted Statistics >>
COAL CK-PLAINVIEW 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	1.736	Historic Events	0
Standard Dev	0.599	High Outliers	1
Station Skew	0.319	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	0.319	Systematic Events	45
		Historic Period	55

--- End of Analytical Frequency Curve ---

```
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Bulletin 17B Frequency Analysis
    10 Jun 2014   06:19 PM
-------------------------------


--- Input Data ---

Analysis Name: STH BLDR CK-ROLL 2013 ST
Description:

Data Set Name: STH BLDR CK-ROLLINSVIL 2013
DSS File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\CH2M_F.dss
DSS Pathname: /SOUTH BOULDER CREEK/ROLLINSVILLE, CO./FLOW-ANNUAL
PEAK/01jan1900/IR-CENTURY/Save Data As: STH BLDR CK-ROLLINSVIL 2013/

Report File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\STH_BLDR_CK-ROLL_2013_ST\STH_BLDR_CK-
ROLL_2013_ST.rpt
XML File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\STH_BLDR_CK-ROLL_2013_ST\STH_BLDR_CK-
ROLL_2013_ST.xml

Start Date:
End Date:

Skew Option: Use Station Skew
Regional Skew: -Infinity
Regional Skew MSE: -Infinity

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---

-----------------------
<< High Outlier Test >>
-----------------------
 Based on 13 events, 10 percent outlier test deviate K(N) = 2.175
                         Computed high outlier test value = 755.7

           0 high outlier(s) identified above test value of 755.7
----------------------
<< Low Outlier Test >>
----------------------
 Based on 13 events, 10 percent outlier test deviate K(N) = 2.175
                          Computed low outlier test value = 258.8

            0 low outlier(s) identified below test value of 258.8
```

--- Final Results ---

<< Plotting Positions >>

STH BLDR CK-ROLLINSVIL 2013

Events Analyzed				Ordered Events			
Day	Mon	Year	FLOW CFS	Rank	Water Year	FLOW CFS	Median Plot Pos
12	Jun	1911	350	1	1949	718	5.22
08	Jun	1912	450	2	1947	622	12.69
31	May	1913	320	3	1914	542	20.15
02	Jun	1914	542	4	1948	498	27.61
20	Jun	1915	484	5	1915	484	35.07
10	Jun	1916	324	6	1912	450	42.54
22	Jun	1917	432	7	1917	432	50.00
28	Jun	1945	410	8	2013	410	57.46
10	Jun	1946	358	9	1945	410	64.93
21	Jun	1947	622	10	1946	358	72.39
22	May	1948	498	11	1911	350	79.85
12	Jun	1949	718	12	1916	324	87.31
13	Sep	2013	410	13	1913	320	94.78

<< Skew Weighting >>

Based on 13 events, mean-square error of station skew = 0.416

Mean-square error of regional skew = -?

<< Frequency Curve >>
STH BLDR CK-ROLLINSVIL 2013

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
1,047	1,436	0.2	1,652	825
937	1,170	0.5	1,403	757
858	1,011	1.0	1,232	707
782	878	2.0	1,076	657
685	731	5.0	888	590
613	637	10.0	758	538
540	550	20.0	637	481
433	433	50.0	487	383
358	354	80.0	402	302
328	320	90.0	372	268
307	296	95.0	351	244
274	256	99.0	320	207

<< Systematic Statistics >>
STH BLDR CK-ROLLINSVIL 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	2.646	Historic Events	0
Standard Dev	0.107	High Outliers	0
Station Skew	0.508	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	0.508	Systematic Events	13

--- End of Analytical Frequency Curve ---

```
-------------------------------
Bulletin 17B Frequency Analysis
    10 Jun 2014   06:19 PM
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--- Input Data ---

Analysis Name: STH BLDR CK GROSS 2013 ST
Description:

Data Set Name: STH BLDR CK-DS GROSS RES 2013
DSS File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\CH2M_F.dss
DSS Pathname: /SOUTH BOULDER CREEK/DS GROSS RESERVOIR/FLOW-
PEAK/01jan1900/IR-CENTURY/EXCEL -2013/

Report File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\STH_BLDR_CK_GROSS_2013_ST\STH_BLDR_CK
_GROSS_2013_ST.rpt
XML File Name: H:\32-176904 Big Thompson
Hydrology\CH2M_F\Bulletin17bResults\STH_BLDR_CK_GROSS_2013_ST\STH_BLDR_CK
_GROSS_2013_ST.xml

Start Date:
End Date:

Skew Option: Use Station Skew
Regional Skew: -Infinity
Regional Skew MSE: -Infinity

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---

----------------------
<< Low Outlier Test >>
----------------------
 Based on 23 events, 10 percent outlier test deviate K(N) = 2.448
                          Computed low outlier test value = 298.4

            0 low outlier(s) identified below test value of 298.4

-----------------------
<< High Outlier Test >>
-----------------------
 Based on 23 events, 10 percent outlier test deviate K(N) = 2.448
                         Computed high outlier test value = 921.8

           0 high outlier(s) identified above test value of 921.8
```

--- Final Results ---

<< Plotting Positions >>

STH BLDR CK-DS GROSS RES 2013

Events Analyzed				Ordered Events			
Day	Mon	Year	FLOW CFS	Rank	Water Year	FLOW CFS	Median Plot Pos
29	Jun	1991	549	1	2003	775	2.99
22	May	1992	464	2	1995	775	7.26
01	Jun	1993	509	3	2000	706	11.54
24	May	1994	585	4	2006	661	15.81
18	Jun	1995	775	5	1996	643	20.09
20	May	1996	643	6	2008	609	24.36
20	Jun	1997	549	7	2013	600	28.63
27	Jun	1998	509	8	1994	585	32.91
10	Jun	1999	526	9	2005	558	37.18
31	May	2000	706	10	1997	549	41.45
20	May	2001	481	11	1991	549	45.73
07	Jun	2002	402	12	1999	526	50.00
30	May	2003	775	13	1998	509	54.27
11	Jun	2004	327	14	1993	509	58.55
31	May	2005	558	15	2010	486	62.82
10	Jun	2006	661	16	2001	481	67.09
13	Jun	2007	405	17	2011	475	71.37
25	Jun	2008	609	18	1992	464	75.64
21	May	2009	429	19	2009	429	79.91
09	Jun	2010	486	20	2007	405	84.19
12	Jun	2011	475	21	2002	402	88.46
20	Jun	2012	344	22	2012	344	92.74
12	Jun	2013	600	23	2004	327	97.01

<< Skew Weighting >>

Based on 23 events, mean-square error of station skew = 0.234

Mean-square error of regional skew = -?

<< Frequency Curve >>
STH BLDR CK-DS GROSS RES 2013

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
957	1,029	0.2	1,190	832
905	957	0.5	1,106	794
863	902	1.0	1,041	764
819	847	2.0	972	730
755	771	5.0	877	681
700	710	10.0	798	638
638	643	20.0	712	587
529	529	50.0	574	488
433	430	80.0	471	389
388	382	90.0	427	340
354	344	95.0	394	302
296	277	99.0	338	240

<< Systematic Statistics >>
STH BLDR CK-DS GROSS RES 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	2.720	Historic Events	0
Standard Dev	0.100	High Outliers	0
Station Skew	-0.223	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	-0.223	Systematic Events	23

--- End of Analytical Frequency Curve ---

Bulletin 17B Frequency Analysis
10 Jun 2014 06:19 PM

--- Input Data ---

Analysis Name: STH BLDR CK-ELDO 2013 ST
Description:

Data Set Name: STH BLDR CK-ELDORADO 2013
DSS File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\CH2M_F.dss
DSS Pathname: /SOUTH BOULDER CREEK/ELDORADO SPRINGS, CO./FLOW-ANNUAL PEAK/01jan1900/IR-CENTURY/Save Data As: STH BLDR CK-ELDORADO 2013/

Report File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\Bulletin17bResults\STH_BLDR_CK-ELDO_2013_ST\STH_BLDR_CK-ELDO_2013_ST.rpt
XML File Name: H:\32-176904 Big Thompson Hydrology\CH2M_F\Bulletin17bResults\STH_BLDR_CK-ELDO_2013_ST\STH_BLDR_CK-ELDO_2013_ST.xml

Start Date:
End Date:

Skew Option: Use Station Skew
Regional Skew: -Infinity
Regional Skew MSE: -Infinity

Plotting Position Type: Median

Upper Confidence Level: 0.05
Lower Confidence Level: 0.95
Use High Outlier Threshold
High Outlier Threshold: 2844.3

Use Historic Data
Historic Period Start Year: ---
Historic Period End Year: ---

Display ordinate values using 0 digits in fraction part of value

--- End of Input Data ---

--- Preliminary Results ---

<< Plotting Positions >>
STH BLDR CK-ELDORADO 2013

Events Analyzed					Ordered Events			
			FLOW		Water	FLOW	Median
Day	Mon	Year	CFS	Rank	Year	CFS	Plot Pos
19	Jun	1888	245	1	1938	7,390*	0.58
31	May	1889	730	2	1951	2,370	1.40
28	May	1890	705	3	2013	2,100	2.22
25	May	1891	650	4	1969	1,690	3.05
24	Jun	1892	730	5	1921	1,440	3.87
03	Jun	1895	1,130	6	1949	1,430	4.70
29	May	1896	382	7	1909	1,340	5.52
11	Jun	1897	650	8	1947	1,290	6.34
17	Jun	1898	475	9	1914	1,240	7.17
20	Jun	1899	700	10	1895	1,130	7.99
09	May	1900	1,100	11	1900	1,100	8.81
24	Jun	1901	360	12	1952	1,080	9.64
05	Jun	1905	740	13	1953	988	10.46
14	Jun	1906	655	14	1918	915	11.29
15	Jun	1907	685	15	1942	913	12.11
15	Jun	1908	315	16	1965	910	12.93
20	Jun	1909	1,340	17	1957	905	13.76
03	Jun	1910	245	18	1915	885	14.58
09	Jun	1911	440	19	1956	852	15.40
25	Jun	1912	645	20	1995	845	16.23
29	May	1913	350	21	1937	780	17.05
24	May	1914	1,240	22	1905	740	17.87
12	Jun	1915	885	23	1950	737	18.70
11	Jun	1916	350	24	1892	730	19.52
18	Jun	1917	563	25	1889	730	20.35
22	Jun	1918	915	26	1890	705	21.17
07	Aug	1919	560	27	1899	700	21.99
26	May	1920	531	28	1940	688	22.82
06	Jun	1921	1,440	29	1907	685	23.64
13	Jun	1922	397	30	1959	680	24.46
09	Jun	1923	646	31	1941	672	25.29
14	Jun	1924	625	32	1933	666	26.11
22	Jun	1925	186	33	1906	655	26.94
24	May	1926	561	34	1897	650	27.76
22	May	1927	343	35	1891	650	28.58
27	May	1928	490	36	1923	646	29.41
06	Jun	1929	310	37	1912	645	30.23
19	Jun	1930	536	38	1948	639	31.05
08	Jun	1931	427	39	1964	626	31.88
23	May	1932	356	40	1924	625	32.70
19	May	1933	666	41	1983	602	33.53
15	May	1934	275	42	1946	568	34.35
11	Jun	1935	477	43	1917	563	35.17
16	May	1936	420	44	1926	561	36.00
26	Jun	1937	780	45	1919	560	36.82

02 Sep 1938	7,390	46	1945	558	37.64	
01 Jun 1939	540	47	1960	556	38.47	
28 Jul 1940	688	48	1939	540	39.29	
12 May 1941	672	49	1943	538	40.12	
13 May 1942	913	50	1930	536	40.94	
30 May 1943	538	51	1920	531	41.76	
02 Jun 1944	528	52	1944	528	42.59	
25 Jun 1945	558	53	1928	490	43.41	
15 Jun 1946	568	54	1955	478	44.23	
21 Jun 1947	1,290	55	1935	477	45.06	
23 May 1948	639	56	1974	475	45.88	
06 Jun 1949	1,430	57	1898	475	46.71	
13 Jun 1950	737	58	1988	474	47.53	
18 Jun 1951	2,370	59	1970	469	48.35	
04 Jun 1952	1,080	60	1967	469	49.18	
15 Jun 1953	988	61	1968	468	50.00	
21 May 1954	247	62	1962	458	50.82	
09 Jun 1955	478	63	1971	455	51.65	
29 May 1956	852	64	1973	450	52.47	
21 Jul 1957	905	65	1911	440	53.29	
06 Jun 1958	345	66	1982	435	54.12	
17 Jun 1959	680	67	1931	427	54.94	
06 Jun 1960	556	68	1936	420	55.77	
21 Jun 1961	375	69	1972	416	56.59	
13 May 1962	458	70	1980	406	57.41	
16 Jun 1963	311	71	1922	397	58.24	
10 Jul 1964	626	72	1978	384	59.06	
16 Jun 1965	910	73	1993	383	59.88	
15 Jul 1966	360	74	1896	382	60.71	
06 Jun 1967	469	75	2003	381	61.53	
07 Jun 1968	468	76	1961	375	62.36	
07 May 1969	1,690	77	1991	368	63.18	
21 May 1970	469	78	1981	366	64.00	
27 Jun 1971	455	79	1989	363	64.83	
12 Jun 1972	416	80	1966	360	65.65	
06 May 1973	450	81	1901	360	66.47	
30 May 1974	475	82	1994	359	67.30	
03 Jul 1975	344	83	1932	356	68.12	
09 Jun 1976	282	84	1990	355	68.95	
07 Jun 1977	318	85	2006	353	69.77	
26 May 1978	384	86	1987	350	70.59	
03 Jul 1979	326	87	1916	350	71.42	
16 Jun 1980	406	88	1913	350	72.24	
04 Jun 1981	366	89	1992	346	73.06	
19 Jun 1982	435	90	1958	345	73.89	
13 Jun 1983	602	91	1975	344	74.71	
03 Jul 1984	334	92	1927	343	75.54	
31 May 1985	274	93	1984	334	76.36	
04 Jun 1986	286	94	2009	331	77.18	
04 Jun 1987	350	95	2005	331	78.01	
20 May 1988	474	96	1979	326	78.83	
01 Jun 1989	363	97	2000	325	79.65	
11 Jun 1990	355	98	2009	322	80.48	
01 Jun 1991	368	99	1977	318	81.30	

24 May 1992	346	100	1908	315	82.13
01 Jun 1993	383	101	1963	311	82.95
02 Jun 1994	359	102	1929	310	83.77
18 Jun 1995	845	103	1996	307	84.60
12 Aug 1996	307	104	2007	304	85.42
17 Jul 1997	301	105	1999	303	86.24
04 Sep 1998	301	106	1998	301	87.07
03 Jul 1999	303	107	1997	301	87.89
13 Jun 2000	325	108	1986	286	88.71
21 May 2001	278	109	2004	282	89.54
08 Jun 2002	257	110	1976	282	90.36
04 Jul 2003	381	111	2001	278	91.19
10 Jun 2004	282	112	1934	275	92.01
02 Jul 2005	331	113	1985	274	92.83
20 Jun 2006	353	114	2012	273	93.66
10 Jun 2007	304	115	2002	257	94.48
19 Dec 2008	331	116	1954	247	95.30
25 Aug 2009	322	117	1910	245	96.13
09 Jun 2010	176	118	1888	245	96.95
19 Dec 2011	199	119	2012	199	97.78
20 Jun 2012	273	120	1925	186	98.60
18 Jun 2013	2,100	121	2010	176	99.42

* Outlier

<< Skew Weighting >>

Based on 121 events, mean-square error of station skew = 0.175
Mean-square error of regional skew = -?

<< Frequency Curve >>

STH BLDR CK-ELDORADO 2013

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
6,267	6,900	0.2	8,567	4,857
4,213	4,513	0.5	5,505	3,384
3,104	3,264	1.0	3,920	2,561
2,274	2,356	2.0	2,777	1,927
1,489	1,519	5.0	1,741	1,306
1,067	1,080	10.0	1,210	958
751	755	20.0	830	686
445	445	50.0	484	408
314	314	80.0	345	283
278	277	90.0	307	248
258	257	95.0	286	229
235	234	99.0	262	207

<< Systematic Statistics >>
STH BLDR CK-ELDORADO 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	2.702	Historic Events	0
Standard Dev	0.244	High Outliers	0
Station Skew	1.342	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	1.342	Systematic Events	121

--- End of Preliminary Results ---

<< High Outlier Test >>

Based on 121 events, 10 percent outlier test deviate K(N) = 3.081
Computed high outlier test value = 2,844.3

1 high outlier(s) identified above input threshold of 2,844.3

* *
* Note - Collection of historical information and *
* comparison with similar data should be explored, *
* if not incorporated in this analysis. *
* *

Statistics and frequency curve adjusted for 1 high outlier(s)

<< Systematic Statistics >>
STH BLDR CK-ELDORADO 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	2.701	Historic Events	0
Standard Dev	0.243	High Outliers	1
Station Skew	1.324	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	1.342	Systematic Events	121
		Historic Period	126

<< Low Outlier Test >>

Based on 126 events, 10 percent outlier test deviate K(N) = 3.095
Computed low outlier test value = 88.8

0 low outlier(s) identified below test value of 88.8

--- Final Results ---

<< Plotting Positions >>
STH BLDR CK-ELDORADO 2013

Events Analyzed			Ordered Events			
		FLOW		Water	FLOW	Median
Day Mon Year		CFS	Rank	Year	CFS	Plot Pos
19 Jun 1888		245	1	1938	7,390*	0.55
31 May 1889		730	2	1951	2,370	1.36
28 May 1890		705	3	2013	2,100	2.19
25 May 1891		650	4	1969	1,690	3.01
24 Jun 1892		730	5	1921	1,440	3.83
03 Jun 1895		1,130	6	1949	1,430	4.66
29 May 1896		382	7	1909	1,340	5.48
11 Jun 1897		650	8	1947	1,290	6.31
17 Jun 1898		475	9	1914	1,240	7.13
20 Jun 1899		700	10	1895	1,130	7.95
09 May 1900		1,100	11	1900	1,100	8.78
24 Jun 1901		360	12	1952	1,080	9.60
05 Jun 1905		740	13	1953	988	10.43
14 Jun 1906		655	14	1918	915	11.25
15 Jun 1907		685	15	1942	913	12.07
15 Jun 1908		315	16	1965	910	12.90
20 Jun 1909		1,340	17	1957	905	13.72
03 Jun 1910		245	18	1915	885	14.55
09 Jun 1911		440	19	1956	852	15.37
25 Jun 1912		645	20	1995	845	16.20
29 May 1913		350	21	1937	780	17.02
24 May 1914		1,240	22	1905	740	17.84
12 Jun 1915		885	23	1950	737	18.67
11 Jun 1916		350	24	1892	730	19.49
18 Jun 1917		563	25	1889	730	20.32
22 Jun 1918		915	26	1890	705	21.14
07 Aug 1919		560	27	1899	700	21.96
26 May 1920		531	28	1940	688	22.79
06 Jun 1921		1,440	29	1907	685	23.61
13 Jun 1922		397	30	1959	680	24.44
09 Jun 1923		646	31	1941	672	25.26
14 Jun 1924		625	32	1933	666	26.08
22 Jun 1925		186	33	1906	655	26.91

24 May 1926	561	34	1897	650	27.73
22 May 1927	343	35	1891	650	28.56
27 May 1928	490	36	1923	646	29.38
06 Jun 1929	310	37	1912	645	30.21
19 Jun 1930	536	38	1948	639	31.03
08 Jun 1931	427	39	1964	626	31.85
23 May 1932	356	40	1924	625	32.68
19 May 1933	666	41	1983	602	33.50
15 May 1934	275	42	1946	568	34.33
11 Jun 1935	477	43	1917	563	35.15
16 May 1936	420	44	1926	561	35.97
26 Jun 1937	780	45	1919	560	36.80
02 Sep 1938	7,390	46	1945	558	37.62
01 Jun 1939	540	47	1960	556	38.45
28 Jul 1940	688	48	1939	540	39.27
12 May 1941	672	49	1943	538	40.09
13 May 1942	913	50	1930	536	40.92
30 May 1943	538	51	1920	531	41.74
02 Jun 1944	528	52	1944	528	42.57
25 Jun 1945	558	53	1928	490	43.39
15 Jun 1946	568	54	1955	478	44.21
21 Jun 1947	1,290	55	1935	477	45.04
23 May 1948	639	56	1974	475	45.86
06 Jun 1949	1,430	57	1898	475	46.69
13 Jun 1950	737	58	1988	474	47.51
18 Jun 1951	2,370	59	1970	469	48.34
04 Jun 1952	1,080	60	1967	469	49.16
15 Jun 1953	988	61	1968	468	49.98
21 May 1954	247	62	1962	458	50.81
09 Jun 1955	478	63	1971	455	51.63
29 May 1956	852	64	1973	450	52.46
21 Jul 1957	905	65	1911	440	53.28
06 Jun 1958	345	66	1982	435	54.10
17 Jun 1959	680	67	1931	427	54.93
06 Jun 1960	556	68	1936	420	55.75
21 Jun 1961	375	69	1972	416	56.58
13 May 1962	458	70	1980	406	57.40
16 Jun 1963	311	71	1922	397	58.22
10 Jul 1964	626	72	1978	384	59.05
16 Jun 1965	910	73	1993	383	59.87
15 Jul 1966	360	74	1896	382	60.70
06 Jun 1967	469	75	2003	381	61.52
07 Jun 1968	468	76	1961	375	62.35
07 May 1969	1,690	77	1991	368	63.17
21 May 1970	469	78	1981	366	63.99
27 Jun 1971	455	79	1989	363	64.82
12 Jun 1972	416	80	1966	360	65.64
06 May 1973	450	81	1901	360	66.47
30 May 1974	475	82	1994	359	67.29
03 Jul 1975	344	83	1932	356	68.11
09 Jun 1976	282	84	1990	355	68.94
07 Jun 1977	318	85	2006	353	69.76
26 May 1978	384	86	1987	350	70.59
03 Jul 1979	326	87	1916	350	71.41

16 Jun 1980	406	88	1913	350	72.23
04 Jun 1981	366	89	1992	346	73.06
19 Jun 1982	435	90	1958	345	73.88
13 Jun 1983	602	91	1975	344	74.71
03 Jul 1984	334	92	1927	343	75.53
31 May 1985	274	93	1984	334	76.35
04 Jun 1986	286	94	2009	331	77.18
04 Jun 1987	350	95	2005	331	78.00
20 May 1988	474	96	1979	326	78.83
01 Jun 1989	363	97	2000	325	79.65
11 Jun 1990	355	98	2009	322	80.48
01 Jun 1991	368	99	1977	318	81.30
24 May 1992	346	100	1908	315	82.12
01 Jun 1993	383	101	1963	311	82.95
02 Jun 1994	359	102	1929	310	83.77
18 Jun 1995	845	103	1996	307	84.60
12 Aug 1996	307	104	2007	304	85.42
17 Jul 1997	301	105	1999	303	86.24
04 Sep 1998	301	106	1998	301	87.07
03 Jul 1999	303	107	1997	301	87.89
13 Jun 2000	325	108	1986	286	88.72
21 May 2001	278	109	2004	282	89.54
08 Jun 2002	257	110	1976	282	90.36
04 Jul 2003	381	111	2001	278	91.19
10 Jun 2004	282	112	1934	275	92.01
02 Jul 2005	331	113	1985	274	92.84
20 Jun 2006	353	114	2012	273	93.66
10 Jun 2007	304	115	2002	257	94.49
19 Dec 2008	331	116	1954	247	95.31
25 Aug 2009	322	117	1910	245	96.13
09 Jun 2010	176	118	1888	245	96.96
19 Dec 2011	199	119	2012	199	97.78
20 Jun 2012	273	120	1925	186	98.61
18 Jun 2013	2,100	121	2010	176	99.43

Note: Plotting positions based on historic period (H) = 126
Number of historic events plus high outliers (Z) = 1
Weighting factor for systematic events (W) = 1.0417

* Outlier

<< Skew Weighting >>

Based on 126 events, mean-square error of station skew = 0.166
Mean-square error of regional skew = -?

<< Frequency Curve >>
STH BLDR CK-ELDORADO 2013

Computed Curve FLOW, CFS	Expected Probability FLOW, CFS	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, CFS	Confidence Limits 0.95 FLOW, CFS
6,131	6,742	0.2	8,359	4,760
4,140	4,431	0.5	5,400	3,331
3,061	3,217	1.0	3,860	2,529
2,250	2,330	2.0	2,744	1,908
1,480	1,509	5.0	1,729	1,298
1,064	1,076	10.0	1,205	955
751	754	20.0	829	686
446	446	50.0	485	409
315	314	80.0	345	284
278	277	90.0	307	248
257	256	95.0	285	228
234	233	99.0	261	206

<< Adjusted Statistics >>
STH BLDR CK-ELDORADO 2013

Log Transform: FLOW, CFS		Number of Events	
Mean	2.701	Historic Events	0
Standard Dev	0.243	High Outliers	1
Station Skew	1.324	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	1.324	Systematic Events	121
		Historic Period	126

--- End of Analytical Frequency Curve ---

Appendix D
Project Correspondence and Response to Review Comments

Meeting Minutes
Phase 1 Hydrology Response Letter [Response to CDOT Flood Hydrology Team Review Comments]
Phase 1 Hydrology Response Letter [Response to Public Review Comments]
Phase 2 Hydrologic Analysis – Response to CDOT Flood Hydrology Team Review Comments

Hydrology Weekly Meeting

ATTENDEES:

Keith Sheaffer
Steve Griffin
Steven Humphrey
Holly Linderholm
Cory Hooper
Heidi Schram
Will Carrier
Collin Haggerty
Bob Jarrett (PH)
John Hunt
Kevin Houck
Jim Wulliman
Derek Rapp

FROM: ICC OPS

DATE: January 9, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

Preliminary Findings

The Consultant team memos regarding the preliminary findings are on track and will be delivered tomorrow Jan. 10th. Kevin Houck will combine into one memo presenting the preliminary findings of the Hydrology Team.

Current Progress and Findings

The Consultant teams are progressing well and have identified their additional needs recorded below.

Some questions that resulted from the discussion on progress are below:

- Should URS combine the gauge data of the two gauges from the South Platte in order to have a larger data set? Is that practice justifiable?
- How to handle skew and outliers? Should be answered by John Hunt and Bob Jarrett
- The Barker reservoir used as a volume calibration?

Steve Griffin has an unpublished HEC-HMS model that can be used and referenced in the memo.

It was determined that Bob has confidence in NRCS numbers and the consultants can include them in their analysis where they do not have numbers from Jarrett.

Kevin Houck brought up the importance of how the memo is messaged in order to reduce misinterpretation.

There was discussion on multiple parameters of the models. Specifics will not be provided here unless the Consultant teams would like to include any specifics.

Additional Data Needs

The Lake Estes dam release information has been requested from the Bureau of Reclamation. We are currently waiting to hear if we need to request the information through a FOIA. Keith Sheaffer will also inquire about the information along with the information on the Button Rock Dam with Jason Smith.

URS cannot complete their evaluation until Bob Jarrett is able to obtain the S. Platte data.

Still need to get the remainder of the rainfall run off data from AWA.

CH2MHill still needs numbers for Boulder Creek near Orodell.

Bob wants authorization to capture the flow estimate that the Jacobs team requested from the site south of Drake. Until the data is collected we will report a range for the findings. At this time Jacobs findings are reporting the additive value.

Additional information needed from Bob Jarrett:

- Points downs stream of critical confluence in the next 4 to 5 days downstream Drake on Big Thompson
- Lyons site – full survey .5 mile length to get longer reach length
- John Hunt will provide LIDAR to Bob
- Little Thompson natural flow estimate to use in the calibration of the model
- Atkins has comparative pre and post aerials (can ICC get these also)
- Bob plans to go out to the S. Platte next week and get data from the field offices the week after that.
- Kevin Houck would like to know whether he should use Jarrett or NRCS (Yokum's) numbers.
- The team would like to get Jarrett's opinion on using gauge analysis.

Project Schedule

Next meeting: Jan.16th 1 to 3pm

We will look at the working Models (not calibrated) in order to get questions answered and consistencies addressed.

S. Platte Extended Scope

Steven Humphrey explained the desire of evaluating the entire South Platte watershed all the way to the Nebraska border that came out of the Staff Bridge Meeting. The Consultants have been asked to provide a draft scope, schedule and cost for the additional effort to complete this additional evaluation. Preliminary limits of the scope are from Platteville to the Nebraska border. The proposal provided by the consultants should be submitted by COB on Friday, January 17th.

Discussion about the additional request resulted in using gauge data from USGS for the additional analysis.

For the additional effort the IC is interested in of the South Platte from Platteville to Nebraska there was discussion on the limits and structure of scope to be in the proposal. It was decided that it will most likely be a gauge study. What is the use of this analysis? Implications of use will likely be used for hydrology design. Will need to limit the scope to just the S. Platte not including any tributaries and a gauge analysis and a tributary chase for calcs gauge analysis

Action Item List

Action Item	Due	By
GIS Map Exhibit to accompany the Memo Deliverable		ICC – Ops Desk
Share all reports with the three consultant teams.		ICC- Ops Desk

Hydrology Weekly Meeting

ATTENDEES:

Keith Sheaffer
Steve Griffin
Steven Humphrey (PH)
Holly Linderholm
Cory Hooper (PH)
Heidi Schram
Will Carrier
Mike Tilko
Bob Jarrett
Morgan Lynch
Kevin Houck
Jim Wulliman
Derek Rapp
Gina DeRosa
Jeff Wulliman (PH)
Spence Kelly (PH)

FROM: ICC OPS

DATE: January 16, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

Preliminary Findings

To finish up the preliminary findings memo these are the additional items needed:

- Bob to get the remaining East sites and visit the field offices to obtain data from the records
    - Ft. Lupton and Kersey are priority sites at US 85, US 34A and US 34D.
    - If Bob needs a survey team then he should contact Will Carrier to coordinate.
- Lake Estes Dam information is needed immediately, Holly to contact Kara at the Bureau of Reclamation to get an ETA of the information.

Kevin Houck and Bob Jarrett discussed presenting the results in a range or a specific number. It was decided that specific numbers will be reported with a note regarding the % uncertainty. Jim Wulliman added that since we reference the NRCS report within our data that we should know what their "fair" rating is so that we include their % uncertainty within ours.

Steve Griffin brought up the concern about timing of different audiences and how the memo is messaged. Right now gearing toward the upward audience and not the local agencies etc…. the dissemination of information should be a phased approach to ensure we keep our partners at the local agencies involved.

Kevin Houck would like to be able to present the preliminary findings to the Colorado Conservation Board on Tuesday the 28th and then to Water Congress that Thursday. Will the results be review and approved to be presented and does the team consider that appropriate timing of making the information public.

USGS is also analyzing the Storm Event, we should recognize their efforts and be aware of the timing of their release of information incase their findings are different than ours.

Bob and Kevin will get together about the areas in the memo where we are missing regulatory information and decide what to present in the Memo.

The team would like to have the memo and exhibits finalized by next Friday the 24th.

Current Progress and Findings

Models:

Bob Jarret asked that if the consultants can't get the model numbers close to his to let him know immediately so they can evaluate the model together. Still need the non-dam break/normal flow numbers from Bob Jarrett as well as confirmation of the Little Thompson River. Bob requested the max rainfall per hour in order to help with his confirmation.

As the teams calibrate their models there needs to be consistency as well as decisions on what the group is comfortable with and what/how they will defend their assumptions as they calibrate their models and find they have to use values outside the commonly accepted ranges.

It was decided to use the AMC 2 throughout the models and to not adjust it for the different time frames of the storm.

Need to be consistent through the analysis on all teams, URS will run a HEC HMS model also to confirm since they are currently using a gauge analysis for the S. Platte.

URS still needs the rainfall data from AWA.

Project Schedule

The next meeting will be held Thursday the 23rd from 1 to 3 pm the meeting after that will be Feb. 3rd or the 4th.

Action Item List

Action Item	Due	By
Get John Hunt's opinion on how to handle outliers and skew coefficients		Via email

Hydrology Weekly Meeting

ATTENDEES:

Keith Sheaffer
Steve Griffin
Steven Humphrey
Holly Linderholm
Heidi Schram
Will Carrier
John Hunt
Morgan Lynch
Kevin Houck
Jim Wulliman
Derek Rapp
Collin Haggerty (PH)
Cory Hooper (PH)

FROM: ICC OPS

DATE: January 23, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

Peak Flow Estimate Memo

The draft memo was reviewed and approved by the IC, Johnny Olson. The ICC is comfortable with Kevin Houck of CWCB presenting the findings to his Board as well as the Water Congress the week of Jan. 27th.

This team would like to look at the results of the USGS study. Bob Kimbrough can provide the information to the ICC. We need to make sure to communicate with Josh Kiel about getting this info.

CWCB does not have a preference on how the memo is distributed to other agencies. It was decided that an effective method of distribution could be through email.

Review Modeling Efforts

Continue to review progress of the consultant's models and discuss consistencies to the teams approach.

Specific details on the modeling:

St. Vrain – the sensitivity of different parameters was analyzed.

- The model is mainly dependent on the curve number.
    - The range is from the mid to low 40's up to 60. The resulting average curve number is 56 between C & D

The consultants would like to have Bob Jarrett review the outcomes of the models to see if he is comfortable with the output.

Ask Bob about the 14 cfs/square mile discharge

James creek – the team has not been able to calibrate the model to some of the discharge outliers.

The team decided to have the rainfall consistent within basins but can change between basins. With this approach it was suggested that an analysis be done if there are differences between basins.

Ayers will have the rainfall runoff match flood frequency model. Are these just for analysis or should the models be calibrated to them?

ICC Ops to contact Bureau of Reclamation about the additional Lake Estes Dam information needed. The policy of the dam storage and handling of attenuation play into the calibration of the model

The model of Lefthand does not match the peak flow numbers at the top or bottom but does match in the middle.

There was concern expressed that the emergency reconstruction of roadways effected the high water marks and consequently the calculations of peak flows. Bob Jarrett was not present at the meeting but it was discussed that his methods take those variables into consideration and account for them in numerous ways.

The consultant teams will continue to collaborate about the models through email. **The ICC Ops will forward on the additional information provided by CH2MHill.**

Data Needs

The team still needs to know what to do about the skew coefficients and handling of outliers. Ayers suggested doing a skew analysis to provide new regional skew coefficients for this analysis.

There was discussion about using Bulletin 17B, the current standard, or the possibility of using the new "expected moments" approach that may be accepted soon by FEMA. There may be an opportunity to use a combination of the two approaches. The new approach includes additional outlier threshold equations. Kevin Houck will check with FEMA to see if they are planning on accepting the Expected Moments approach.

Need additional natural flows from Bob Jarrett.

URS is running a CUHP model on Coal Creek Canyon, they will also run a HEC-HMS to compare. URS still needs S. Platte information and bridge plans.

Project Schedule

The next meeting is scheduled for Monday February 3rd from 1 to 3 pm at the ICC.

Decision Register

Decision	Made By
CWCB approved to present findings to the Board and Water Congress	ICC- Johnny Olson
Email distribution of the Memo	Hydrology Team
Keep rainfall consistent within the sub basins but can vary between basins	Hydrology Team

Action Item List

Action Item	Due	By
Forward the information from CH2MHill to team		ICC Ops

Hydrology Weekly Meeting

ATTENDEES:

Steve Griffin
Steven Humphrey
Holly Linderholm
Heidi Schram
Will Carrier
Gina DeRosa
John Hunt
Morgan Lynch
Doug Stewart
John Hunt
Kevin Houck
Jim Wulliman
Naren Tayal (PH)
Cory Hooper (PH)

FROM: ICC OPS

DATE: February 3, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

Peak Flow Estimate Memo

It seems that the memo was distributed in some fashion, now that it is public the team can provide to anyone who is asking for it. **ICC Ops will provide the most current version for the team to distribute.**

It is important to ensure that the local agencies understand that this is just the start of these efforts. CDOT will be collaborating with them throughout the rest of the process. This effort was completed to have a starting point for the future efforts that the Region and Local Agencies will complete in the future.

Lyons is particularly interested in the memo and the hydrology efforts, ICC Ops should ensure they received the memo and should start coordinating with them in these efforts.

The Drake numbers are a concern, there are no places that allow for attenuation so how is it possible that the flow is smaller downstream. Needs further analysis. At this time there is no way to explain these differences.

FEMA is starting to work on St. Vrain and Lefthand and looking at structure flow rates as they pertain to the Boulder County Structures (Apple Valley Road, Longmont Dam Road). There is work currently in these locations that CFL is performing. The results of FEMAs efforts will not impact the current work being completed. Naren Tayal from FEMA will attend these meetings in order to coordinate the two efforts.

Review Modeling Efforts

Jacobs

The best comparison was the discharge/max rainfall by square mile and the best fit curve number was 50.

Ran a comparison to some of the CH2MHill stuff and the results were pretty consistent.

The operation of the Lake Estes Dam is to pass the flows through so surface water doesn't rise or fall that much. It was asked if the dam operations waited until the water arrived in the reservoir or if they opened it up in anticipation of the higher flows.

So if the models won't match Jarrett's numbers should those values be abandoned?

All information related to this evaluation is in the email Jim Wulliman sent out.

<u>CH2MHill</u>

Orodell gauge and Bob Jarrett's peak flow estimate were very close, this time they calibrated the model to Jarrett's numbers.

They reduced the peaking coefficient to 0.1 and the generally accepted value is 0.4. If the parameter is changed back to 0.4 then the flows would raise but still not above the NOAA.

Barker Reservoir was completed in 1910 approx.10 years after data started being collected; so can be considered natural flows since the dam has been in place with similar operations for more than 50 years.

Is this how the team wants to treat the reservoir in this analysis? There needs to be a policy decision made.

An option would be to analyze when the peaks occurred and how that relates to the storage in the reservoir. Morgan will look into if the reservoir has any surface level or discharge information.

Andersons updated the 77 FIS model in 2012.

It was confirmed that the routing method being used is the Muskingum-Cunge.

Are we at the point on this that there needs to be a meeting with Anderson, Boulder and FEMA to discuss appropriate approach?

CH2MHill will re-run the model with the current parameters but with a full reservoir to further the analysis.

The email that Houck provided to the team expressed that there is presence of regulatory rates for the Little Thompson. However, the location that is referenced in the email is actually 10 miles downstream so the hydrology is different.

The Little Thompson model is calibrated to Bob Jarrett's natural flows only at this time.

Regional skew analysis efforts need to be completed in order to finish this analysis. John Hunt with Ayers will get costs to ICC Ops could come from remaining CH budget or ICC. The immediate priority is the new regional skew for mountain regions in order to apply to Orodell

<u>URS</u>

For Coal Creek Canyon the infiltration rate change is unjustifiable. In order to match flows had to increase the infiltration rate at first than decrease it later in the model to reach the design points.

What direction would CDOT want to go with this watershed? The URS recommendation would be to update the watershed to the NOAA Atlas 14.

Look at the Jefferson County recommendation/replacement memo and get the hydrology teams thoughts.

Deliverables

Provide recommendations of changing/updating the regulatory rate s to CWCB and CDOT to review by the end of Feb.

Format should follow closely to a FEMA submittal, CDOT and CWCB will coordinate on what they would like to see and get back to the Consultants.

Project Schedule

The next meeting is scheduled for Monday February 10th from 1 to 3 pm at the ICC.

Action Item List

Action Item	Due	By
Find out who F&A has distributed the memo to.		ICC Ops
Send a copy of the Phase I memo to Naren with FEMA		ICC Ops
URS needs S. Platte from Bob		Bob Jarrett
Find out if there are any videos at US 85.		Steve Griffin
Boulder Creek: Comparison with and without a full reservoir with the current parameters		CH2MHill
Big Thompson: compare sept. rainfall to NOAA rainfall, what affect it has, good with Lake Estes approach		Jacobs
St. Vrain: Updated flood frequency from Ayers (for Left hand also)		Jacobs
Coal Creek: Additional analysis just for fun, send data to Jacobs to add to the comparison analysis		URS
Regional skews (approach to be emailed and approved by CWCB and CDOT, hopefully have preliminary skews by Friday)		Ayers
Jacobs and CH2MHill to run aerial reduction		Jacobs and CH2Mhill
Format of recommendations on regulatory rates		CDOT and CWCB

Hydrology Weekly Meeting

ATTENDEES:

Steve Griffin
Steven Humphrey
Holly Linderholm
Heidi Schram
Will Carrier (PH)
Gina DeRosa (PH)
John Hunt
James Hitchenson
Morgan Lynch
Doug Stewart
John Hunt
Kevin Houck
Jim Wulliman
Naren Tayal
Cory Hooper
Derek Rapp
Bob Jarrett (PH)
Ed Tomlinson (PH)

FROM: ICC OPS

DATE: February 10, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

US 36 CFL Project

The meeting began with the request of the peak flow numbers this team would like CFL to use in the existing hydrology model to make sure there are no fatal flaws in the current design. 3,400cfs will be used for the Little Thompson and the Jacobs team will need until COB to provide the number to be used for the N. St. Vrain.

FEMA

FEMA requested shape files for the CDOT structures, these can be provided by Staff Bridge.

FEMA will be continuing to participate in these meetings to ensure that CDOT and FEMA are aware of the efforts by both agencies.

Feedback and Historical Information

Kevin Houck then asked to add an agenda item. He would like Bob Jarrett to comment on the current feedback on memo, and specifically speak to the questions regarding the variance of flows on Boulder Creek.

It was mentioned that the hydrologic evaluations done back in ‘76 and ‘90 caused diverging opinion’s especially when it was found that on average the insurance floodplain was 60% larger than the analyzed gage’s 100yr data.

The resulting discussion concluded with an emphasis that this team is a technical group and to stay committed to what we are doing here and there will be other teams who will consider the other ramifications of this effort.

Bob Jarrett suggests that in order to support the technical expertise behind the analysis the team should do the best they can to quantify the uncertainty in the analysis. There was an expressed interest in what feedback has been received on the phase I memo.

The main feedback has been the question of how the flows decrease from 30,000 cfs to 15,000 cfs on the Big Thompson downstream of Drake? Along that stretch there isn't much opportunity for attenuation so hard to explain the large drop in flows. Bob Jarrett indicated that this was a location where he had used an additive method since he was unable to find a good location to collect data, he will try again to get data from this area. The only place where there may be some attenuation would be around Cedar Cove but not enough to justify the significant drop in estimates peak flows.

This team needs to be prepared to justify their assumptions and estimates especially since the USGS isn't currently sharing any information and their analysis is scheduled to come out shortly.

With additional information the Big Thompson below Drake data may change after further analysis.

The debris bulking and dam failures could potentially account for some of the attenuation as well as sediment. Obtaining the timing of the wave through Glen Haven would be beneficial in the analysis of this area.

Bob Jarrett would like the information provided on the Lake Estes dam releases. Bob is interested to see if there is any evidence of dam failures along Fish creek, would like any aerials that CDOT or the Consultants teams may have of this area.

The St. Vrain information at Lyons and I-25 were also questioned. Steve Griffin collected data at I-25 and with his available resources along with his conservative method to keep the resulting cfs numbers high; it is difficult to provide a rebuttal without more information regarding the USGS' "significantly higher" findings.

Team Efforts

Gauge Analysis:

Ayers has begun to developed regional skew estimate have not yet finalized, An example from the analysis resulted in a weighted average by drainage area of 0.46 which would have been -0.2 from 17B Map. Using the new skew analysis the Boulder Creek watershed would result in "100-year flood" cfs to between the "100 and 50-year flood"

For the St. Vrain the 100-year would be lower without proper use of outliers. Outliers get a much lower weighting.

Ayers analysis is complete however, they will confirm that Bob Jarrett supports the results and will then finish up and finalize. The final analysis will be provided in a memo and be distributed to the team. URS will send Ayers their Coal Creek gage analysis to include in the current analysis.

Jacobs Modeling:

The team changed the modeling approach to look at an adjusted 24-hr period of only the max rainfall. The team expressed concern with how the curve number method oversimplifies the model for timing and infiltration.

The timing of this event is what is causing the issues in the modeling efforts. What is the right way to proceed and which approach is this team going to move forward with as the "correct" approach? It was discussed and decided to move forward with the curve number approach and raise back up with a logical approach to get back to gages. Take the 24-hr max range and compare to the NOAA. (Jacobs team will send an example: of this in an email to the team). A memo will be generated to document the approach, and test in an alternate modeling approach such as Green-Ampt Infiltration Modeling

Next steps:

Complete the gage analysis, finalize the flood frequency of the following locations:

a. Big Thompson at the mouth Canyon
b. Big Thompson in Loveland
c. Big T confluence with Buckhorn Creek
d. North Fork of the Big Thompson
e. St. Vrain below the confluence
f. Boulder Creek at Orodell

Regional analysis is not applicable to the S. Platte, Ayers only did the mountain region at this time but will complete the analysis of the plains region if asked and have a contractual vehicle to use to do the work.

Additional Needs

URS needs As-builts for S. Platte River Bridges.

Steve Griffin has reports that Bob Jarrett requested if he still wants them.

The teams will communicate by email until the next meeting and send along results of the continued analysis.

ICC/CWCB needs to provide the Consultants expectations of the deliverable for Phase II. The audience for this will be two-fold, technical and a brief easy to understand executive summary that the general public can understand.

It was decided the meeting with City of Boulder should be postponed until the hydrology efforts are to a point that they can contribute value to the meeting.

Project Schedule

The next meeting is scheduled for Tuesday, February 25th from 1 to 4 pm at the ICC.

Hydrology Weekly Meeting

ATTENDEES:

Steve Griffin
Steven Humphrey
Holly Linderholm
Heidi Schram
Will Carrier
Gina DeRosa
Kevin Houck
Jim Wulliman
Naren Tayal
Doug Stewart
Cory Hooper
Derek Rapp

FROM: ICC OPS

DATE: March 11, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

General

Concern about the USGS numbers that were presented at the CASFM event. Kevin Houck will schedule a meeting with Bob Jarrett and USGS to discuss the differing findings.

From the publicity recently it is even more important now that this team provides the same messaging of the information.

Steve Yokum would like the Big Thompson information, Steve Griffin to provide this to him.

For the stakeholder meetings regarding each of the watersheds, **the consultants will send their availability for the month of April and first week of May**. **The ICC will coordinate the meetings per watershed.** It is anticipated that these meetings will consist of a short presentation of our findings and model results in order to engage the coalitions in this effort as we now have a starting point.

Review of Reporting Efforts

CH2M Hill

It was confirmed that Boulder Creek will move forward with the 24hr storm with an AMC III for reporting instead of the 48hr storm.

A meeting with Boulder County and the City of Boulder will be scheduled hopefully before the 10th. This meeting is critical in moving forward as this watershed information needs to be incorporated into the remaining watersheds. This team would like to know where the regulatory rates are coming from.

Jacobs

Drafts will be ready for the next meeting.

URS

Drafts will be ready and the **team will check into the rumored 2006 Army Corps of Engineering model of the S. Platte Watershed**.

Final Draft for the next Meeting (3/21)

The final drafts of the reports will be provided in an electronic form with the modeling on a CD/DVD as well as 5 hard copies.

After submission, there will be a designated review and comment time frame. **The ICC OPS will combine and distribute all comments for the consultants to address.**

Ayers' contribution to the reports is still needed, ICC Ops to request from John Hunt.

The description of the process on how the presented results were reached only needs to be expressed qualitatively within the text.

Additional Hydrologic Services

The local watershed meetings will be added to the additional services scope.

AWA rainfall information will be used and requested. URS needs to indicate if AWA will need additional budget or time on their contract and include that in their task order amendment. The consultants should provide AWA with the additional sites they will want for the extended scope and if they will be providing additional flood frequency analysis. Along with this it needs to confirmed or denied that Ayers should complete the regional skew analysis for the plains region and if there needs to be contractual modifications associated with that.

As the teams start these additional efforts the **ICC will check for available LiDAR.**

Schedule

The next meeting is scheduled for 8 AM to 11 AM on March 21st at the Downtown Denver Jacobs Office.

Action Item List

Action Item	Due	By
Availability to meet with coalitions for the month of April and first week of May		Consultant Teams
Coordinate the meetings per watershed.		ICC OPS
2006 Army Corps of Engineering model of the S. Platte Watershed.		URS
Combine and distribute all comments for the consultants to address.		ICC OPS
Ayers' contribution to the draft reports.		ICC OPS
Additional available LiDAR		ICC OPS

Hydrology Weekly Meeting

ATTENDEES:

Steve Griffin
Steven Humphrey
Holly Linderholm
Heidi Schram
Will Carrier
Gina DeRosa
Kevin Houck
Jim Wulliman
Naren Tayal
Doug Stewart
Derek Rapp
John Hunt (PH)

FROM: ICC OPS

DATE: March 21, 2014

The following is a summary of the Hydrology Weekly Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

General

The ICC leadership team currently does not share the team's perspective that teaming with the coalitions and bringing them into this effort now as valuable. This team agrees that it is worth an additional meeting with ICC leadership to convey the long term benefits of teaming with the local agencies and coalitions on the revised hydrology in the flood effected areas. **Steve Griffin, Kevin Houck and Steve Humphrey will meet with the ICC leadership the first week of April.**

The anticipated revisions to the Phase I memo can take place now. There will be a meeting with USGS regarding the discrepancy in reported peak flows on the St. Vrain Friday, March 28th at the Muller office in Lakewood.

The ICC DAR reports that are applicable to the studied watersheds will need a brief write up regarding the hydrology. **ICC OPS will send the template out to the consultants in order to facilitate the brief write up.**

Final Draft Review of Reporting Efforts

The consultant teams provided the draft reports in electronic and hard copy format.

Steve Griffin will provide a review comment template that will be used for the review process that will conclude Friday March 28th. At that time **ICC OPS will compile all the comments and distribute to the consultant teams.**

AWA Gridded Rainfall Data

Kevin Houck will follow up with Bill McCormick on what information is being requested.

Additional Hydrologic Services

Everything is in order to move forward with the amendments to the existing task order for the additional services. **Once URS receives the additional information from AWA they will need to resubmit their Task Order #2 Amendment.**

ICC Ops checked for new processed LiDAR of the extended scope areas but there hasn't been anything new posted. In order to request what is needed for this effort the **consultant teams should provide ICC Ops with a shape file of the limits of the additional study areas** so that **Ops can request specific tiles** in order to expedite the information transfer.

Schedule

Review comments should be in by Friday the 28th then will be combined and sent out to the Consultant teams.

The next meeting is scheduled for April 10th from 1-3 PM at the Flood Recovery Office, located at 1901 56th Ave., Greeley, CO.

Action Item List

Action Item	Due	By
FEMA acceptance of the 48-hr storm parameter on Boulder Creek	April 3rd AM	ICC OPS, CDOT & CWCB
DAR template for Hydrology summary		ICC OPS
Review Comments to the teams		ICC OPS
Revised Amendment to TO #2		URS
Shape files of extended study area limits		Consultant Teams
US34 Presentations to Jacobs team		ICC OPS
Consultants provide availability for April 21st through May 2nd for watershed meetings		Consultant Teams

COLORADO
Department of Transportation
Region 4

Flood Recovery Office
1901 56th Ave, Suite 110
Greeley, CO 80634

2013 Flood Hydrology Meeting

Attendees:

Steven Humphrey	Cory Hooper
Holly Linderholm	Morgan Lynch
Kevin Houck	Derek Rapp
Bob Jarrett (PH)	Jim Wulliman
Steve Griffin	Heidi Schram
Will Carrier (PH)	Naren Tayal
Ed Tomlinson	Doug Stewart (PH)

FROM: Flood Recovery Office

DATE: April 21, 2014

The following is a summary of the 2013 Flood Hydrology Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

1. Introductions and General

N/A

2. Incorporation of Review Comments

The consultant teams have addressed most of the comments provided. There was discussion of sharing between the teams the responses to the general comments to ensure consistency in the responses. At this time CH2MHill delivered their revised draft reports, Jacobs will delivered once their executive summary has been reviewed in the next 24 hrs, and URS will deliver their revised reports on Thursday at the FRO.

There was discussion around the type of Executive Summary the team wants for these reports. It was settled that the summaries would be more technical in nature as typical in these reports. Every summary will include the standard language that was provided by Steven Humphrey and then the teams will include the information necessary per watershed. It was noted that each summary should include the tables of "modeled peak flows compared to current regulatory discharges" and the "Estimate of Sept. 2013 peak discharge recurrence interval."

The consultant teams should deliver 5 hard copies of the revised draft reports.

3. Scheduling of Meetings with the Local Jurisdictions

The team would like to complete all the local meetings by May 16th 2014.

In general, the information from this team will not be provided prior to the meetings but will be communicated along with the teams' process and intent at the meeting. The general structure of the meeting will be introductions, purpose and intent by Steve Griffin, Steven Humphrey or Kevin Houck followed by the study and results from the consultant teams. The consultant teams should use a method of communication that works best to walk the audience through the results and process.

The desired order of the meetings is:

- Big Thompson – week of 4/28
- St. Vrain / Lefthand Creek - TBD
- Boulder Creek - TBD
- Coal Creek - TBD
- Little Thompson – TBD

Houck and Griffin will check their schedules for available times and Steven Humphrey will engage PIO to ensure messaging and coordination is completed to CDOT's expectations.

CDOT to check into the requirements of the Open Records Department as they relate to this effort and these draft reports as we intend to share all this information with our local partners.

4. Additional Hydrologic Services

The task orders for the additional services are moving forward. The consultant teams who have not already, need to provide which LiDAR tiles they will need for the additional study areas. **Ed Tomlinson will get Bob Jarrett's most recent list of peak flow estimate locations** so that the consultants can check that against their desired locations in order to keep the additional locations to be evaluated to the 20 sites in the scope.

Steven Humphrey will provide the HEC-RAS model from RESPEC to Steven Griffin and Bob Jarrett.

5. Project Schedule

The next meeting will be held at the Jacobs Denver Office on May 7th from 9 am – 11 am in the Echo Lake Conference Room.

6. Action Item List

Action Item	Due	By
PIO involvement in the Local meetings		Steven Humphrey
Availability for Local meetings		Kevin Houck, Steve Griffin, Jacobs Team
Open records requirements		Steven Humphrey
Bob Jarrett's latest locations and estimates list		Ed Tomlinson
Consultants cross check Bob Jarrett's lists with their wish list of locations, then provide remaining desired additional sites.		Consultant Teams
HEC-RAS model to Bob Jarrett and Steve Griffin		Steven Humphrey

COLORADO
Department of Transportation
Region 4

Flood Recovery Office
1901 56th Ave, Suite 110
Greeley, CO 80634

2013 Flood Hydrology Meeting

Attendees:

Steven Humphrey
Holly Linderholm
Kevin Houck
Naren Tayal
Steve Griffin
Will Carrier
Cory Hooper (PH)
Morgan Lynch
Derek Rapp
Jim Wulliman
Heidi Schram

FROM: Flood Recovery Office

DATE: May 7, 2014

The following is a summary of the 2013 Flood Hydrology Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

1. Introductions and General

N/A

2. Status of Phase 1 Hydrology Reports

The updated reports and models need to be posted to the CDOT FTP site. The consultant teams will be included in this distribution.

3. Little Thompson Meeting with DWR

Little Thompson DWR doesn't agree with the assumption of the dam failures and would like this team to remove the language from the reports. This team has agreed to remove the language but not change the model ect. The DWR report is anticipated to be public within 2 weeks and then the two teams can meet again.

Bob Jarret thinks he could get a new peak flow number of the main stem. This team would need very compelling evidence to change our numbers. So far our analysis still contains more data than the other analysis.

As we continue to encounter debate CDOT should strategize how they prefer to handle disagreements to our analysis in the future in order to be prepared.

4. I-25 Crossings

Steve Griffin will push on the email about the I-25 crossings. Will Carrier will coordinate with Bob Jarrett on what needs to be collected from the plains sites.

This team will move forward since the USGS is not ready for another meeting at this time. Additional analysis is warranted in this situation and there is potential to need additional survey data.

This team is in agreement that we will stick with our numbers at the St. Vrain.

5. Big Thompson Meeting

This meeting went very well and the presentation was excellent and delivered the intended amount of information. Any changes will come from the comments received from the meeting attendees.

6. St. Vrain, Left Hand and Boulder Creek Meeting

In order to prepare for this meeting the power point from the Big Thompson meeting will be distributed for the other watersheds to be adapted into the same format. The power points will be merged into one in order to reference more quickly during the Q&A section. The Q&A section will be held at the end for all watersheds. **CH2MHill will provide their slides to the Jacobs team to incorporate by Thursday the 8th.**

7. Additional Hydrologic Services

CWCB is being asked when the extended scope will be completed. At this time the team feels that Phase II will be complete in approx. 3 months after we collect all the data required.

8. Project Schedule

The next meeting will be held at the Flood Recovery Office in Greeley on May 28th from 9 am – 11 am.

9. Action Item List

Action Item	Due	By
Check on delivery of LOT 8 & 9 of the LiDAR		Steven Humphrey / Naren Tayal
Delivery of the Rainfall Data		Will Carrier / AWA
Data needed from plains as well as Bob Jarrett availability		Will Carrier

COLORADO
Department of Transportation
Region 4

Flood Recovery Office
1901 56th Ave, Suite 110
Greeley, CO 80634

2013 Flood Hydrology Meeting

Attendees:

Steven Humphrey
Holly Linderholm
Kevin Houck
Naren Tayal
Steve Griffin
Cory Hooper
Morgan Lynch
Derek Rapp
Jim Wulliman
Heidi Schram

FROM: Flood Recovery Office

DATE: May 28, 2014

The following is a summary of the 2013 Flood Hydrology Meeting. Decisions are highlighted and are summarized in a table at the end of this document. Action Items are shown in bold type and are summarized in a table at the end of this document.

1. Introductions and General

Kevin Houck inquired about the timeline of this effort in order to get an idea of the flood plain timeline that Lyons has asked about. The effected communities are more interested in the schedule of the revised flood plain mapping since that affects them more.

Confirmed that the review schedule of the different watersheds so that the teams are aware of the dates:

St. Vrain by Friday, June 6th
Left Hand Creek by Wednesday, June 18th
Boulder Creek by Thursday, July 3rd

The main push from the communities is for the new flood plain mapping so they can move forward with projects and policy.

2. Boulder County Meeting (May 12th)

The meeting went well. Longmont is concerned with their current design projects along the watershed.

3. Scheduling of Coal Creek Meeting

We would like to schedule the Coal Creek meeting within the next couple weeks. This team along with Region 1 will confirm who should attend this meeting. The attendees list needs to be confirmed for this meeting.

Holly Linderholm will get the updated reports posted to the CDOT FTP site.

4. Executive Summary of South Platte River

Still need an executive summary for the South Platte.

5. Little Thompson

Little Thompson is in a holding pattern but have decided to leave out the language about the dam failures**.**

Additionally, the St. Vrain at I-25 numbers are also on hold until the USGS ready.

Kevin Houck will check in with DWR to see if their report is ready.

6. Big Thompson Review and Comments

Loveland comments were sent electronically to Steve Griffin, he will forward along to the teams. Hard copies were reviewed briefly during this meeting.

Derek Rapp will email John Hunt and AWA about the rainfall information needed to address some of the comments.

Objective to this effort not go deep into tributaries but provide to the locals in order to get where they want.

7. Additional Hydrologic Services

Will Carrier to provide Bob Jarrett's availability and peak flows, what is his staffs' availability. From previous communication it sounds like Bob will not be available. The other teams will start identify staff and times that they can get high water marks. Steve Griffin will provide the list of models that CDOT has. The other teams will also check into who can offer survey or other people for high water marks if griffin can't get them in this week. The data needs to be collected quickly and we need to identify options outside of Bob Jarrett.

It may work out better for the schedule is the consultants collect data for their own watersheds. This has not been decided but considered in order to address the limited timeframe. If this is decided then there would need to be contract amendments to each consultant's scope and budget.

Steven Humphrey will talk with Will Carrier when he is back from vacation and then communicate if URS will collect all the data or if the other Consultants will be needed.

All LiDAR has come in and all the consultants have indicated they have what they need for now.

We will provide response to B.T. comments and collect the additional data and then see if the USGS would like to meet again.

8. Project Schedule

The next meeting will be held at the Jacobs Office in Denver on June 11th, from 9 am – 11 am.

9. Action Item List

Action Item	Due	By
Post updated reports to the FTP Site		Holly Linderholm
DWR Little Thompson report ready		Kevin Houck
Rainfall data from AWA		Derek Rapp

Phase I Hydrology Response Letter

PREPARED FOR: Colorado Department of Transportation

COPY TO: Colorado Water Conservation Board

PREPARED BY: Morgan Lynch, PE, CFM

DATE: April 18, 2014

PROJECT NUMBER: 482330

General Comments

1. **Comment:** The following comment was appropriate for all six reports. Within the model calibration discussion, three concepts are being explained at the same time. One concept is the incorporation of actual September 2013 rainfall data into rainfall-runoff model. The second concept is the calibration of the outputs of that model to estimates of actual peak flows from September 2013 *(estimates usually made by Bob Jarrett)*. The third concept is the development via the calibrated model of various frequencies of rainfall hydrographs and resultant frequencies of peak flows, including those utilized by FEMA. The discussion could be edited to better clarify each of these three concepts. It appears that they represent the heart of this report and the other 5 reports, so it should be easy for the reader to distinguish the three concepts from each other and to follow how they tie together. The informed readers can then decide if they buy the reasoning *(i.e. "Does the set of assumptions modeled for the role of landslides make sense or not?")*
   Response: Additional language has been added to Section 2.4.1 to better define the models and subsequent sections.
2. **Comment:** This approach is dependent upon the fundamental assumption that the rainfall amounts used in these studies are accurate. One of the key problematic issues with rainfall-runoff modeling of actual storms is simulating with accurate rainfall depths. There are well-known issues with using NEXRAD estimates for rainfall depth estimates. These issues should be at least discussed in a brief literature review, so that readers are aware of the potential problems. These DRAFT reports do not introduce the potential sources of error in these values, leading readers to believe that they should be used without question.
   Response: Additional information on how the rainfall was analyzed has been included.
3. **Comment:** The NOAA precipitation depths have confidence intervals that express some of the expected uncertainty in the rainfall depths. This uncertainty was not addressed in the methods or mentioned as a caveat on the accuracy of the rainfall depth values used in the modeling.
   Response: Additional language has been added to Section 2.4.5 to better explain the inherent error with these depths.
4. **Comment:** A brief literature review should also be provided to discuss the appropriateness of the CN method for rainfall-runoff modeling in forested landscapes. In general, the selection of appropriate CN values in forested landscapes is problematic, though this may be less of a concern for large rain events (i.e. the Sept floods) and due to the calibration efforts implemented. Though these caveats should be discussed in each report.

Response: A discussion was included documenting why the curve number parameter was appropriate for calibration.

5. **Comment:** For reaches that have stream gages with a reasonable length of record, the frequency analysis of these gage data should be used to develop the recommended flow frequency. Actual data are preferred to the results of rainfall-runoff analyses. Is this planned but just unclear in the reports?
   Response: The flood frequency analysis was incorporated for comparison purposes only. For this analysis it was critical to be able to document flows in areas where gage information was not available.
6. **Comment:** I noticed that each report completed by separate agencies has a different way of phrasing the purpose of these studies. It seems to be, after reading them, that it would be best if each report had an identical statement of purpose and identification of the project sponsors. We could just copy the language verbatim from one report to the next.
   Response: Language has been standardized.

Little Thompson

1. **Comment:** I like that an Executive Summary has been placed at the beginning of the report. However, it is quite verbose for an Exec Summary and much of the information is more appropriately contained later in the report. I would recommend 1-2 paragraphs max. with the appropriate tables showing the new recommended regulatory numbers, 2013 flood peak estimate, and comparison with accepted hydrology.
   Response: The Executive Summary has been updated with standardized text provided by CDOT.
2. **Comment:** The site numbers won't hold any meaning for the reader, unless referred to a map.
   Response: Site numbers have been added to the figures.
3. **Comment:** I would recommend a different term instead of "Measured Peak". These discharges were reconstructed based on field observations, but were not actually "measured" using a flow meter or real-time river measurements during the flood event. The term might be confusing.
   Response: Has been updated to Observed Peak.
4. **Comment:** "…were then compared to concurrent alternative estimates of high-flow hydrology." This phrase is unclear.
   Response: This sentence has been rephrased.
5. **Comment:** Page 1-2 - Be careful to refer to "data" as a plural term.
   Response: Revised.
6. **Comment:** Page 1-2 - "The Little Thompson River has no record of flooding prior to September 2013." I would eliminate or rephrase. There are records of previous flooding on the Little Thompson.
   Response: Statement has been omitted.
7. **Comment:** There are slight differences in the predicted flows presented in Table 7 and Table 8.
   Response: These tables have been combined to omit confusion.
8. **Comment:** Dam Safety has just completed a hydrology analysis of the Little Thompson above 7 Bar Ranch using HEC-HMS, might be a useful for comparison.
   Response: This report is currently not available but will be considered in the next Phase of work.

9. **Comment:** In **Section 2.4.2**, is it possible to create a graphic of the rainfall over the 7 days simultaneously illustrating the ebbs and peaks of the streamflows? That way the reader understands more clearly why the choices about 24-hours vs. 7-days were made in the development of the calibrated model.
   Response: A graphic was added to the Appendix to show the rainfall event.
10. **Comment:** In **Section 2.4.5 – Rainfall Inputs subsection**, it would be helpful to have graphics of the actual rainfall distribution over the entire time and the 24-hour rainfall used in the model for the various sub-basins. The basic questions are, "*How well, in terms of rainfall input throughout the watershed, does the model represent what actually happened in September 2013?*" and "*Should we be persuaded or not?*" -
    Response: A graphic was added highlighting the 24-hour window used for the calibrated model.
11. **Comment:** In **Section 3.1**, it would be interesting to add one more table showing the actual 24-hour rainfall *(for the specific time period that was used to build the model)* at various points to the various frequencies of rainfall for each of those various points. That way, the conclusion later on in the report that the September 2013 peak flows in the Little Thompson were greater than a 500-year frequency flow, we can look at the estimated frequency of the rainfall that lead to those peak flows and decide if they make sense.
    Response: Table B-4 has been updated to show the rainfall for the September 2013 storm for each basin.
12. **Comment:** The conclusion in **Section 4.2** that the peak flows experienced in the study area in September 2013 were all greater than 500-year flows raises the question, *"So what happened on the Little Thompson downstream of Highway 36, all the way to Milliken, during that event?"* Although it is beyond the scope of this contract, the inclusion of a very short description of estimated peak flows, and, perhaps a brief discussion of some of the flood damages, in the more populated areas of the watershed downstream of Highway 36 would provide a useful context for this report's findings. A 500-year flood in a forested area with few inhabitants is too easily forgotten. Maybe CWCB can provide that information.
    Response: More on what happened downstream will be provided with the next phase of work. Some discussion on this item has been added to the conclusion.
13. **Comment:** The USGS collected 17 years of record at the Little Thompson River gaging station near Berthoud (06742000) before the station was discontinued in 1961. Apparently the station is now operated by the Colorado Division of Water Resources. If the total record at this station greatly exceeds 17 years, then frequency analyses at this gaging station could be used to evaluate the reasonableness of flood discharges in the upstream study reach.
    Response: This gage was referenced in the report. However, due the location relative to the study area was not utilized for this study but will be evaluated for the next phase of work.
14. **Comment:** The peak discharges for the September 2013 flood are referenced as being determined from "paleoflood methodology". Paleoflood methods use slackwater deposits, peak stage indicators and carbon dating of deposits for floods that occurred prior to systematic data collection. The peak discharges for September 2013 floods are based on recent high-water marks and channel geometry during the recent flood and should be referred to as indirect measurements (such as the slope-area method, critical depth computations, flow over the road computations, etc.).
    Response: More discussion was provided in Section 2.3 to document how the observed discharges were collected.
15. **Comment:** Evaluate if the large differences in 1-percent chance discharge between the Little Thompson River sub-watersheds and West Fork Little Thompson River sub-watersheds (shown

in Figure 1) are reasonable.

Response: More documentation was included on the differences in land use cover and soil types between the two watersheds. These differences lead us to conclude that the results are reasonable.

16. **Comment:** Determine if the 1-percent chance discharges for Little Thompson River are reasonable. The trend line through the 1-percent chance discharge is greater than 1 suggesting that the upstream 1-percent chance discharges may be too low relative to downstream areas.
    Response: The trendline for Little Thompson included a point that is downstream of the confluence at drainage area 43 sq. miles. This point was omitted from the trendline and this figure was added to the appendix.
17. **Comment:** The September 2013 was determined to be greater than a 500-year flood at all locations where the peak discharge of the September 2013 flood was available from indirect measurements. The study team should determine if this assessment is consistent with other nearby watersheds (e.g., Big Thompson River, St. Vrain, etc.) given the geographic distribution of rainfall for the September 2013 flood.
    Response: The Big Thompson generally had 100 year rainfall and 100 year discharge. We added 24 hour September 2013 precipitation totals to Table B-4 (Little Thompson River Rainfall Depths) to show the same correlation with 500 year rainfall and 500 year discharge.
18. **Comment:** Page 1-1: It is stated that LiDAR data includes changes in channel geometry. LiDAR does not penetrate water; in non low flow conditions and anything but riffle areas, LiDAR does not well define the channel bed. This has less significance for higher flows and it is not expected that this significantly impact results. This should simply be discussed as a dataset limitation.
    Response: This is correct and it was noted that the LiDAR documented horizontal changes.
19. **Comment:** At the calibration point, flow was reduced from the estimated peak flow of 12,300 cfs to 7800 cfs. How was this reduction performed? Details on how this lower value was obtained needs to be provided.
    Response: A clarification was provided in Section 2.3 documenting that the values were determined based on nearby sites and similar watersheds.

<u>Boulder Creek</u>

1. **Comment:** Section 2.4.2 under Calibration of Model to Entirety of September 2013 Event says that using the 7 day timeframe resulted in inappropriate model parameters and the methodology was rejected, but a summary of the model is still included in Appendix B. It seems confusing to leave those parameters in the report; the explanation was enough to show why it was rejected.
   Response: This information has been omitted from the reports.
2. **Comment:** Not sure if it is necessary to include the discussion of the calibration to the 48-hour storm. It seemed to work well, but was rejected because 48-hour is an unusual storm to report. Since the exercise didn't seem to affect the resulting model, maybe it can be left out of the report.
   Response: This information has been omitted from the reports.
3. **Comment:** Table 9 compares the predicted flows to other data sources, including the FIS discharges. I can't seem to match up the flows in Table 9 with the Summary of Discharges Table provided in the appendix. Were those FIS flows taken directly from the USACE model or report? An explanation of the data source and documentation should be included.
   Response: Additional documentation has been added to clarify the source of the table values.

4. **Comment:** In **Section 1.2**, "The watershed is generally bounded by…the City of Boulder to the ***east*** *(not the west)*…"
Response: This has been updated.
5. **Comment:** In **Section 1.5.2**, is it possible to create a graphic of the rainfall over the 7 days simultaneously illustrating the ebbs and peaks of the streamflows? That way the reader understands more clearly why the choices about 24-hours vs. 7-days were made in the development of the calibrated model.
Response: A graphic was added to the Appendix to show the rainfall event.
6. **Comment:** In **Section 2.4.2** the current final sentence reads, "*Therefore, this method was discarded in favor of calibration to the peak 24-hour event and use of the commonly accepted 24-hour design hyetograph.*" Having just read about how well the application of the peak 48-hour event worked, the reader is left wondering if the 24-hour event works well enough or not, or if it was used simply for convenience.
Response: This discussion has been removed from the report per Comment 2.
7. **Comment:** In **Section 2.4.4** there is no mention of the 4-Mile Fire and its hydrologic impacts. I realize that complicates things, but wouldn't it be wise either to incorporate some representation of those impacts or to state explicitly that a conscious decision was made not to do so, for whatever reasons that decision might be made?
Response: Additional discussion regarding the Four Mile burn area has been included in the report.
8. **Comment:** In **Section 2.4.5 – Rainfall Inputs subsection**, it would be helpful to have graphics of the actual rainfall distribution over the entire time and the 24-hour rainfall used in the model for the various sub-basins.
Response: A graphic was added highlighting the 24-hour window used for the calibrated model.
9. **Comment:** In **Section 3.1**, it would be interesting to add one more table showing the actual 24-hour rainfall *(for the specific time period that was used to build the model)* at various points to the various frequencies of rainfall for each of those various points. That way, if the conclusion later on in the report is that the September 2013 peak flow was such and such frequency *(perhaps lower or higher than we might have anticipated)*, we can look at the estimated frequency of the rainfall that lead to that peak flow and decide if it makes sense.
Response: Table B-4 has been updated to show the rainfall for the September 2013 storm for each basin.
10. **Comment:** In **Section 4.1** it would be helpful to provide a comparison of the proposed flows to the current design/regulatory flows. The reader should see immediately just how much of a change is recommended.
Response: This information was provided in Table 9 and has been clarified with additional documentation in the report.
11. **Comment:** In **Section 4.2** there are some extremely sobering thoughts. I fear they may be lost. Is there a good way to give them a lot more punch? Maybe it could be done graphically???? There is a very big lesson here, but much of it could easily be lost.
Response: Additional discussion was added to Section 4.2
12. **Comment:** Base flood estimate of Fourmile Creek near Orodell by the prediction model is approximately 55% of the effective estimate, which is based on an USGS 1977 analysis. Comparison of unit flow (cfs/sq mi.) with the other sites in Boulder Creek watershed indicates that the unit discharge at Fourmile Creek is 83% higher than the value of Middle Boulder Creek, which has the second highest unit discharge value. Impact of burned area in Fourmile Creek watershed is difficult to assess; however flood peaks of Sept 2013 event were estimated (measured) at several other locations in the watershed (Figure B-2), is it possible to use these estimates/measurements to further confirm the calibration?
Response: Table 5 includes calibration points for Fourmile Creek.

13. **Comment:** Base flood of Boulder Creek at Orodell station estimated by the prediction model is 86% of the effective discharge. It is still a conservative estimate compared to the much lower estimate from gage frequency analysis. One of the reasons could be due to mixed population of peaks from rain-on-snow and storm events in the frequency analysis. Impact of Barker Reservoir could be another reason that modeled peak flow is on high side. Although the base flood estimate in this study is lower than the effective value, it is unlikely that the peak is underestimated.
    Response: Comment noted.
14. **Comment:** Gage 06725500, Middle Boulder Creek at Nederland has 87 year of record, with annual peak recorded from 1945 to 1995. Frequency curve from this station was not mentioned in the report. Is there any reason that the gage data are not suitable to use to calibrate the HMS model?
    Response: This gage has been added to the analysis and included in the report where applicable.
15. **Comment:** The source cited is from 1948, but contains data from 1969…? Double-check.
    Response: The source for the 1969 reference has been added.
16. **Comment:** May want to include additional background on how the Ayres stream gage analysis supplements the rainfall-runoff models.
    Response: Discussion was included and these points were used for comparison.
17. **Comment:** Table 5: The site numbers will not hold any significance for the reader unless shown on a map and referenced.
    Response: These locations were shown in the Appendix. A note has been added to direct the reader to the appendix.
18. **Comment:** Table 11: It is unclear here if the Annual Chance Peak Discharge numbers are the current regulatory numbers or a proposed set of numbers.
    Response: The headings and title of the table have been revised to help eliminate confusion.
19. **Comment:** See the comments for the Little Thompson for any text that was copied between the two reports.
    Response: Updated with the same responses for Little Thompson.

Phase I Hydrology Response Letter

PREPARED FOR: Colorado Department of Transportation

COPY TO: Colorado Water Conservation Board

PREPARED BY: CH2M HILL

DATE: August 8, 2014

PROJECT NUMBER: 482330

The Colorado Department of Transportation (CDOT) and the Colorado Water Conservation Board (CWCB) partnered with CH2M Hill to perform hydrologic analysis of the Boulder Creek watershed after the flooding of September 2013. The results of this analysis were published in the Draft report "*Boulder Creek Hydrologic Analysis*", April 2014. This report was distributed to interested agencies and communities for comments. The comments received are captured below with responses to how the comments were addressed.

Urban Drainage and Flood Control District Comments:

1. **Comment:** It is not clear in this report how the SCS 24-hr Type II rainfall distribution was selected. Shall the SCS 24-hr Type II rainfall distribution be also recommended for design flood predictions?
   Response: *See Page 2-9 of the April report, at the end of the "Rainfall Inputs" section: "Per the* Colorado Floodplain and Stormwater Criteria Manual *(CWCB, 2009), the standard NRCS 24-hour Type II rainfall distribution was used as the design hyetograph to distribute the 24-hour rainfall depths to generate hydrographs for the 10, 4, 2, 1, and 0.2 percent annual chance discharge."*
2. **Comment:** A design rainfall distribution shall be conservatively selected as the enveloping curves to the extreme rainfall cases (Guo and Harrigan 2009). To clarify how to select the design rainfall distribution, I suggest that this report may further provide a comparison between the middle 2-hour sharp rising curve in the SCS Type II rainfall distribution and the UDFCD's 100-yr 2-hr rainfall curve. If the difference is minimal, then the SCS Type II rainfall curve shall be acceptable for the predictive hydrologic models. Otherwise the SCS Type IIA rainfall curve may be a good substitute.
   Response: *The Type II NRCS Rainfall Distribution was selected per guidance in the* Colorado Floodplain and Stormwater Criteria Manual *(CWCB, 2009). In a review of a 57-year rainfall record at the Stapleton International Airport in Denver, CO, Guo (2008) recommended that a conservative rainfall distribution be developed "using the low enveloping curve for the leading portion, the high enveloping curve for the tail portion, and a sharp rise in between" and showed that the NRCS Type II rainfall distribution met this criteria for the analyzed rainfall record[1]. Given the proximity of Denver, CO to the study basin, the NRCS Type II rainfall distribution is appropriate for the Boulder Creek watershed as well. In reference to other hyetographs, the UDFCD's rainfall curves were developed in small, urbanized basins east of the foothills of the Front Range and were not considered representative for the much-larger and predominantly mountainous terrain of the study basin. The NRCS Type IIA rainfall distribution was not considered, as the Type IIA rainfall distribution was originally created for New Mexico, transferred to Colorado, and later discarded by the NRCS when NRCS concluded that the Type II storm yielded accurate results in Colorado (JR Engineering, LTD, unpublished response letter, September 4, 1992).*

[1] Guo, J.C.Y. (2008). *Design Rainfall Curve.* < *http://carbon.ucdenver.edu/~jguo/PaperWeb/(W2)RainDesignCurve.pdf* > *(August 5, 2014).*

3. **Comment:** It that model is used and having been involved in the development of design storms for UDFCD in the past, my recommendation would have been to use Type IIA storms instead.
   Response: *See response to Comment #2.*
4. **Comment:** As is common with modelling, the model was calibrated using the runoff rates of the most intense 24-hour precipitation period of the September 2013, an event that may, or may not be representative of much more intense, short duration storms like ones experienced along the front range foothills of Colorado.
   Response: *While intense, short-duration storms may cause extreme runoff in smaller basins near the foothills, a review of the flood history of Boulder Creek indicates that the September 2013 event is comparable to some of the largest flood events (1876, 1894, and 1921) along Boulder Creek: all the storms were large, general storms that lasted several days and spanned large portions of the Front Range such that the September 2013 storm is considered representative of extreme events along Boulder Creek. The report will be revised to include this discussion.*
5. **Comment:** Once saturated, something that I have observed to often occur between 1- to 2-inches of heavy precipitation, the surfaces acts as 100% impervious. Recognizing this and proper application of the Green-Ampt method can yield realistic runoff results.
   Response: *As discussed on Page 2-7 of the April report, an attempt to calibrate the model using the Green-Ampt method was made, but there was not a defensible way to assign Green-Ampt parameters based on soil data in the USDA Soil Survey that would result in modeled runoff volumes comparable to observed runoff measurements (modeled runoff was approximately an order-of-magnitude less than what was observed).*
6. **Comment:** Although the watershed parameters used in this computer model were calibrated by six stream gages along Boulder Creek during September 9th to 18th in 2013, the validity of this calibrated watershed model is only justified for this single event.
   Response: *Noted. While this is true for any hydrologic event, the calibrated model is considered representative of hydrologic conditions during extreme rainfall events; see response to Comment #4.*
7. **Comment:** Another point I would like to offer for your consideration is that the rainfall-runoff modeling for Boulder Creek used a 30-minute time step for the input of the Type II NRCS hyetograph.
   Response: *A 5-minute NRCS Type II hyetograph was used in the model; the report will be revised to clarify this.*
8. **Comment:** There is sufficient evidence that the current regulatory numbers are quite representative of what Boulder Creek is capable of producing and are inherently more protective of the public residing along it today and in the future.
   Response: *Noted. The intention of the report is to provide an improved estimate of the peak discharge-probability along Boulder Creek to accurately assess the recurrence interval of the September 2013 flood and limit the overdesign of planned CDOT improvements. While this analysis represents the most recent science and available data, the adoption and regulation of flow rates is a decision made by effected communities and regulatory agencies and is outside the purview of this report.*
9. **Comment:** The common practice when doing statistical analysis (e.g., Log Pearson) is that it is assumed that extreme event statistics are driven by the same population of meteorological and hydrologic events that drive smaller events. It is more than likely that the 1-percent and larger events may be a separate population of meteorological events.
   Response: *Noted. It is partially for this reason that little weight was given to the statistical gage analyses in calibrating the rainfall-runoff model or estimating the magnitude of extreme events.*

10. **Comment:** One of the other items described in the aforementioned report was the use of statistical analysis of the flow gage along Boulder Creek upstream of the City of Boulder. What struck me is that the two large floods, one in 1876 and another in 1894 (i.e., approaching 11,000 to 12,000 cfs), were not included in the Log Pearson analysis.

    Response: *There are two reasons these floods were not included in the statistical gage analysis: 1) the flows were recorded in Boulder, downstream of Orodell and thus inclusive of Fourmile Creek which is referenced in the FIS as the "primary source of flooding", and 2) these flows pre-date the construction of Barker Reservoir which, while not operated for flood control, has provided some flow attenuation since its construction. As a discussion point, the statistical gage analysis was re-run with a historic flow of 10,000 cfs occurring in 1894 (four times greater than the peak flow, 2,500 cfs, recorded at the Orodell gage in 1921) and the 100-year estimate increased to 3,182 cfs (Ayres Associates, e-mail correspondence, August 6, 2014). The report will be revised to indicate that historical flow estimates pre-dating the installation of the Orodell and Nederland gages do not exist.*

11. **Comment** Two calibrated and verified models have been in existence for number of years and it is my understanding that they were used by UDFCD in estimating the flows at the mouth of the canyon very shortly after the September flooding occurred.

    Response: *Based on e-mail conversations with UDFCD, there is no published documentation describing the use of these models to predict discharge-probability curves along Boulder Creek (Kevin Stewart, e-mail correspondence, May 29, 2014).*

12. **Comment:** In addition, UDFCD has 1-sq. km. pixel-by-pixel ground calibrated radar imagery virtual temporally dense rainfall depths for the entire watershed.

    Response: *Due to the resolution and rigorous QC procedure (described on page 2-8 of the April report, under "Rainfall Analysis"), the hyetographs generated by AWA will continue to be used for this study.*

<u>Boulder County Land Use Department Comments:</u>

13. **Comment**: The reference document was not provided. The technique to obtain the estimate was described as the Paleoflood method which appears to have mainly been a critical depth analysis. It is necessary to distinguish it from a full-scale paleoflood analysis which involved other observation and techniques.

    Response: *Section 2.3 of the report details the estimation of peak discharges; the report will be revised to remove ambiguity in other sections. Bob Jarrett's report describing the estimation of peak discharges will be included as an attachment.*

14. **Comment**: The effective peak flow at the outlet is significantly higher than the HMS estimated flow. For the calibrated model, the time to peak flow from Fourmile Creek is eight hours prior to the time to peak flow from and Boulder Creek including Middle and North Boulder Creek watersheds. Comparing the HMS model hydrographs and time to peak flow from the various sub watersheds with the 1977 model hydrographs and time to peaks may help better evaluate the HMS estimates.

    Response: *The peak discharges estimated by the calibrated HEC-HMS model occurred between 30 minutes prior to (Orodell) and 90 minutes following (Nederland) peak discharges measured at gage locations. In contrast, the 1977 USACE model was not calibrated, nor was it compared to actual gage measurements following rainfall events. The report will be revised to present and discuss the timing of computed peak discharges in relation to observations.*

15. **Comment**: A study contractor may conduct a critical storm analysis utilizing storm events of varying lengths to determine the most suitable precipitation parameters to use for peak discharge estimation.

Response: *See response to Comment #2.*

16. **Comment**: A noticeable difference between the USACE (Anderson) model and the CH2MHILL model is that a 6-hr storm event from NOAA 2 was used in the USACE (Anderson) model while, a 24-hr storm event from NOAA 14 was used in the CH2MHILL model. In their effort to match the results from the original 1977 USACE study, Anderson ran multiple scenarios, among them a modified USACE 6-hr Standard Project Storm and a variation of the 6-hr Southwestern Division Criteria Standard Project Storm. These two storm patterns produced relatively close 1-percent-annual-chance discharge estimates on Boulder Creek at Orodell (5230 cfs vs. 5910 cfs), but produced dramatically different estimates at the Boulder Creek Canyon mouth (5260 cfs vs. 9980 cfs). The Anderson evaluation concluded that the variation of the 6-hr Southwestern Division Criteria Standard Project Storm produced results that most closely aligned with the results from the original 1977 USACE study.

    Response: *To evaluate the impact of differing storm durations and hyetographs, the Fourmile Creek hydrologic components of the calibrated HEC-HMS model were extracted to a separate HEC-HMS model and re-calibrated to a 6-hour event. Similar to the 24-hour calibration, the Fourmile Creek HEC-HMS model was calibrated by adjusting the CN to match peak flows; runoff due to rainfall that occurred prior to the calibration period was not considered such that calibrated CNs would be conservative (due to discounting the portion of the peak discharge that was attributable to rainfall that occurred prior to the calibration period). Initial abstraction was set to zero inches to reflect the effect of rainfall immediately prior to the calibration period. Following calibration of the Fourmile Creek model, the CNs were adjusted from AMCIII to AMCII to develop discharge-probability curves. Utilizing a 6-hour NRCS Type II hyetograph, the estimated 1 percent chance annual exceedance discharge was 3,630 cfs – a 6 percent increase over the 24-hour estimation. For comparison, an average CN of 93 would be needed to replicate the 6,230 cfs estimated at the mouth of Fourmile Creek by the 1977 USACE model. To further analyze the impacts of varying rainfall patterns, the 6-hour rainfall distribution used in the USACE 1977 study (referred to as the "modified 6-hour Southwestern Division Criteria" by Anderson) was evaluated as well; the estimated 1 percent chance annual exceedance discharge was slightly less than that estimated using the NRCS Type II hyetograph, showing a negligible sensitivity of the estimated peak discharges to rainfall duration and distribution. A discussion regarding the 6-hour storm event has been added to report.*

17. **Comment**: Run Fourmile with the 6-hour Southwestern Division Criteria Standard Project Storm.

    Response: *See response to Comment #16.*

18. **Comment**: The calibration model should be improved to better match the volume of the 2013 storm event, or the study should clearly state that the model should be used only for the prediction of peak discharges. The peak of the computed [MBC @ Nederland] hydrograph is much narrower than that of the observed, resulting in a total volume for the computed hydrograph of 0.20 inches. This value is 0.31 inches less than the observed hydrograph of 0.51 inches. The calibration of the computed peak flow [at Orodell] of 1950 cfs matches the observed peak reasonably well; however the computed volume is 0.24 inches less than that of the observed hydrograph.

    Response: *The volumes referred to above are over a 48-hour window that was selected to illustrate the recession limb of the modeled hydrograph that resulted from the 24-hour period of rainfall that was modeled. Comparing the modeled volume against the observed volume only over the 24-hour period that rainfall was modeled, the modeled and observed volumes are as follows:*

Modeled and Observed Volumes (24-hour Analysis Window)

Gage	Modeled Volume (watershed-inches)	Observed Volume (watershed-inches)	Difference (watershed-inches)
Middle Boulder Creek at Nederland	0.10	0.22	-0.12
Boulder Creek at Orodell	0.26	0.34	-0.08

While the modeled discharges are still less than the observed volumes, it should be noted that significant rainfall occurred prior to the analysis window. As the model does not account for runoff occurring from rainfall prior to the 24-hour analysis window, the observed hydrograph does; thus, due to the modeling methodology, the observed volumes are expected to be greater than the modeled volumes. Analyzing the Nederland gage record, runoff from rainfall preceding the analysis window could account for 35 to 65 percent of the observed volume. The report will be revised to report and discuss the modeled volumes in comparison to observed volumes.

19. **Comment**: The calibration focused on matching peaks using the CN value as the calibration parameter. Typically, CN values are most sensitive to hydrograph volumes, and routing parameters are better-suited to adjust the peaks.

    Response: *As discussed on page 2-11 of the April report, the model was relatively insensitive to changes in routing parameters; halving or doubling the Manning's n value resulted in an approximate 5 percent change in the modeled peak discharge. Presumably, this is due to the steep slopes of the study basin channels. While the model was somewhat sensitive to subbasin lag time and Snyder's peaking factor, subbasin lag times were not calibrated as the modeled times-to-peak correlated well with observations and Snyder's peaking factors were not calibrated as a satisfactory calibration was achieved using C_p values within the range recommended in published literature.*

20. **Comment**: The model was calibrated using a storm that occurred at a dry time of year in Colorado which may have resulted in higher than normal loss rate. Design hydrographs generated from the calibrated model parameters may not be conservative. The model parameters should be modified to account for this or a discussion should be added to the report that indicates why the selected model parameters adequately account for this.

    Response: *The 24-hour calibration period occurred several days into the storm event. Thus, at the start of the calibration period, the soils were likely partially- or fully-saturated, as evidenced by the observation that peak discharges occurred approximately a day after the peak rainfall, suggesting that the infiltration capacity of the Boulder Creek soils were largely expended prior to the calibration period. A brief discussion of this will be added to the revised report.*

21. **Comment**: The storm occurred after a prolonged dry period, meaning that the infiltration rates would be higher than at the normal condition. Loss rates are 90% or higher in sub-watersheds in North Boulder and Middle Boulder Creeks, which hardly reflect typical conditions.

    Response: *See response to Comment #21.*

22. **Comment**: We have determined that the reported "Modeled Discharges" in Table 6 were not directly derived from the HEC-HMS model results, and, therefore, comparisons can't be verified. Any additional analysis or computations should be included in the report.

    Response: *The calibration points were located approximately halfway between model junctions where peak discharges between the two junctions differed by 50 to 100 percent. Thus, the modeled peak discharge at these calibration points were estimated by interpolating between the two bounding model junctions based on contributing drainage area; discussion of this interpolation process will be provided in the revised report.*

23. **Comment**: The burn in the watershed was mentioned in the report but the size of the burned area was not clearly defined.

Response: *On Page 1-2 of the April report, the area of the Fourmile Canyon fire was identified as 10 square miles. Of this, 7.5 square miles was within the Fourmile Creek watershed and an additional 0.5 square miles elsewhere in the Boulder Creek watershed (above Orodell). The Fourmile Canyon Fire burn area will be added to the watershed overview figure.*

Phase 2 Boulder Creek Hydrologic Analysis – Response to CDOT Flood Hydrology Team Review Comments

PREPARED FOR: Colorado Department of Transportation

COPY TO: Colorado Water Conservation Board

PREPARED BY: CH2M HILL

DATE: April 3, 2015

PROJECT NUMBER: 494613

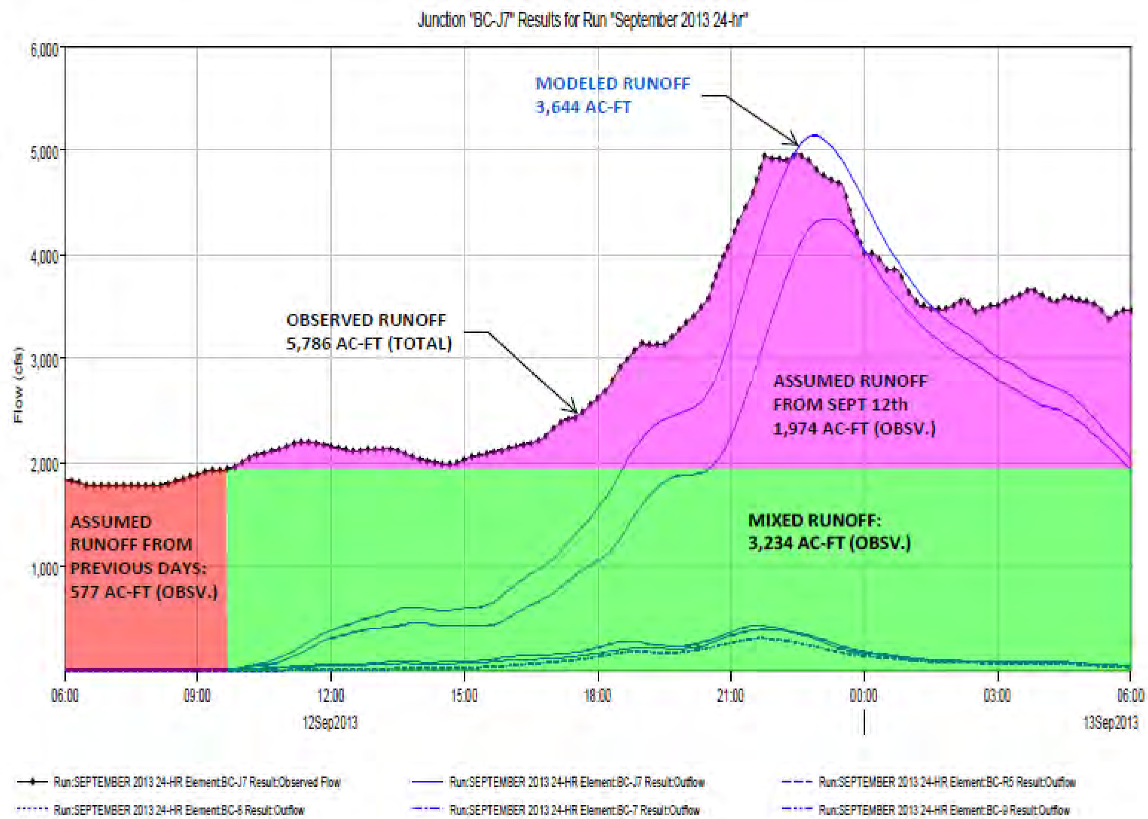
The Colorado Department of Transportation (CDOT) and the Colorado Water Conservation Board (CWCB) partnered with CH2M HILL to extend the Phase 1 hydrologic analysis of the Boulder Creek watershed above Orodell, CO to the confluence of Boulder Creek and St. Vrain Creek. The results of this analysis were published in the Draft report "*Boulder Creek Hydrologic Analysis, Phase 2: Boulder Creek above St. Vrain Creek*", February 2015. This report was distributed to the CDOT Flood Hydrology Team for comments prior to public release. The comments received are captured below with responses to how the comments were addressed.

Michael Baker International Comments, prepared for Federal Emergency Management Agency:

1. **Comment:** The study concluded that a generalized regional storm generates higher peak discharge and the watershed-wide 24-hr storm is the critical event. Although spatially concentrated thunderstorm at a subbasin was tested for critical storm determination, the scenario assumed that the storm only occurs at a single subbasin while there is no precipitation at all other subbasins. The analysis did not consider that high discharges could be the result of coincidental storms in more than one subbasin or moving of a storm center during the modeling period.
   Response: *Spatially-concentrated storms considered as part of the critical storm analysis were concentrated over multiple subbasins, not individual subbasins. A brief description of the potential critical storms considered has been added to Section 2.4.2 of the report to clarify this.*
2. **Comment:** The study used a local depth-areal reduction curve created by the AWA which extends beyond the watershed size of 400 square miles, which is the upper size limit of the depth-area reduction curve created by the NOAA. For basin sizes of 315 to 449 square miles, the depth-areal reduction curve is gradually transited from the NOAA curve of 0.92 to the local AWA curve of 0.78. The AWA curve is not the subject of this review, however, it [is] worth mentioning the basin assumption behind areal reduction factors. As explained by the NOAA Hydrometeorological Design Study Center (HDSC), there is dependence between the point and areal values, and such correlation between point estimates reduces as they get farther apart until the values become independent, therefore the dependence relation between a point and an area breaks down as well. NOAA HDSC does not recommend extending the point and areal relationship.
   Response: *Applied Weather Associates provided the following response:*

   "AWA did not extend [NOAA] point values to larger areas. AWA used actual Depth-Area-Reduction data from individual storm events that have occurred in the area and are of the storm type that are appropriate for this analysis. These provide explicit data and the areal reduction of a given storm as the rainfall values are analyzed over various area sizes. The storm centered approach, methodology followed by AWA, is a mathematical calculation that compares the amount of rainfall at a given area size at a given duration to an amount of rainfall at a different area size at the same duration for the same storm. Therefore, if the application of the areal reduction factors are applied to basins and storms that were explicitly considered and evaluated as part of this analysis, no unjustified assumptions are being made. This is in contrast to what the HDSC discussion is referring to, as there is no dependency between point and areal values in our analysis. They are discussing the relationship between point precipitation frequency estimate and areal reduction factors using an among (sic) storm statistical analysis where it is possible that the relationships do not hold beyond certain area sizes because of the potentially mixed population of storms."

3. **Comment:** South Boulder Creek is a major tributary to Boulder Creek that, at its confluence, almost doubles the drainage area of Boulder Creek. The effective 100-yr discharge of South Boulder Creek at its mouth was estimated at 4,980 cfs with a drainage area of 136 square miles. The report only documented the discharge at each of [the] HEC-HMS "basins" in Appendix B, it did not provided the modeled peak flow at key locations along this major tributary.
   Response: *It is assumed that the peak discharge estimates referenced in this comment are pertaining to the modeled 10, 4, 2, 1, and 0.2 percent annual chance peak discharges rather than modeled September 2013 peak discharges (presented in Table 12). Recognizing the contribution of South Boulder Creek to flooding along Boulder Creek, peak discharge estimates for the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges along South Boulder Creek will be reported in the revised report and presented graphically as an additional peak discharge profile. However, as 1) the scope of the Boulder Creek Phase 2 hydrologic analysis was to estimate the recurrence interval of the September 2013 event and the magnitude of the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges along Boulder Creek, not tributaries, 2) critical storm analyses were not performed for tributaries, and 3) detailed hydrologic analysis of South Boulder Creek has been recently completed, modeled 10, 4, 2, 1, and 0.2 percent annual chance peak discharges estimated for South Boulder Creek are not recommended over the effective HDR, 2007 hydrologic study.*
4. **Comment:** Coal Creek is the largest among plain tributaries; its estimated peak discharges to Boulder Creek were not provided in the report either.
   Response: *It is assumed that the peak discharge estimates referenced in this comment are pertaining to the modeled 10, 4, 2, 1, and 0.2 percent annual chance peak discharges rather than modeled September 2013 peak discharges (presented in Table 12). Recognizing the contribution of Coal Creek to flooding along Boulder Creek, peak discharge estimates for the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges along Coal Creek will be reported in the revised report and presented graphically as an additional peak discharge profile. However, as 1) the scope of the Boulder Creek Phase 2 hydrologic analysis was to estimate the recurrence interval of the September 2013 event and the magnitude of the 10, 4, 2, 1, and 0.2 percent annual chance peak discharges along Boulder Creek, not tributaries, 2) critical storm analyses were not performed for tributaries, and 3) detailed hydrologic analysis of Coal Creek has been recently completed, modeled 10, 4, 2, 1, and 0.2 percent annual chance peak discharges estimated for Coal Creek are not recommended over the effective RESPEC, 2012 hydrologic study.*
5. **Comment:** The total volume of the entire hydrograph is an important factor. The modeled runoff appears 2000 ac-ft less than the observed Sept 2013 runoff (see Report Figure 14 below [provided on following page]). Is there a total volume comparison of the modeled 1- and 2- percent annual chance flood with the Sept 2013 observed runoff? Does such comparison support the above estimate of recurrence interval?



Response: *No such comparison was made as a direct comparison of the September 2013 event runoff volume to modeled 10, 4, 2, 1, and 0.2 percent annual chance runoff volumes is complicated by 1) the difference in duration of the events, 2) the subjective nature of the hydrograph separation needed to compare similar durations of rainfall, and 3) that interflow (contributions from shallow groundwater on the receding limb of the hydrograph) was not considered in the calibrated nor predictive hydrologic models. As an example, the figure referenced alongside the review comment illustrates that between 10 to 65 percent of the observed runoff may be attributable to runoff from rainfall that preceded the 24-hour analysis window.*

6. **Comment:** We recommend running additional scenarios with multiple storm center to evaluate and/or verify the critical storm event for foothill communities. The comparison should not only include instantaneous peaks but also volume of the hydrographs. The FIS discharge table can be developed from the composite peak from multiple scenarios if necessary.
   Response: *Multiple scenarios were analyzed as part of the critical storm analysis, with spatially-concentrated storms located in areas more likely to generate high peak discharges, specifically over areas of higher runoff potential that were below the influence of major in-stream reservoirs. The result of the critical storm analysis was that peak discharges at all locations along Boulder Creek were controlled by the general storm event.*
7. **Comment:** The study revealed the limitation of routing options in the HEC-HMS model. The calibrated rating curves and the Modified Puls storage routing method were not used in the predictive model to estimate peak discharges. Unlike the Boulder Creek effective discharges as well as gage estimates, the predictive model discharges did not show the peak flow attenuation. Hydraulic routing can generate better, more consistent estimates for both discharge and water surface elevation. In a future restudy, Boulder Creek would be better modeled by an unsteady flow analysis with HEC-HMS hydrograph inputted at selected location directly and route through reaches with complex hydraulic conditions.

Response: *It is unclear whether this comment recommends the parallel use of an unsteady hydraulic model to attenuate hydrographs in place of the adopted attenuation methods, or whether an unsteady hydraulic model should be used in future re-delineations of the Boulder Creek floodplain. In regards to the former, it is agreed that unsteady hydraulic modeling will better model attenuation of the hydrograph, however, for the predictive hydrologic model, the unsteady hydraulic modeling methodology is inappropriate as it is not compatible with current floodplain regulations that would allow future development of floodplain areas that currently provide attenuation. In regards to the latter, no such flood hazard area delineation is planned as part of this study.*

Colorado Department of Transportation Review Comments:

8. **Comment:** Under the References at the back of the report, for "URS 2015" - we should probably indicate that this was a memo/letter, not a full-blown report.
   Response: *The reference has been updated to reflect a memorandum.*
9. **Comment:** Section 2.1, I recommend eliminating the first sentence - we don't need to speculate as to why there is the volume of study performed on the watershed (could be politically sensitive statement). Just say something like, there are multiple studies in the watershed.
   Response: *The sentence has been revised to only state that there are multiple previous studies.*

Department of Natural Resources Review Comments:

10. **Comment:** Table ES-1: Including that many significant figures in the table for modeled discharge is fine, as the percent difference is included. However, the Boulder Creek at St. Vrain Creek modeled discharge of 16,139 cfs should not be used later in the report. This value has too many significant figures given the data used in the model, and should be reported to two significant figures. The percent difference of -6.1% should be taken into account when reporting the modeled discharge later in the report (making the value 17,000 cfs including significant figures and estimated percent difference). Though this does not change the estimated recurrence interval range (50-100 years), it's a more accurate representation of the final estimate.
    Response: *Per the decision of the CDOT Flood Hydrology Team, the report will be revised to present modeled discharge values with three significant figures; percent differences will be updated accordingly. In regards to the specific modeled September 2013 peak discharge of Boulder Creek at St. Vrain Creek in question, the ultimate use of the estimate is to assess the recurrence interval of the September 2013 event. As the estimated recurrence interval does not change if two significant figures are used, three significant figures were used to maintain a consistent level of precision for modeled peak discharges across the report.*
11. **Comment:** Figure ES-2: Flipping the x axis to show distance downstream of initial estimate makes more sense.
    Response: *Peak discharge profiles were developed to be consistent with Flood Profiles presented in FEMA Flood Insurance Studies; this includes the orientation of the X axis.*
12. **Comment:** Section 2.4.3: Using GIS software (basin delineation hydrology tools) along with the new LiDAR and NED datasets to refine sub-basins would lead to more refined sub-basin boundaries, and estimates for basin characteristics.
    Response: *This comment is noted. It was decided that the additional detail of using GIS to delineate subbasins was not justified by the time required to "clean" the LiDAR dataset and manually revise subbasins where such tools did not accurately model subbasins east of the Front Range.*
13. **Comment:** Table 11: Modeled Discharge footnote for Fourmile Creek downstream of Emerson Gulch is the same as the footnote presented for Table ES-1's Percent Difference value for Boulder

Creek at St. Vrain Creek. Observed Discharge footnotes for South Boulder Creek at Highway 39 and S Boulder Creek at S. Boulder Creek Rd. are the same.
Response: *Table 12 (Table 11 in the previous draft of the report) has been revised to provide the correct footnote for Fourmile Creek at Emerson Gulch. The footnote provided for South Boulder Creek at South Boulder Creek Road and South Boulder Creek at Highway 93 applies to both locations and Table 11 (now Table 12) was correct as presented.*

14. **Comment:** Section 3.1: Second paragraph, final sentence, the part stating "suggesting land use is an important…" can be removed as this relationship is already known.
Response: *The text has been updated to reflect the suggestions in the comment.*
15. **Comment:** Section 3.2.1: The final sentence of the second paragraph near the bottom should be revised so that the word "reasonableness" is not used.
Response: *In conjunction with addressing Comment #3, the text has been updated to reflect the suggestions in the comment.*
16. **Comment**: Section 3.2.2: Revise sentences that use the word "reasonableness."
Response: *The text has been updated to reflect the suggestions in the comment.*
17. **Comment:** Section 2.4.2 could use more clarification on DARF methodology. Appendix F provides more info on what that is and why it is used but it is not described in the report that more clarification is provided. There is also a separate section on DARF on page 32 in section 2.4.5 that could be pointed out or moved to section 2.4.2 for ease of reading.
Response: *A reference to section 2.4.5 has been added to Section 2.4.2.*
18. **Comment:** Summary of Modeling approaches. In section 2.3 on page 25, the paragraph describes Peak Discharge estimates in Figure 3, but I believe it's in Figure 4.
Response: *The text has been updated to reflect the suggestions in the comment.*
19. **Comment:** Section 2.4.4 Basin Characterization – might be a good place to reference Figure 3 A & B which are maps showing the urban stream and ditch conditions, and OSMP ditch/headgate/dam damage assessments. These figures are not mentioned anywhere else in the report.
Response: *References to Figure 3a and Figure 3b have been added to Section 1.6.2.*
20. **Comment:** Page 33, Subbasin Parameters, acronyms should be listed out to be consistent with other sections. CN, AMC, NLCD.
Response: *Acronyms are provided following the first use of the fully-expanded term; beyond the first use, the reader is directed to Page VII for a full list of acronyms and what they stand for.*
21. **Comment**: Page 34 refers to Figure 4 to provide a visual layout of reach elements, but I think it should say Figure 5.
Response: *The text has been updated to reflect the suggestions in the comment.*
22. **Comment:** The bookmarks should have another TAB to list Figures separately. Hard to find initially as I wasn't exactly sure where it was located.
Response: *The bookmarks have been updated.*

Phase 2 Boulder Creek Hydrologic Analysis – Response to Stakeholder Review Comments

PREPARED FOR:	Colorado Department of Transportation
COPY TO:	Colorado Water Conservation Board
PREPARED BY:	CH2M HILL
DATE:	June 5, 2015
PROJECT NUMBER:	494613

The Colorado Department of Transportation (CDOT) and the Colorado Water Conservation Board (CWCB) partnered with CH2M HILL to extend the Phase 1 hydrologic analysis of the Boulder Creek watershed above Orodell, CO to the confluence of Boulder Creek and St. Vrain Creek. Following review by the Colorado Department of Transportation, the Colorado Department of Natural Resources (which includes CWCB), and the Federal Emergency Management Agency, the results of this analysis were published for stakeholder review in the Draft report "*Boulder Creek Hydrologic Analysis, Phase 2: Boulder Creek above St. Vrain Creek*", dated April 2015. This report was distributed to representatives of Boulder County, the City of Boulder, the City of Longmont, the Town of Superior, Weld County, and Urban Drainage and Flood Control District for review and comment prior to public release. The comments received are captured below with responses to how the comments were addressed.

Boulder County Transportation Department Review Comments:

1. **Comment:** Section 2.3 Peak Discharge Estimates: Just for clarification, could one paragraph of summary be provided at the beginning of this section to describe how gages functioned during the flood and to outline various peak discharge estimation methods?
   Response: *A summary has been added to Section 2.3 to summarize the various peak discharge methods and a new Section 2.3.1 has been added to document the function of stream gages which was previously provided in Section 2.2 of the report.*
2. **Comment:** Related to Section 2.3: Could a short description be provided to document the methodology used to estimate the time to peak and the runoff volume during the flood, as well as the selection of calibration points?
   Response: *Section 2.3.1 has been added to the report to document how the time-of-peak and runoff volume were estimated during the flood.*
3. **Comment:** Section 2.4.5 Model Development – Subsection "Rainfall Hyetographs" discussed the recurrence intervals of the measured 24-hour rainfall depths within the model calibration window; Section 4.2 Assessment of September 2013 Event discussed the recurrence intervals of the measured rainfall depths during the entire September 2013 event. Is it possible to list these discussions together somewhere and provide a brief discussion about the different recurrence intervals for various rainfall durations? Many citizens like to cite the rainfall recurrence intervals and it might be helpful to clarify a bit.
   Response: *Section 4.2 has been revised to clarify that recurrence intervals are relative to measured 24-hour depths. In addition, Section 4.3 has been revised to address the reviewer's comment that citizens often cite rainfall recurrence intervals to characterize the September 2013 event.*
4. **Comment:** Section 2.4.5 Model Development – Subsection "Subbasin Parameters": "During the process of model calibration, it was recognized that due to the embankments separating the gravel pits from Boulder Creek, rainfall on the gravel pits adjacent to Boulder Creek did not reach Boulder

Creek as a hydrologic response such that the gravel pits effectively acted as sinks". Not knowing much about the timing on the breaching of gravel pit embankments, we are curious about whether those gravel pit breaches played a role here. Could you please address that?

Response: *While the timing of gravel pit embankments breaches is unknown, assessment of how the gravel pit embankments overtopped would provide indication of how they should be treated in the hydrologic model. The breaching of the gravel pit embankments was inferred to be a result of Boulder Creek overtopping the embankment "towards the gravel pit" rather than accumulated rainfall water within the gravel pit overtopping the embankment "towards Boulder Creek". This was based on a comparison of measured rainfall depths to the average height between the normal gravel pit water surface elevation and the elevation of the gravel pit embankment. Depositional patterns evident in aerial imagery support this inference as the observed depositional patterns suggest flow from Boulder Creek to the gravel pit as the gravel pit embankment was overtopped. What this "direction of breaching" suggests is that water was flowing* into *rather than* out of *the gravel pits as Boulder Creek peaked. Although the gravel pits eventually drained back to Boulder Creek as the flow receded, this "return flow" likely occurred after the time-of-peak and thus would not have impacted the modeled peak discharge. A footnote has been added this portion of the report to clarify the hydrologic effect of the gravel pit embankments breaching.*

Comment: Section 2.4.5 Model Development – Subsection "Reach Parameters": "The Modified Puls method was used to model select reaches of Boulder Creek in the calibrated hydrologic model". Please specify the extent of selected reaches. Also, please add a brief statement at the end of the paragraph on why the Modified Puls method was replaced in the predictive hydrologic model, to be consistent with other paragraphs (removal of high roughness values, removal of exfiltration losses, etc.)

Response: *Section 2.4.5 has been revised to provide the reasoning for conversion of reaches modeled using the Modified Puls methodology in the calibrated hydrologic model to the Muskingum-Cunge methodology in the predictive hydrologic model.*

Appendix E
September 2013 Peak Discharge Estimates Documentation

Estimated Peak Discharge – Phase 2 (URS, 2015)

URS

Technical Memorandum

Date: March 27, 2015

To: Steven Griffin, CDOT- Region 4
Kevin Houck, Colorado Water Conservation Board

From: William Carrier, P.E.

Subject: **ESTIMATED PEAK DISCHRGES – PHASE 2**

Introduction

In late summer 2013, the Colorado Front Range experienced an extensive rainstorm event spanning approximately ten days from September 9th to September 18th. The event generated widespread flooding as the long-duration storm saturated soils and increased runoff potential. Flooding resulted in substantial erosion, bank widening, and realigning of stream channels; transport of mud, rock and debris; failures of dams; landslides; damage to roads, bridges, utilities, and other public infrastructures; and flood impacts to many residential and commercial structures. Ten fatalities were attributed to the floods.

During and immediately following the rainstorm event, the Colorado Department of Transportation (CDOT) engaged in a massive flood response effort to protect the traveling public, rebuild damaged roadways and bridges to get critical travel corridors open again, and engage in assessments and analyses to guide longer term rebuilding efforts. As part of this effort, CDOT partnered with the Colorado Water Conservation Board (CWCB) to initiate hydrologic analyses in several key river systems impacted by the floods. The work was contracted to three consultant teams led by the following firms.

Boulder Creek, Little Thompson River	CH2M HILL
Big Thompson River, St. Vrain Creek, Lefthand Creek	Jacobs
Coal Creek, South Platte River	URS

The purpose of the analyses is to ascertain the approximate magnitude of the September flood event in key locations throughout the watershed and to prepare estimates of peak discharge that can serve to guide the design of permanent roadway and other infrastructure improvements along the impacted streams. These estimates of peak discharges for various return periods will be shared with local floodplain administrators for their consideration in revising or updating any current regulatory discharges.

The primary tasks of the hydrologic analyses include:

1. Estimate peak discharges that were believed to have occurred during the flood event at key locations along the study streams. Summarize these discharges along with estimates provided

by others in comparison to existing regulatory discharges. Document the approximate return period associated with the September flood event based on current regulatory discharges.

2. Prepare rainfall-runoff models of the study watersheds, input available rainfall data representing the September rainstorm, and calibrate results to provide correlation to estimated peak discharges.

3. Prepare updated flood frequency analyses using available gage data and incorporate the estimated peak discharges from the September event.

4. Use rainfall-runoff models to estimate predictive peak discharges for a number of return periods based on rainfall information published by the National Oceanic and Atmospheric Administration (NOAA) [NOAA Atlas 14, Volume 8, Updated 2013]. Compare results to updated flood frequency analyses and unit discharge information and calibrate as appropriate.

The hydrologic analyses were divided into two phases of work. Phase 1 focused on the mountainous areas in the upper portion of the watersheds, extending from the upper divides of the Big Thompson River, Little Thompson River, St. Vrain Creek, Lefthand Creek, Coal Creek, and Boulder Creek watersheds to the mouth of their respective canyons. The Phase 1 analyses have been documented in six reports with the following titles and dates.

1. Hydrologic Evaluation of the Big Thompson Watershed, August 2014
2. Little Thompson River Hydrologic Analysis Final Report, August 2014
3. Hydrologic Evaluation of the St. Vrain Watershed, August 2014
4. Hydrologic Evaluation of the Lefthand Creek Watershed, August 2014, revised December 2014
5. Coal Creek Hydrology Evaluation, August 2014
6. Boulder Creek Hydrologic Evaluation Final Report, August 2014

Copies of these Phase 1 reports can be downloaded from the CWCB website at the following link:

http://cwcb.state.co.us/water-management/flood/pages/2013floodresponse.aspx

Phase 2 of the hydrologic analyses focused on the plains region of the Big Thompson River, Boulder Creek, Little Thompson River, and St. Vrain Creek from the downstream limit of the Phase 1 studies at the mouth of the canyons to the downstream confluences of the watersheds with their respective receiving streams. The hydrologic analyses were contracted to two consultant teams led by the following firms:

Boulder Creek, Little Thompson River	CH2M HILL
Big Thompson River, St. Vrain Creek	Jacobs

Phase 2 hydrologic analyses for each of the watersheds included flows from the original Phase 1 watersheds, as appropriate: the downstream reach of the Big Thompson River was modeled to include flows from the Little Thompson River. Likewise, the downstream reach of St. Vrain Creek included flows from Lefthand Creek and Boulder Creek, with Boulder Creek in turn receiving flows from Coal Creek.

This Memorandum documents the Phase 2 the high water estimation at designated locations along the watersheds. The purpose of the analyses is to ascertain the approximate magnitude of the September flood event in key locations throughout the watersheds and to prepare estimates of peak discharge that can serve to guide the design of permanent roadway and other infrastructure improvements along the impacted streams.

Methodology

Collection of Data:

URS sent a survey team to each bridge location that was to be calibrated with the high flow. . At each location, the team surveyed at least four cross sections that included the main channel and the floodplain. The locations were surveyed even though pre-flood models existed as the flood changed the topography of the landscapes. A minimum of four cross sections is are needed to properly evaluate flows by the modeling program, HEC-RAS, in order to properly evaluate flows at each location; a cross section directly upstream and downstream of the bridge, a cross section located upstream of the bridge roughly the distance of the bridge opening upstream of the bridge (1:1 opening), and a downstream cross section located about four times the bridge opening downstream of the bridge (4:1 opening). These distances are based on approximate expansion and contraction zones as recommended by the HEC-RAS manual. Additional cross sections were surveyed at a location if deemed necessary due to increased complexity at a location such as drop structures near the bridge or bends in the area.

During the surveys, the team looked for evidence of high water marks from the September 2013 floods. This included debris in bushes, trees, bridges, or a high point on the ground. These points were recorded during the survey as high water marks. In order to help with calibration, the locations of these points were near the surveyed cross sections.

In addition, information about the bridges was collected in order to properly model each location. The information collected included, the width of the bridge, the length of the bridge opening, the number of piers, the width of the piers, the location of the piers, abutment information, the distance from the bottom of the channel to the low chord of the of the bridge (the bridge opening), the distance from the bottom of the bridge to top of the guard rails, and any other bridge information deemed necessary for use in the modeling software.

Processing of Data:

Once the data was collected, it was transformed from the local surveying system to the Northern Colorado State Plane System where each point in the cross section had a northing, an easting, and an elevation. The surveyed cross sections and high water marks were exported into ESRI shapefiles. These were then reviewed for accuracy and completeness in ArcMap. The data was converted into excel format and exported to HEC-RAS. The left side facing downstream of each cross section was initially set as Station 0. There were about 30 to 50 surveyed points for each cross section. The distances between the cross sections were used to assign the river station with the most downstream cross section arbitrarily labeled as station 1000.

In some cases, the field surveyed cross sections did not extend far enough to contain flows in the modeled cross section. This occurred in areas where the floodplain was extremely wide, exceeding 2,000 feet in width or in locations that were adjacent to rock and gravel quarry ponds. In these instances, the surveyed cross sectional data was supplemented with post flood LiDAR data. The LiDAR was used to create a digital elevation model (DEM) to extract elevation points.

HEC-RAS Modeling:

HEC-RAS, Version 4.1.0, is a 1-dimensional step backwater river analysis system created by the United States Army Corps of Engineers. It was selected due to wide spread use, prominent use in previous models at the same locations, and the many tools for bridge modeling that exist in this software.

Many of the locations had existing HEC-RAS (or HEC-2) models from when the bridges were designed and constructed and were provided by CDOT. In these cases, the bridge data was already available and stations were adjusted to reflect these models. For all locations, the new surveyed cross sections were added into the HEC-RAS model. The bridge data was also verified with the field survey data. For locations without existing models, the bridge data recorded in the field was included as well.

The Manning's "n" values in the model were selected based upon field conditions and existing model values. In order to test the sensitivity of the flow in relation to the Manning's value, the Manning's value was increased and decreased in at least two (2) models on each stream, Big Thompson, Little Thompson, and St. Vrain. Results of this sensitivity analysis are summarized below.

The contraction and expansion coefficients were selected based on recommendations used in the HEC-RAS manual. To properly model bridges, ineffective areas were added to the upstream and downstream of bridges to account for the flow contraction and expansion at the bridge openings. For upstream of the bridge, there was a 1:1 contraction ratio meaning at the bridge the ineffective area would extend at a 45 degree angle to the bridge. Downstream of the bridge, a 3:1 expansion ratio was modeled. Generally, the ineffective areas extend for the two cross sections upstream and downstream of the river. In some cases, they were extended into additional cross sections depending on the width of the floodplain and cross section versus the bridge opening.

The bridges were modeled using the Energy Equation with over topping weir coefficient of 2.6. The energy Equation was selected as the High Flow Bridge Modeling Method. This method was selected as the majority of the bridges modeled were not overtopped, and as a result pressure and/or weir flow was not present.

Once the model parameters were complete, the estimated flow at each location was adjusted until the model water surface elevation approached the high water marks. In the case where the high water marks couldn't be matched well with the all of the cross sections, emphasis was placed on the cross section just downstream or upstream of the bridge The downstream locations provided a better representation of free flow during the flood event as compared to the upstream locations that could have potentially had backups and created artificially high debris marks.

For each model, subcritical and subcritical flow regimes were run and each calibrated to the surveyed high water mark.

Results

Most of the sites had consistent correlation between the field observations and the results of the model at each location. Generally, the calculated water surface elevations were within 0.1 feet of the observed high water elevation with a few exceptions. Subcritical flow modeling produced a more consistent match of water surface values. This could be attributed to the mild slopes of the channel in the lower reaches located in the plains and the wide floodplains. In some locations such as at Coal and Rock Creek, running the model as supercritical resulted in more accurate results as both of these tributaries have steeper slopes and more incised channels.

For some sites, the HEC-RAS model was unable to match the field observations. This was mainly due to overtopping of the bridge or nearby road. The high water survey occurred months after the floods and in some cases emergency repairs had been performed making it difficult to locate high water locations. There were also few photos from which to estimate the flood widths. In areas where flow overtopped the road, high water marks were recorded upstream and downstream of the structure; beyond the contraction and expansion limits. Flow estimates were made based on these high water marks and top of bridge elevations were used in the approach sections. In some cases, such as Little Thompson at County Road 17 and N. 107th St., flow backed up against the upstream face of the bridge structure until a split flow condition was created at an adjacent low point in the road and at the bridge. Flow estimates were made at these areas; however, due to the complexity of the flow paths and the possible attenuation at the split flows (or if the split even returned to the source flow), a relative uncertainty exists with these estimates.

The models had little sensitivity to changes in the Manning's n values. For the models tested, a 0.01 change in the Manning's value resulted in variance of less than 5% in the modeled flows. This held true regardless of the magnitude of the flows from the smaller flows 1,500 cfs to larger flows exceeding 20,000 cfs.

The following table summarizes the discharge estimates, the high water marks, and the calculated water surface elevation, and comments regarding each location.

URS

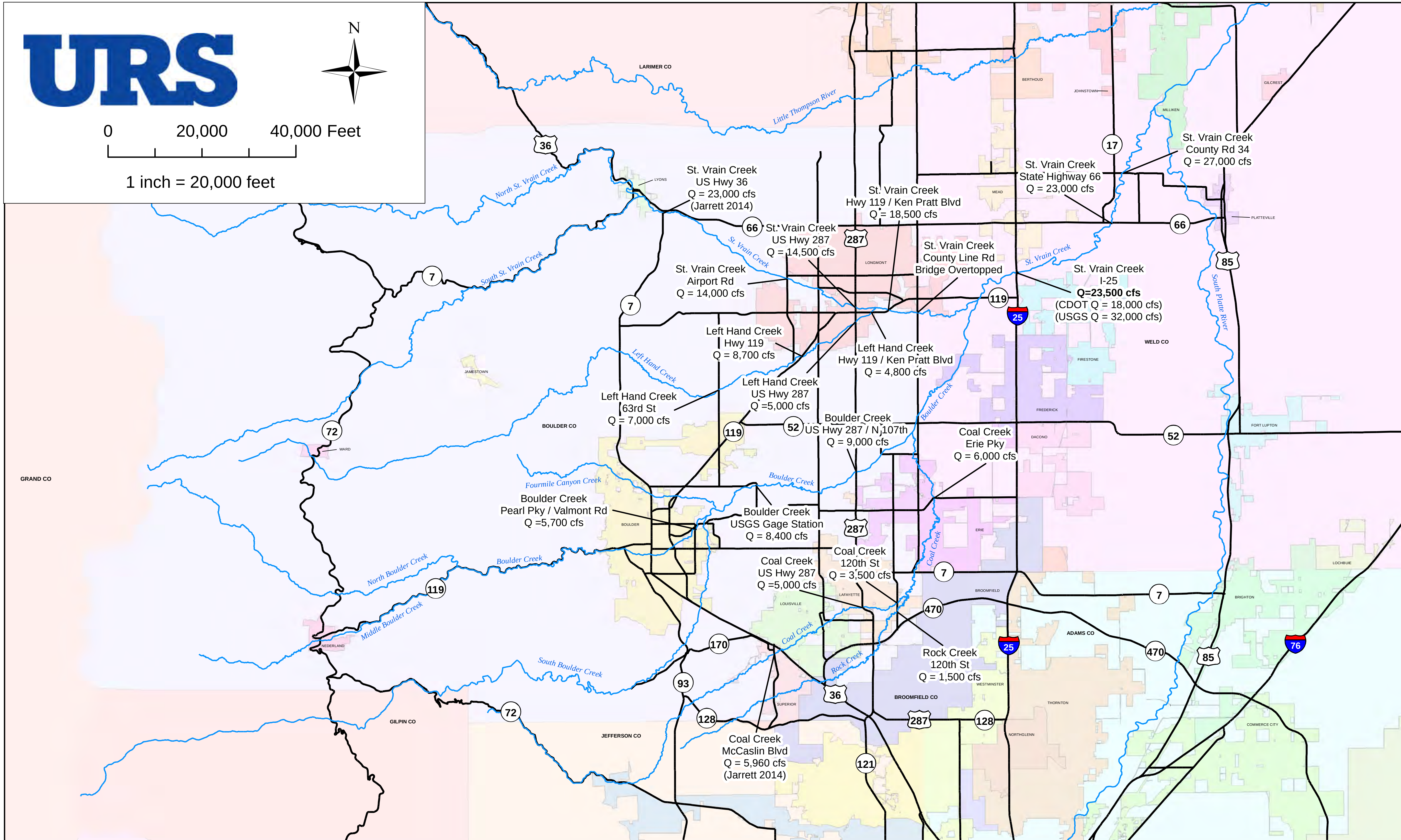
Technical Memorandum

Summary of Estimated Discharges for September 2013

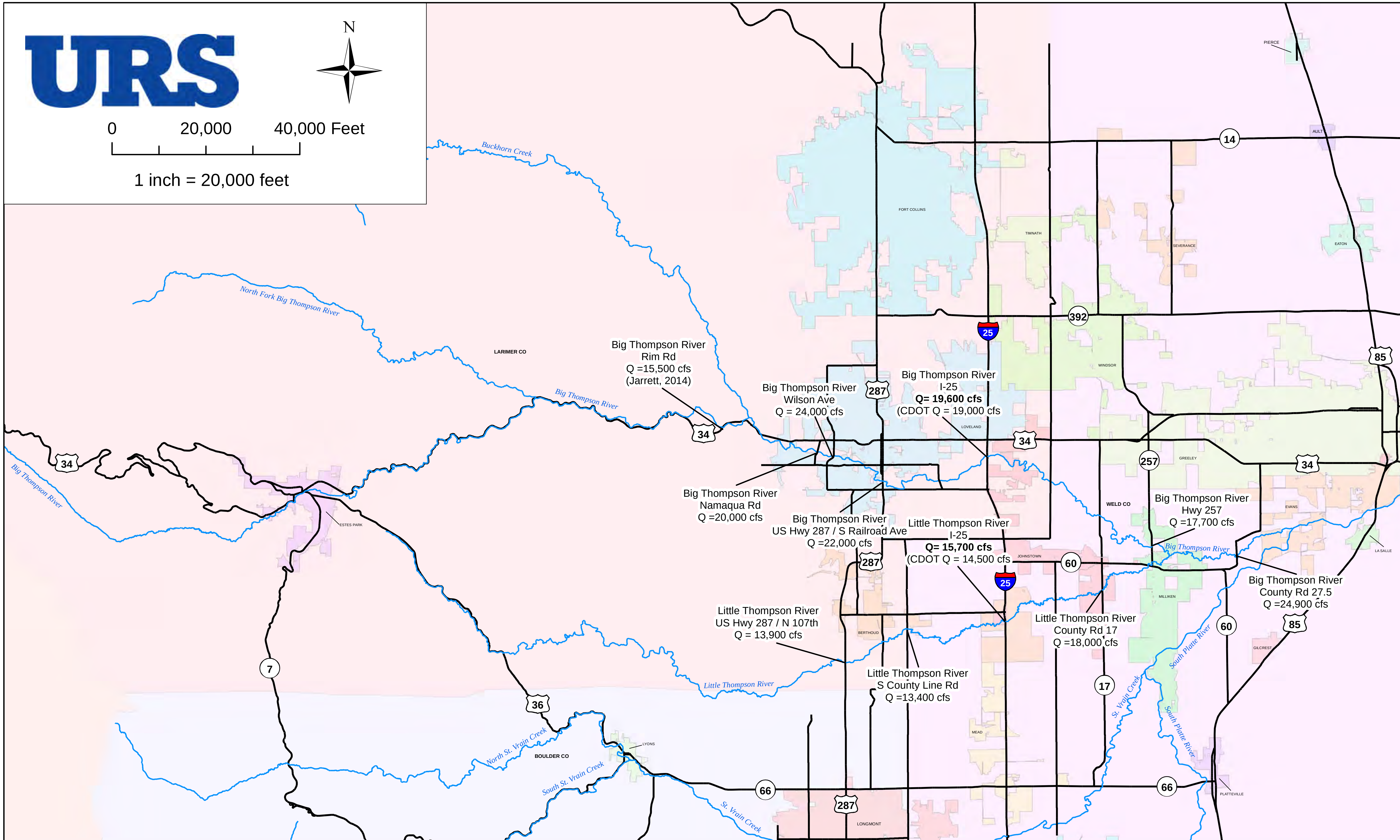
Location			Discharge (cfs)	High Water Elevation (ft) NAVD 88	Water Surface Elevation (ft) NAVD 88	Comments
Little Thompson						
1	At N 107th Crossing (287)		13,900	4998.73	4998.74	
2	At S County Line Road Crossing	FEMA Point	13,400	4938.17	4938.58	
3	At I-25 Crossing		15,700	4857.11	4857.12	
4	At County Road 17 Crossing		18,000			Bridge overtopped/unreliable
Big Thompson						
1	Namaqua Road *		20,000	5002.42	5002.04	Area very hard to calibrate given ponds and overtopping.
2	Wilson Avenue*		24,000	4990.07	4990.26	Flows rates based on downstream ponds being full.
3	S. Railroad Avenue or Hwy 287	FIS Location	22,000	4933.3	4933.3	
4	I-25	FIS Location	19,600	4849.91	4849.97	3,000 cfs overtopped I-25 north of cross section.
5	County Line Road (Larimer-Weld)	FIS Location	8,800	4813.44	4813.47	Unreliable results. Bridge was overtopped.
6	U/S of Confl with Little Thompson (Hwy 257, CR 21)		17,700	4746.7	4746.73	
7	D/S of Confl with Little Thompson (CR 25)					No Model
8	County Road 27.5		24,900	4701.93	4701.93	
Boulder Creek						
1	Boulder Creek at Pearl Pky / Valmont Road	FEMA Point	5,700	5200.51	5200.49	4300 cfs at subcritical flows
2	Boulder Creek at N 107 Street/Boulder 287		9,000	5016.35	5016.38	
3	Coal Creek at Bridge Street (N of Erie)	FEMA Point				No Model
4	Coal at Erie		6,000	5021.267	5021.66	
5	Coal Creek at Highway 287		5,000	5206.66	5206.65	Possible attenuation /blowouts DS of structure
6	Coal Creek at the Confluence with Rock Creek	FEMA Point				No Model
7	Rock Creek at S 120th Street	FEMA Point	1,500	5149.65	5149.8	
8	Coal Creek At 120th		3,500	5140.59	5140.5	
Lefthand						
1	N. 63rd St.		7,000	5159.71	5159.7	
2	Diagonal Highway (Hwy 119 near Airport Road)		8,700	5019.09	5019.07	Model does not account for influence of railroad bridge.
3	Hwy 287 (Main Street)		5,000	4950.17	4950.7	
4	U/S of Confl with St. Vrain (Hwy 119/Ken Pratt Blvd.)	FIS Location	4,800	4937.36	4937.36	
St. Vrain						
1	85th Street/Airport Road	FIS Location	14,000	5027.85	5027.77	No Bridge in HEC-RAS model.
2	U/S of Confluence w/ Lefthand Creek (US Hwy 287)		14,500	4948.87	4949.37	
3	D/S of Confl. w/ Lefthand Creek and UIS of Confl w/ Boulder Creek (Hwy 119/Ken Pratt Blvd)		18,500	4924.81	4924.29	
4	County Line Road (Boulder-Weld)	FIS Location				Not a good point-road washed out around the bridge, downstream work completed.
5	D/S of Confl. w/ Boulder Creek (1-25)		23,500	4834.93	4834.73	
6	State Hwy 66 (CR 30)		23,000	4791.11	4791.13	
7	Country Road 34		27,000	4770.88	4770.88	

*Recommended flow value of 22,000 cfs.

Peak Flow Discharge for the September 2013 Floods - St. Vrain Creek Drainage Area



Peak Flow Discharge for the Spetember 2013 Floods - Big Thompson River Drainage Area



As previously mentioned, for most locations high water elevation observed in the field correlated well with the calculated water surface elevations in the models. There were a few exceptions. A summary of the model results for each stream reach are included below.

Little Thompson River

1. North 107th Crossing (US Hwy 287) - The cross section directly upstream of the bridge was calibrated to the high water mark. The calculated water surface for the downstream cross sections did not match well with the surveyed high water marks. This was due to the bridge overtopping and may have resulted in a split flow into the adjacent farmland.

2. S County Line Road – No issues. The model correlated very well.

3. I-25-For this location there were three bridges modeled, North I-25, South I-25 and the frontage road to the east. This location gave good results which allowed it to be calibrated at three different high water marks. Both cross sections on either side of the frontage road were calibrated and the most upstream cross section was calibrated.

4. County Road 17- Flow backed up against the upstream face of the bridge structure until a split flow condition was created at an adjacent low point in the road and at the bridge. Flow estimate were made at these areathis site; however, due to the complexity of the flow paths and the possible attenuation at the split flows (or if the split even returned to the source flow), relative uncertainty exists with this estimate.

Big Thompson River

The Namaqua Road and Wilson Avenue locations were very difficult to determine flow rates. The locations have numerous quarry ponds directly upstream and downstream of each location. When the sections were modeled, the water surface elevation was assumed to be 1 foot below the pond embankment. Because these ponds occupy approximately 1,500 feet of the floodplain, the actual water surface elevation plays a large role in the flow calculation. A 1 foot increase or decrease in the water surface of the ponds varies the flow by approximately 1,000 cfs. In addition, flows jumped the northern bank upstream of the Namaqua Road crossing.

1. Namaqua Road – Flows estimated at 20,000 cfs but, it is recommended that flows be averaged with Wilson Avenue crossing. Suggested value of 22,000cfs.

2. Wilson Avenue – See Namaqua Road note.

3. Hwy 287 – Model correlated well to high water marks.

4. I-25- This location has three different bridges, North I-25, South I-25 and the frontage road. For modeling purposes, the cross section between the two I-25 bridges was calibrated to the high water location. The water surface elevation was 4849.9’. The flow value includes 3,000 cfs that overtopped I-25 north of the cross section road.

5. County Line Road (Larimer-Weld) - This didn't yield reliable results as it overtopped the road.

6. Hwy 257-This location was calibrated to the section just upstream of the bridge to a water surface elevation of 4746.73'.

7. Downstream confluence with Little Thompson – No model developed.

8. County Road 27.5 – Model match field observations.

The cross sections at Namaqua Road, Wilson Avenue and US Hwy 287 were supplemented with LiDAR data to fully contain the flow and be calibrated correctly.

Boulder Creek:

1. Boulder Creek at Pearl Parkway and Valmont Road - This section was calibrated to the upstream section.

2. Boulder Creek at 287 - This section was calibrated to just downstream of the bridge and has an extra cross section both down and upstream.

Rock and Coal Creek:

3. Coal Creek at Bridge Street (N of Erie) – No Model developed due to limited access.

4. Coal Creek at Erie - At this location three bridges were modeled: one for a pedestrian bridge before the road, one for the road, and one for a railroad bridge downstream. It was calibrated to the cross section just before the road bridge. Reliability of the estimated flow is questionable due to the complexity of the model.

5. Coal Creek at Highway 287- Here there was some attenuation possible as well as blowouts of downstream of the structure.

6. Coal Creek at the Confluence with Rock Creek – No Model developed as high water elevation could no e determined.

7. Rock Creek at 120th Street - An additional cross section was modeled upstream of the bridge. The calibration point here is the cross section just downstream of the bridge.

8. Coal Creek at 120th- An additional cross section was modeled upstream of the bridge. The calibration point here is the cross section just downstream of the bridge.

The calibration of the confluence of Coal Creek and Rock Creek was not modeled as the high water mark was difficult to establish.

Lefthand Creek:

1. N. 63rd St. - This location was calibrated to the most downstream cross section. The two upstream cross sections were close to the surveyed high water marks.

2. Diagonal Highway (Hwy 119 near Airport Road) - Two separate bridges were modeled for this location. The most downstream cross section was added using LiDAR data. The cross section between the two bridges was the calibration point.

3. Hwy 287- The cross section just downstream at this location was used for the calibration point.

4. Hwy 119/ Ken Pratt Blvd- This model included two additional cross sections upstream of the bridge.

<u>St. Vrain Creek</u>

1. Hwy 287/Airport Road – Model correlated well to the observed high water marks. However, bridge information was not available and therefore not included in the HEC-RAS model. There were no bridge as-built plans available and at the time of the survey, the creek flows were too great to safely perform a bridge survey.

2. U/S of Confluence w/ Lefthand Creek (US Hwy 287) – Model matched survey data.

3. Hwy 119/Ken Pratt Blvd. - This section had two extra cross sections upstream and downstream to help increase the accuracy of the model. The upstream cross section and the cross section just downstream of the bridge were used as calibration points.

4. County Line Road (Boulder-Weld) - This location was not modeled. The road on both sides of the bridge had washed away and there had been downstream work completed.

5. I-25 - In this location, it was modeled as two bridges. The drop structure downstream of the bridges was also added. The structure was not in the original model. The model was calibrated to the upstream face of the upstream bridge.

6. State Highway 66 (CR33) – model match field observations. Te bridge was replaced as part of the emergency repairs.

7. County Road 34 – No Issues.

REFERENCES

US Army Corps of Engineers (USACE) HEC-RAS River Analysis System, Ver. 4.1.0, January 2010.

CDOT hydraulic models

Appendix A
HEC-RAS Results

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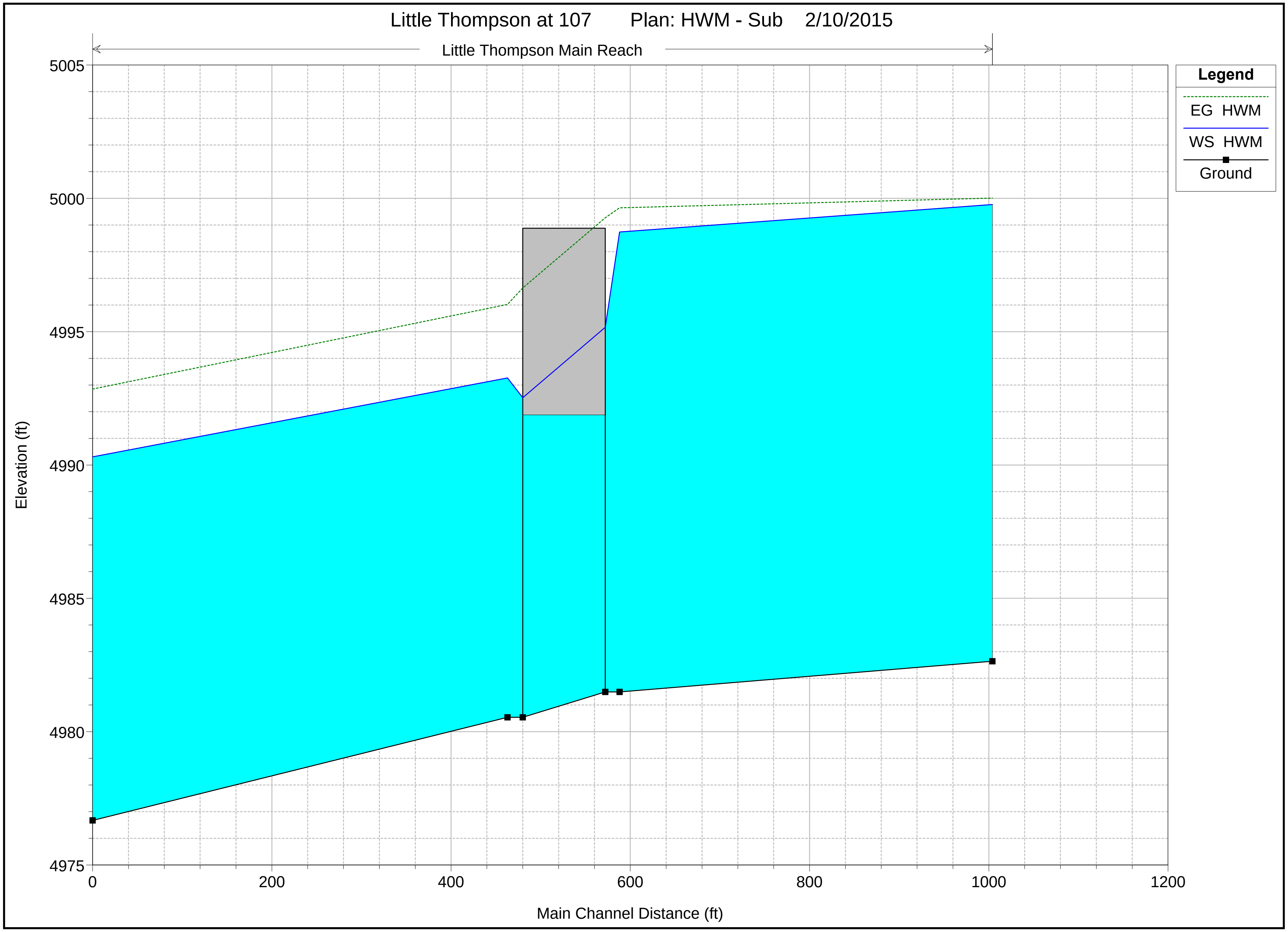
Little Thompson
HEC-RAS Results

Little Thompson at 107th

HEC-RAS Plan: HWM - Sub River: Little Thompson Reach: Main Reach Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Reach	1104	HWM	13900.00	4982.64	4999.77	4992.93	5000.01	0.000459	4.65	3771.28	337.29	0.22
Main Reach	688	HWM	13900.00	4981.49	4998.74	4992.27	4999.65	0.001247	8.07	1892.70	224.74	0.36
Main Reach	625		Bridge									
Main Reach	563	HWM	13900.00	4980.54	4993.26	4992.22	4996.02	0.006745	13.63	1086.86	158.47	0.77
Main Reach	100	HWM	13900.00	4976.67	4990.30	4990.30	4992.85	0.006698	14.99	1316.99	224.29	0.76

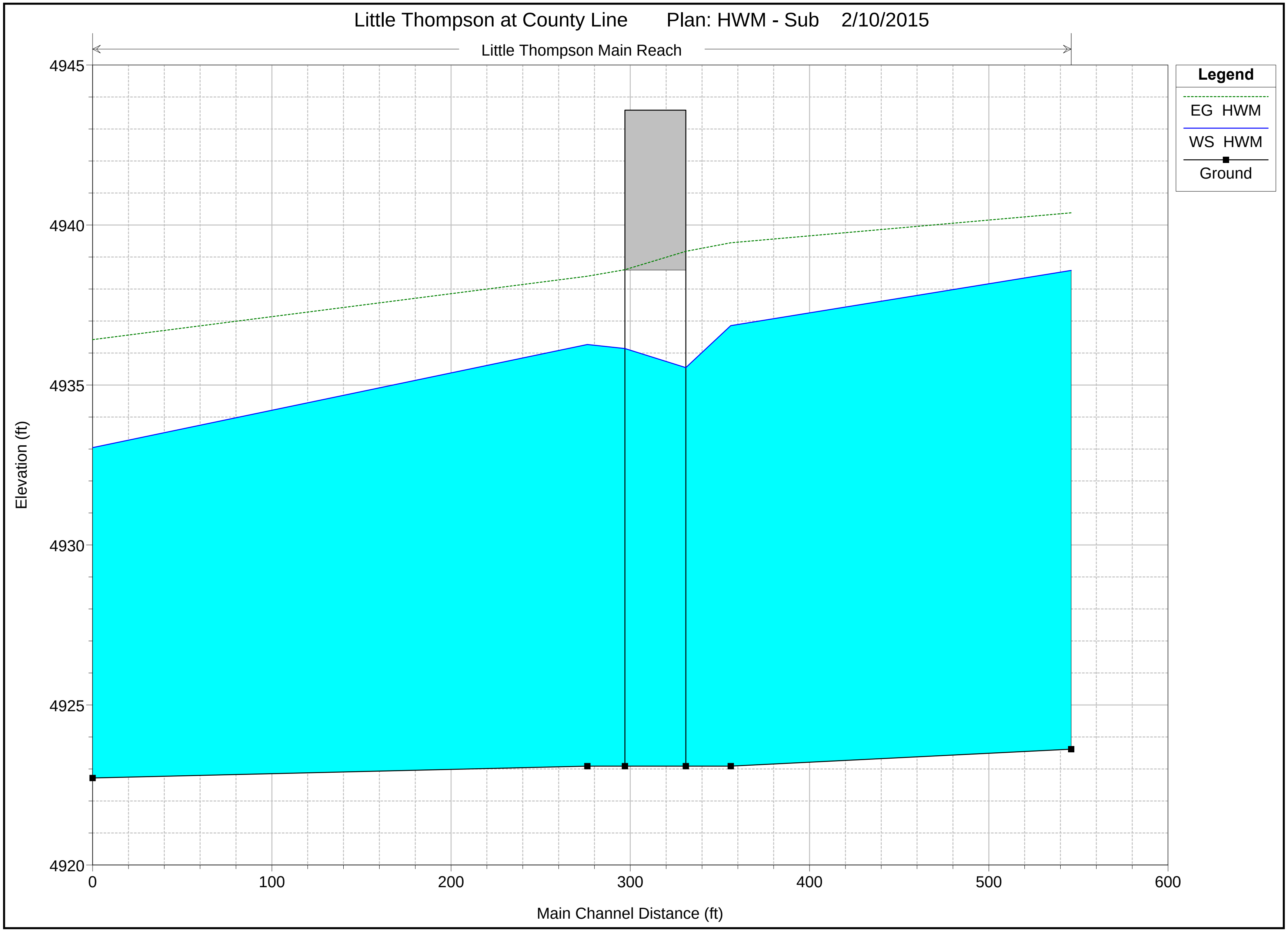
Little Thompson at 107th



Little Thompson at S County Line

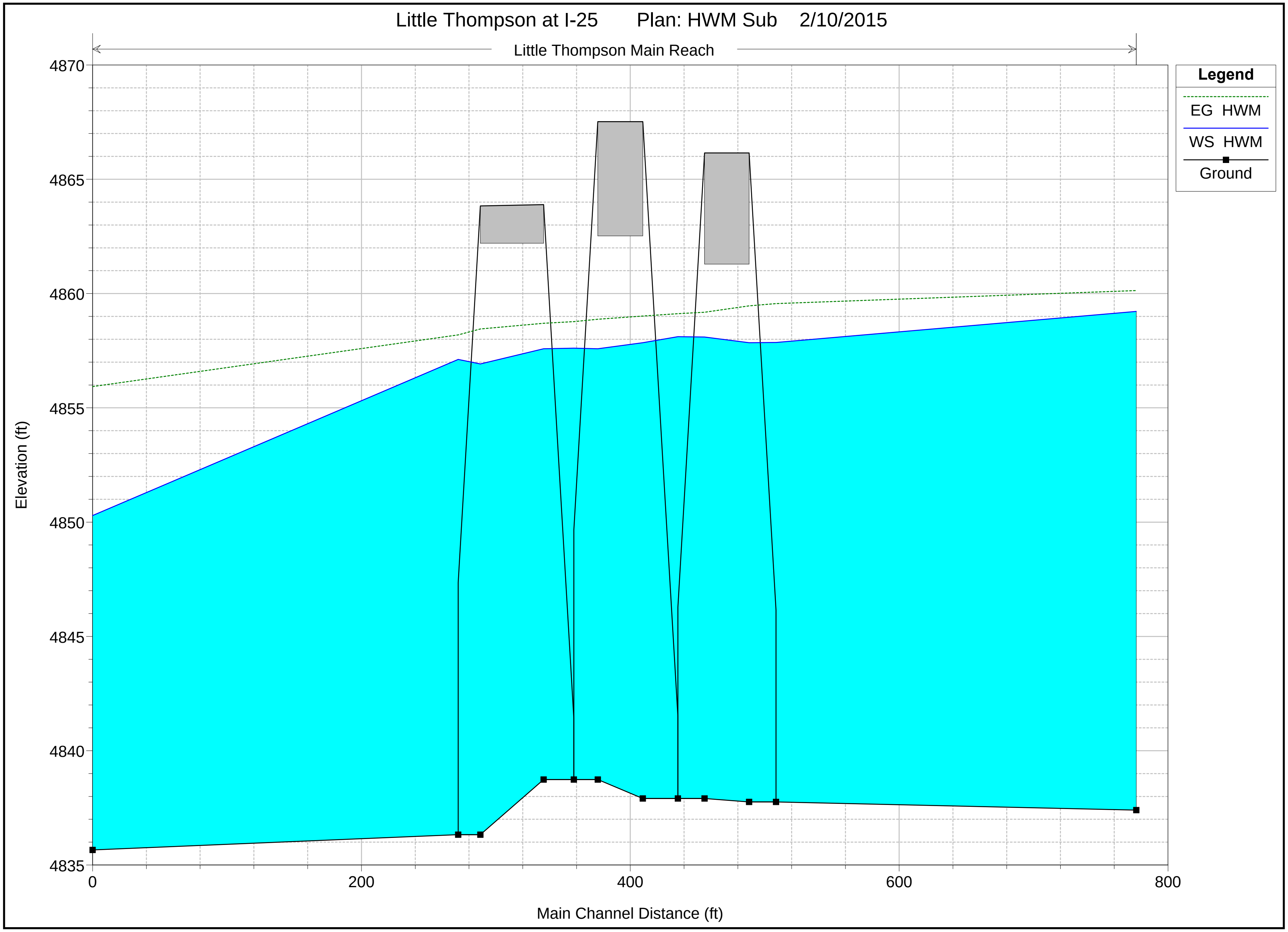
HEC-RAS Plan: HWM - Sub River: Little Thompson Reach: Main Reach Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Reach	675	HWM	13400.00	4923.62	4938.58	4936.06	4940.38	0.003837	12.09	1361.73	144.75	0.59
Main Reach	460	HWM	13400.00	4923.09	4936.85	4934.82	4939.44	0.005135	13.29	1078.23	153.78	0.69
Main Reach	420		Bridge									
Main Reach	381	HWM	13400.00	4923.09	4936.27	4933.71	4938.40	0.004802	11.87	1152.04	150.34	0.65
Main Reach	100	HWM	13400.00	4922.72	4933.04	4933.04	4936.42	0.010002	15.26	983.02	159.49	0.92


Little Thompson at County Line Plan: HWM - Sub 2/10/2015
Little Thompson Main Reach
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4945
4940
4935
4930
4925
4920
0
100
200
300
400
500
600
Main Channel Distance (ft)

HEC-RAS Plan: HWM - Sub River: Little Thompson Reach: Main Reach Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Reach	2595.635	HWM	15700.00	4837.40	4859.22	4853.35	4860.13	0.001358	8.57	2069.01	219.51	0.35
Main Reach	2327.635	HWM	15700.00	4837.76	4857.86	4853.99	4859.56	0.002620	12.67	1744.94	170.12	0.52
Main Reach	2307.635		Bridge									
Main Reach	2254.640	HWM	15700.00	4837.91	4858.12	4850.56	4859.12	0.001423	8.17	2010.57	152.53	0.38
Main Reach	2228.62		Bridge									
Main Reach	2177.256	HWM	15700.00	4838.74	4857.61	4851.13	4858.77	0.001664	10.19	2053.02	182.47	0.43
Main Reach	2154.767		Bridge									
Main Reach	2091.285	HWM	15700.00	4836.33	4857.12	4850.02	4858.19	0.001588	10.42	2114.56	177.43	0.42
Main Reach	1819.285	HWM	15700.00	4835.66	4850.29	4850.29	4855.93	0.010311	20.10	881.95	82.62	0.99

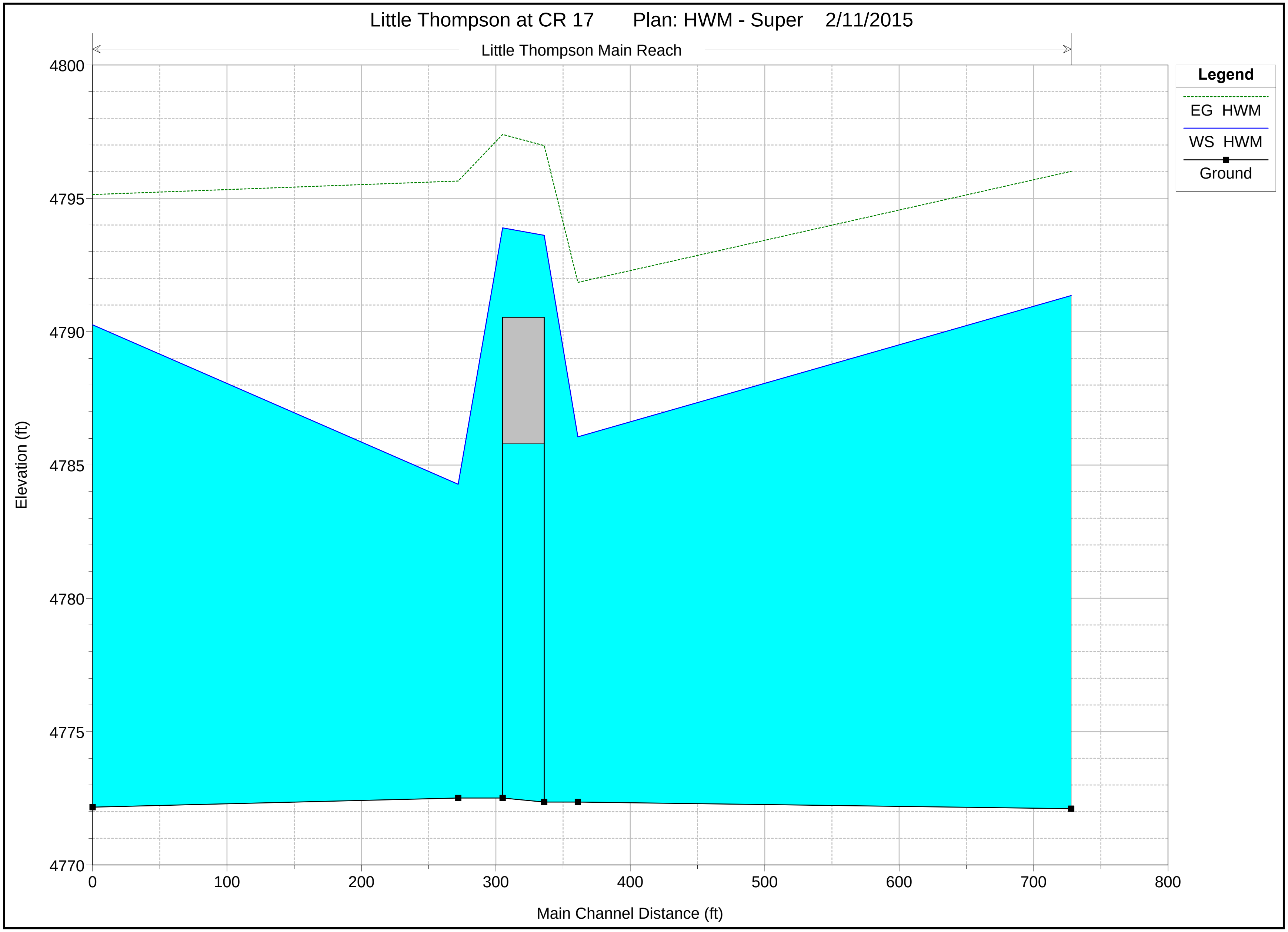


Little Thompson at I-25 Plan: HWM Sub 2/10/2015
Little Thompson Main Reach
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4870
4865
4860
4855
4850
4845
4840
4835
0
200
400
600
800
Main Channel Distance (ft)

Little Thompson at CR 17

HEC-RAS Plan: HWM - Super River: Little Thompson Reach: Main Reach Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Reach	828	HWM	18000.00	4772.11	4791.35	4791.35	4796.01	0.009333	19.37	1163.14	119.08	0.89
Main Reach	461	HWM	18000.00	4772.36	4786.06	4786.87	4791.85	0.013259	19.61	962.00	131.26	1.07
Main Reach	417		Bridge									
Main Reach	372	HWM	18000.00	4772.51	4784.28	4787.77	4795.65	0.032953	27.31	689.21	139.47	1.61
Main Reach	100	HWM	18000.00	4772.17	4790.26	4790.26	4795.14	0.009435	20.71	1130.05	108.67	0.91


Little Thompson at CR 17 Plan: HWM - Super 2/11/2015
Little Thompson Main Reach
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4800
4795
4790
4785
4780
4775
4770
0
100
200
300
400
500
600
700
800
Main Channel Distance (ft)

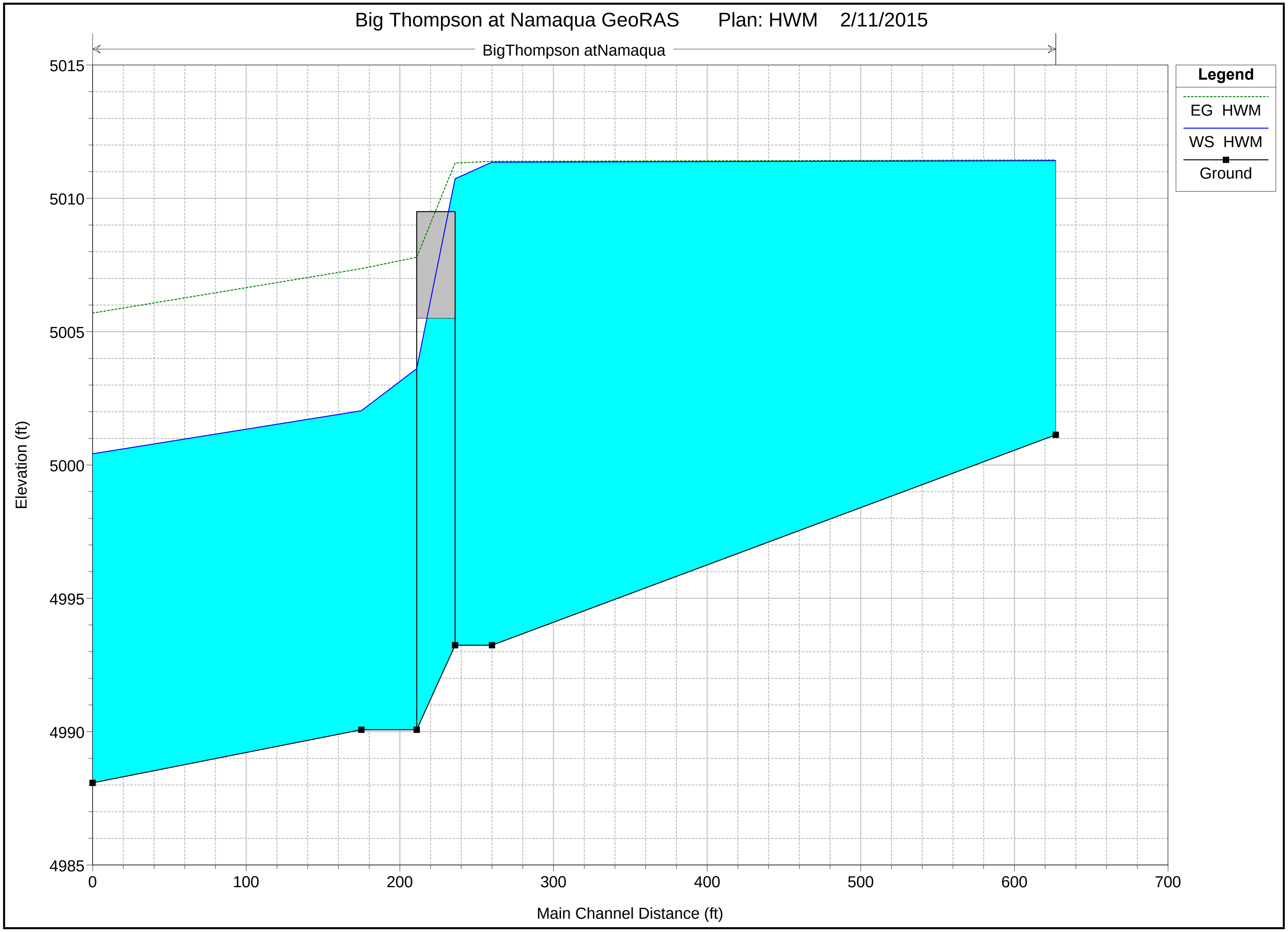
Big Thompson

HEC-RAS Results

HEC-RAS Plan: HWM - Sub River: BigThompson Reach: atNamaqua Profile: HWM

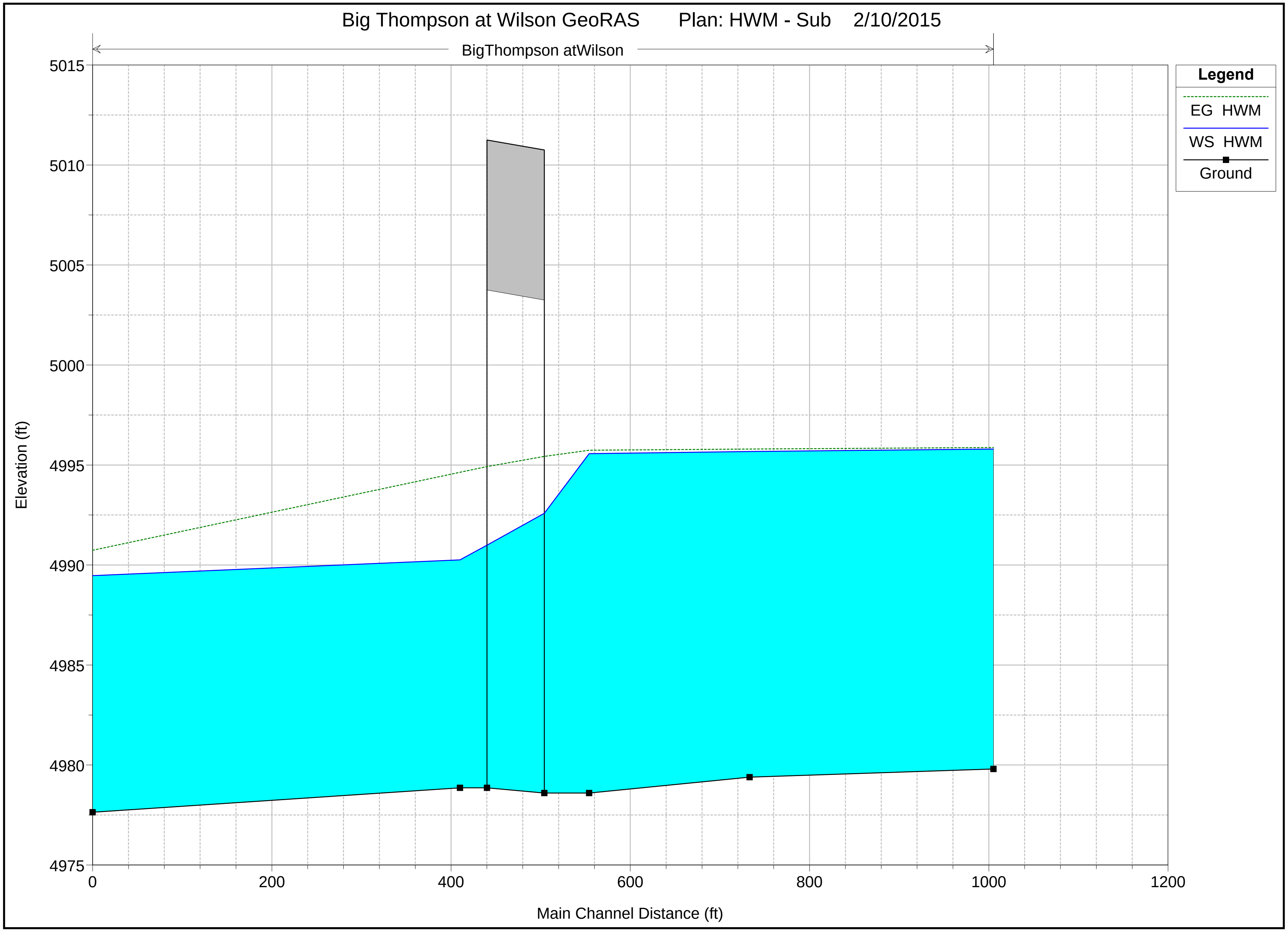
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
atNamaqua	906.0839	HWM	20000.00	5001.13	5011.41	5007.42	5011.44	0.000185	2.62	16549.89	3325.48	0.15
atNamaqua	539.4245	HWM	20000.00	4993.24	5011.35	5005.94	5011.39	0.000110	2.89	17214.33	2673.16	0.12
atNamaqua	512.7339		Bridge									
atNamaqua	454.7339	HWM	20000.00	4990.07	5002.04	5001.46	5007.36	0.008801	19.67	1206.31	631.62	1.04
atNamaqua	279.7508	HWM	20000.00	4988.08	5000.42	5000.42	5005.70	0.010125	18.87	1210.15	764.12	1.08

Big Thompson at Namaqua



HEC-RAS Plan: HWM - Sub River: BigThompson Reach: atWilson Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
atWilson	1357.954	HWM	24000.00	4979.80	4995.80		4995.88	0.000217	3.71	14225.99	2419.93	0.17
atWilson	1085.827	HWM	24000.00	4979.39	4995.67		4995.80	0.000304	4.59	12241.83	2230.26	0.20
atWilson	906.7098	HWM	24000.00	4978.60	4995.57	4989.97	4995.74	0.000346	4.87	10839.57	1895.19	0.22
atWilson	852.6332		Bridge									
atWilson	762.6332	HWM	24000.00	4978.86	4990.26	4990.26	4994.64	0.008262	16.96	1467.20	675.66	0.97
atWilson	352.6946	HWM	24000.00	4977.64	4989.47	4989.47	4990.74	0.003542	12.20	4308.02	2150.21	0.65

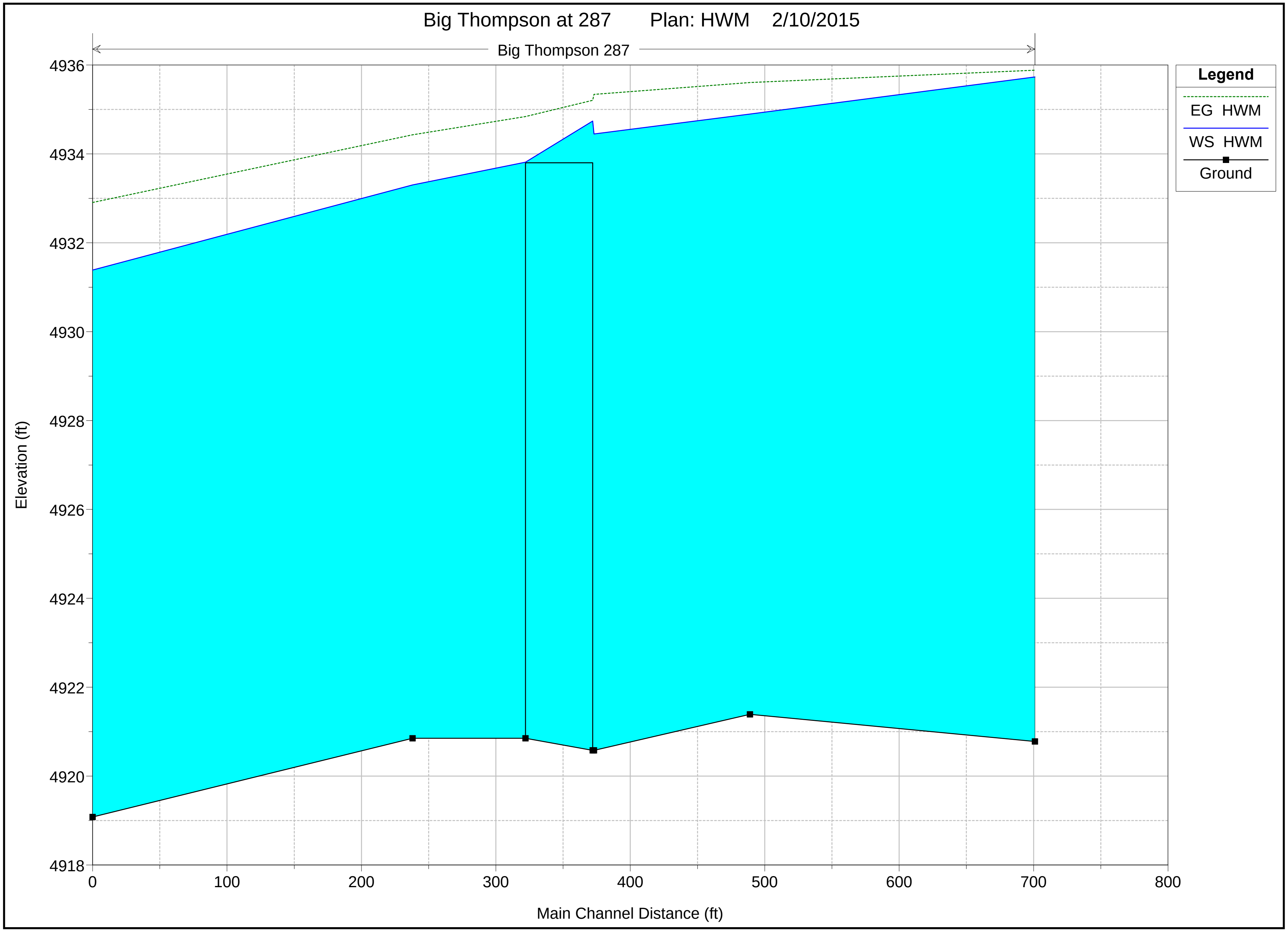


Big Thompson at Wilson GeoRAS Plan: HWM - Sub 2/10/2015
BigThompson atWilson
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
5015
5010
5005
5000
4995
4990
4985
4980
4975
0
200
400
600
800
1000
1200
Main Channel Distance (ft)

HEC-RAS Plan: HWM - Sub River: Big Thompson Reach: 287 Profile: HWM

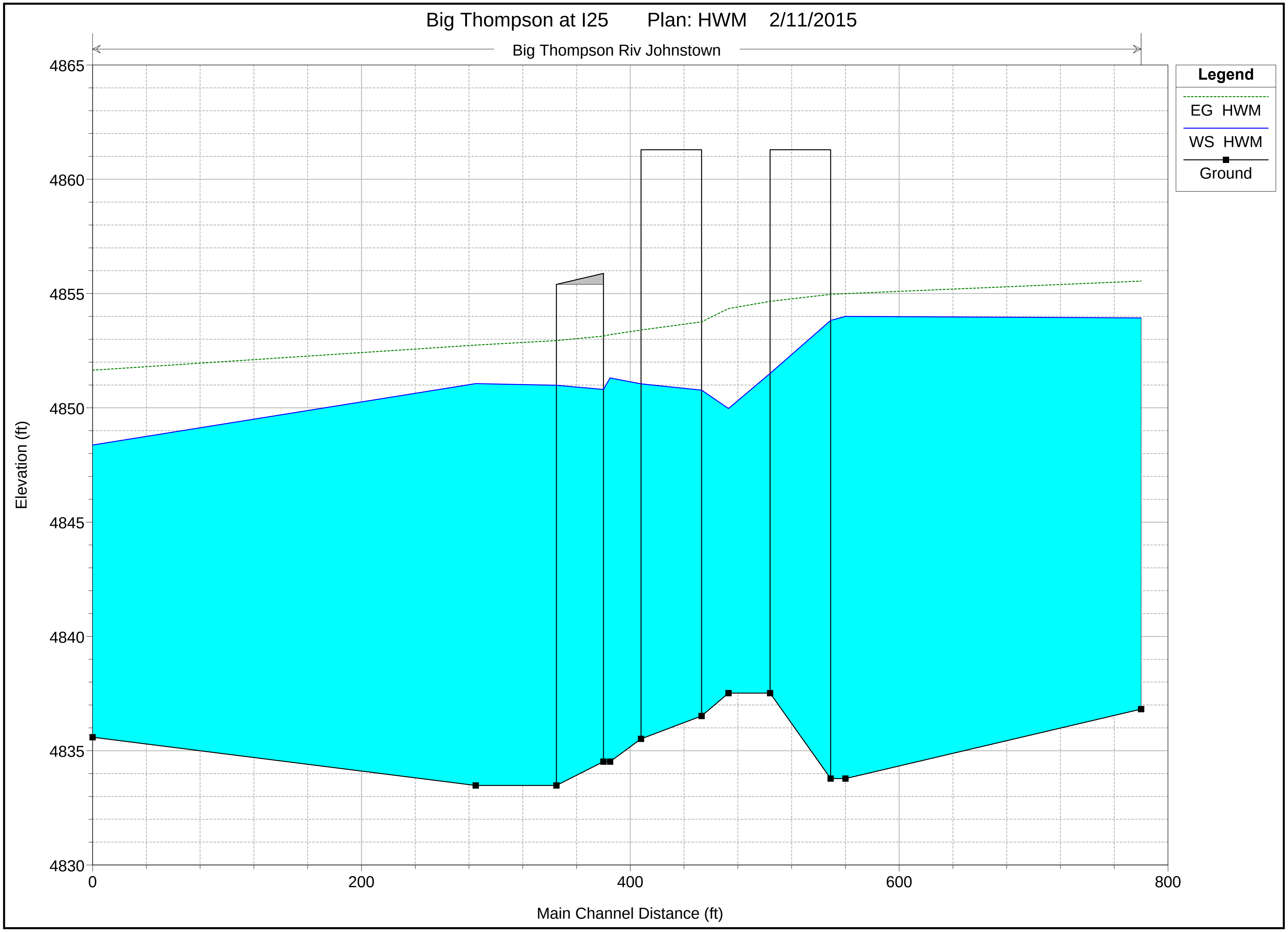
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
287	1201	HWM	22000.00	4920.78	4935.73	4930.86	4935.88	0.000626	5.56	9575.16	2281.27	0.27
287	989	HWM	22000.00	4921.39	4934.90	4933.99	4935.61	0.002111	9.49	5569.71	2200.01	0.50
287	873	HWM	22000.00	4920.58	4934.45	4933.82	4935.34	0.002171	10.62	5347.52	2444.13	0.53
287	872		Bridge									
287	738	HWM	22000.00	4920.85	4933.30	4933.30	4934.43	0.002943	11.69	4691.34	2662.32	0.61
287	500	HWM	22000.00	4919.08	4931.39	4931.39	4932.91	0.006289	15.01	4018.16	3198.84	0.84

Big Thompson at 287



HEC-RAS Plan: HWM - Sub River: Big Thompson Riv Reach: Johnstown Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Johnstown	1780	HWM	16600.00	4836.82	4853.93	4850.12	4855.54	0.002358	12.05	1918.19	163.39	0.54
Johnstown	1560	HWM	16600.00	4833.78	4854.00	4848.48	4855.00	0.001224	8.61	2247.86	321.14	0.40
Johnstown	1548		Bridge									
Johnstown	1473	HWM	16600.00	4837.52	4849.97	4849.97	4854.34	0.007920	18.81	1142.53	133.26	0.98
Johnstown	1453		Bridge									
Johnstown	1385	HWM	16600.00	4834.52	4851.31	4846.97	4853.20	0.002352	12.69	1761.16	152.12	0.56
Johnstown	1380		Bridge									
Johnstown	1285	HWM	16600.00	4833.48	4851.06	4846.08	4852.74	0.001838	10.83	1681.49	315.43	0.49
Johnstown	1000	HWM	16600.00	4835.59	4848.37	4848.37	4851.65	0.007493	16.81	1332.76	290.97	0.93

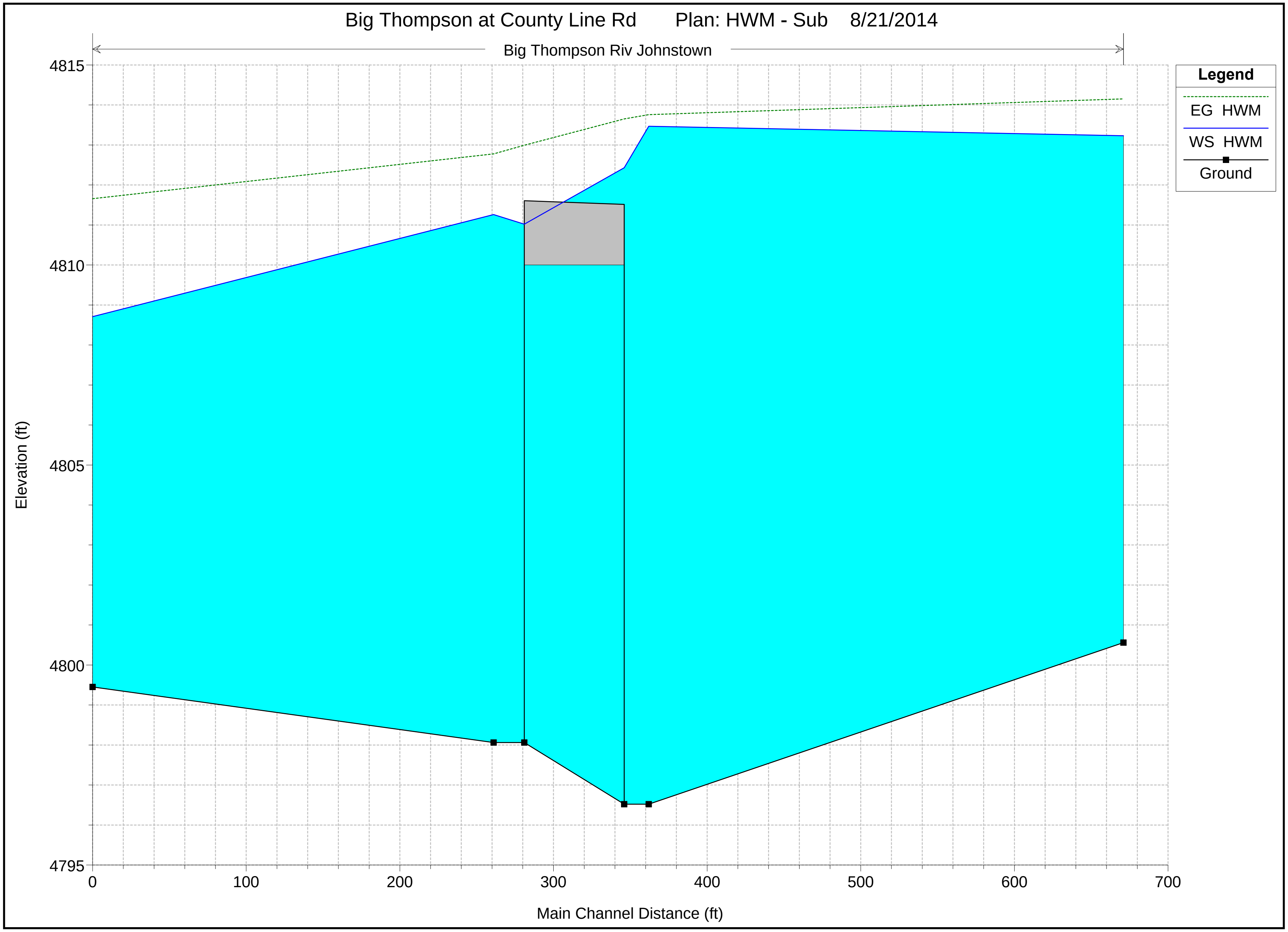

Big Thompson at I25 Plan: HWM 2/11/2015
Big Thompson Riv Johnstown
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4865
4860
4855
4850
4845
4840
4835
4830
0
200
400
600
800
Main Channel Distance (ft)

Big Thompson at County Line Road

HEC-RAS Plan: HWM Sub River: Big Thompson Riv Reach: Johnstown Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Johnstown	1171	HWM	8800.00	4800.56	4813.23	4810.19	4814.15	0.001898	8.71	1320.61	162.61	0.47
Johnstown	862	HWM	8800.00	4796.52	4813.47	4804.86	4813.76	0.000330	4.83	2474.43	238.52	0.21
Johnstown	846		Bridge									
Johnstown	761	HWM	8800.00	4798.06	4811.26	4806.87	4812.78	0.002140	9.91	895.04	158.55	0.50
Johnstown	500	HWM	8800.00	4799.45	4808.71	4808.71	4811.66	0.008132	14.63	714.97	178.75	0.93

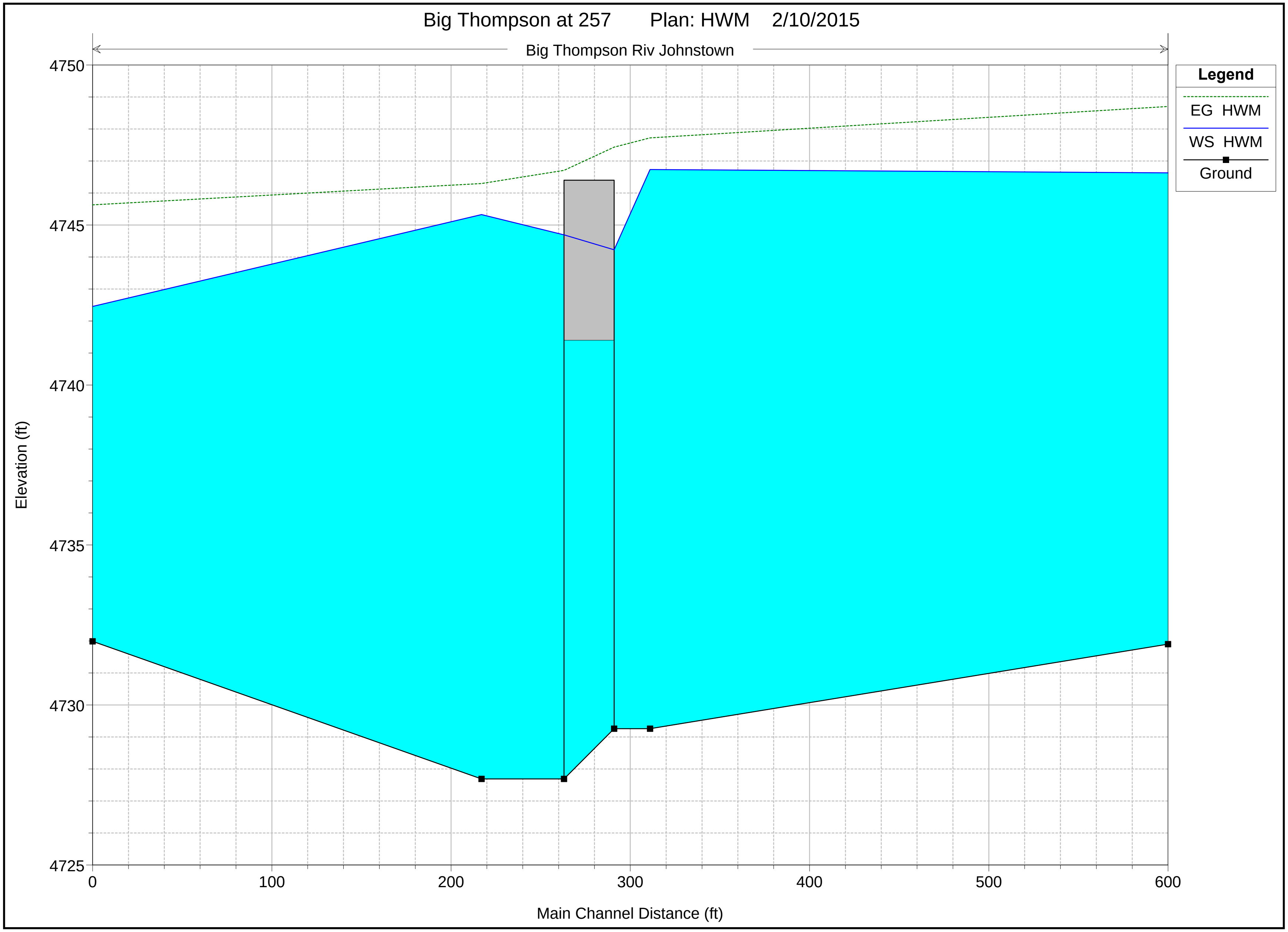
Big Thompson at County Line Road



Big Thompson at 257

HEC-RAS Plan: HWM Sub   River: Big Thompson Riv   Reach: Johnstown   Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Johnstown	1600	HWM	17700.00	4731.90	4746.63	4744.57	4748.70	0.004722	14.95	1728.32	172.67	0.72
Johnstown	1311	HWM	17700.00	4729.26	4746.73	4740.73	4747.72	0.001324	8.02	2288.56	255.13	0.40
Johnstown	1291		Bridge									
Johnstown	1217	HWM	17700.00	4727.69	4745.32	4737.62	4746.30	0.000936	8.10	2367.79	262.00	0.35
Johnstown	1000	HWM	17700.00	4731.99	4742.45	4742.45	4745.63	0.007722	15.49	1403.46	230.45	0.93

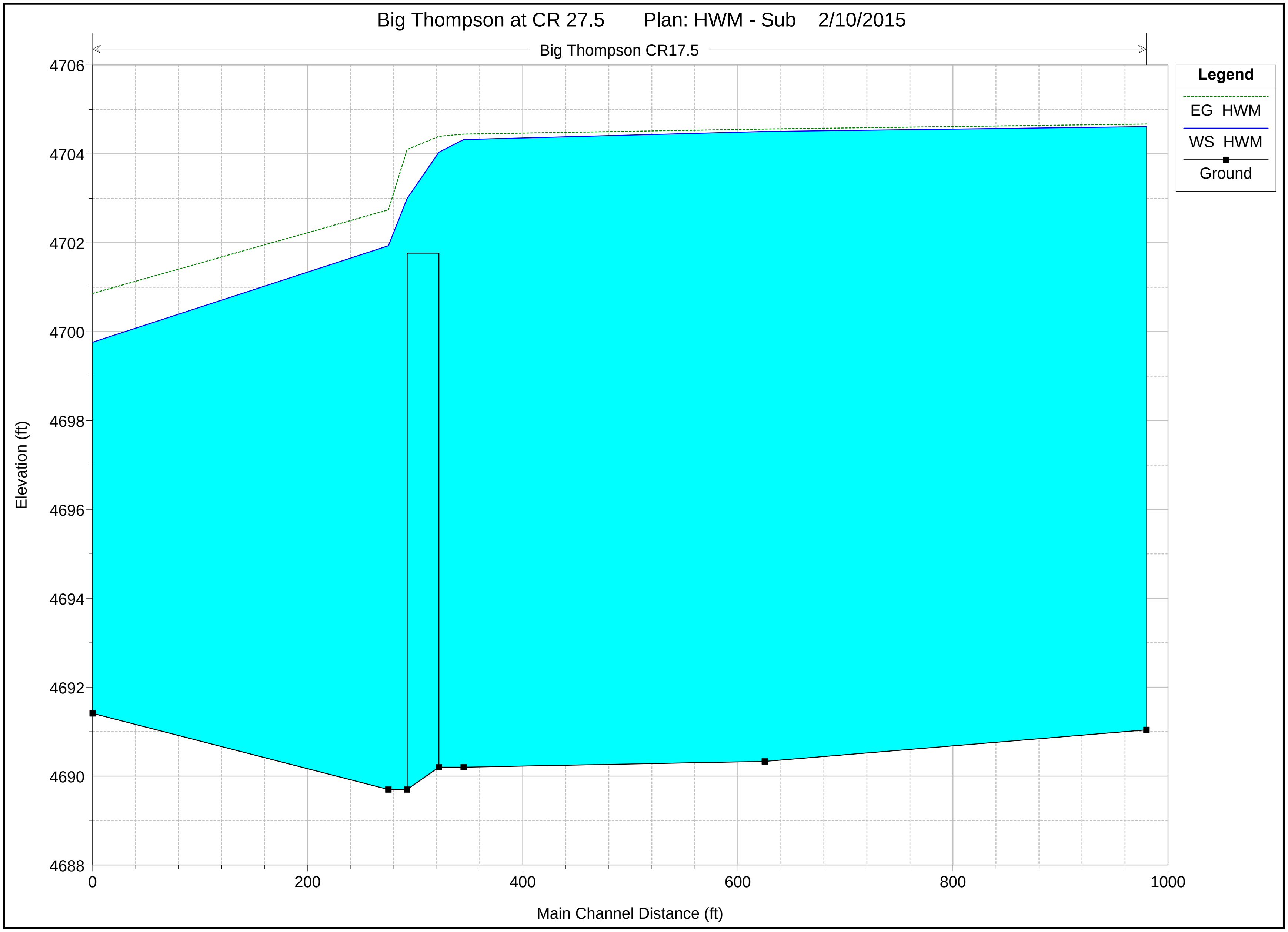


Big Thompson at 257 Plan: HWM 2/10/2015
Big Thompson Riv Johnstown
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4750
4745
4740
4735
4730
4725
0
100
200
300
400
500
600
Main Channel Distance (ft)

Big Thompson at CR 27.5

HEC-RAS Plan: HWM - Sub River: Big Thompson Reach: CR17.5 Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
CR17.5	1480	HWM	24900.00	4691.04	4704.61	4702.12	4704.67	0.000360	3.39	15809.33	3885.42	0.20
CR17.5	1125	HWM	24900.00	4690.33	4704.50	4701.53	4704.56	0.000277	3.06	16517.65	3683.36	0.18
CR17.5	845	HWM	24900.00	4690.20	4704.32	4702.41	4704.45	0.000558	4.58	12727.37	3473.96	0.26
CR17.5	822		Bridge									
CR17.5	775	HWM	24900.00	4689.70	4701.93	4701.93	4702.74	0.005179	10.37	5764.35	3171.61	0.72
CR17.5	500	HWM	24900.00	4691.41	4699.76	4699.76	4700.86	0.009108	11.97	4175.16	2008.44	0.92



Big Thompson at CR 27.5 Plan: HWM - Sub 2/10/2015
Big Thompson CR17.5
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4706
4704
4702
4700
4698
4696
4694
4692
4690
4688
0
200
400
600
800
1000
Main Channel Distance (ft)

Technical Memorandum

Boulder Creek

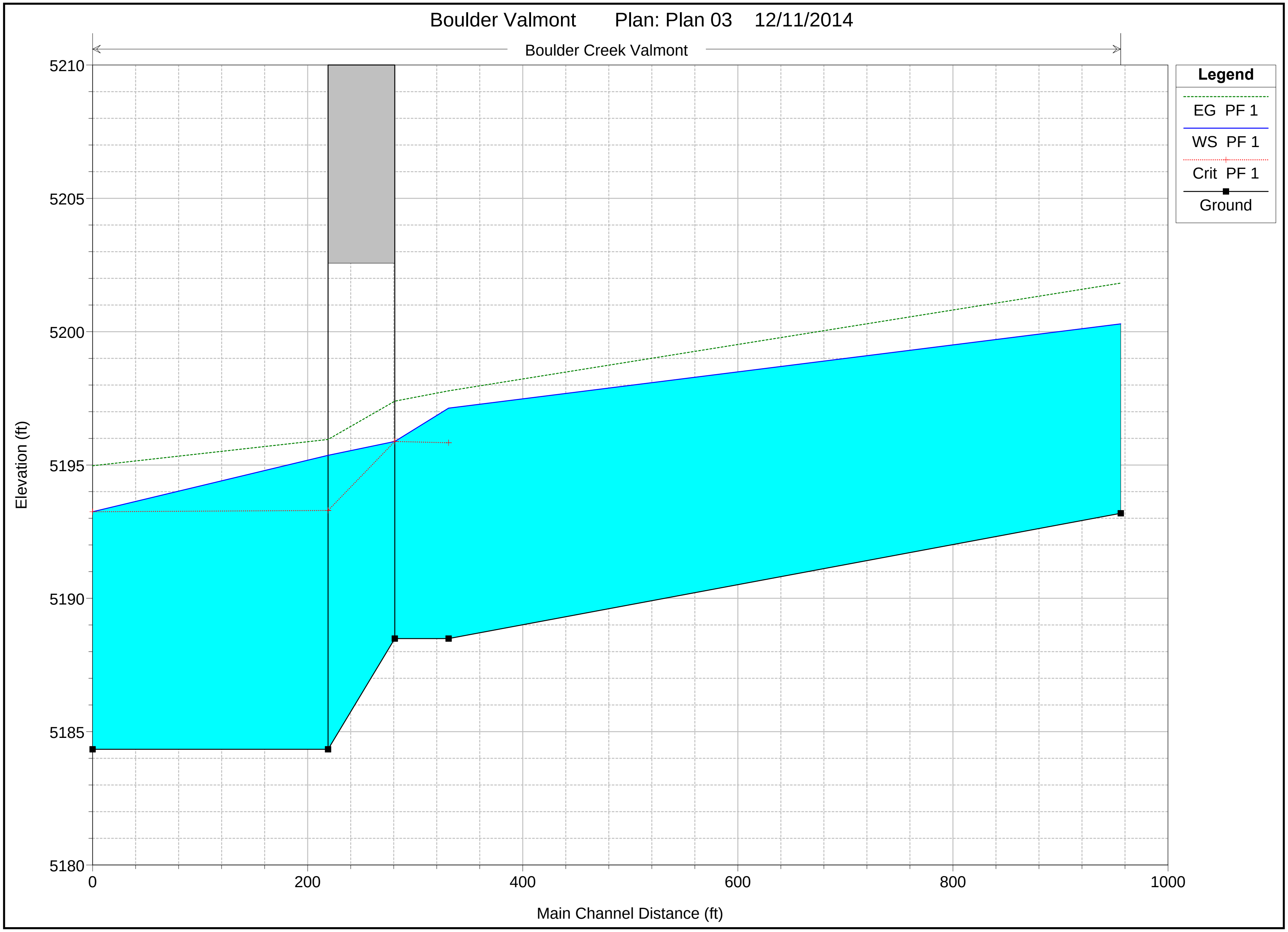
HEC-RAS Results

Boulder at Valmont

HEC-RAS Plan: Plan 03   River: Boulder Creek   Reach: Valmont   Profile: PF 1

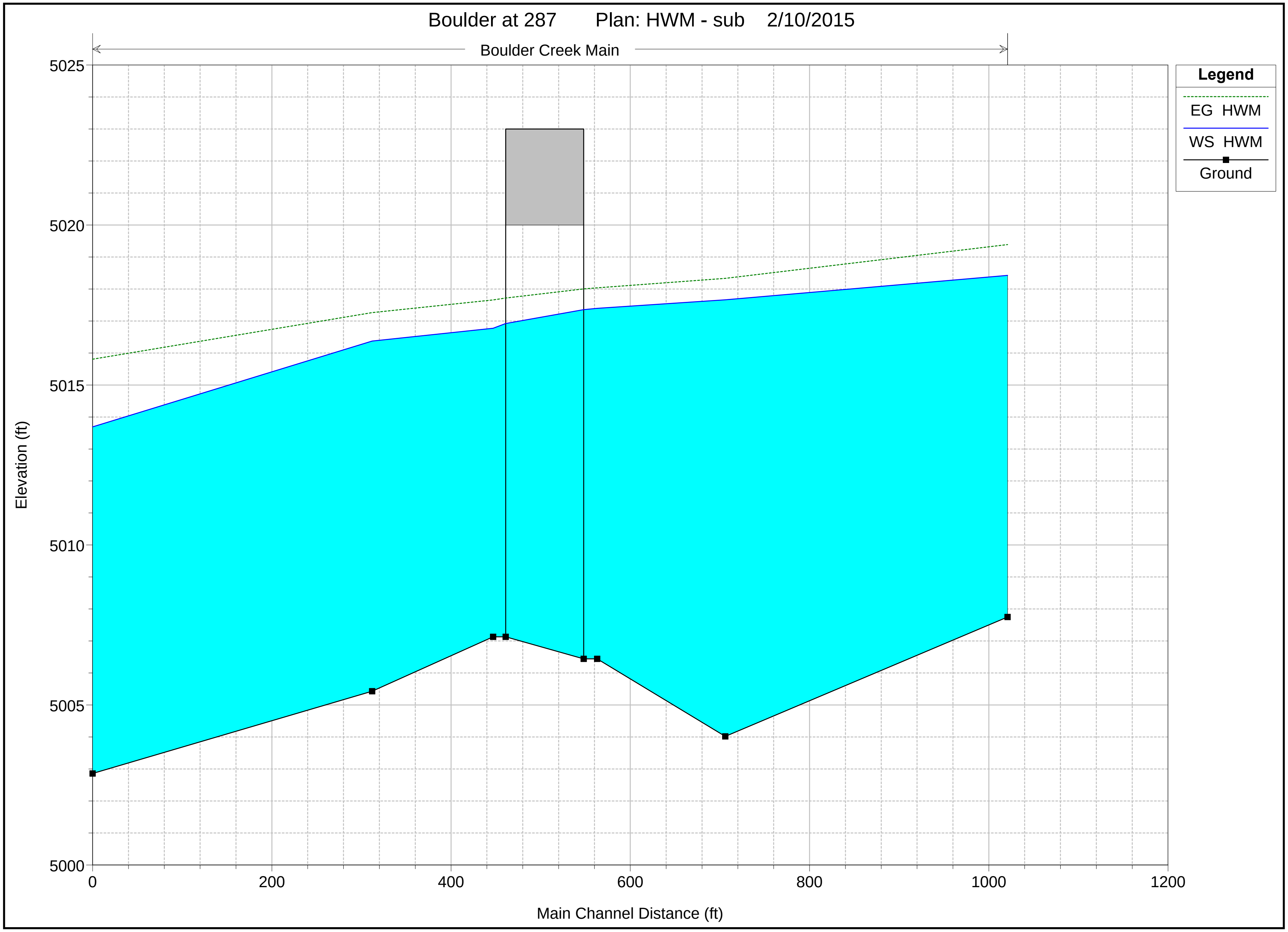
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Valmont	1956	PF 1	4300.00	5193.19	5200.29		5201.82	0.010375	10.55	460.25	109.11	0.82
Valmont	1331	PF 1	4300.00	5188.49	5197.13	5195.83	5197.78	0.003751	7.73	760.05	180.19	0.53
Valmont	1081		Bridge									
Valmont	1000	PF 1	4300.00	5184.34	5193.25	5193.25	5194.97	0.008304	11.80	513.68	155.69	0.77

Boulder at Valmont



HEC-RAS Plan: HWM - Sub   River: Boulder Creek   Reach: Main   Profile: HWM

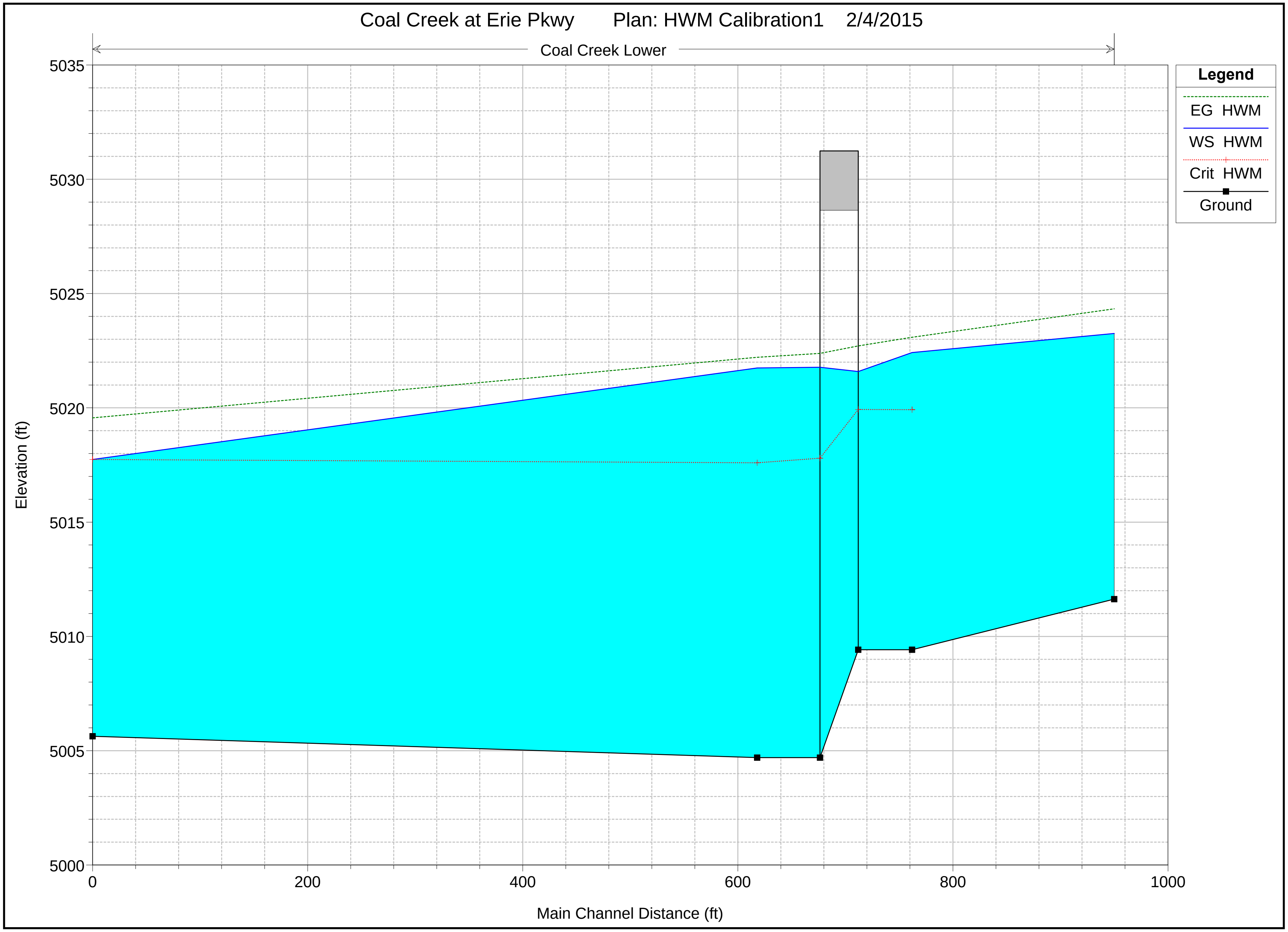
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	2021	HWM	9000.00	5007.75	5018.43	5018.10	5019.39	0.004807	10.13	1529.85	446.05	0.61
Main	1706	HWM	9000.00	5004.02	5017.66	5015.27	5018.33	0.002121	8.27	1687.08	282.04	0.43
Main	1563	HWM	9000.00	5006.44	5017.40	5014.00	5018.04	0.001876	7.35	1553.92	208.62	0.41
Main	1505		Bridge									
Main	1447	HWM	9000.00	5007.13	5016.77	5014.56	5017.66	0.003056	8.51	1324.66	208.55	0.52
Main	1312	HWM	9000.00	5005.43	5016.38	5014.19	5017.26	0.002832	8.22	1376.82	244.13	0.49
Main	1000	HWM	9000.00	5002.86	5013.69	5013.69	5015.81	0.007230	13.40	962.39	208.12	0.76


Boulder at 287 Plan: HWM - sub 2/10/2015
Boulder Creek Main
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
5025
5020
5015
5010
5005
5000
0
200
400
600
800
1000
1200
Main Channel Distance (ft)

HEC-RAS Plan: HWM 1 Bridge   River: Coal Creek   Reach: Lower   Profile: HWM

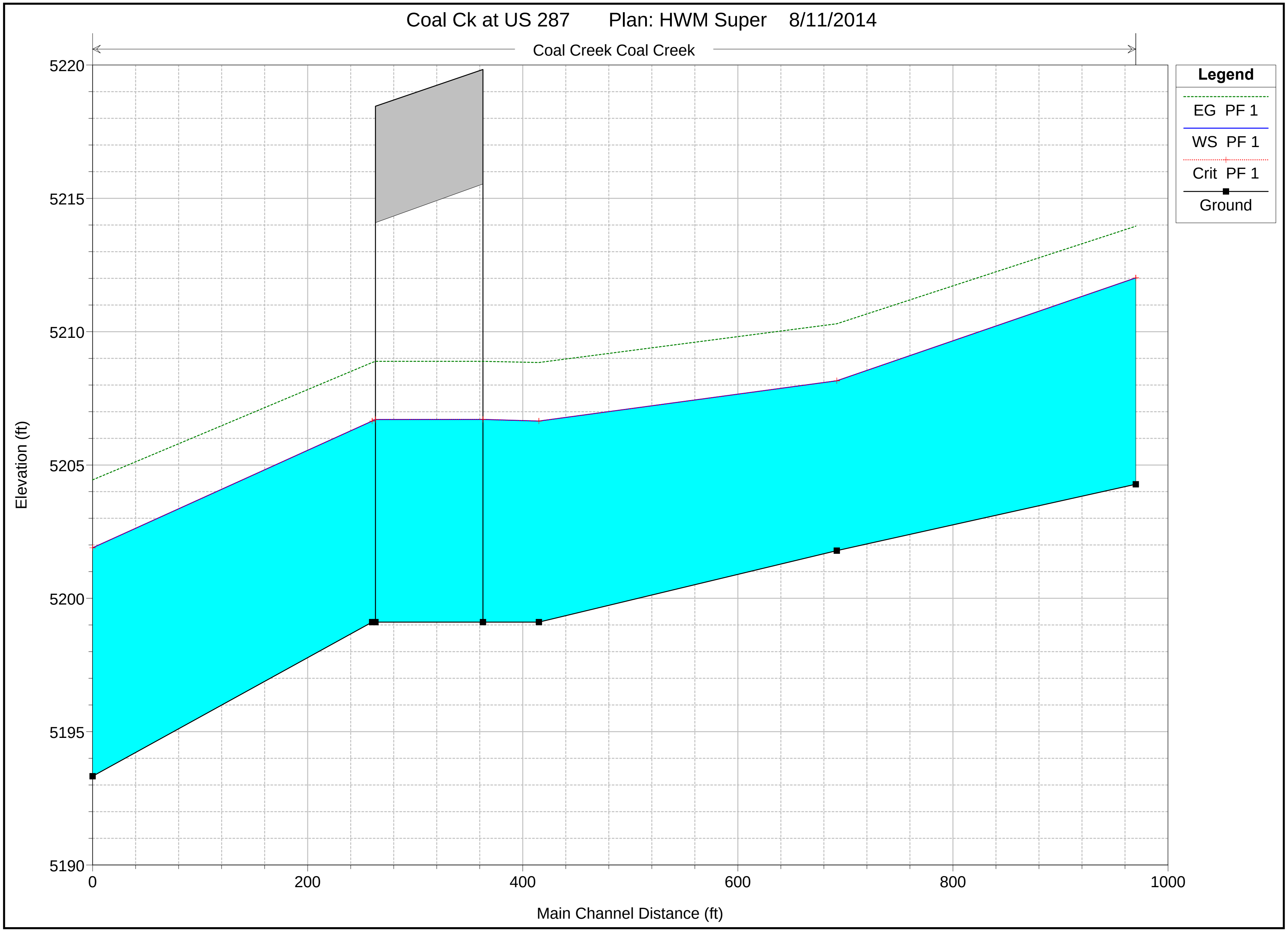
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Lower	19370	HWM	6000.00	5011.63	5023.26		5024.33	0.008024	9.22	740.79	143.95	0.51
Lower	19182	HWM	6000.00	5009.42	5022.42	5019.92	5023.09	0.004605	6.72	918.56	176.19	0.36
Lower	19154		Bridge									
Lower	19038	HWM	6000.00	5004.70	5021.75	5017.60	5022.21	0.001853	5.55	1155.46	204.33	0.27
Lower	18420	HWM	6000.00	5005.63	5017.74	5017.74	5019.56	0.014899	12.05	588.19	154.27	0.74

Coal at Erie Pkwy



HEC-RAS Plan: Super Crit River: Coal Creek Reach: Coal Creek Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Coal Creek	82873.73	PF 1	5000.00	5204.28	5212.02	5212.02	5213.96	0.060211	12.09	458.53	114.90	0.92
Coal Creek	82595.73	PF 1	5000.00	5201.79	5208.16	5208.16	5210.30	0.067647	12.20	447.71	145.18	0.97
Coal Creek	82318.73	PF 1	5000.00	5199.11	5206.65	5206.65	5208.84	0.061620	12.75	430.27	97.03	0.94
Coal Creek	82260		Bridge									
Coal Creek	82163.73	PF 1	5000.00	5199.11	5206.65	5206.65	5208.84	0.061620	12.75	430.27	97.03	0.94
Coal Creek	81903.73	PF 1	5000.00	5193.33	5201.89	5201.89	5204.44	0.052203	13.60	411.22	79.80	0.90

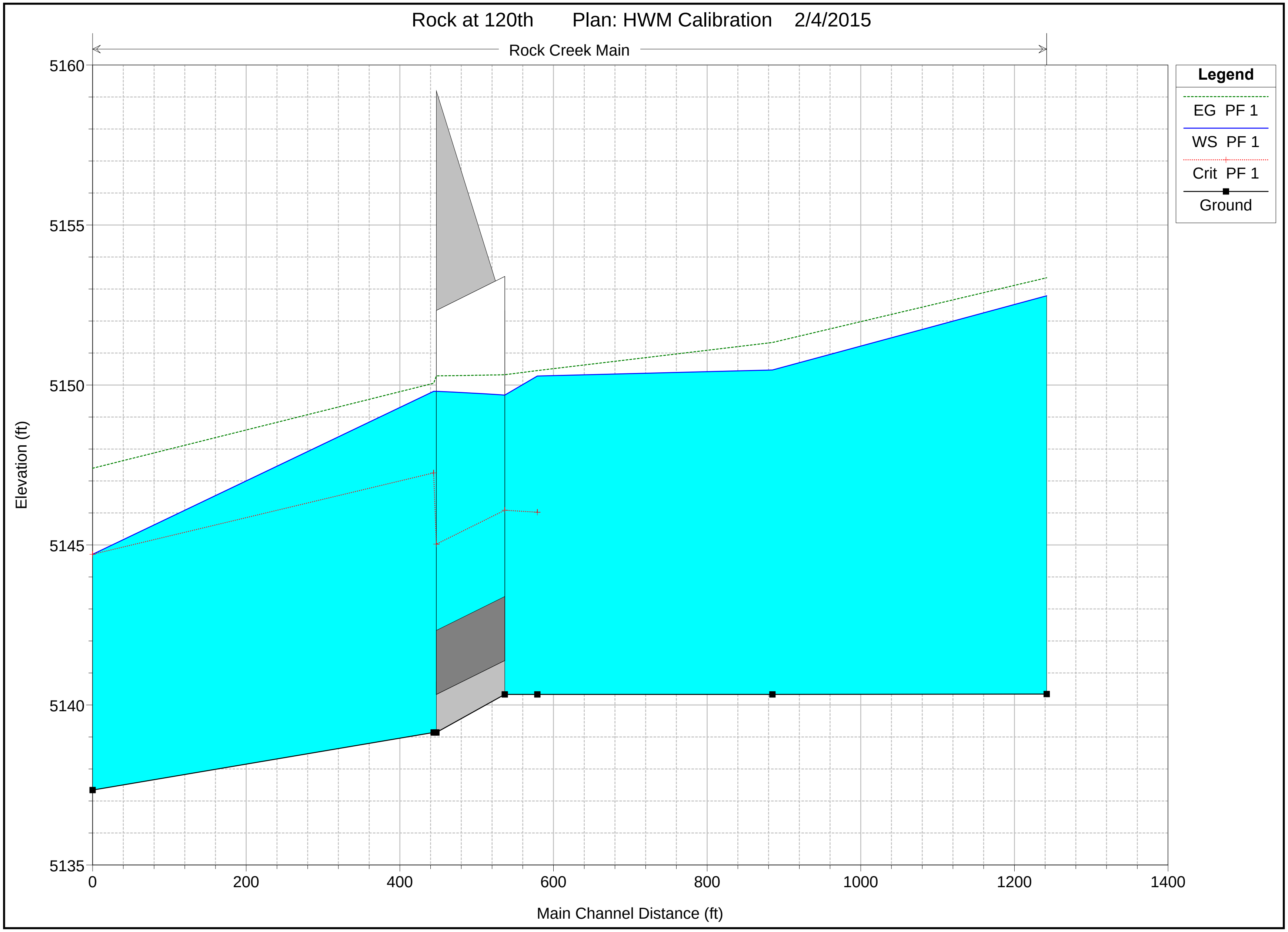


Coal Ck at US 287 Plan: HWM Super 8/11/2014
Coal Creek Coal Creek
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
5220
5215
5210
5205
5200
5195
5190
Elevation (ft)
0
200
400
600
800
1000
Main Channel Distance (ft)

Rock at 120th

HEC-RAS Plan: HWM Calibration   River: Rock Creek   Reach: Main   Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	207844	PF 1	1500.00	5140.34	5152.79		5153.35	0.004839	6.07	258.07	58.77	0.44
Main	207487	PF 1	1500.00	5140.33	5150.47		5151.33	0.006494	7.92	236.32	76.93	0.51
Main	207181	PF 1	1500.00	5140.33	5150.28	5146.02	5150.45	0.001093	3.82	485.95	83.66	0.23
Main	207119		Culvert									
Main	207046	PF 1	1500.00	5139.14	5149.80	5147.26	5150.05	0.002091	5.00	419.99	106.00	0.30
Main	206602	PF 1	1500.00	5137.34	5144.71	5144.71	5147.40	0.035533	13.48	119.51	35.59	1.07

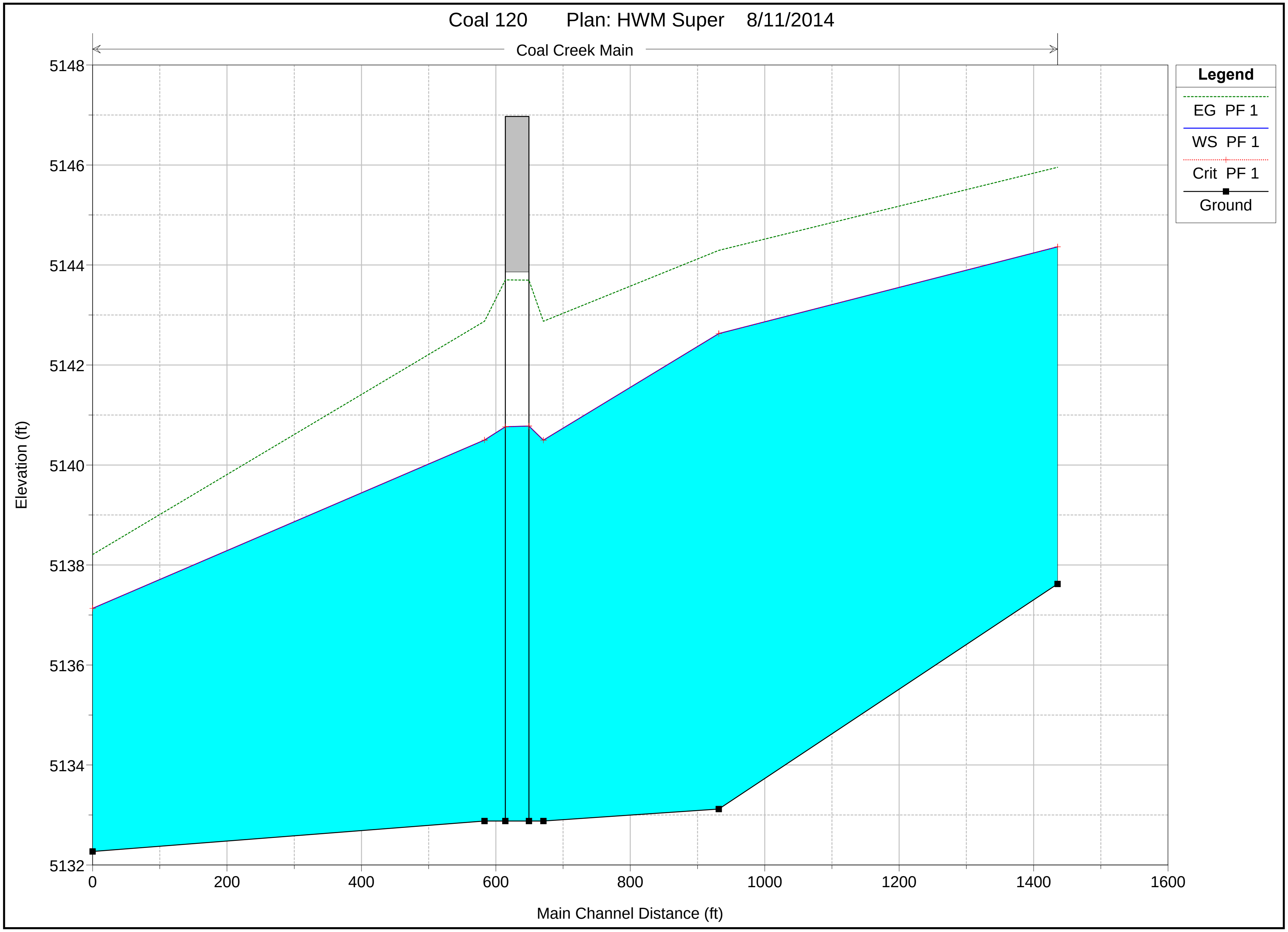

Rock at 120th Plan: HWM Calibration 2/4/2015
Rock Creek Main
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
Elevation (ft)
5160
5155
5150
5145
5140
5135
0
200
400
600
800
1000
1200
1400
Main Channel Distance (ft)

Coal at 120

HEC-RAS Plan: Super Crit   River: Coal Creek   Reach: Main   Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main	72657.6	PF 1	3500.00	5137.62	5144.36	5144.36	5145.96	0.020221	12.87	378.53	114.48	0.93
Main	72153.6	PF 1	3500.00	5133.12	5142.63	5142.63	5144.29	0.015926	13.03	397.17	112.42	0.81
Main	71892.6	PF 1	3500.00	5132.88	5140.50	5140.50	5142.87	0.019779	14.06	302.32	74.90	0.97
Main	71836		Bridge									
Main	71805	PF 1	3500.00	5132.88	5140.50	5140.50	5142.87	0.019727	14.05	302.62	74.97	0.97
Main	71222	PF 1	3500.00	5132.27	5137.13	5137.13	5138.21	0.016879	9.14	481.07	219.26	0.84

Coal at 120



Coal 120 Plan: HWM Super 8/11/2014
Coal Creek Main
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
Elevation (ft)
5148
5146
5144
5142
5140
5138
5136
5134
5132
0
200
400
600
800
1000
1200
1400
1600
Main Channel Distance (ft)

Technical Memorandum

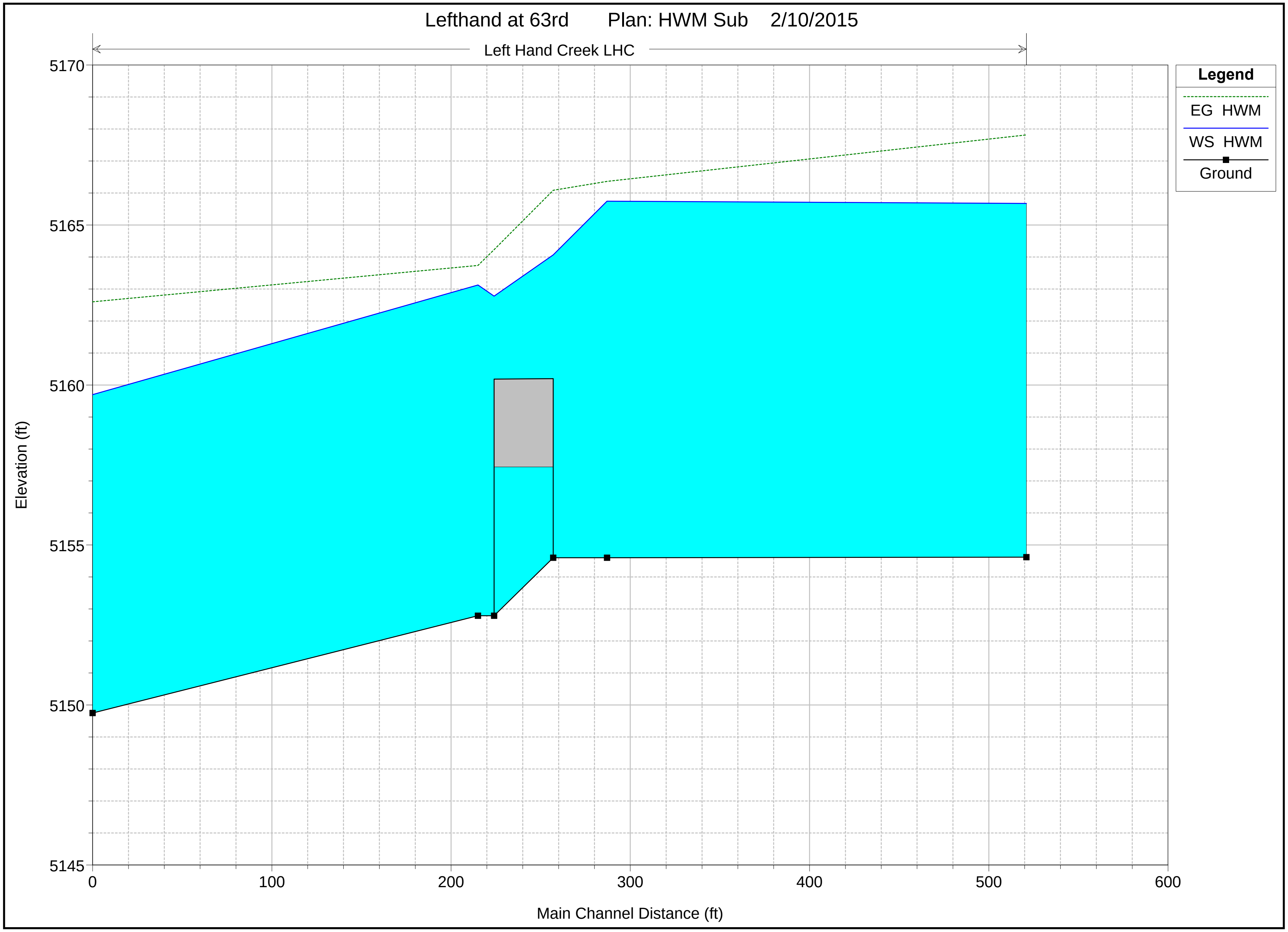
Lefthand Creek

HEC-RAS Results

Left Hand at 63rd

HEC-RAS Plan: HWM Sub River: Left Hand Creek Reach: LHC Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
LHC	1521	HWM	7000.00	5154.62	5165.67	5165.67	5167.81	0.008699	13.88	771.10	163.02	0.83
LHC	1287	HWM	7000.00	5154.60	5165.74	5161.55	5166.36	0.001709	6.44	1203.36	197.39	0.38
LHC	1257		Bridge									
LHC	1215	HWM	7000.00	5152.79	5163.13	5160.56	5163.74	0.002252	6.78	1290.28	246.23	0.43
LHC	1000	HWM	7000.00	5149.75	5159.70	5159.70	5162.60	0.010550	15.47	607.18	113.06	0.93



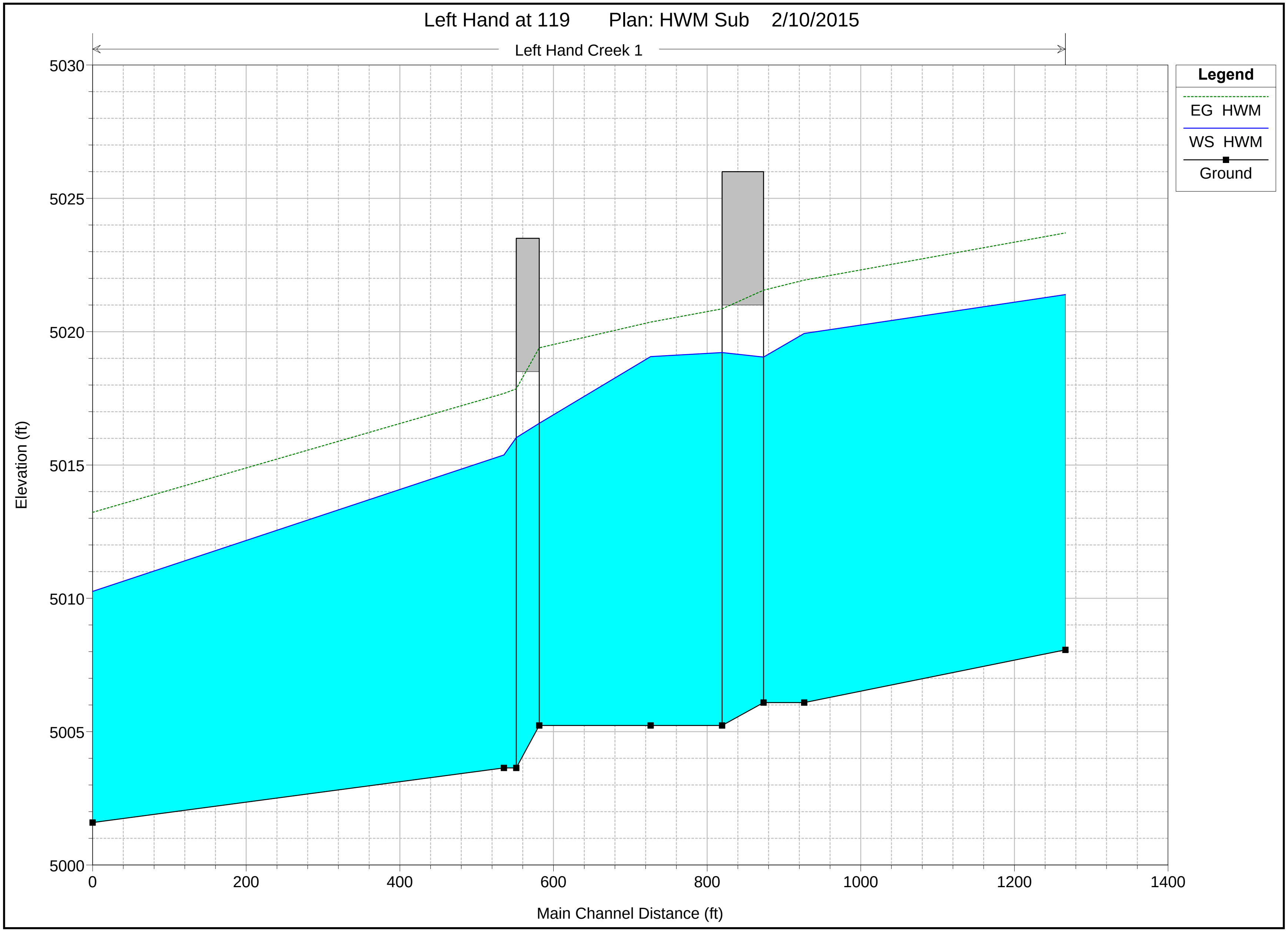
Lefthand at 63rd Plan: HWM Sub 2/10/2015
Left Hand Creek LHC
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
5170
5165
5160
5155
5150
5145
0
100
200
300
400
500
600
Main Channel Distance (ft)

Left Hand at 119th

HEC-RAS Plan: HWM Sub   River: Left Hand Creek   Reach: 1   Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	1731	HWM	8700.00	5008.07	5021.39	5020.04	5023.70	0.006282	12.81	777.98	157.33	0.71
1	1391	HWM	8700.00	5006.09	5019.93	5017.19	5021.93	0.003965	11.74	858.66	131.02	0.60
1	1338		Bridge									
1	1191	HWM	8700.00	5005.23	5019.07	5016.48	5020.36	0.003057	10.27	1124.41	183.64	0.52
1	1046		Bridge									
1	1000	HWM	8700.00	5003.64	5015.38	5014.38	5017.68	0.006716	12.97	830.02	134.17	0.75
1	464.5513	HWM	8700.00	5001.59	5010.26	5010.26	5013.22	0.010261	14.17	687.36	247.13	0.92

Left Hand at 119th

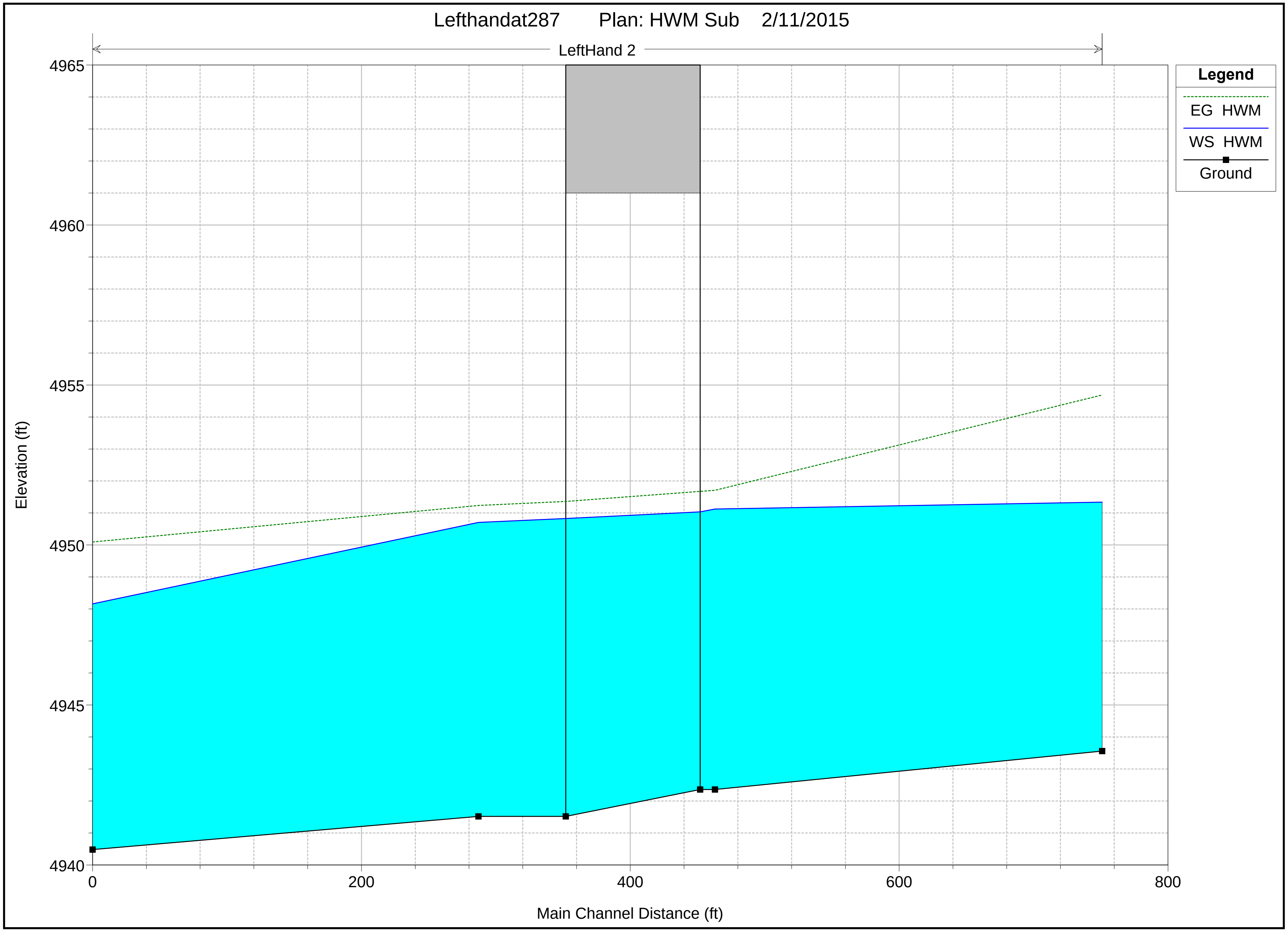


Left Hand at 287

HEC-RAS Plan: HWM Sub River: LeftHand Reach: 2 Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
2	1751	HWM	5000.00	4943.56	4951.34	4951.34	4954.69	0.012627	14.68	340.50	70.85	0.99
2	1463	HWM	5000.00	4942.36	4951.12	4947.62	4951.71	0.001884	6.27	852.72	119.08	0.39
2	1452		Bridge									
2	1287	HWM	5000.00	4941.52	4950.70	4946.88	4951.24	0.001545	6.10	921.21	136.30	0.36
2	1000	HWM	5000.00	4940.48	4948.16	4948.16	4950.09	0.014139	12.55	499.97	152.36	0.99

Left Hand at 287

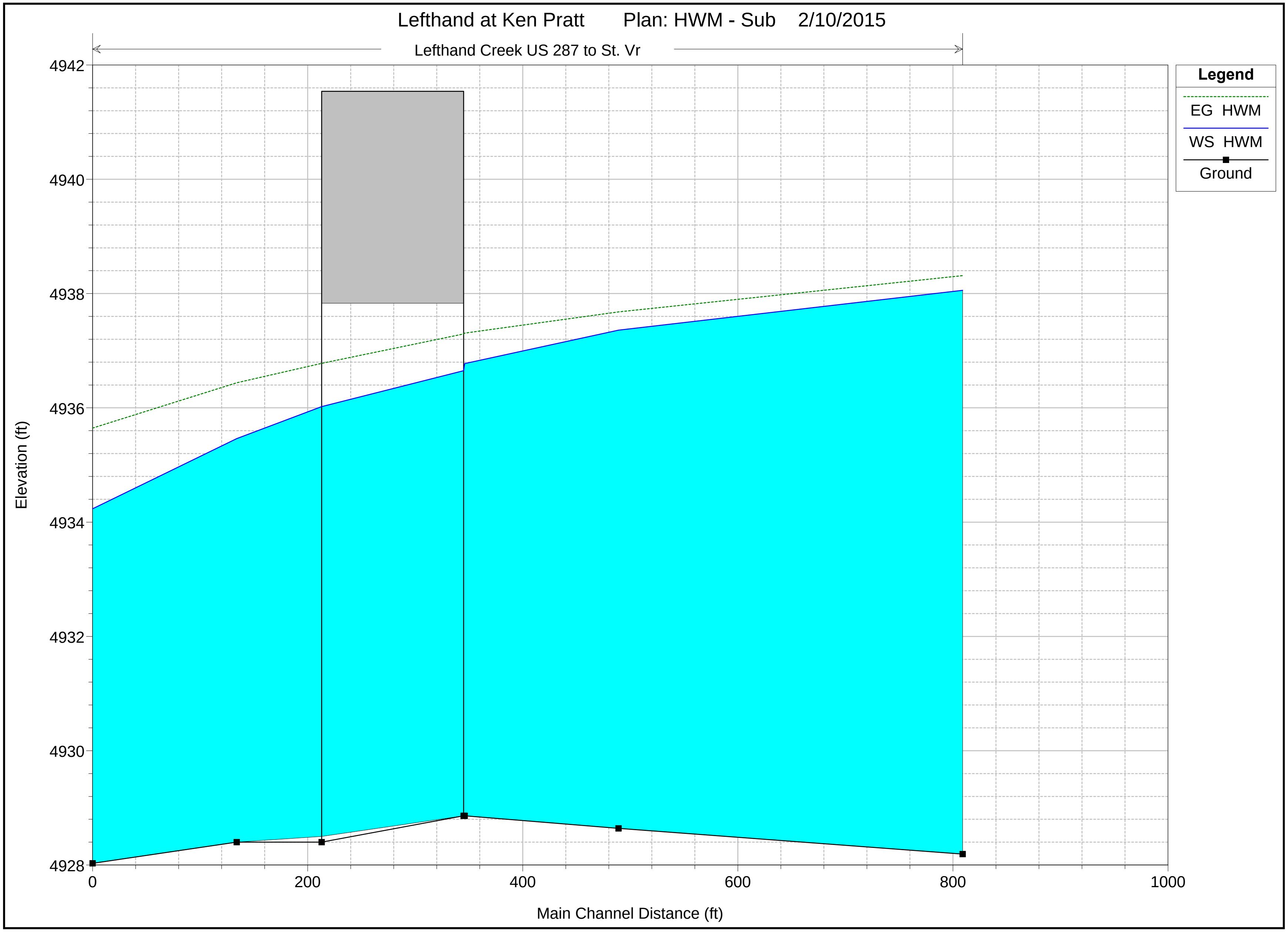


Left Hand at Ken Pratt

HEC-RAS Plan: HWM Sub River: Lefthand Creek Reach: US 287 to St. Vr Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
US 287 to St. Vr	1609	HWM	4800.00	4928.19	4938.06	4934.73	4938.31	0.001930	6.08	1304.98	232.20	0.38
US 287 to St. Vr	1289	HWM	4800.00	4928.64	4937.36	4933.80	4937.68	0.002011	6.43	1229.18	222.88	0.41
US 287 to St. Vr	1146	HWM	4800.00	4928.86	4936.77	4934.25	4937.31	0.003027	7.88	945.39	165.40	0.50
US 287 to St. Vr	1067		Bridge									
US 287 to St. Vr	934	HWM	4800.00	4928.40	4935.46	4934.11	4936.44	0.004171	9.00	724.98	147.51	0.65
US 287 to St. Vr	800	HWM	4800.00	4928.03	4934.23	4934.23	4935.65	0.007855	10.53	649.98	230.27	0.85

Left Hand at Ken Pratt



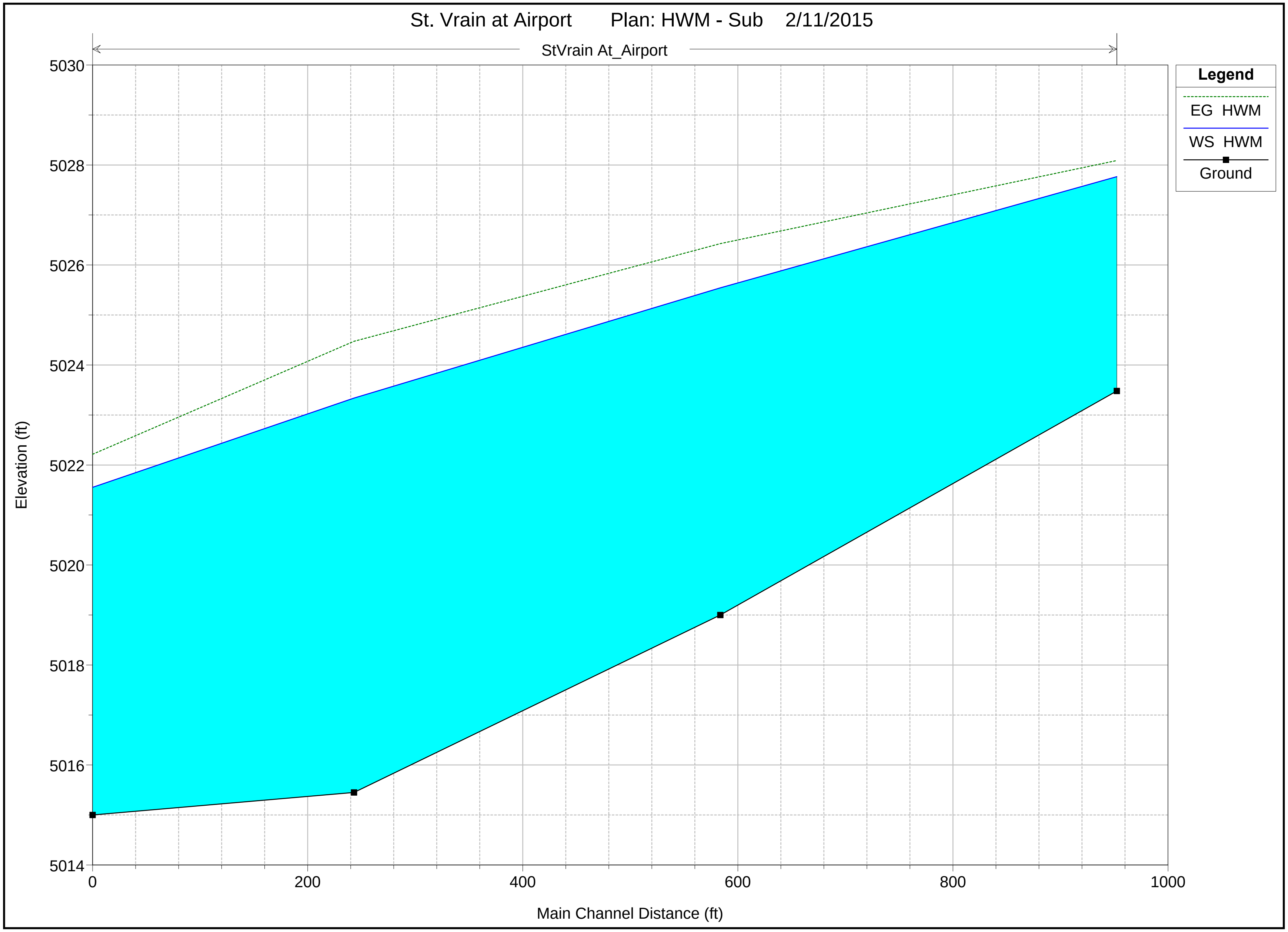
St. Vrain Creek

HEC-RAS Results

St. Vrain at Airport

HEC-RAS Plan: HWM Sub River: StVrain Reach: At_Airport Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
At_Airport	1486.316	HWM	14000.00	5023.48	5027.77	5026.83	5028.09	0.003893	6.35	4226.68	2147.94	0.58
At_Airport	1117.65	HWM	14000.00	5019.00	5025.54	5025.54	5026.43	0.004906	8.92	2986.14	1672.45	0.69
At_Airport	777.0211	HWM	14000.00	5015.45	5023.34	5023.34	5024.47	0.005145	9.85	2410.87	1751.79	0.72
At_Airport	533.9273	HWM	14000.00	5015.00	5021.55	5021.55	5022.22	0.004387	8.36	3757.45	2709.84	0.65

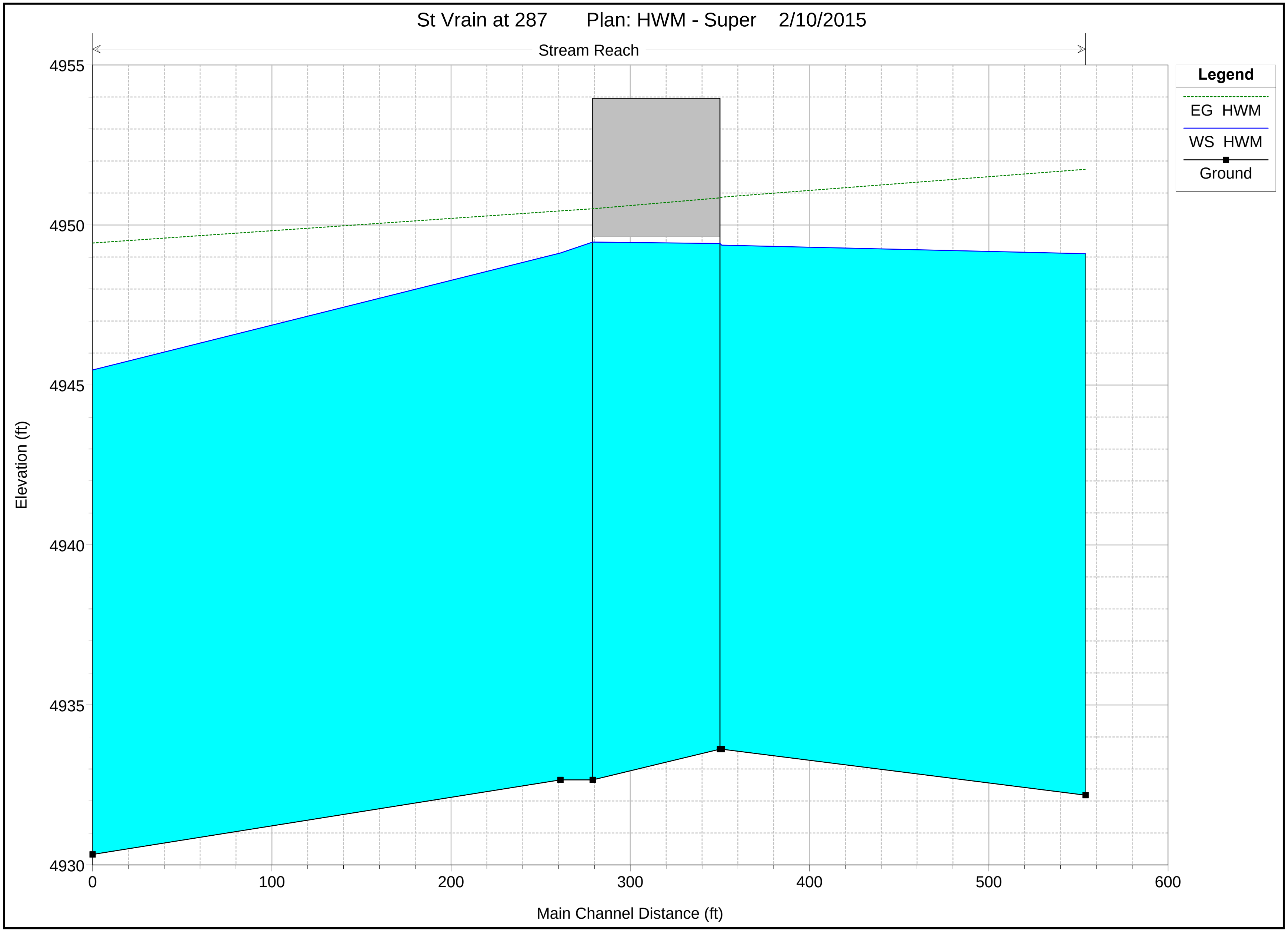


St. Vrain at Airport Plan: HWM - Sub 2/11/2015
StVrain At_Airport
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
5030
5028
5026
5024
5022
5020
5018
5016
5014
0
200
400
600
800
1000
Main Channel Distance (ft)

St. Vrain at 287

HEC-RAS Plan: HWM - Super River: Stream Reach: Reach Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach	654	HWM	14500.00	4932.18	4949.10	4946.57	4951.74	0.003888	15.41	1423.46	148.47	0.71
Reach	451	HWM	14500.00	4933.62	4949.37	4944.80	4950.87	0.001850	10.87	1743.20	159.65	0.50
Reach	450		Bridge									
Reach	361	HWM	14500.00	4932.66	4949.13	4944.46	4950.44	0.001685	10.52	1846.43	181.47	0.48
Reach	100	HWM	14500.00	4930.33	4945.47	4945.47	4949.44	0.005772	17.65	1168.03	169.34	0.84

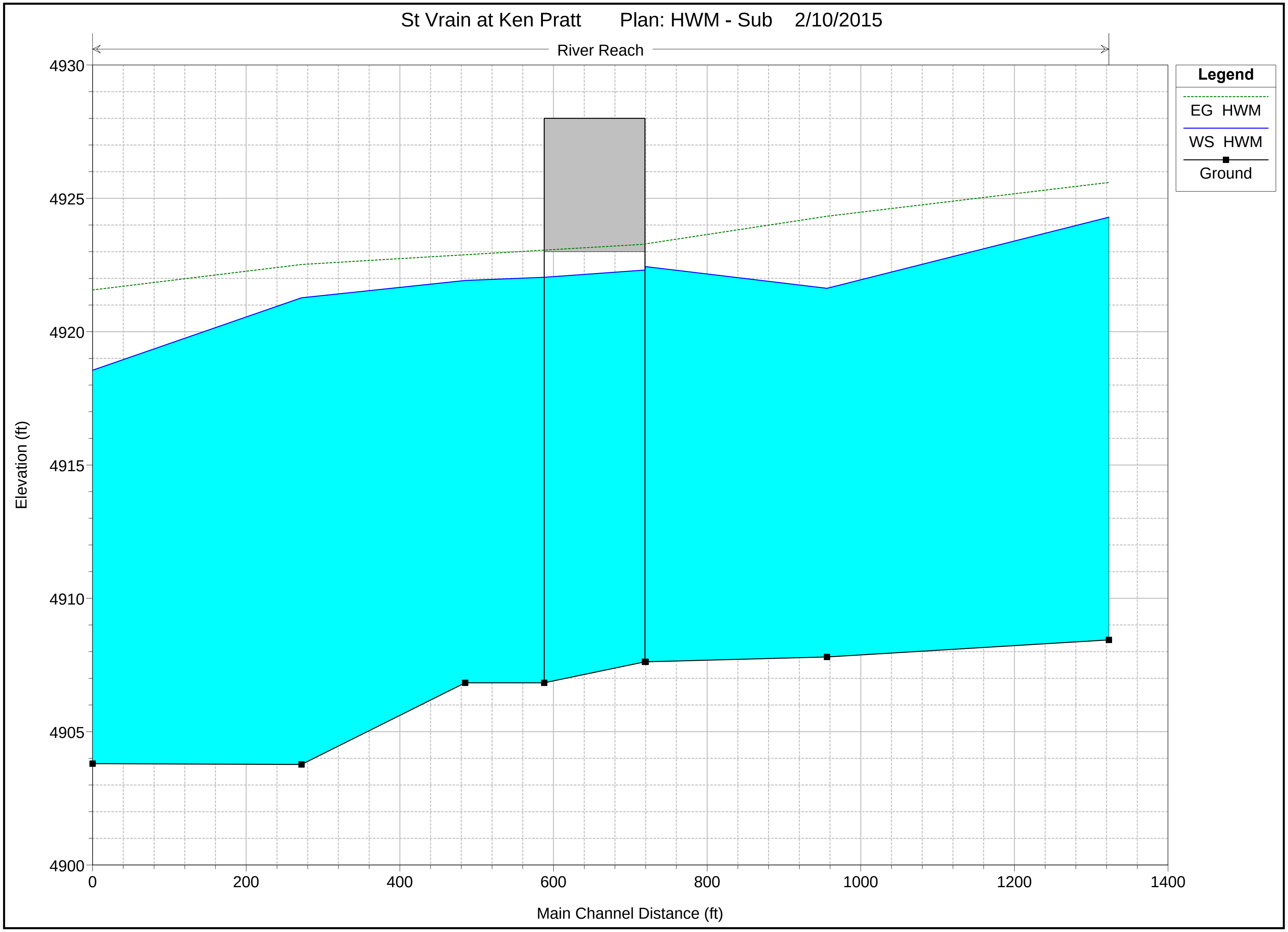


St Vrain at 287 Plan: HWM - Super 2/10/2015
Stream Reach
Legend
EG HWM
WS HWM
Ground
4955
4950
4945
4940
4935
4930
Elevation (ft)
0
100
200
300
400
500
600
Main Channel Distance (ft)

St. Vrain at Ken Pratt

HEC-RAS Plan: HWM - Sub River: River Reach: Reach Profile: HWM

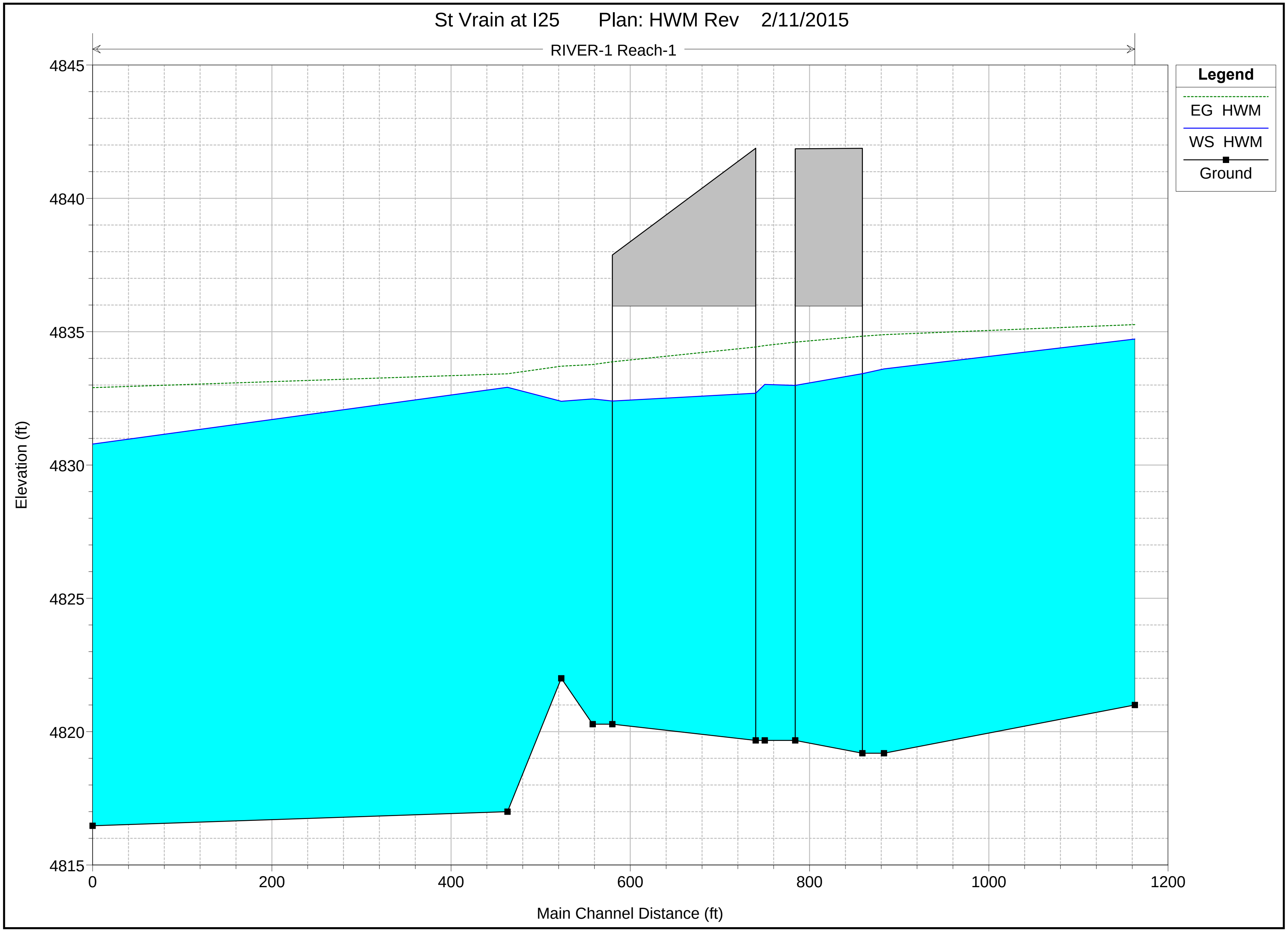
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach	1378	HWM	18500.00	4908.44	4924.29	4920.97	4925.59	0.002364	11.62	2608.53	263.71	0.54
Reach	1011	HWM	18500.00	4907.80	4921.63	4920.82	4924.33	0.004165	14.69	1821.17	239.69	0.72
Reach	775	HWM	18500.00	4907.62	4922.44	4917.13	4923.29	0.001192	7.67	2657.07	290.11	0.38
Reach	774		Bridge									
Reach	540	HWM	18500.00	4906.83	4921.92	4916.94	4922.89	0.001357	8.07	2494.23	282.47	0.41
Reach	327	HWM	18500.00	4903.77	4921.27	4917.26	4922.52	0.001858	10.54	2460.61	300.95	0.49
Reach	55	HWM	18500.00	4903.80	4918.55	4918.55	4921.56	0.005052	16.26	1844.45	278.21	0.79


St Vrain at Ken Pratt Plan: HWM - Sub 2/10/2015
River Reach
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4930
4925
4920
4915
4910
4905
4900
0
200
400
600
800
1000
1200
1400
Main Channel Distance (ft)

HEC-RAS Plan: HWM Rev River: RIVER-1 Reach: Reach-1 Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Reach-1	1766.598	HWM	23500.00	4821.00	4834.73	4829.05	4835.27	0.000851	6.74	4275.77	441.00	0.37
Reach-1	1486.598	HWM	23500.00	4819.19	4833.60	4829.64	4834.89	0.001444	9.37	2757.65	283.90	0.49
Reach-1	1462.498		Bridge									
Reach-1	1353.598	HWM	23500.00	4819.67	4833.02	4829.96	4834.48	0.001880	9.99	2571.49	289.39	0.55
Reach-1	1343.498		Bridge									
Reach-1	1161.598	HWM	23500.00	4820.28	4832.48	4829.18	4833.77	0.001689	9.27	2664.22	322.91	0.52
Reach-1	1126.598	HWM	23500.00	4822.00	4832.39	4829.14	4833.71	0.001722	9.36	2637.57	322.12	0.53
Reach-1	1066.598	HWM	23500.00	4817.00	4832.91	4824.14	4833.42	0.000372	5.86	4306.12	384.59	0.26
Reach-1	603.598	HWM	23500.00	4816.47	4830.78	4828.32	4832.90	0.002503	12.52	2418.26	357.78	0.65

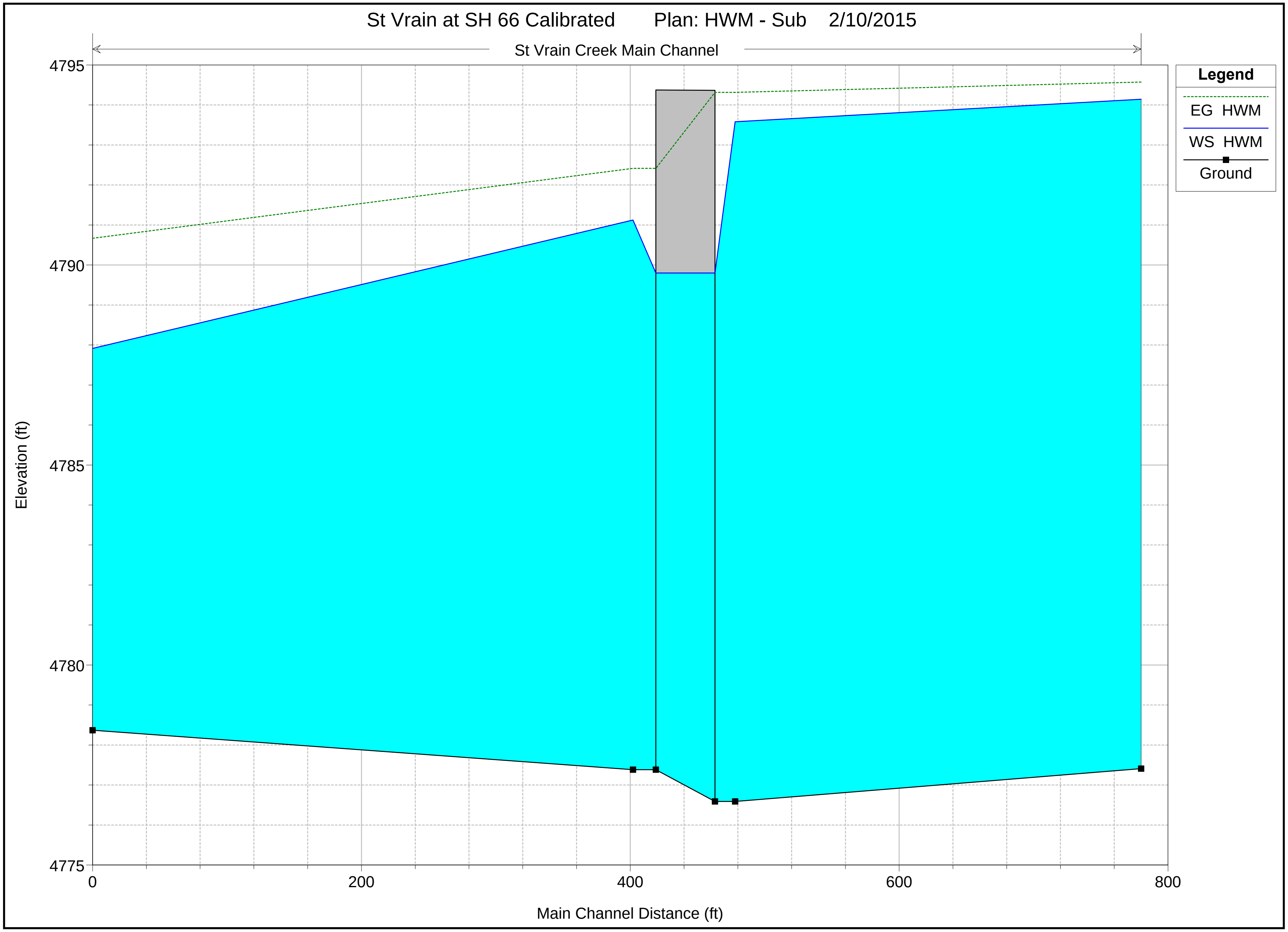
St. Vrain at I-25



St. Vrain at SH 66

HEC-RAS Plan: HWM - Sub River: St Vrain Creek Reach: Main Channel Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Main Channel	1780	HWM	23000.00	4777.41	4794.14	4786.83	4794.57	0.000586	5.82	4790.88	400.71	0.26
Main Channel	1478	HWM	23000.00	4776.59	4793.58	4786.94	4794.32	0.001041	6.90	3353.10	299.65	0.34
Main Channel	1463		Bridge									
Main Channel	1402	HWM	23000.00	4777.38	4791.13	4787.60	4792.42	0.002598	9.40	2570.84	276.69	0.52
Main Channel	1000	HWM	23000.00	4778.37	4787.92	4787.92	4790.67	0.008608	13.97	1882.23	333.27	0.89

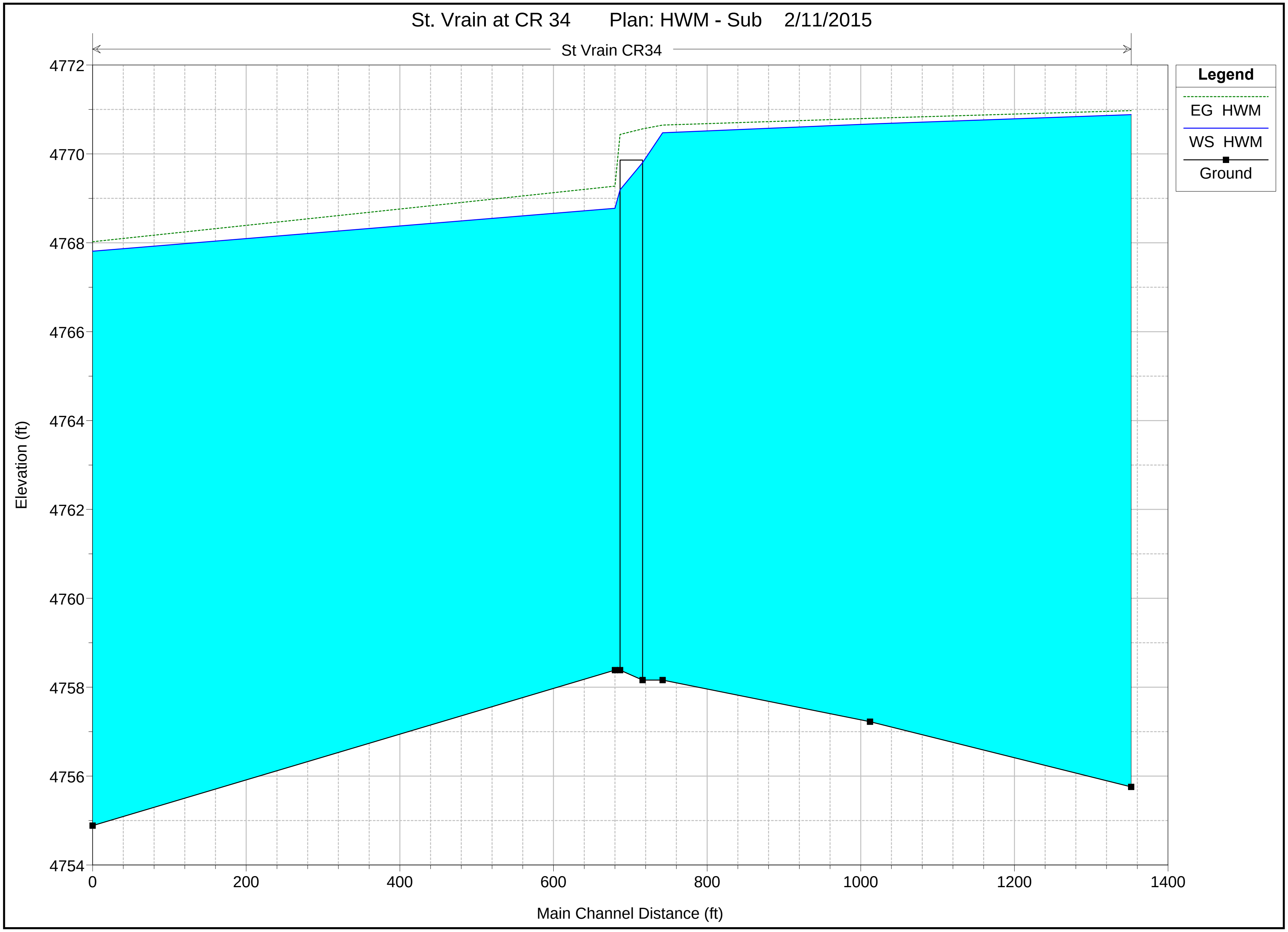

St Vrain at SH 66 Calibrated Plan: HWM - Sub 2/10/2015
St Vrain Creek Main Channel
Legend
EG HWM
WS HWM
Ground
Elevation (ft)
4795
4790
4785
4780
4775
0
200
400
600
800
Main Channel Distance (ft)

St. Vrain at CR 34

HEC-RAS Plan: HWM - Sub River: St Vrain Reach: CR34 Profile: HWM

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
CR34	1852	HWM	27000.00	4755.76	4770.88	4767.78	4770.97	0.000521	3.71	12188.08	3320.76	0.22
CR34	1512	HWM	27000.00	4757.22	4770.67	4767.64	4770.80	0.000477	4.38	12318.03	3639.24	0.22
CR34	1242	HWM	27000.00	4758.16	4770.48	4768.40	4770.65	0.000633	4.66	10680.74	2913.67	0.26
CR34	1206		Bridge									
CR34	1180	HWM	27000.00	4758.38	4768.78	4768.01	4769.28	0.002085	7.36	6862.47	2945.71	0.45
CR34	500	HWM	27000.00	4754.89	4767.81	4766.57	4768.02	0.001435	6.87	9135.60	3445.60	0.38

St. Vrain at CR 34



Appendix F
Depth Area Reduction Factor Documentation

Colorado Front Range 24-hr Rainfall Areal Reduction Factors (Applied Weather Associates, 2015)

PO Box 175
Monument, CO 80132
(719) 488-4311
http://appliedweatherassociates.com

March 27, 2015

Memo for Record

To: CDOT Flood Hydrology Committee

Subject: Colorado Front Range 24-hr Rainfall Areal Reduction Factors

1. Overview

The Colorado Department of Transportation (CDOT) Flood Hydrology Committee tasked Applied Weather Associates (AWA) to derive 24-hour areal reduction factors (ARFs) for the Front Range of Colorado for area sizes of 1- to 1000-sqmi. In addition, basin specific ARFs for the September 2013 rainfall event were calculated for four basins (Boulder Creek, St Vrain Creek, Big Thompson River, and Thompson River).

This study was initiated due to areal limitations associated with the National Ocean and Atmospheric Administration (NOAA) Atlas 2 ARF curves. NOAA Atlas 2 ARF curves extend from 1-sqmi to 400-sqmi. For Phase I of the CDOT September 2013 Flood Study, the NOAA Atlas 2 ARFs were used since drainage area sizes analyzed were less than 400-sqmi. For Phase II of the CDOT September 2013 Flood Study, the NOAA Atlas 2 ARFs required an update specific to each basin because the drainage area sizes were larger than 400-sqmi. The Phase II 24-hour ARF curve extends out to 1,000-sqmi and are only applicable to Phase II of the CDOT September 2013 Flood Study.

2. Introduction

Information about extreme precipitation is of interest for a variety of purposes, which include meteorological and hydrologic engineering applications such as dam design, river management, and rainfall-runoff-relations. These entail knowledge on the spatial and temporal variability of precipitation over an area. In order to obtain areal average values for an area, point rainfall amounts are transformed to average rainfall amounts over a specified area. These issues are addressed using depth-area curves which require the use of ARFs. The derivation of ARFs is an important topic that has been dealt with using several methodologies.

The National Ocean and Atmospheric Administration (NOAA) defines an ARF as the ratio between area-averaged rainfall to the maximum depth at the storm center (NOAA Atlas 2, 1973). The most common sources for generalized ARFs and depth-area curves in the United States are from the NOAA Atlas 2 (NOAA Atlas 2, 1973) (Figure 1), and the U.S. Weather

Bureau's Technical Paper 29 (U.S. Weather Bureau, 1957-60). Examples of site specific ARFs and depth-area curves are referenced in the NOAA Technical Report 24 (Meyers and Zehr, 1980) for the semi-arid southwest, the NOAA Technical Memorandum Hydro- 40 (NOAA Hydro-40, 1980) for the semi-arid southwest, and the city of Las Vegas, Nevada (Gou, 2011).

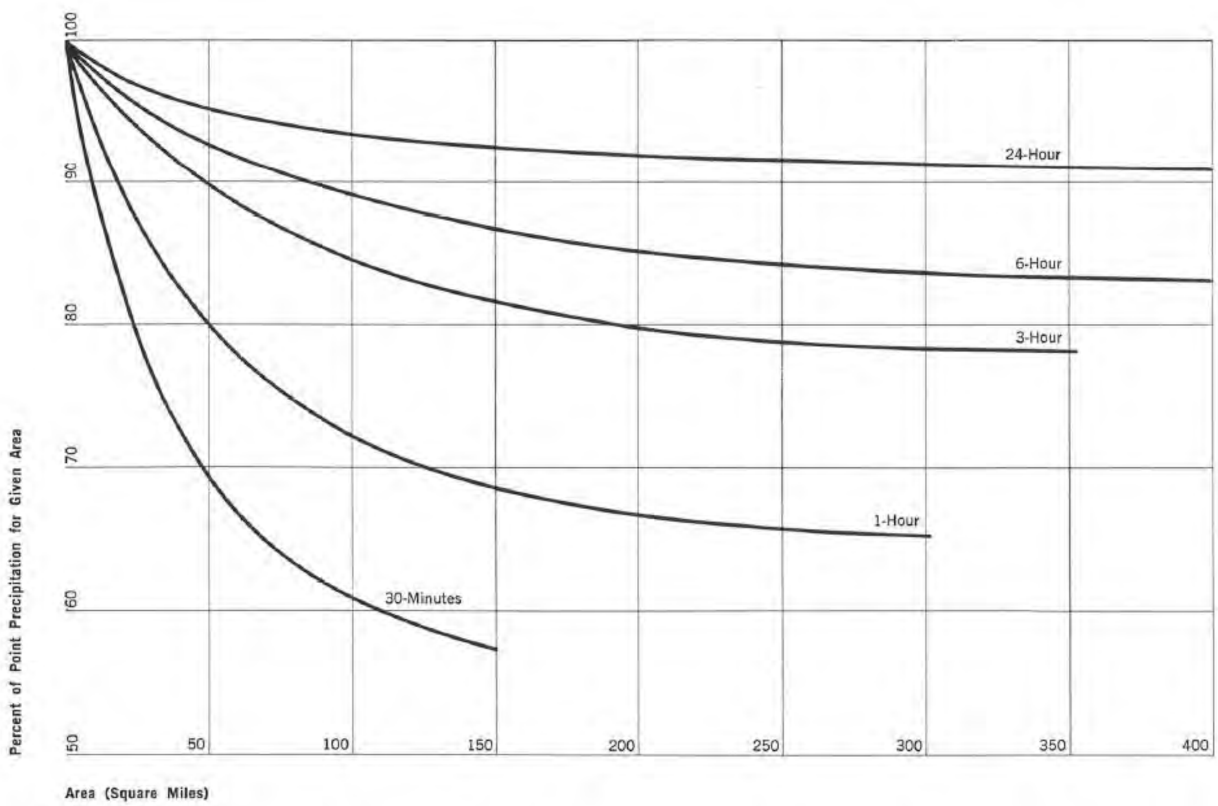


Figure 1: NOAA Atlas 2 Volume 3 ARF curves

There are two common methods for deriving ARFs: geographically fixed and storm centered. Geographically fixed ARFs originate from rainfall statistics, whereas storm centered ARF values are based on discrete rainfall events. Geographically fixed ARFs relate the precipitation depth at a point to a fixed area. The representative point is the mean of annual maximum point rainfall values at gauged points located within the network (U.S. Weather Bureau, 1957-60; NOAA Atlas 2, 1973; Osborn et al., 1980). This is a hypothetical point rather than a point for a particular location. The areas within the network are known beforehand and are both fixed in time and space (U.S. Weather Bureau, 1957-60; Osborn et al., 1980). With geographically fixed ARFs, the storm center does not correspond with the center of the location and does not need to fall within the area at all (Omolayo, 1993). Geographically fixed ARFs are based on different parts of different storms instead of the maximum point values located at the representative storm centers. A geographically fixed ARF is calculated as:

$$ARF_{Fixed} = \frac{\frac{1}{n}\sum_{j=1}^{n}\hat{R}_j}{\frac{1}{k}\sum_{i=1}^{k}\left(\frac{1}{n}\sum_{j=1}^{n}R_{ij}\right)},$$

where $\hat{R}_j$ is the annual maximum areal rainfall for year *j*, R_{ij} is the annual maximum point rainfall for year *j* at station *i*, *k* is the number of stations in the area, and *n* is the number of years.

The storm centered ARF does not have a fixed area in which rain falls but changes dynamically with each storm event (NOAA Atlas 2, 1973; Gou, 2011). Instead of the representative point being an average, the representative point is the center of the storm, defined as the point of maximum rainfall. Storm centered ARFs are calculated as the ratio of areal storm rainfall enclosed between isohyets equal to or greater than the isohyet value to the maximum point rainfall at the storm center. A storm centered ARF is calculated as:

$$ARF_{center} = \frac{\overline{R}_i}{R_{center}},$$

where $\overline{R}_i$ is the areal storm rainfall enclosed between isohyets equal to or greater than the isohyets, and R_{center} is the maximum point rainfall at the storm center.

3. Methods

AWA calculated ARFs using a storm centered depth-area approach based on gridded hourly rainfall data from the Storm Precipitation Analysis System (SPAS). SPAS has demonstrated reliability in producing highly accurate, high resolution rainfall analyses during hundreds of post-storm precipitation analyses (Tomlinson and Parzybok, 2004; Parzybok and Tomlinson, 2006). SPAS has evolved into a hydrometeorological tool that provides accurate precipitation data at a high spatial and temporal resolution for use in a variety of sensitive hydrologic applications. AWA and METSTAT, Inc. initially developed SPAS in 2002 for use in producing storm centered Depth-Area-Duration (DAD) values for Probable Maximum Precipitation (PMP) analyses. SPAS utilizes precipitation gauge data, “basemaps” and radar data (when available) to produce gridded precipitation at time intervals as short as 5-minutes, at spatial scales as fine as 1-km^2 and in a variety of customizable formats. To date, (January 2015) SPAS has analyzed over four-hundred storm centers across all types of terrain, among highly varied meteorological settings and with some events occurring over 100-years ago. For more detailed discussions on SPAS and DAD calculations refer to (Tomlinson et al., 2003-2012, Kappel et al., 2012-2014).

4. September 2013 Basin ARFs

The September 2013 can be classified as an upslope synoptic storm event associated with an area of low pressure to the east/southeast causing the air to flow into the Front Range (upslope) from the Midwest and Southern Plains. This air was forced to lift by both interaction with the terrain and the lift associated with the storm system. The storm event exhibited low to moderate intensity rainfall that occurred over long durations and contained periods of higher intensity rainfall. A detailed description of the meteorology associated with the storm can be found at http://coflood2013.colostate.edu/meteo.html.

The Colorado September 8-17, 2013 rainfall event was analyzed using the SPAS (SPAS number 1302) for use in several PMP and hydrologic model calibration studies (Figure 2). The hourly gridded rainfall data, based on gauge adjusted radar data, were used to derive basin specific ARFs. Four basins (Table 1) located along the Colorado Front Range were used to derive the 24-hour basin specific ARFs. The SPAS DAD program was used to derive basin specific 24-hour depth-area values. The point maximum (1-mi^2) 24-hour rainfall (within each basin) was selected as the storm center. The maximum average basin 24-hour rainfall depth for standard area sizes (1-, 10-, 25-, 50-, 100-, 200-, 300-, 400-, and 500-mi^2) up to the basin total area were calculated. The point maximum and maximum areal averages depths were used to calculate the basin specific ARFs.

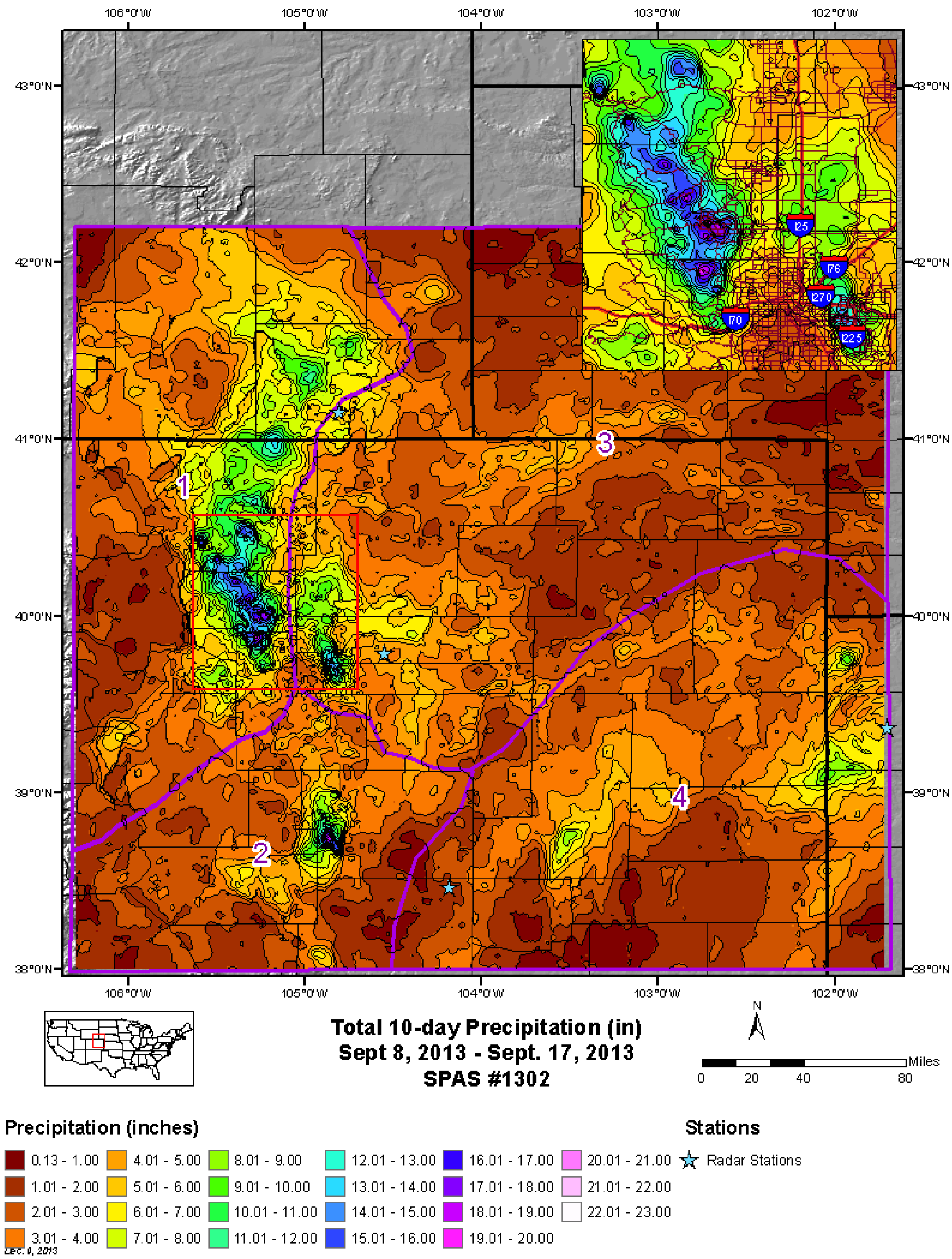


Figure 2: SPAS total rainfall for the Colorado September 8-17, 2013 storm event.

Table 1: Basin specific 24-hour ARFs for the September 2013 storm event

Basin	Area (mi^2)	ARF
Boulder Creek	446	0.352
St. Vrain Creek	982	0.384
Big Thompson River	630	0.357
Thompson River	827	0.355

The four calculated basin specific 24-hour ARFs for the September 2013 event were compared to NOAA Atlas 2 24-hour ARF curve and to the HMR 55A Orographic C 24-hour ARF curve (Hansen et al., 1988) (Figure 3). Table 1 shows the basin specific 24-hour ARF values. As expected, the four September 2013 basin ARF values have a significantly larger reduction in rainfall than published NOAA Atlas 2 and HMR 55A ARFs.

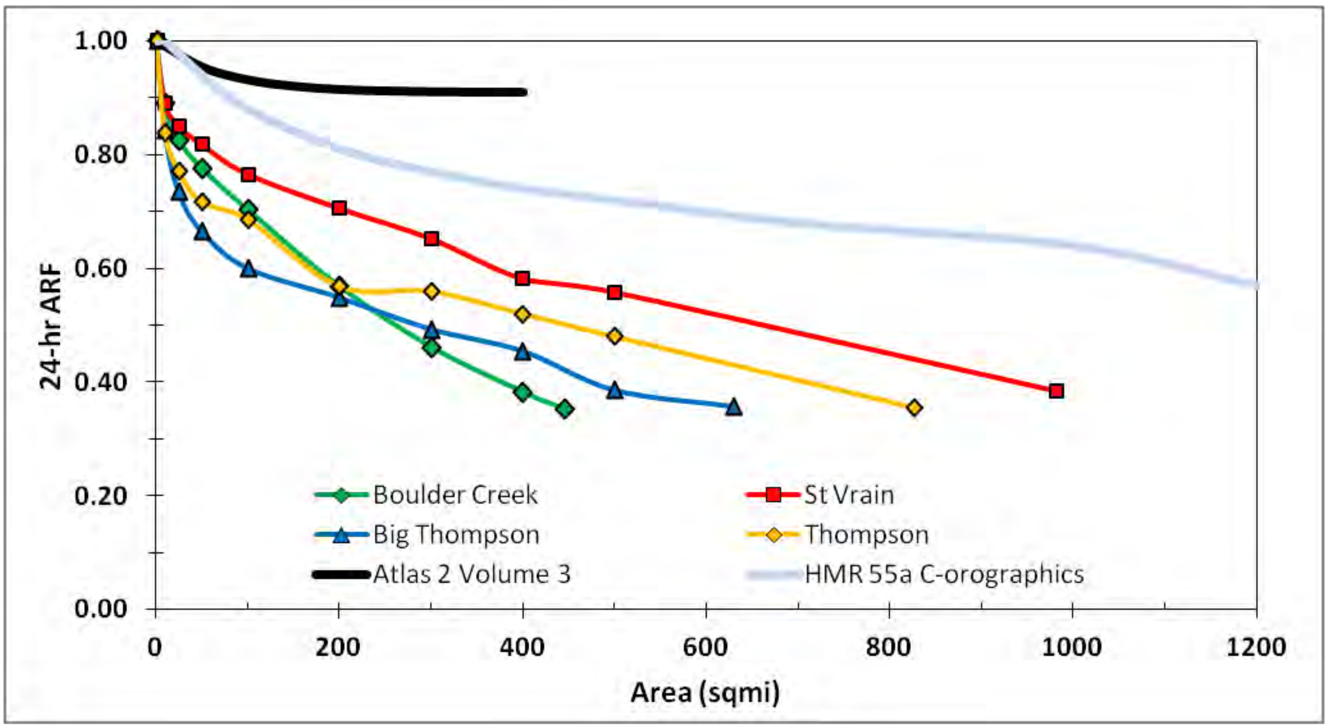


Figure 3: Basin specific 24-hour ARFs for the September 2013 event compared to NOAA Atlas 2 24-hour ARF curve and to the HMR 55A Orographic C 24-hour ARF curve

5. Colorado Front Range ARFs

Initially, 28 SPAS storm center DAD zones were identified to have occurred over similar meteorological and topographic regions as the September 2013 storm event that occurred along the Colorado Front Range (Figure 4). The initial list was refined to nine storm centers that had storm characteristics representative of an upslope synoptic event similar to the four basins analyzed in this study. Each storm event utilized in this analysis represented meteorological and topographical characteristics that were similar to each other and similar to the September 2013 event. All storms were of the synoptic type (aka HMR 55A General Storm). Each were associated with an area of low pressure to the east/southeast causing the air to flow into the Front Range (upslope) from the Midwest and Southern Plains. This air was forced to lift by both interaction with the terrain and the lift associated with the storm system. All nine events used exhibited low to moderate intensity rainfall, which occurred over long durations, interspersed with periods of higher intensity rainfall. Storm events removed from the initial list were representative of shorter duration, higher intensity storms, i.e. local storms/thunderstorms or occurred in significantly different topographical settings. This allowed the ARF data derived during this analysis to represent the same storm type and meteorological setting as occurred during the September 2013 event. The final set of nine storm centers (Table 2 and Figure 5) were used to derive 24-hour storm center ARFs.

The point maximum (1-mi^2) 24-hour rainfall (within each SPAS DAD zone) was selected as the storm center. The maximum average 24-hour rainfall depth for standard area sizes (1-, 10-, 25-, 50-, 100-, 150-, 200-, 250-, 300-, 350-, 400-, 450-, 500-, 700-, and 1000-mi^2) were calculated. The point maximum and maximum areal averages depths were used to calculate each events specific ARFs. Based on the nine events, an average ARF for each area size was calculated. Several other ARF curves were created for comparison purposes: maximum, minimum, +1-sigma, 85% confidence, 90% confidence, and 95% confidence. Based on discussions with the CDOT flood review committee and Nolan Doesken (Colorado State Climatologist), the 85% confidence ARF ($ARF_{85\%}$) was selected as the best representation of ARFs along the Colorado Front Range. The 85% confidence limit ARF was selected based on several justifications. Similar use of the 85% percentile was employed in the HMRs in determining various Depth-Area and Depth-Duration relationships. Further, during the site-specific Probable Maximum Precipitation (PMP) study for Lewis River, WA, the 85% was used to determine which Depth-Duration relationship were appropriate for deriving PMP values at durations other than 24-hours. That study was accepted for use by Federal Energy Regulatory Commission (Tomlinson et al., 2011). In addition, the 85% ARF curve is similar to independent study in HMR 55A (see Figure 6 and Table 3 below). Finally, the 85% ARF curve adds a level of conservatism compared to using the average ARF which is typical in most ARF studies. The final equation used to represent Colorado Front Range 24-hour ARFs is:

$$ARF_{85\%} = 0.646 + 0.354 * \exp(-kA)$$

where $ARF_{85\%}$ is the 85% confidence ARF, k is a decay coefficient, and A is storm area in square miles. The average ARF curve and final 85% confidence ARF curve are shown in Figure 6. The NOAA Atlas 2 ARF curve and HMR 55A Orographic C curve are also shown for comparison (Figure 6 and Table 3).

Table 2: Final SPAS storm centered locations with similar meteorology and topography as the September 2013 storm event used to derive 24-hr ARFs

ID	SPAS ID	Storm Location	Dates	Latitude	Longitude	Max Precipitation	HMR 55A CLASS	HMR 55A SUBUNIT
1	1211	Gibson Dam, MT	Jun. 6-8, 1964	48.3541	-113.3708	19.16	Orographic	Orographic "A"
2	1251	Lake Maloya, NM	May 17-21, 1955	37.0090	-104.3410	14.82	Orographic	Orographic "E"
3	1252	Waterton Red Rock, AB	June 14-21, 1975	49.0875	-114.0458	14.46	Orographic	Orographic "A"
4	1253	Big Elk Meadow, CO	May 3-8, 1969	40.2700	-105.4200	20.01	Orographic	Orographic "C"
5	1302	Northeast Colorado	Sep. 8-17, 2013	40.0150	-105.2650	20.41	Orographic	Orographic "C"
6	1320	Calgary, AB	Jun.19-22, 2013	50.6350	-114.8550	13.78	Orographic	Orographic "A"
7	1325	Savageton, WY	Sep. 27-Oct. 1, 1923	43.8458	-105.8042	17.56	Nonorographic	Min. Nonorographic "A"
8	1335	Warrick, MT	Jun. 5-10, 1906	48.0791	-109.7041	13.69	Orographic	Orographic "A"
9	1338	Spionkop Creek, AB	Jun. 4-7, 1995	49.1708	-114.1625	14.48	Orographic	Orographic "A"

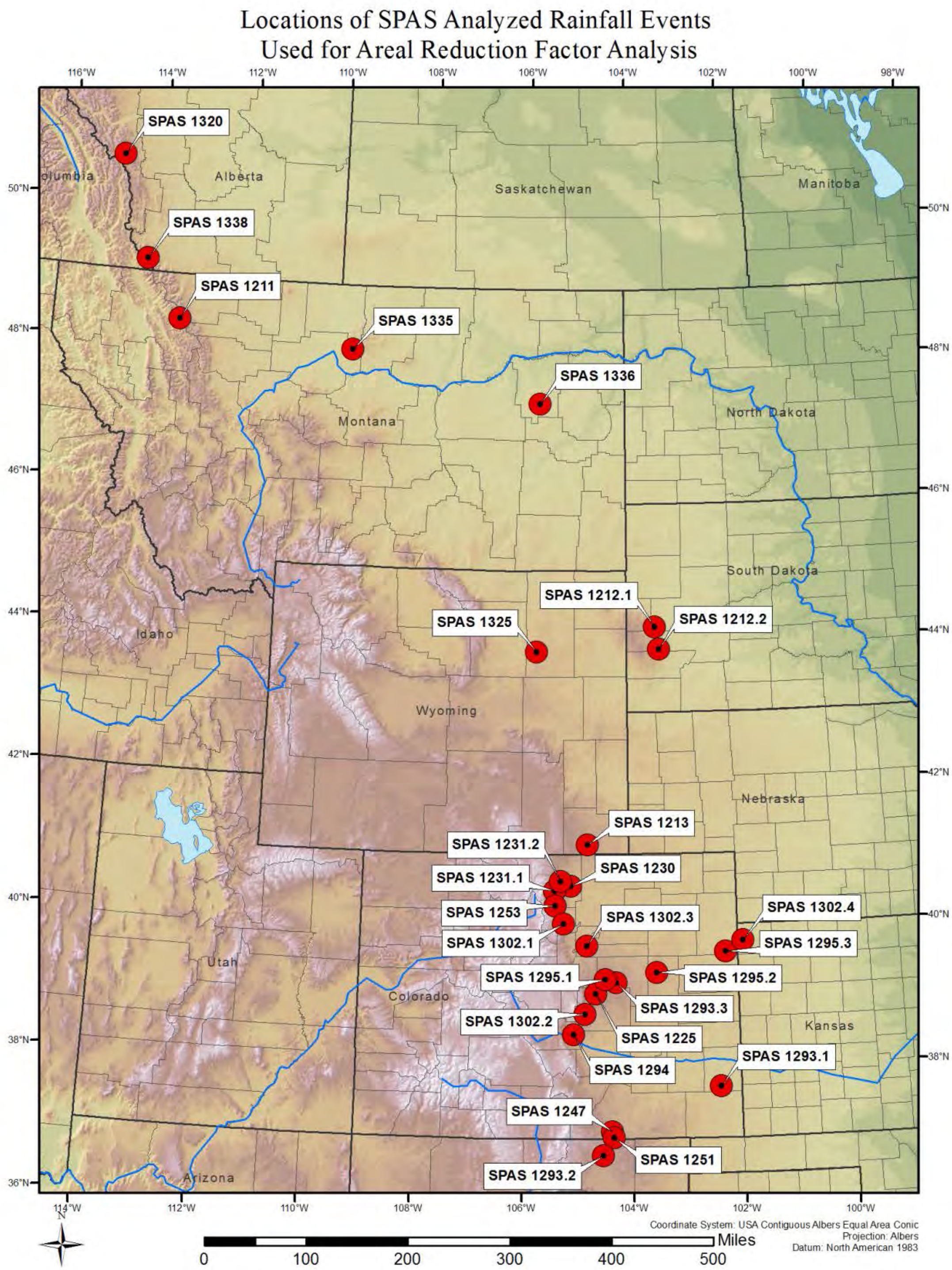


Figure 4: Initial 28 SPAS storm center locations with similar meteorology and topography as the September 2013 storm event

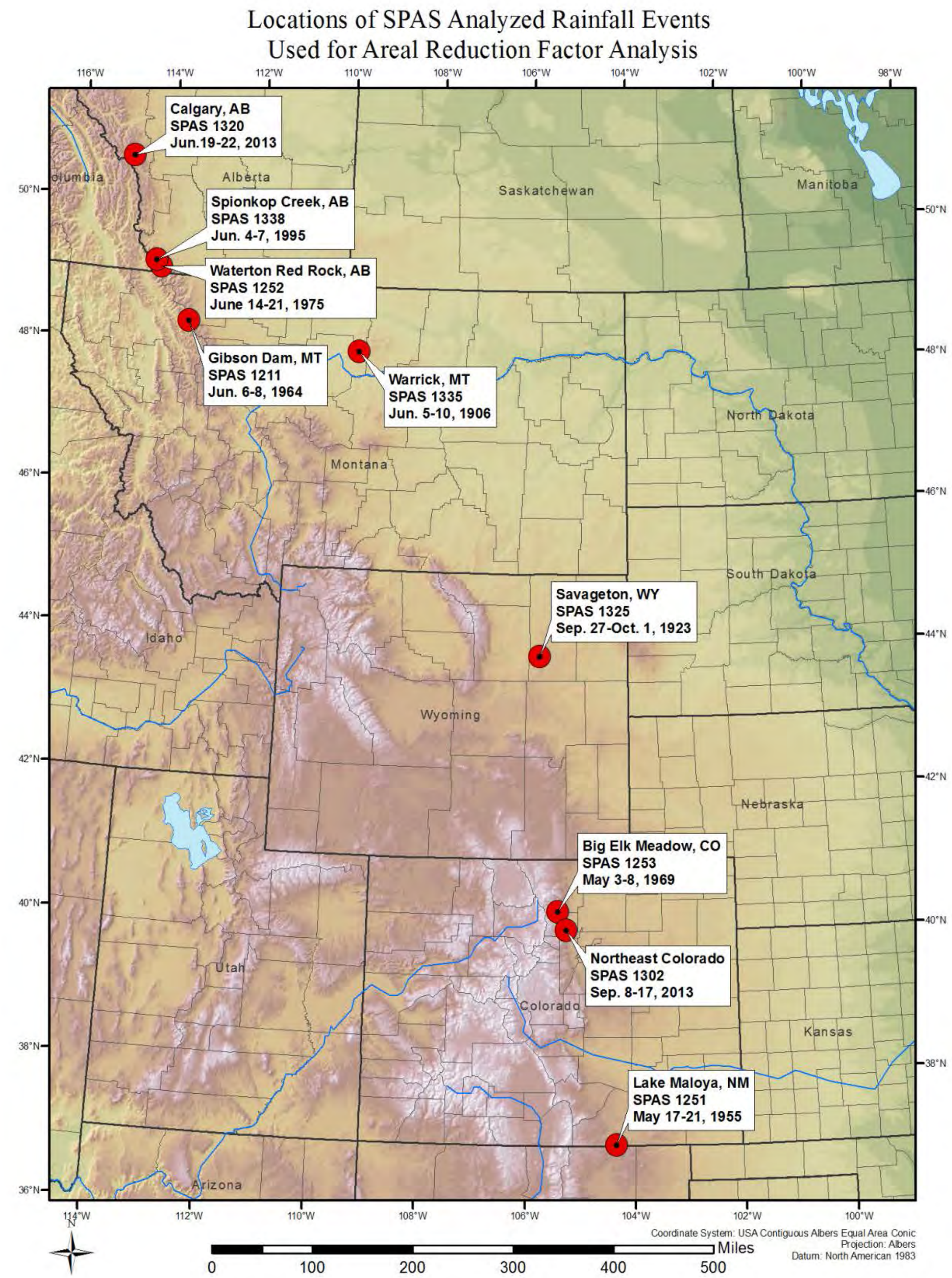


Figure 5: Final SPAS storm center locations used to derive 24-hr ARFs

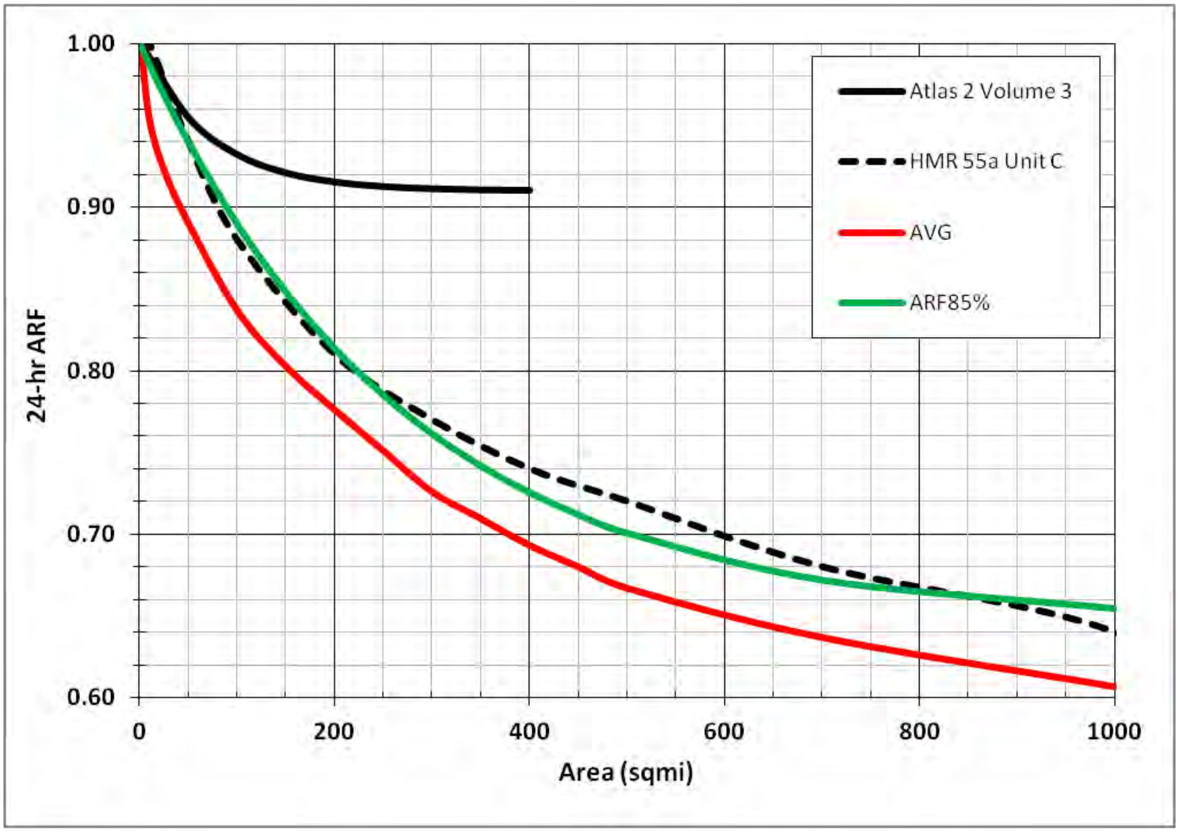


Figure 6: The average 24-hour ARF curve and final 85% confidence 24-hour ARF curve. The NOAA Atlas 2 24-hour ARF curve and HMR 55A Orographic C 24-hour ARF curve are shown for comparison.

Table 3: Comparison of 24-hour ARF values. AVG is the average ARF, ARF85% is the 85% confidence ARF, HMR 55A is HMR 55A Orographic C ARF, and Atlas 2 is NOAA Atlas 2 ARF.

*** General Storms 24-hr ARF				
Area (sqmi)	AVG	ARF85%	HMR 55a	Atlas 2
1	1.00	1.00	1.00	1.00
10	0.95	0.99	1.00	-
25	0.92	0.97	0.97	-
50	0.89	0.94	0.94	0.95
100	0.84	0.89	0.88	0.93
150	0.80	0.85	0.85	0.92
200	0.78	0.81	0.81	0.92
250	0.75	0.78	0.79	0.91
300	0.73	0.76	0.77	0.91
350	0.71	0.74	0.76	0.91
400	0.69	0.73	0.74	0.91
450	0.68	0.71	0.73	-
500	0.67	0.70	0.72	-
700	0.64	0.67	0.68	-
1000	0.61	0.65	0.64	-

6. Results

The final derived $ARF_{85\%}$ values created significantly larger reductions in point rainfall as compared to NOAA Atlas 2. Because results of the Phase I CDOT September 2013 Flood Study are not being changed as part of this work, a smooth transition between NOAA Atlas 2 24-hour ARF and the derived 24-hour $ARF_{85\%}$ is needed for Phase II basins. The largest basin used in Phase I was 315-mi^2 and the smallest basin used in Phase II was 446-mi^2. In order to maintain consistency between Phase I results and Phase II results, a linear transition was applied between NOAA Atlas 2 315-mi^2 ARF value and $ARF_{85\%}$ 500-mi^2 (Figure 7 and Table 4). Based on the areal limitations of NOAA Atlas 2, the larger point precipitation reductions based on $ARF_{85\%}$, and maintaining consistency with Phase I study the linear transition between NOAA Atlas 2 315-mi^2 ARF value and $ARF_{85\%}$ 500-mi^2 was chosen for application of Phase II of the CDOT September 2013 Flood Study. In addition, application of this transition in the hydrologic modeling for the four basins investigated showed good agreement and acceptable results. The final 24-hour $ARF_{85\%}$ curve is compared to the four basin specific 24-hour ARF curves for the September 2013 event (Figure 8).

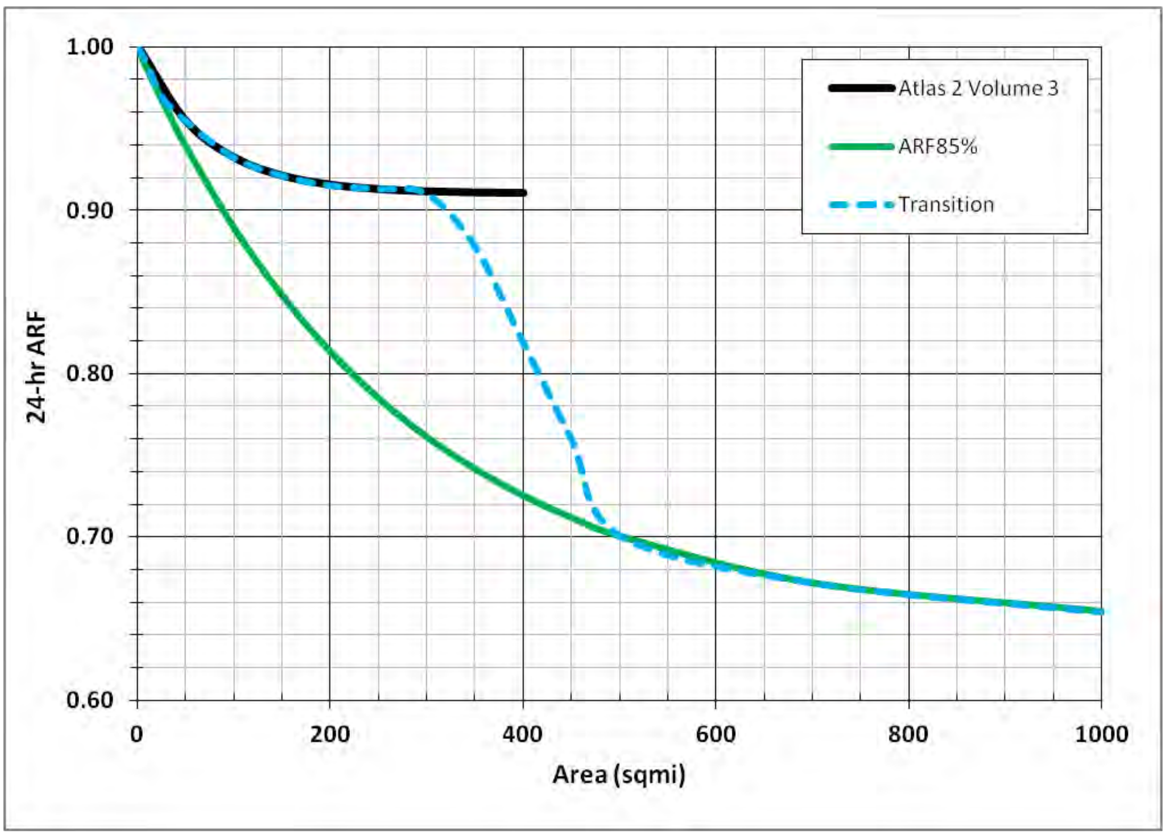


Figure 7: Final 24-hr ARF curve with transition between NOAA Atlas 2 and AWA $ARF_{85\%}$

Table 4: Comparison of final 24-hour ARF values. ARF85% is the 85% confidence ARF. Transition is the transition between NOAA Atlas 2 and ARF85%, and Atlas 2 is NOAA Atlas 2 ARF.

*** General Storms 24-hr ARF			
Area (sqmi)	ARF85%	Transition	Atlas 2
1	1.00	1.00	1.00
10	0.99	0.99	-
25	0.97	0.97	-
50	0.94	0.95	0.95
100	0.89	0.93	0.93
150	0.85	0.92	0.92
200	0.81	0.92	0.92
250	0.78	0.91	0.91
300	0.76	0.91	0.91
350	0.74	0.88	0.91
400	0.73	0.82	0.91
450	0.71	0.76	-
500	0.70	0.70	-
700	0.67	0.67	-
1000	0.65	0.65	-

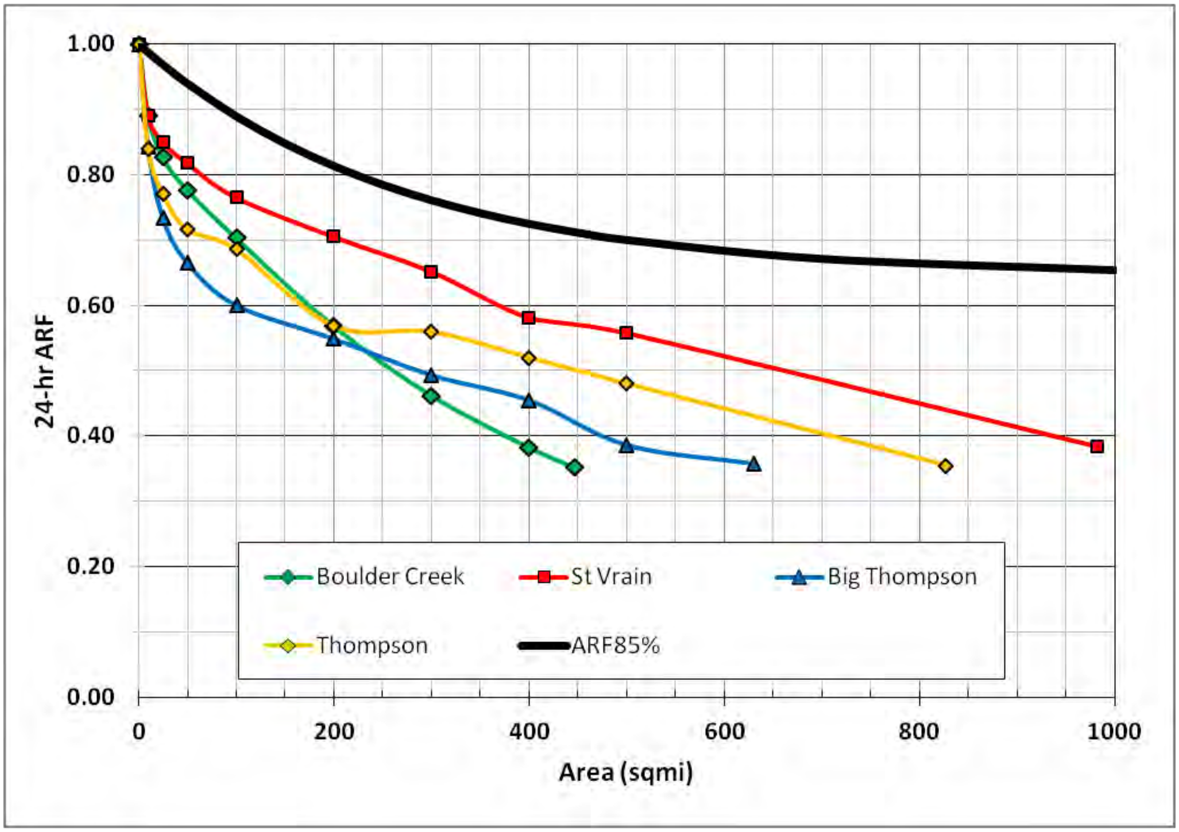


Figure 8: 24-hour ARF curve compared to basin specific ARFs for the September 2013 event

7. Conclusion

The final 24-hour $ARF_{85\%}$ values create significantly larger reductions of point rainfall at larger area sizes as compared to NOAA Atlas 2. These are based on actual storms that have occurred along the Front Range of the Rockies and of similar storm type as the September 2013 event. These updated ARF values produce more realistic and representative point to areal reductions for synoptic storm events along the Colorado Front Range. The 24-hour $ARF_{85\%}$ curve is only representative and applicable for large synoptic and orographic storm events similar to the September 2013 storm event in Colorado. Future hydrology and engineering flood studies should utilize a more site and duration specific ARF curve based on procedures applied in this study and storms specific to a given locations. This investigation has shown that the generalized ARF curves provided in NOAA Atlas 2 are not necessarily representative of spatial rainfall accumulations along the Colorado Front Range.

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Appendix G
Digital Data
(electronic only)

September 2013 Rainfall Data (Applied Weather Associates, 2014)
NOAA Rainfall Depths
ESRI ArcGIS Shapefiles
HEC-SSP Files
Calibrated HEC-HMS Hydrologic Model
Predictive HEC-HMS Hydrologic Model
Peak Discharge Table and Profile
Outfall Hydrographs for St. Vrain Creek Modeling [DARF = 0.66]