Geotechnical Extreme Events Reconnaissance

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Report
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GEOTECHNICAL EFFECTS OF INTENSE PRECIPITATION ON AUGUST 9, 2013, ON SLOPES ABOVE MANITOU SPRINGS, COLORADO, THAT WERE BURNED IN THE 2012 WALDO CANYON FIRE

Geotechnical Extreme Events Reconnaissance (GEER) Association
Reconnaissance Dates: August 16 to 18, 2013

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TABLES AND FIGURES FOR THE GEER REPORT ON MANITOU SPRINGS

TABLES

FIGURES

GEOTECHNICAL EFFECTS OF INTENSE PRECIPITATION ON AUGUST 9, 2013, ON SLOPES ABOVE MANITOU SPRINGS, COLORADO, THAT WERE BURNED IN THE 2012 WALDO CANYON FIRE

1.0 Introduction

A team from the Geotechnical Extreme Events Reconnaissance (GEER) Association, supported by the National Science Foundation, mobilized on August 16, 2013, to document the effects of high-intensity precipitation that fell on August 9, 2013 on slopes above the Manitou Springs area west-northwest of Colorado Springs that burned in the 2012 Waldo Canyon fire (Figure 1.1). Steering Committee members of GEER monitor news sources for extreme events that may meet GEER's mission to document geotechnical effects of extreme events that have the potential for short-lived effects to be documented with the intent of advancing or verifying understanding of geotechnical processes.

Early news reports of damage in Manitou Springs were enhanced substantially by numerous videos take from many perspectives by individuals with Smartphones during the event. The brunt of the storm hit at approximately 5:30 PM Mountain Daylight Time on Friday afternoon, August 9, 2013. Residential and commercial structures in the downtown Manitou Springs area were damaged; local streets and U.S. Highway 24 were closed by water and sediment. One person died and many others were rescued from vehicles that were swept down the highway that became a river by the flash flood. The GEER Steering Committee members considered the news reports of debris flows accompanied by videos of sediment-laden flood flows, along with the one-year-old burned slopes, and decided to mobilize a small team of mostly Colorado-based geotechnical professionals to conduct a reconnaissance.

The GEER team (Table 1.1) was comprised of one consultant, two university professors, and one federal agency engineer supported by two geologists from the U.S. Geological Survey who specialize in investigating and predicting post-wildfire sediment discharge, particularly debris flows. One of the university professors is a younger GEER member. The consultant and the federal agency members are both members of the GEER Steering Committee. The GEER team members have a strong background in engineering geology and geotechnical engineering.

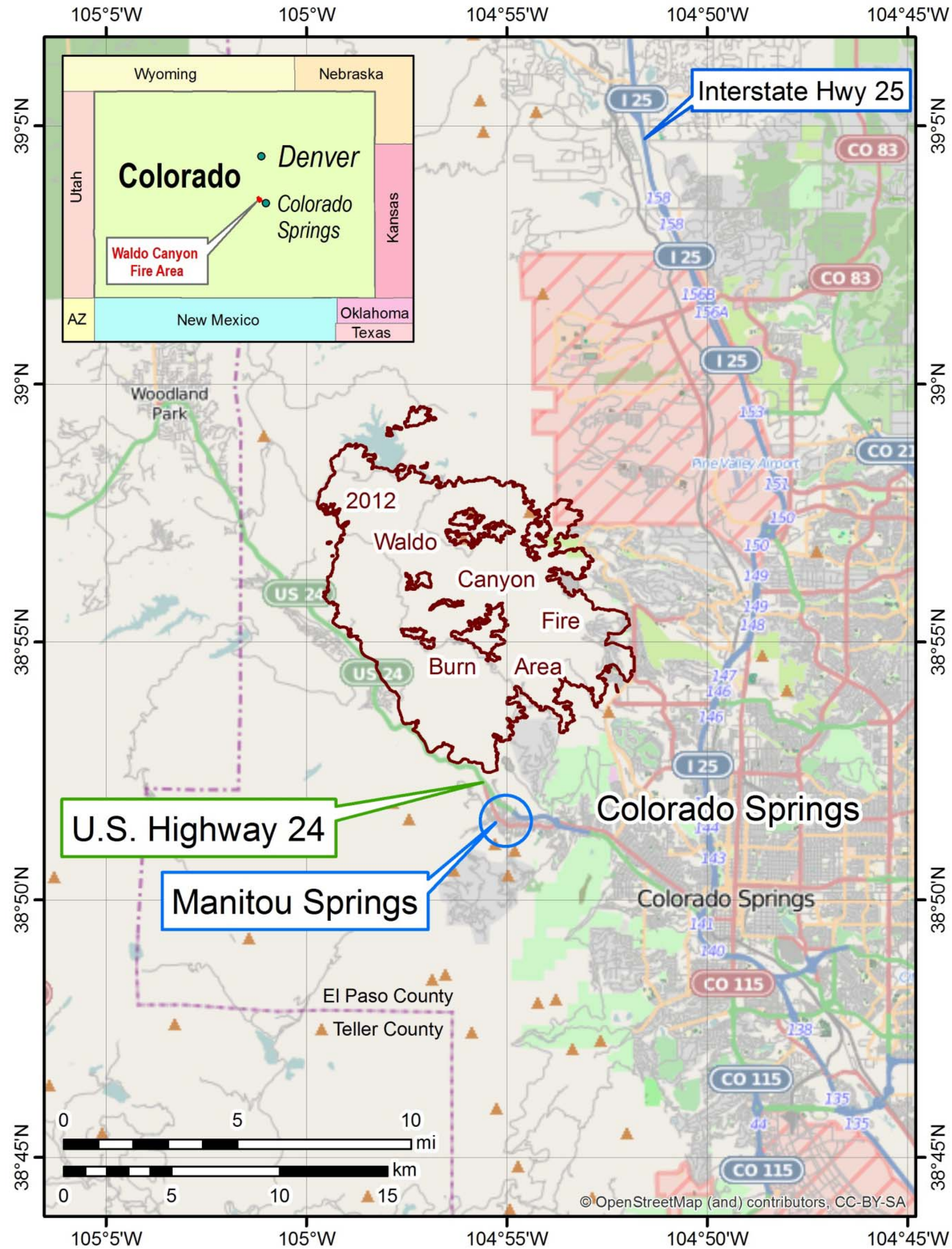


Figure 1.1. Location map showing the 2012 Waldo Canyon Fire perimeter, Manitou Springs, and U.S. Highway 24.

Table 1.1. Individuals involved with the August 9, 2013, Manitou Springs storm damage GEER reconnaissance.

Name	Affiliation	Role
Scott Anderson, Ph.D.	Federal Highway Administration, Denver, CO	Geotechnical Engineer and Engineering Geologist, Team Member
Shideh Dashti, Ph.D.	University of Colorado, Boulder, CO	Geotechnical Engineer, Younger Team Member
Joseph Gartner, Ph.D.	U.S. Geological Survey, Golden, CO	Geologist, Advisor to GEER Team
Jason Kean, Ph.D.	U.S. Geological Survey, Golden, CO	Geologist, Advisor to GEER Team
Jeffrey Keaton, Ph.D.	AMEC Americas, Los Angeles, CA	Engineering Geologist and Geotechnical Engineer, Team Leader
Paul Santi, Ph.D.	Colorado School of Mines, Golden, CO	Engineering Geologist, Team Member

2.0 BACKGROUND

This GEER report focuses on a relatively small area northwest of Colorado Springs near Manitou Springs where a cloudburst storm on August 9, 2013, dropped high-intensity precipitation on burned watershed slopes. This background information regarding geology, topography, climate, the June 2012 Waldo Canyon fire, and post-fire precipitation events in July and August 2013 provide context for descriptions of geotechnical effects in subsequent sections.

2.1. Geology, Topography, and Climate

The geology of the Manitou Springs area consists of bedrock, surficial deposits, and geologic structure. The bedrock formations consist of metamorphic (gneissic) rocks, igneous (granitic) rocks, and sedimentary rocks. The general distribution of rock types and surficial deposits is shown in Figure 2.1. The primary sources of geologic information are publications by Scott et al. (1978), Morgan et al. (2003), Keller et al. (2005), and Rust (2012). The main parts of the Rocky Mountains of Central Colorado that are relevant to this GEER reconnaissance are the Rampart Range, Pikes Peak Massif, and Fountain Creek Canyon which separates the Rampart Range from Pikes Peak Massif.

Two major fault zones are present in the area of the 2012 Waldo Canyon Fire: the Ute Pass fault zone and the Rampart Range fault zone, both of which are labeled in Figure 2.1. Erosion along the Ute Pass fault zone created the canyon in which Fountain Creek flows. The Rampart Range fault zone marks the east edge of the Rocky Mountains with moderately to steeply dipping sedimentary rock formations and surficial deposits to the east marking the Denver Basin part of the Great Plains.

Nearly the entire 2012 Waldo Canyon fire perimeter lies within the Rampart Range, with a small area of the burn extending to the east side of the Rampart Range fault zone onto sedimentary rocks or surficial deposits (“M” or “Q” on Figure 2.1). It is apparent that 90 percent or more of the burn area lies within granitic rocks (“Y” on Figure 2.1). The southeast limit of the burn lies on metamorphic rocks (“X” on Figure 2.1) and sedimentary rocks (“P” on Figure 2.1).

Surficial deposits on slopes are important because they support the vegetation on the slopes that burned, can respond to the heat of the fire, and produce sediment by erosion that contributes to damage in cloudburst storms. Alluvial deposits (silts, sands, gravels) accumulate in stream channels and on floodplains at varying rates; these deposits are available for erosion and remobilization during flash floods. Partially dissected remnants of older gravel deposits are present along Fountain and Monument Creek and the piedmont. Alluvial (fluvial) processes are dominant in stream channels and on flood plains, whereas gravity (colluvial) and sheetwash processes are dominant on ungullied hillslopes. Climate processes (freezing-thawing, wetting-drying, heating-cooling) act on mountain slopes, including exposed bedrock, and can produce substantial amounts of loose soil material (dry ravel) that moves downslope mainly by gravity, gradually and progressively. Surficial deposits and bedrock geology was mapped in Waldo Canyon by Rust (2012) as a part of the 2012 Waldo Canyon Burned Area Emergency Response (BAER) team report.

Different types of hazardous geologic processes have been mapped by the Colorado Geological Survey, including debris flows. Past debris flow activity has been recognized in the Manitou Springs region. Intense rainfall on steep slopes underlain by shallow bedrock can produce substantial runoff. Severe wildfire on steep drainage-basin slopes produces conditions for enhanced storm water runoff; even moderate storms are expected to produce increased flow volumes and velocities in channels that are capable of transporting sediment eroded from the slopes. Intense rainfall and increased runoff volume results in high potential for surficial deposits on steep slopes to move into drainages and be transported downstream. Large sediment and debris loads could become deposited within the lower-gradient channel reaches and at drainage devices, such as corrugated metal pipe or concrete box culverts. Channel capacities that are exceeded can result in peak discharge and debris being intercepted by federal, state, county, and private roadways and being directed into downstream residential and commercial areas causing damage to property and threatening life and safety.

The Köppen-Geiger climate classification for Colorado Springs is BSk (Kottek et al. 2006) which denotes arid climate, Steppe precipitation, and cold arid temperature. The nearby foothills are classified as Dfb and the higher mountains are classified as Dfc which denote snow climate, fully humid precipitation, and warm summer temperature or cool summer temperature, respectively.

Climate data in the form of monthly 30-year normal precipitation depths from National Climate Data Center (NCDC), National Oceanographic and Atmospheric Administration (NOAA) of U.S. Department of Commerce, for the periods 1971-2000 and 1981-2010 for Colorado Springs Municipal Airport are plotted in Figure 2.2. Similar climate summary data are not available for Manitou Springs; however, Manitou Springs is adjacent to Colorado Springs, but at a slightly higher elevation. It can be seen in Figure 2.2 that the normal precipitation for these two intervals are nearly coincident for January, February, March, July, September, October, November, and December. April, May, and August normal precipitation in 1971-2000 exceeded normal precipitation in 1981-2010. In June, normal precipitation in 1981-2010 exceeded normal precipitation in 1971-2000.

Also plotted in Figure 2.2 are monthly normal precipitation values for the Fountain and Ruxton Park gages for the 30-year interval 1981-2010; the earlier 30-year period was not available on the NCDC normal precipitation webpage. The Fountain gage is on Fountain Creek at a lower elevation than Colorado Springs Municipal Airport but closer to the base of the Front Range. The Ruxton Park gage is at a much higher elevation than the other gages. Figure 2.2 shows that the normal precipitation for June, July, August, and October at the Fountain gage exceeds the Colorado Springs Municipal Airport data, whereas the normal precipitation for the other months are nearly coincident. The Ruxton Park gage normal precipitation generally is higher than the Colorado Springs Municipal Airport gage, except for May and June which are approximately coincident.

The precipitation data from the August 9, 2013, storm are presented discussed in a subsequent section. For comparison to 30-year August normal precipitation depths, the August 9, 2013, daily totals for the four stations with the greatest precipitation are plotted in Figure 2.2.

2.2. Waldo Canyon Fire

The Waldo Canyon Fire initiated on June 23, 2012 and was contained on July 10, 2012 (BAER Report 2012). Approximately 18,247 acres, nearly entirely within foothills and mountains of the Rampart Range, were burned by this fire. The initial Burned Area Emergency Response (BAER) assessment includes an executive summary report, as well as maps of fire progression and burn severity and photographs of the burned areas. Figure 2.3 shows the location and severity of the Waldo Canyon fire, whereas Figure 2.4 provides the soil burn severity map of the burned area (BAER Report 2012). The geologic formations within the burn perimeter (Figure 2.1) are dominated by granitic rock with some metamorphic rock. Runoff and sediment yield were identified as potential hazards within the first 3-7 years following the fire, until vegetation is reestablished on slopes in the majority of the burned area. Potential threats to health and safety of communities in the downstream perimeter of the burned area from increased post-fire watershed responses were identified and treatment options were recommended. The BAER assessment report summarizes recommended post-fire stabilization treatments. Further, as part of a preliminary emergency assessment, and using the burn severity mapping in Figure 2.4, the probability and estimated volume of potential post-wildfire debris flows originating on slopes within the Waldo Canyon Burn Area were estimated by the US Geological Survey (Verdin et al. 2012), as shown in Figures 2.5 and 2.6 and listed in Table 2.1.

2.3. Precipitation and Climate Post Fire

The storm that is the subject of this GEER report occurred on August 9, 2013. However, a storm occurred on July 1, 2013, that also caused local flooding in Manitou Springs. No earlier post-fire flooding was reported. Temperature and precipitation summaries in Colorado Springs following the fire in June of 2012 are shown in Figure 2.7. The temperature trends follow seasonal variations as expected. Total precipitation depths at the Colorado Springs Municipal Airport in the months following the Waldo Canyon fire are summarized in Table 2.2 and compared to monthly normal precipitation. Except for the months of July 2012, September 2012, and February 2013, and the local flooding in July 2013, the months following the Waldo Canyon fire had below normal monthly precipitation, and six of those months had less than 50 percent of normal monthly precipitation. Precipitation in July 2013 was approximately 165 percent of normal for July. The relative dryness through the spring months may have inhibited vegetation regrowth and the July 2013 precipitation may have contributed to antecedent soil moisture conditions on the slopes of the Waldo Canyon burn for the August 9, 2013, storm.

Average monthly temperature and precipitation values for the months of June, July, and August 2009 through 2013 at the Colorado Springs Municipal Airport gage are compared in Figure 2.8. It can be seen in Figure 2.8 that June precipitation exceeded the normal value for

2009 but fell far short of normal in 2010 through 2013. The July precipitation exceeded the normal value in four of the five years in Figure 2.8 and came close to the value in 2010. The August precipitation was substantially below normal in 2009 through 2012 and greatly exceeded the normal value in 2013. The precipitation during July 2013 contributed to antecedent soil moisture for the storm on August 9, 2013, but did not exceed the normal value by a wide margin, suggesting that the rainfall intensity of the August 9, 2013, storm may have been more important than the degree of saturation of the surficial soil deposits on the slopes in the burned watershed.

The August 9, 2013, storm was preceded by a storm on July 1, 2013, that caused local flooding in Manitou Springs. The context of the July 1 and August 9 storm events is provided with cumulative records from two precipitation gages: Lower Waldo Canyon and Manitou Springs (Figures 2.9). The precipitation at Colorado Springs Municipal Airport was substantially below normal for the months of March, April, May, and June 2013 (Figure 2.7); likely, the precipitation at the Lower Waldo Canyon and Manitou Springs gages also was below normal for these months. Approximately 4 inches of precipitation fell at the Lower Waldo Canyon gage and at the Manitou Springs gage between July 1, 2013, and August 8, 2013, (Figure 2.9).

More details about precipitation are presented in Section 3. The assessment of precipitation and climate described in Section 2.3 suggests that the storm of August 9, 2013, may be explained as an effect of weather variability.

2.4. Areas Visited During GEER Evaluation

The GEER team members mobilized on August 16, 2013, and met for the first time in Manitou Springs on that afternoon. Vehicle trips were made in the afternoon of August 16, in the morning and in the afternoon of August 17, and in the morning of August 18 (Figure 2.10). In addition to ground-based reconnaissance trips, a fixed-wing aerial reconnaissance flight was conducted in the afternoon of August 17. GPS track locations and waypoints collected during the reconnaissance are shown in Figure 2.10.

Table 2.1. Estimated probability and volume of potential post-wildfire debris flows in the 2012 Waldo Canyon Burn Area near Colorado Springs, Colorado.

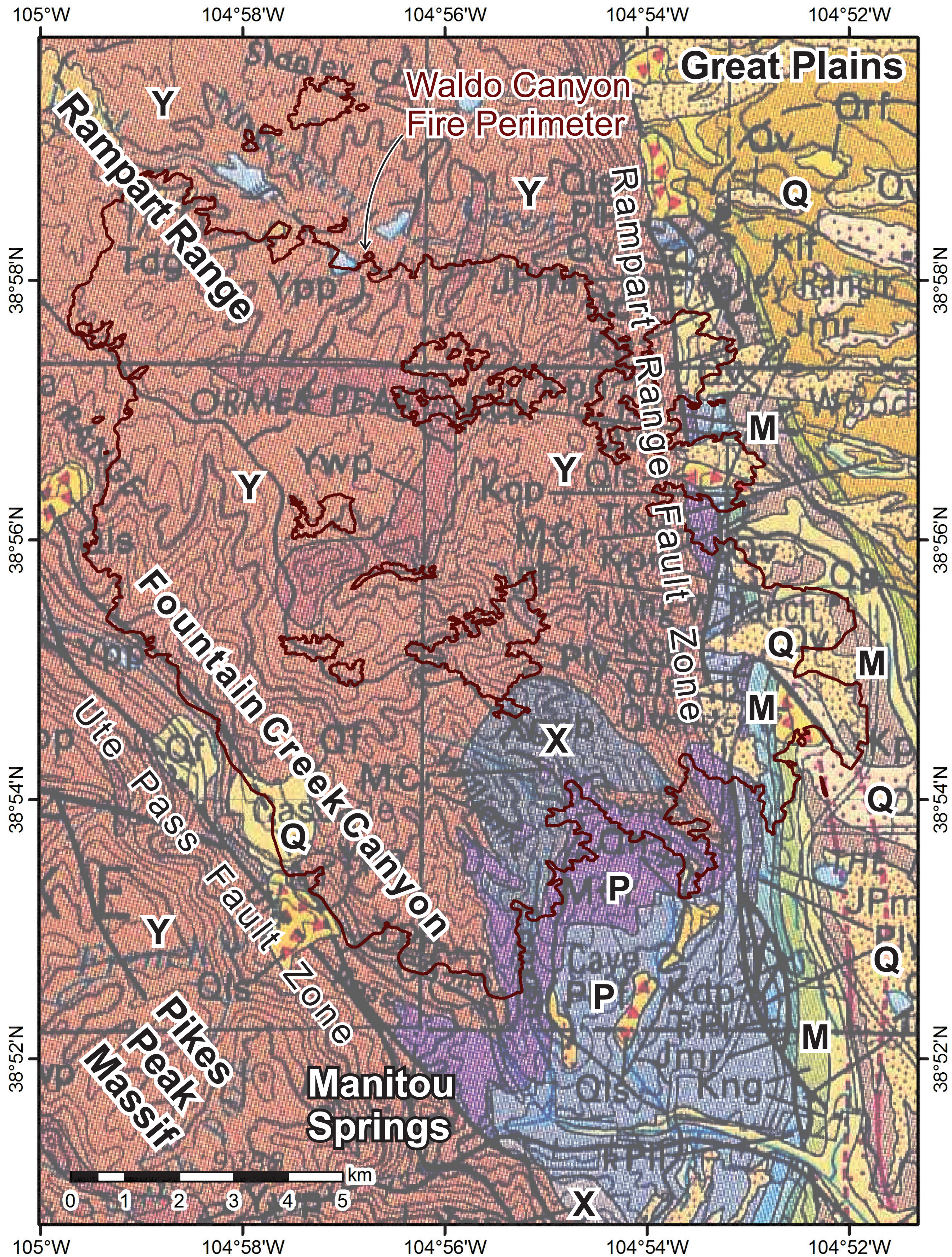
					2-year/1-hour precipitation		10-year/1-hour precipitation		25-year/1-hour precipitation	
		Basin Pour Point *		Drainage	29 mm		42 mm		48 mm	
Basin	Description	Latitude (degrees)	Longitude (degrees)	Area (km^2)	Probability (%)	Volume (m^3)	Probability (%)	Volume (m^3)	Probability (%)	Volume (m^3)
1	Unnamed Creek 1 to Rampart Reservoir	38.9806	-104.9788	0.7	0	2,400	1	2,900	2	3,200
2	Unnamed Creek 2 to Rampart Reservoir	38.9787	-104.9722	0.3	1	1,500	1	1,800	2	2,000
3	Unnamed Creek 3 to Rampart Reservoir	38.9736	-104.9711	1.1	0	2,700	0	3,300	0	3,600
4	Wildcat Gulch	38.9747	-104.9570	3.9	0	6,200	0	7,700	1	8,400
5	Unnamed Creek to Nichol's Reservoir	38.9702	-104.9508	3.4	3	16,000	8	20,000	12	22,000
6	Unnamed Creek to Filtration Plant	38.9728	-104.9404	1.3	10	8,000	21	9,900	29	11,000
7	Unnamed Creek (Devil's Kitchen)	38.9705	-104.9208	2.9	5	17,000	12	21,000	18	23,000
8	Unnamed Creek (Pour Point near Water Tank)	38.9708	-104.9138	3.0	3	16,000	7	20,000	10	22,000
9	Dry Creek	38.9478	-104.8784	3.6	2	16,000	4	20,000	6	22,000
10	Douglas Creek	38.9254	-104.8634	5.5	22	46,000	41	57,000	51	62,000
11	Unnamed Creek (Aquaduct/30th Street)	38.9002	-104.8696	3.4	13	20,000	27	25,000	36	27,000
12	Queens Canyon	38.8949	-104.8895	20.6	24	>100,000	45	>100,000	55	>100,000
13	Williams Canyon	38.8637	-104.9171	6.8	32	62,000	54	77,000	64	84,000
14	Waldo Canyon	38.8764	-104.9320	4.6	31	39,000	53	48,000	63	53,000
15	Unnamed Creek 1 to CO Hwy 24 (W of Milepost 295)	38.8898	-104.9587	1.4	54	11,000	74	14,000	82	16,000
16	Unnamed Creek 2 to CO Hwy 24 (W of Milepost 295)	38.8889	-104.9639	0.5	1	1,800	2	2,200	3	2,500
17	Unnamed Creek 3 to CO Hwy 24 (Cascade)	38.8953	-104.9712	2.0	54	17,000	74	21,000	82	23,000
18	Unnamed Creek 4 to CO Hwy 24 (S of Milepost 293)	38.9052	-104.9712	0.3	15	2,900	30	3,600	40	3,900
19	Unnamed Creek 5 to CO Hwy 24 (NW of Milepost 293)	38.9078	-104.9732	0.7	33	6,200	55	7,700	65	8,500
20	Unnamed Creek 6 to CO Hwy 24 (NW of Milepost 293)	38.9122	-104.9766	0.9	45	8,100	67	10,000	76	11,000
21	Wellington Gulch	38.9171	-104.9851	4.5	48	41,000	69	52,000	78	56,000
22	Sand Gulch	38.9205	-104.9935	2.9	6	16,000	13	20,000	18	22,000

Source: Verdin et al. 2012

*Numbered circles on Figures 2.5 and 2.6

Table 2.2. Summary of monthly total precipitation at Colorado Springs Municipal Airport following the Waldo Canyon Fire. Data from National Climate Data Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Month	Actual Monthly Total Precipitation (in)	Monthly Normal Precipitation (in)	Actual Precipitation as Percentage of Normal
June 2012	0.6	2.50	24.0
July 2012	3.5	2.84	123.2
August 2012	0.2	3.34	6.0
September 2012	1.4	1.19	117.6
October 2012	0.2	0.82	24.4
November 2012	0.1	0.40	25.0
December 2012	0.3	0.34	88.2
January 2013	0.2	0.32	62.5
February 2013	0.9	0.34	264.7
March 2013	0.2	1.00	20.0
April 2013	0.3	1.42	21.1
May 2013	1.1	2.03	54.2
June 2013	0.6	2.50	24.0
July 2013	4.7	2.84	165.5
August 2013	5.7	3.34	170.7



Source of geology map: Scott et al. (1978)

EXPLANATION

Q Quaternary sedimentary deposits; chiefly alluvial silt, sand, and gravel; also includes colluvial, glacial, and mass-wasting deposits

M Mesozoic bedrock; sedimentary rocks, chiefly shale and sandstone with limestone and claystone

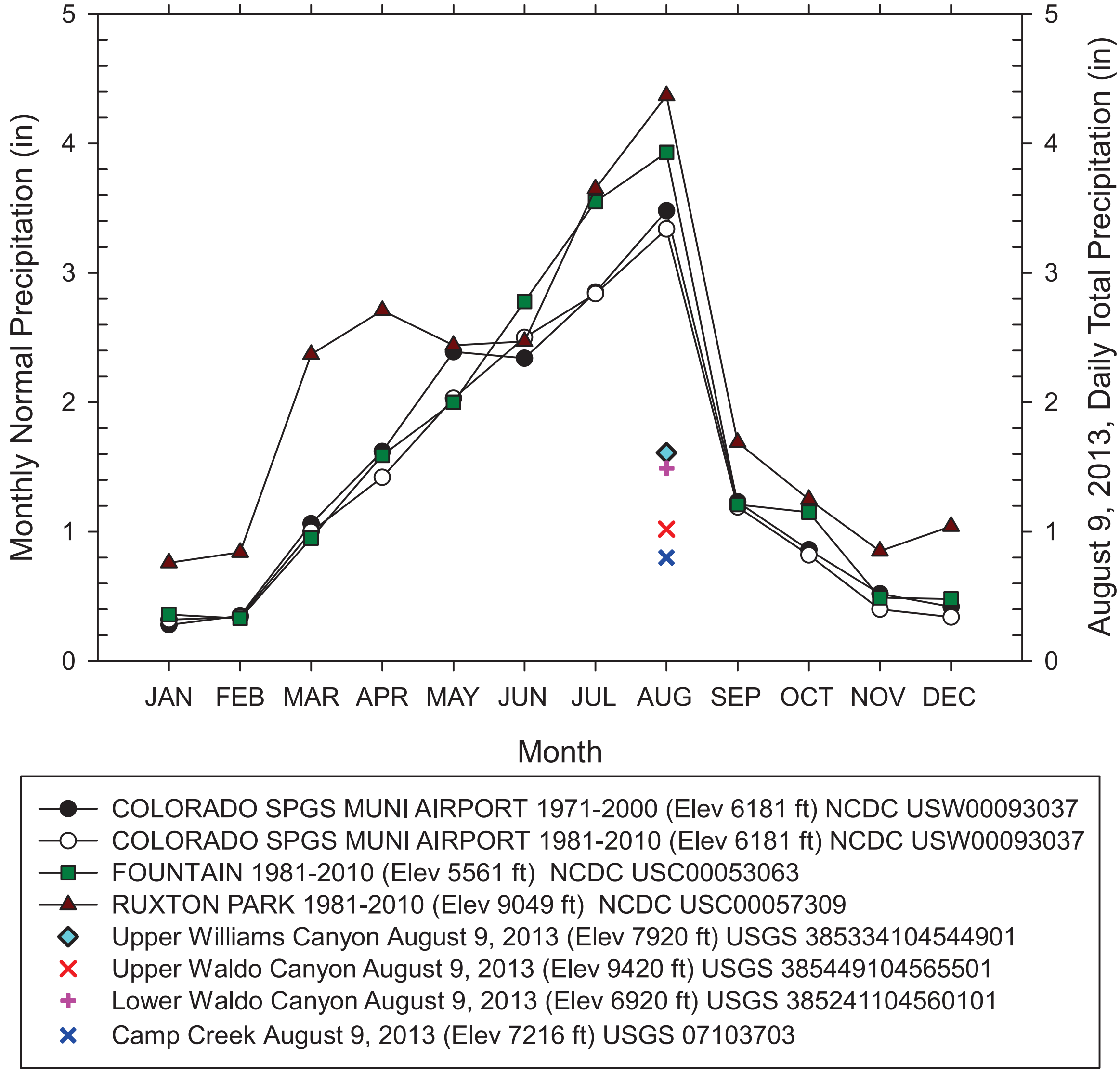
P Paleozoic bedrock; sedimentary rocks, chiefly limestone and sandstone with siltstone and dolostone

Y Precambrian Y bedrock; plutonic rocks, chiefly granite with some mafic dikes, chiefly diabase and quartz diorite

X Precambrian X bedrock; metamorphic and plutonic rocks, chiefly migmatitic gneiss and granodiorite

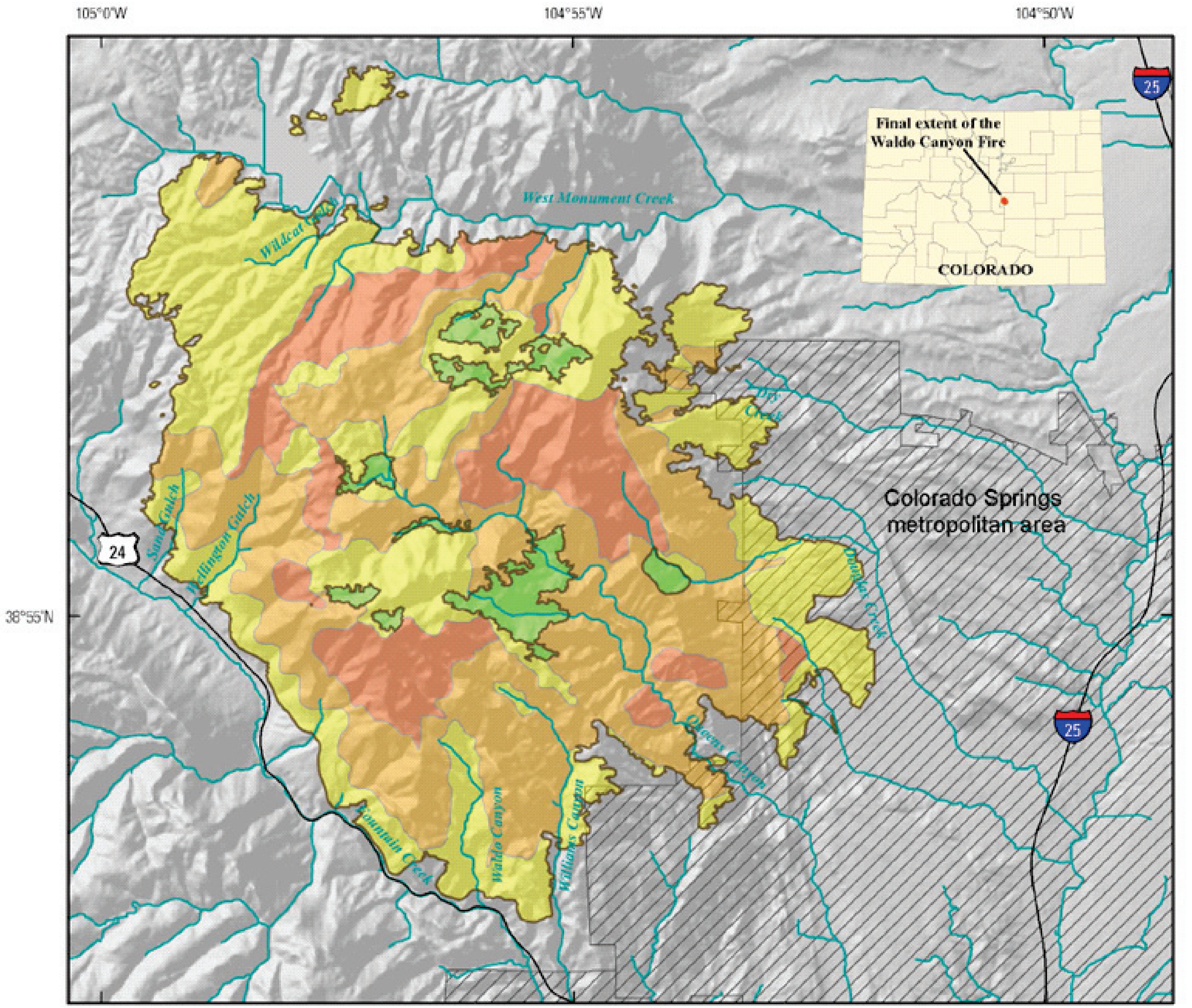
Source of geology explanation: Scott et al. (1978), Morgan et al. (2003), and Keller et al. (2005)

Figure 2.1
Generalized Geologic Map
of the Waldo Canyon Fire Area



Source: National Climate Data Center, NOAA;
http://www.ncdc.noaa.gov/cdo-web/search
U.S. Geological Survey; [http://waterdata.usgs.gov/co/nwis/current?type=customized&sort_key=site_no&sort_key_2=site_no&PARAmeter_cds=STATION_NM,DATETIME,00045,00065,00060&format=sitefile_output&sitefile_output_format=xml&column_name=agency_cd&column_name=site_no&column_name=station_nm&column_name=site_tp_cd&column_name=dec_lat_va&column_name=dec_long_va&column_name=agency_use_cd] string previous lines

Figure 2.2. Normal monthly precipitation at Colorado Springs for the period 1981 to 2010 plus selected daily values for August 9, 2013



Base from U.S. Geological Survey, U.S. Forest Service,
and Colorado Department of Transportation digital data, 2012
Universal Transverse Mercator, Zone 13 North
North American Datum 1983

Source: Vertdin et al. 2012

0 1 2 KILOMETERS
0 1 2 MILES

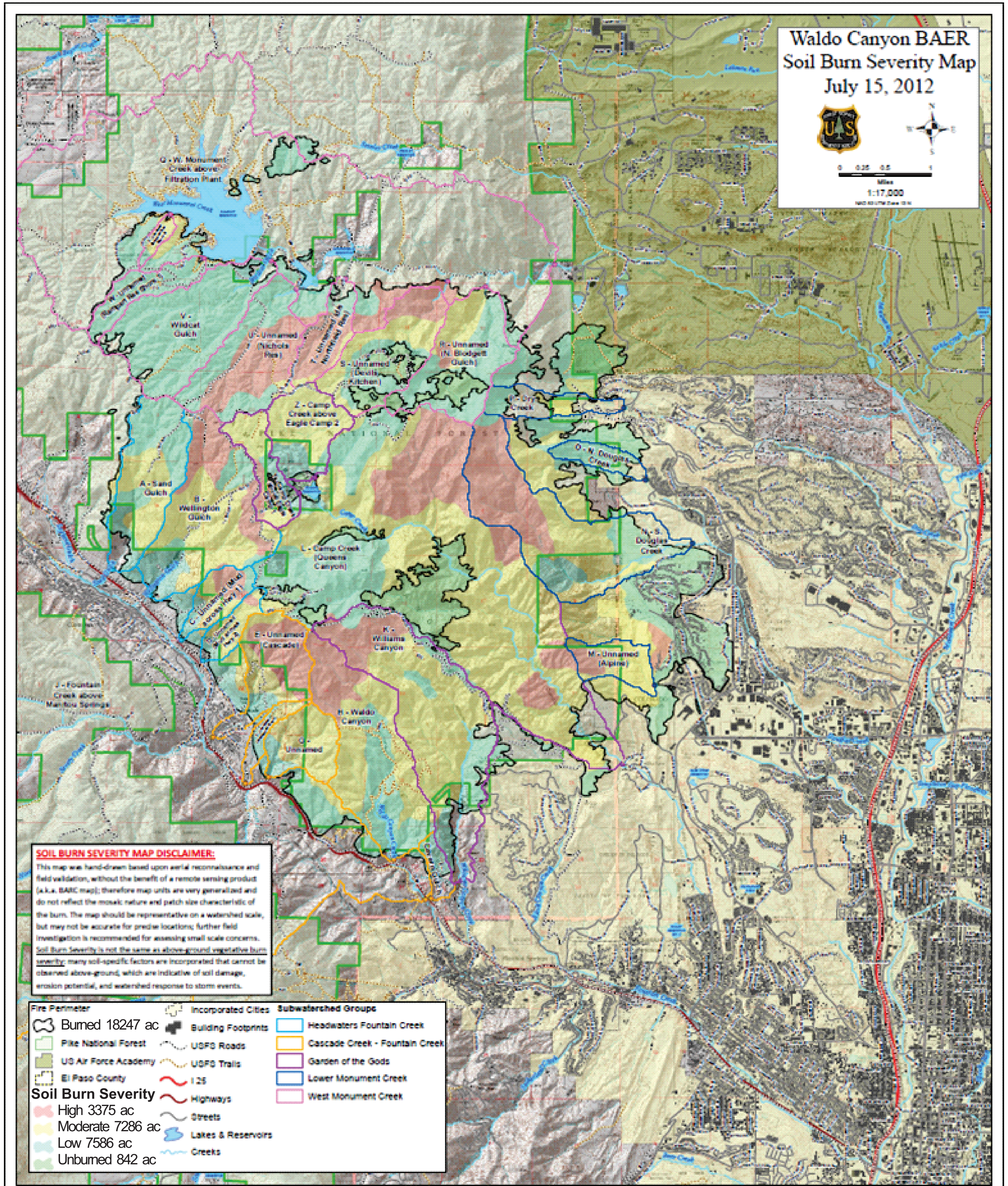
EXPLANATION

Burn severity

- High
- Moderate
- Low
- Unburned

- Final extent of Waldo Canyon Fire
- Urban area

Figure 2.3.
Location and Severity
of the 2012 Waldo Canyon Wildfire
near Colorado Springs, Colorado



Source: BAER Report 2012

Figure 2.4
Soil Burn Severity Map
of the Waldo Canyon Fire

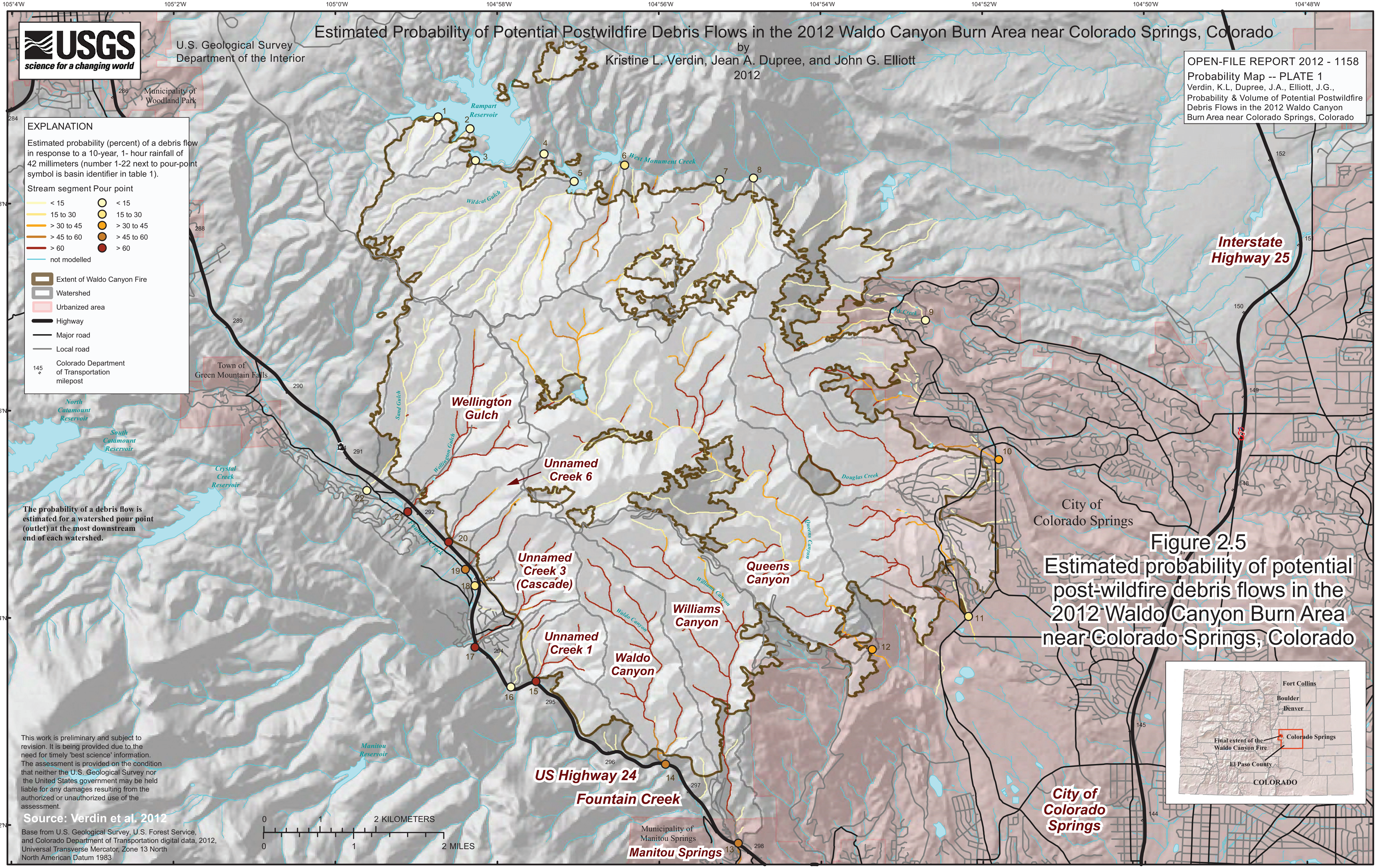


Figure 2.5
Estimated probability of potential post-wildfire debris flows in the 2012 Waldo Canyon Burn Area near Colorado Springs, Colorado

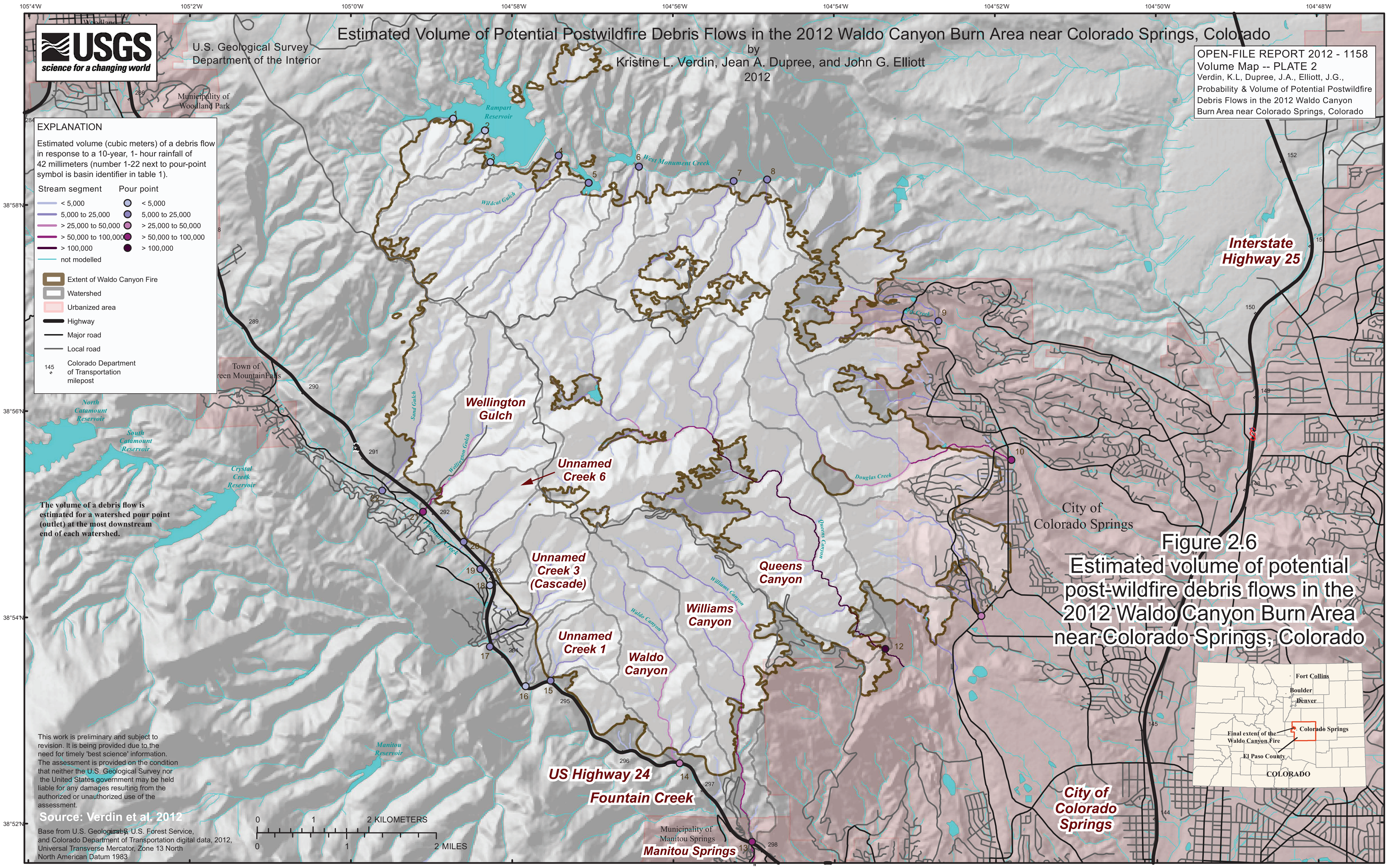
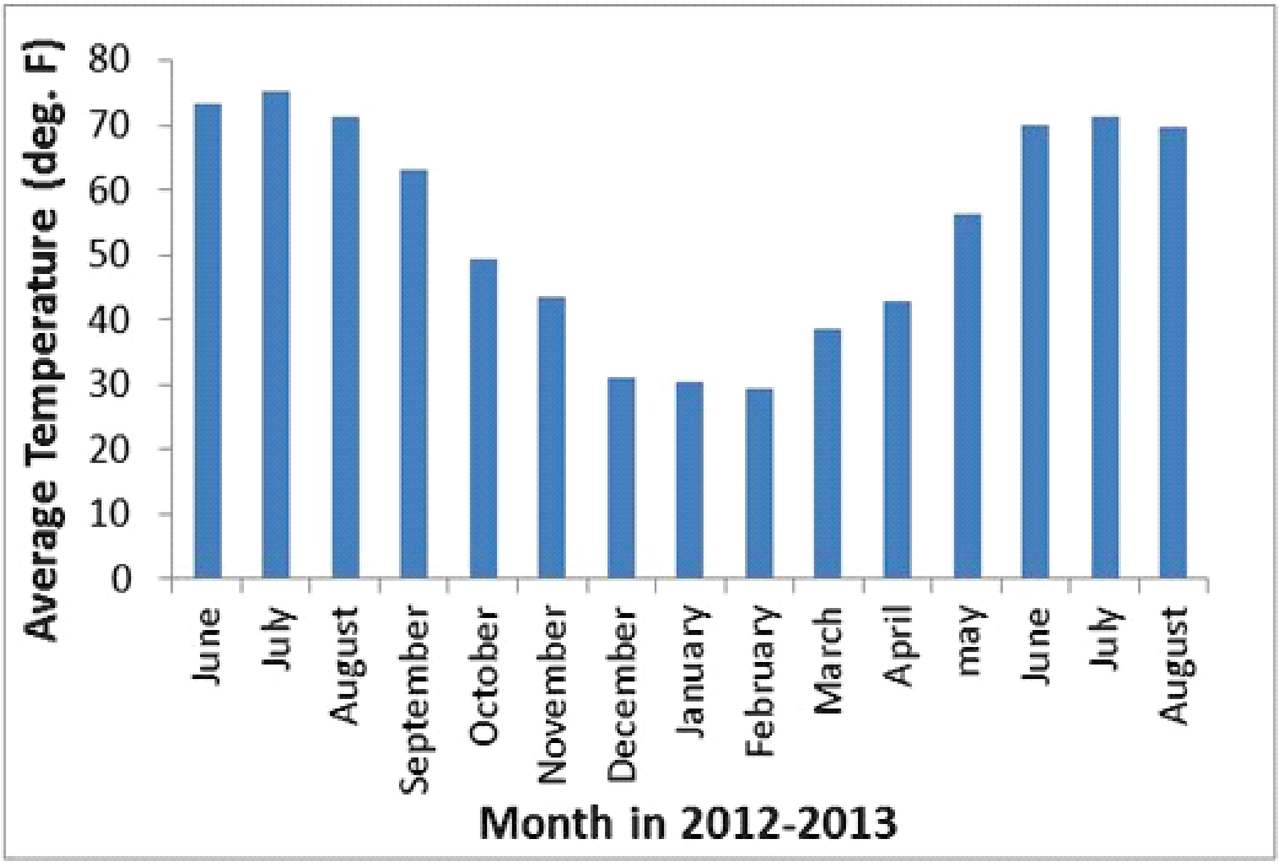


Figure 2.6
Estimated volume of potential post-wildfire debris flows in the 2012 Waldo Canyon Burn Area near Colorado Springs, Colorado



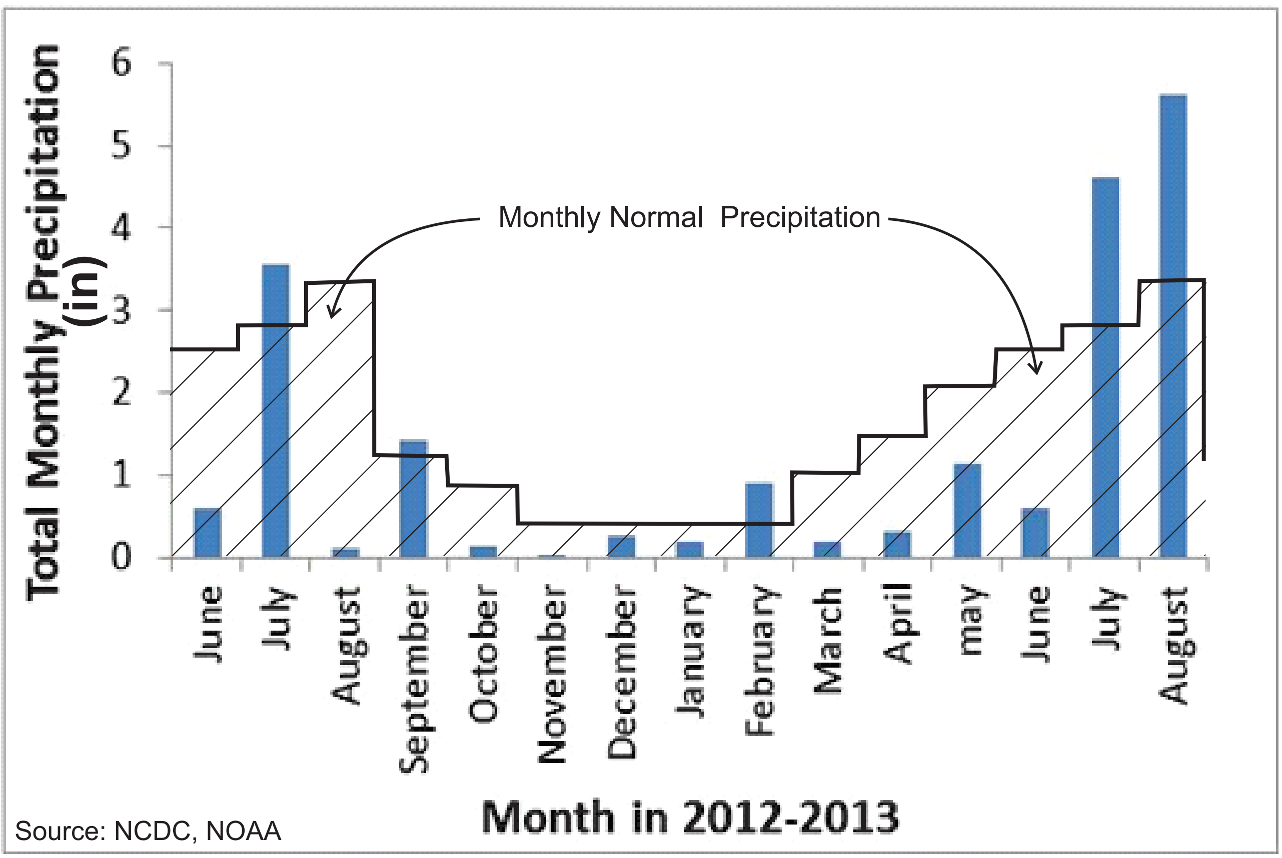


Figure 2.7. Average monthly temperature and total monthly precipitation at Colorado Springs Municipal Airport after the June 2012 Waldo Canyon Fire

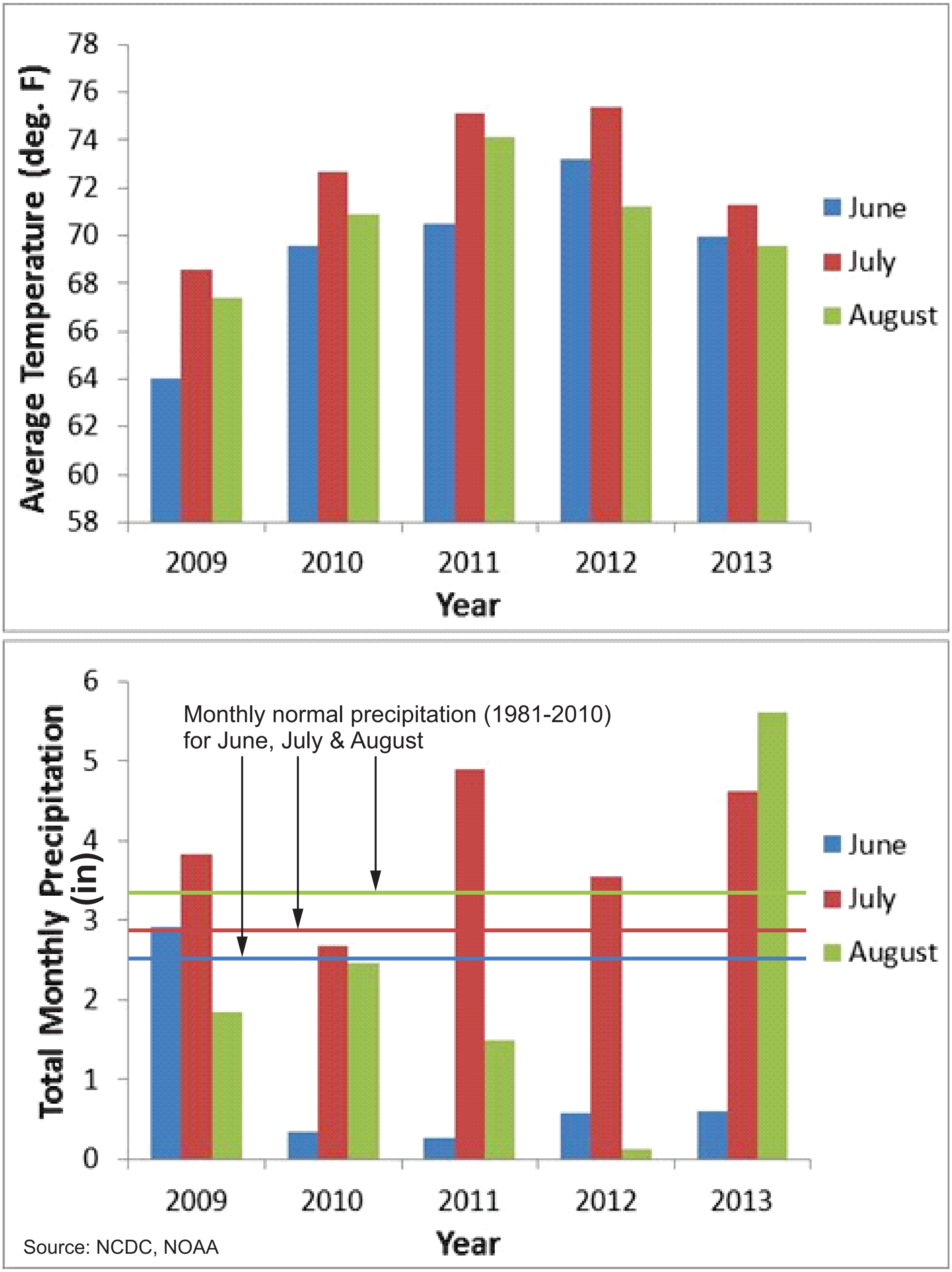
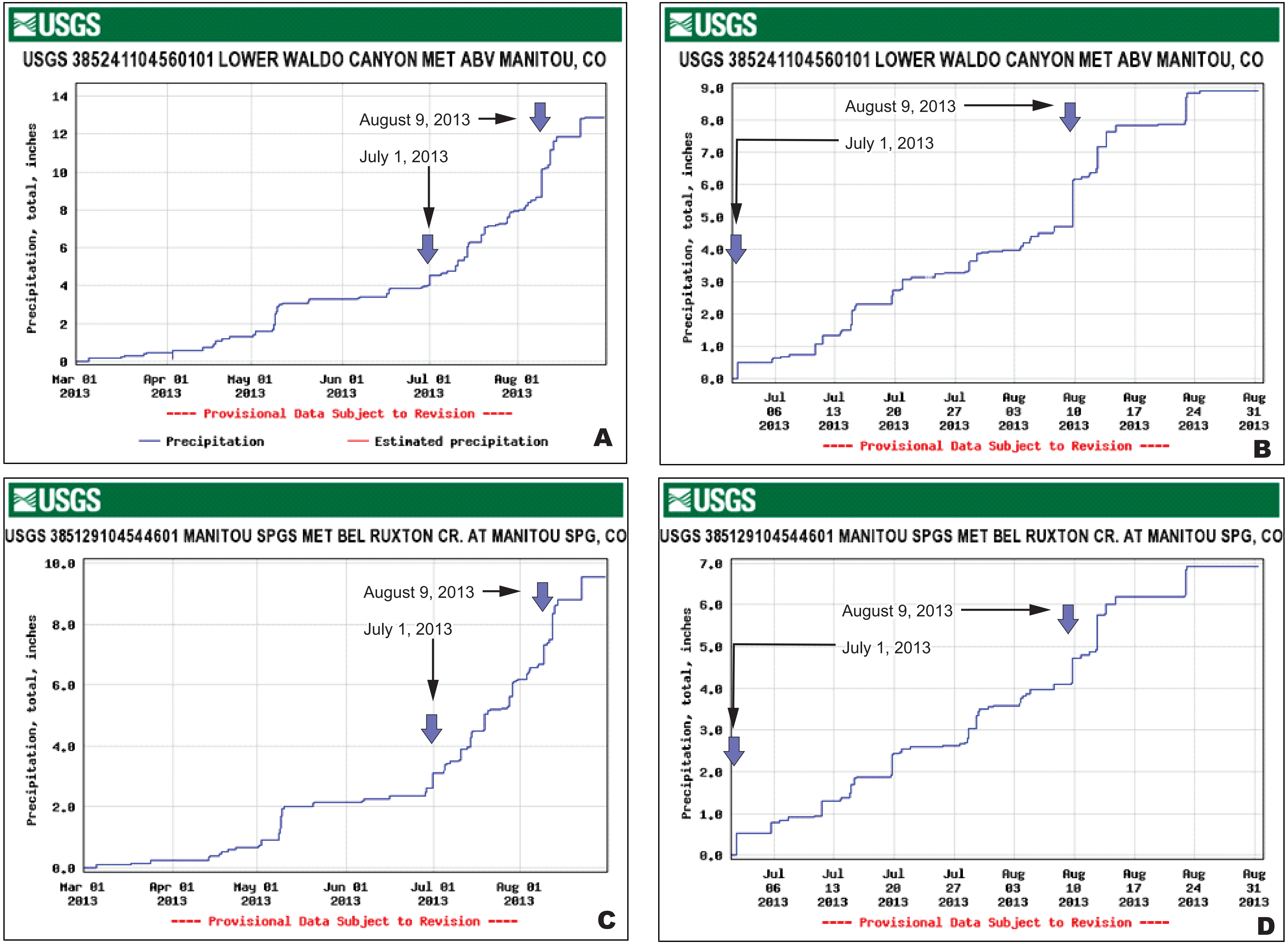
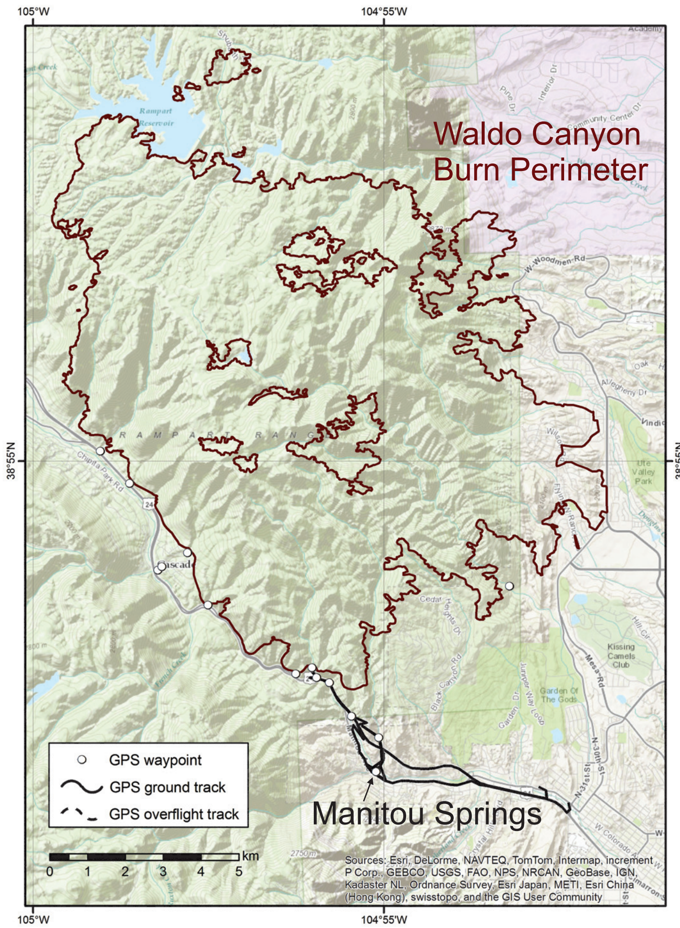


Figure 2.8. Average monthly temperature and total monthly precipitation at Colorado Springs Municipal Airport during June, July, and August 2009 to 2013

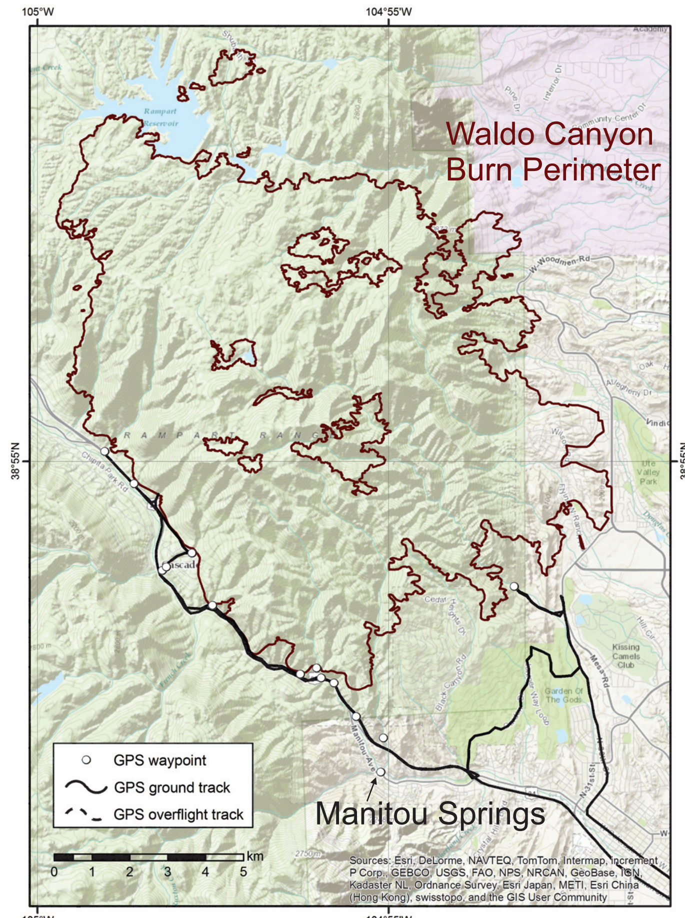


Source: http://waterdata.usgs.gov/co/nwis/current

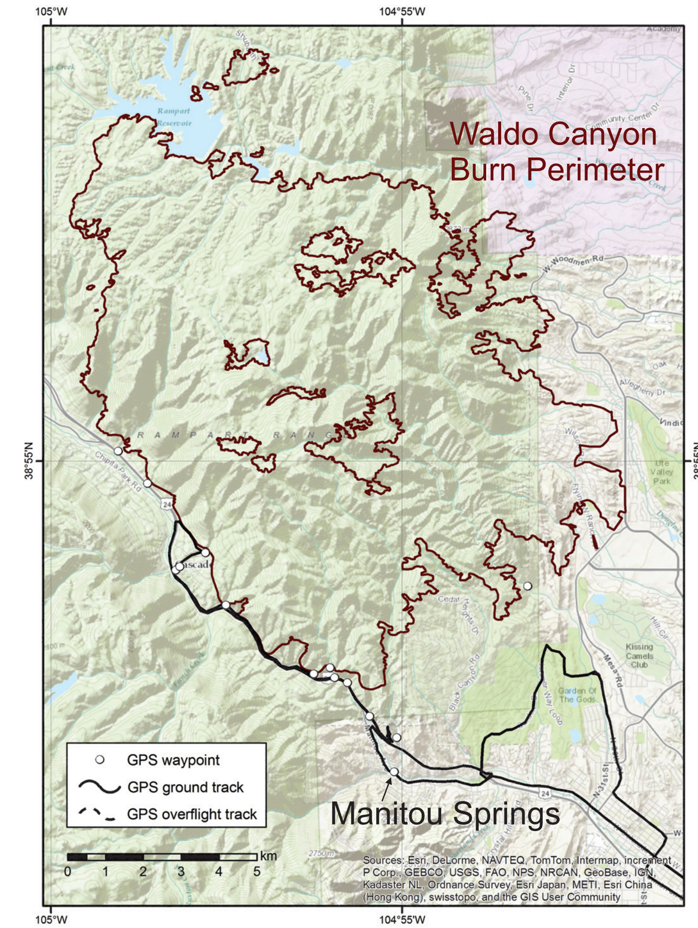
Figure 2.9. Total precipitation observed at the Lower Waldo Canyon (top) and Manitou Springs (bottom) gages near Manitou Springs, Colorado.



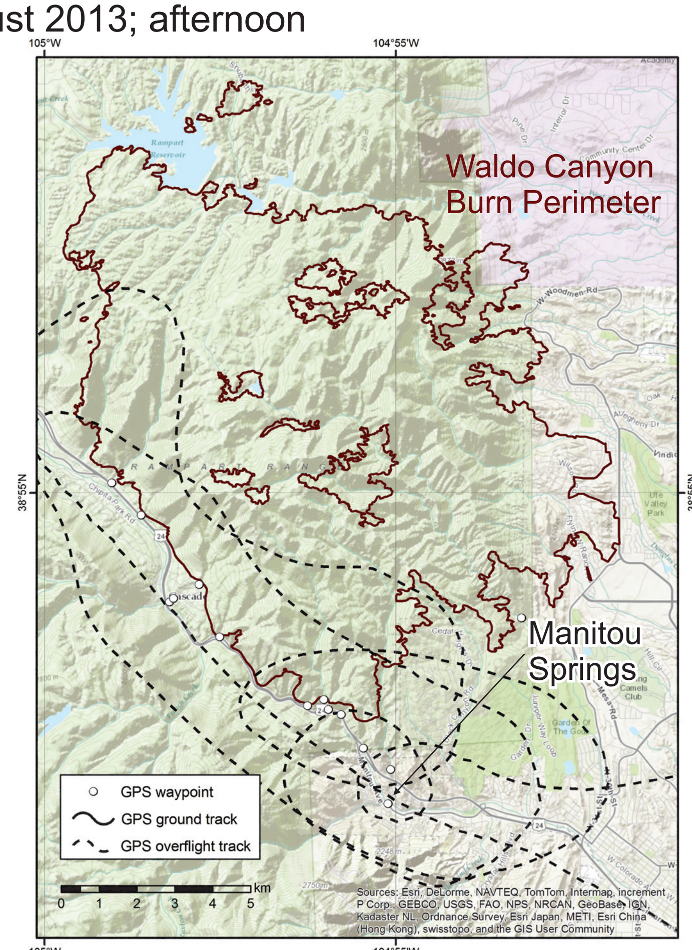
16 August 2013; afternoon



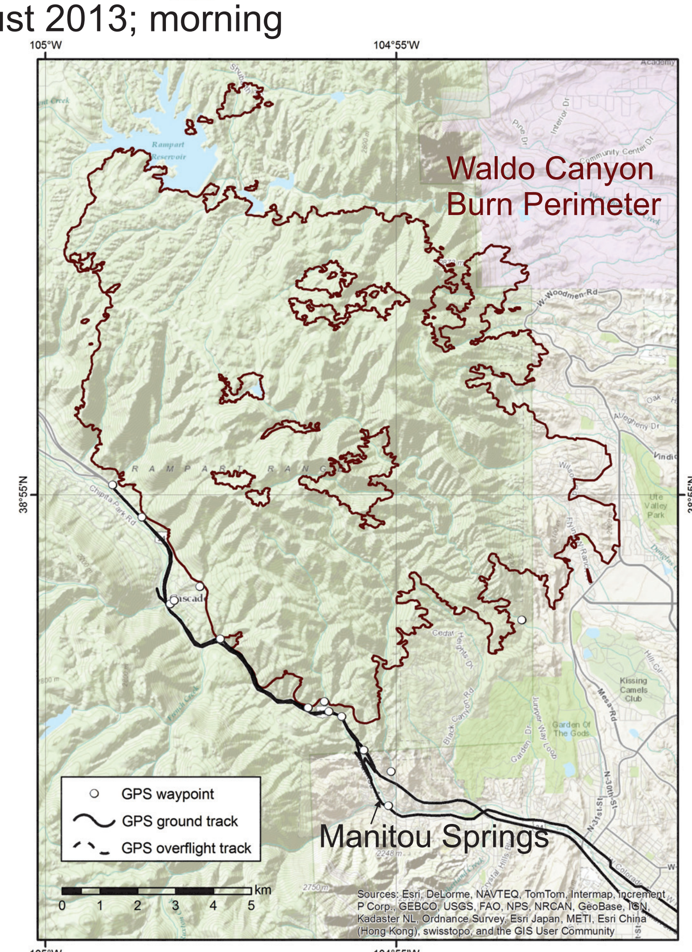
17 August 2013; morning



17 August 2013; afternoon



17 August 2013; aerial reconnaissance



18 August 2013; morning

Figure 2.10
GPS Tracks Collected by the GEER Team in the Vicinity of Manitou Springs, Colorado

3.0 AUGUST 9, 2013, FLOOD AND SEDIMENT DISCHARGE EFFECTS

3.1 Precipitation and Hydrographs

The August 9, 2013, storm was captured by the Pueblo, CO, NEXRAD Doppler radar station operated by National Weather Service, National Oceanic and Atmospheric Administration (NOAA), US Department of Commerce. Eleven NEXRAD scenes over the one-hour period when the storm passed over the Waldo Canyon Burn are presented in Figure 3.1.1. The storm moved from west to east a distance of about 10.4 to 11.4 km between 5:16 and 5:34 PM Mountain Daylight Time (MDT), which is equivalent to a speed of 35 to 38 km/hr. The highest Doppler radar reflectivity passed over the southern half of the burn area between 5:20 and 5:50 PM MDT. The average radar reflectivity appears to be between 50 and 55 dbZ with a maximum of between 60 and 65 dbZ occurring at 5:34 PM MDT northwest of a gage at Camp Creek above Glen Eyrie (Figure 3.1.1B). The approximate average precipitation intensity suggested by the NEXRAD data is between 2 and 4 in/hr (50 and 100 mm/hr). The precipitation intensity associated with the maximum radar reflectivity is between 8 and 16 in/hr (200 and 400 mm/hr); guidance on the radar information page of the NOAA website indicates that hail can produce higher reflectivity values than rainfall without hail.

Precipitation gages were installed by the USGS at six locations within and adjacent to the Waldo Canyon Burn Area following the 2012 fire to supplement existing gages in are region. Precipitation gage locations are shown in the NEXRAD maps presented in Figure 3.1.1. Selected parameters for these precipitation gages are listed in Table 3.1.1. Three stream gage stations are included in Table 3.1.1, two of which also record precipitation.

Precipitation depths for the gages shown in Figure 3.1.1 and listed in Table 3.1.1 are plotted in Figure 3.1.2. Five-minute precipitation depths and cumulative precipitation depths are plotted in Figure 3.1.2. Hydrographs of two stream gages on Camp Creek and one gage on Fountain Creek also are plotted in Figure 3.1.2. The Fountain Creek stream gage is located upstream of the junction with Camp Creek. The peak discharge in the upstream of the two Camp Creek gages occurred 20 minutes earlier than the peak discharge in the downstream gage. The shapes of all three stream gages demonstrate the flashy nature of runoff from the drainage basins in the Waldo Canyon Burn Area.

The four precipitation gages in Figure 3.1.2 that recorded the largest cumulative precipitation amounts are listed with large, bold, red numbers 1 through 4. These numbers correspond to smaller red numbers placed on the map in Figure 3.1.2 next to the gage locations. Three gages recorded more than 1 inch of precipitation on August 9, 2013, for the storm that lasted approximately 35 minutes. The Upper Williams Canyon gage recorded 1.61 inches of cumulative precipitation. The Lower Waldo Canyon gage recorded 1.49 inches and the Upper Waldo Canyon gage recorded 1.02 inches of cumulative precipitation on August 9, 2013. The Camp Creek Above Glen Eyrie gage recorded 0.8 inches of cumulative precipitation over a period of about 3 hours with about 1/4 to 1/3 of the precipitation occurring in the primary 35-minute duration of high-intensity storm.

The five-minute precipitation depths were used to calculate five- and ten-minute precipitation intensities (Figure 3.1.3). The largest precipitation intensities were calculated for the Upper Williams Canyon gage (bold number 1 in Figure 3.1.3) at 131 mm/hr for five minutes and 125 mm/hr for ten minutes; these intensities occurred at 5:40 and 5:45 PM MDT, respectively. NEXRAD radar reflectivity scenes for 5:39 and 5:43 PM MDT (Figure 3.1.1C) indicate between 55 and 60 dbZ at 5:39 PM and between 50 and 55 dbZ at 5:43 PM MDT, which would correspond to intensities between 100 and 200 mm/hr and between 50 and 100 mm/hr. The two

NEXRAD scenes are four minutes apart, so calculated five- and ten-minute precipitation intensities above 100 mm/hr appear to be consistent with the radar data.

The Lower Waldo Canyon gage (Figure 3.1.3) recorded five-minute precipitation depths that indicate five-minute intensities of 106 and 110 mm/hr at 5:40 and 5:45 PM MDT, respectively, and a ten-minute intensity of 108 mm/hr at 5:45 PM MDT. The NEXRAD radar reflectivity scenes for 5:39 PM and 5:43 PM (Figure 3.1.1C) show between 45 and 50 dbZ and between 50 and 55 dbZ, respectively. These radar reflectivity values correspond to rainfall intensities between 24 and 50 mm/hr and between 50 and 100 mm/hr. The radar reflectivity scene at 5:34 PM (Figure 3.1.1B) indicates between 50 and 55 dbZ at the Lower Waldo Canyon gage. Therefore, the precipitation gage data and the NEXRAD Doppler radar data appear to be consistent with each other.

The Upper Waldo Canyon gage recorded five-minute precipitation depths that indicate a five-minute intensity of 122 mm/hr and a ten-minute intensity of 90 mm/hr at 5:35 PM MDT (Figure 3.1.3). The NEXRAD radar reflectivity scene at 5:25 PM (Figure 3.1.1B) shows the Upper Waldo Canyon gage in a cell between 50 and 55 dbZ, whereas the scene at 5:34 PM shows between 55 and 60 dbZ at the gage location. These reflectivity values correlate to rainfall intensities of 50 to 100 mm/hr and 100 to 200 mm/hr, respectively. Thus, the gage and radar reflectivity data appear to be consistent.

The Camp Creek Above Glen Eyrie gage is located on the edge of the highest NEXRAD radar reflectivity cell recorded in the August 9, 2013, storm – between 60 and 65 dbZ at 5:34 PM (Figure 3.1.1B). This reflectivity range corresponds to a rainfall intensity of 200 to 400 mm/hr. The precipitation intensity values for the Camp Creek Above Glen Eyrie gage (Figure 3.1.3) for 5:30 and 5:35 PM show a maximum of 37 mm/hr for a five minutes and 20 mm/hr for ten minutes. Clearly, the precipitation gage data and the radar reflectivity are not consistent. A possible explanation is that hail with higher radar reflectivity was mixed with rain at 5:34 PM adjacent to the Camp Creek gage.

The precipitation gage data presented in Figures 3.1.2 and 3.1.3 indicate that the August 9, 2013, storm was relatively fast-moving and localized. The short-duration, high-intensity precipitation distribution appears to be represented reasonably well by the NEXRAD Doppler radar reflectivity scenes in Figure 3.1.1. Therefore, the southern part of the Waldo Canyon Burn Area experienced the heaviest precipitation. Examination of the geologic map (Figure 2.1) reveals that most of the heaviest precipitation fell on slopes underlain by granitic rock (i.e., all of Waldo Canyon and the northern part of Williams Canyon). The southern part of Williams Canyon is underlain by Precambrian gneiss and Paleozoic sedimentary rocks.

Table 3.1.1. Selected Precipitation and Stream Gage Information

USGS 385129104544601 MANITOU SPGS MET BEL RUXTON CR. AT MANITOU SPG, CO
Latitude 38°51'28.8", Longitude 104°54'46.5" NAD83
El Paso County, Colorado, Hydrologic Unit 11020003
Datum of gage: 6,285 feet above NAVD88. July 1, 2013: 0.51”

USGS 385241104560101 LOWER WALDO CANYON MET ABV MANITOU, CO
Latitude 38°52'41.2", Longitude 104°55'59.9" NAD83
El Paso County, Colorado, Hydrologic Unit 11020003
Datum of gage: 6,920 feet above NAVD88. July 1, 2013: 0.52”

USGS 385449104565501 UPPER WALDO CANYON MET ABV CASCADE, CO
Latitude 38°54'48.2", Longitude 104°57'01.4" NAD83
El Paso County, Colorado, Hydrologic Unit 11020003
Datum of gage: 9,420 feet above NAVD88. July 1, 2013: 0.35”

USGS 385653104583101 SAND GULCH MET STATION ABOVE CHIPITA PARK, CO
Latitude 38°56'55.1", Longitude 104°58'29.3" NAD83
El Paso County, Colorado, Hydrologic Unit 11020003
Datum of gage: 9,460 feet above NAVD88. July 1, 2013: 0.24”+ [gage went offline at 15:55]

USGS 385640104555701 UPPER QUEENS CANYON MET NEAR ORMES PEAK, CO
Latitude 38°56'39.7", Longitude 104°55'57.4" NAD83
El Paso County, Colorado, Hydrologic Unit 11020003
Datum of gage: 9,380 feet above NAVD88. July 1, 2013: 0.19”

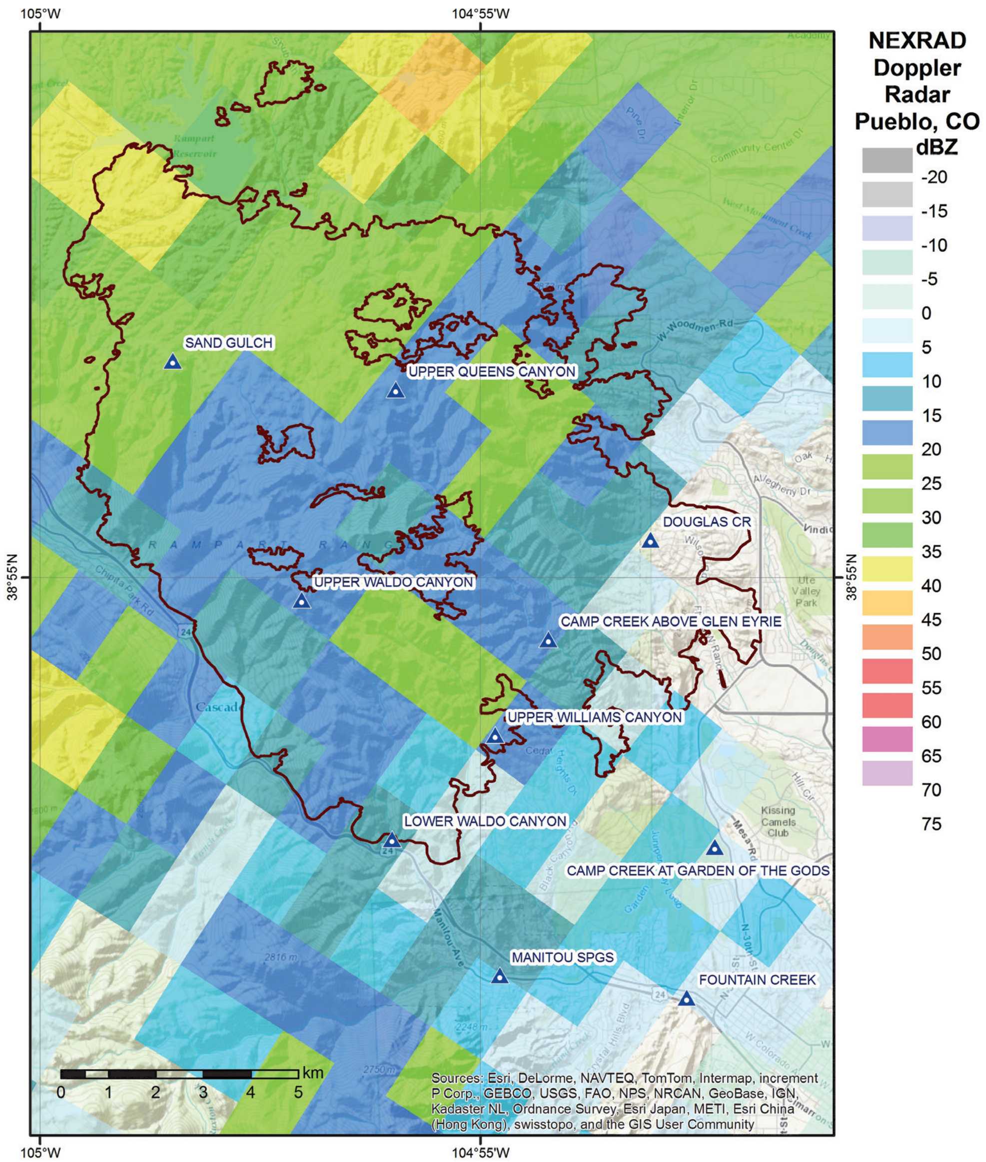
USGS 385520104530401 DOUGLAS CR MET ABV FLYING W RNCH RD AT CO SPRS, CO
Latitude 38°55'20.0", Longitude 104°53'03.8" NAD83
El Paso County, Colorado, Hydrologic Unit 11020003
Datum of gage: 7,099 feet above NAVD88. July 1, 2013: 0.12”

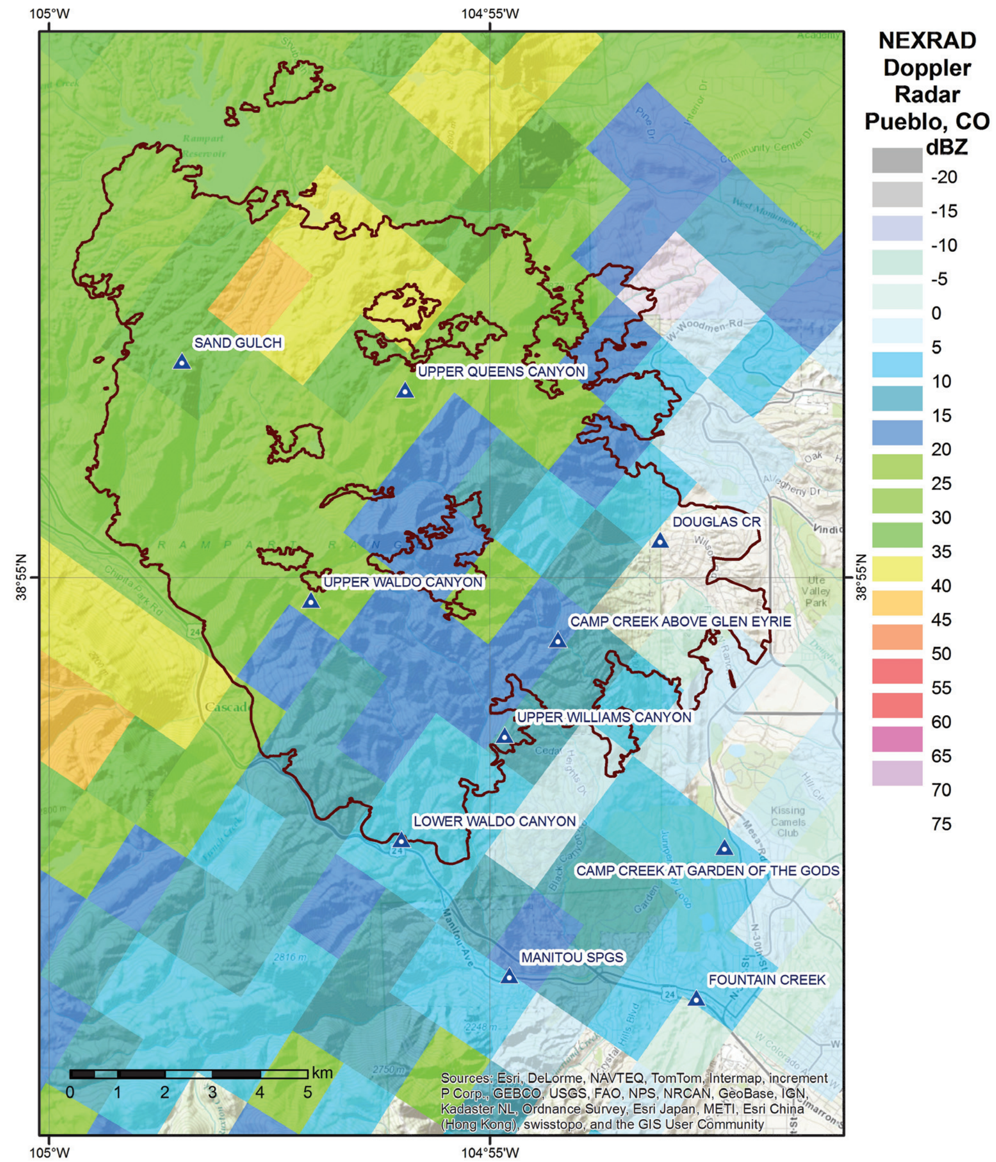
USGS 385334104544901 UPPER WILLIAMS CANYON MET ABV MANITOU, CO
Latitude 38°53'36.4", Longitude 104°54'49.6" NAD83
El Paso County, Colorado, Hydrologic Unit 11020003
Datum of gage: 7,920 feet above NAVD88. July 1, 2013: 0.59”

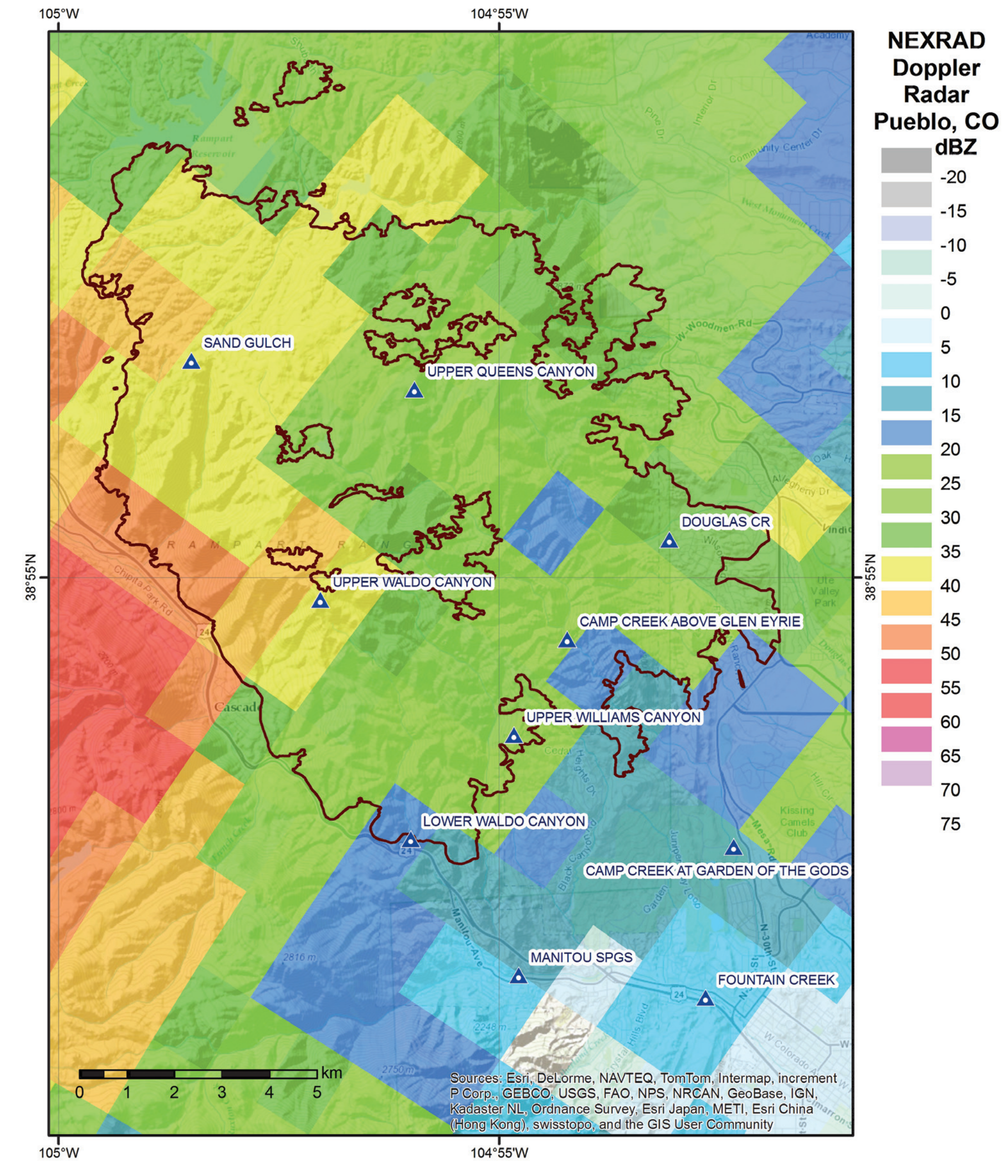
USGS 07103702 CAMP CREEK ABOVE GLEN EYRIE NEAR COLO SPRINGS, CO
Latitude 38°54'27.19", Longitude 104°54'13.42" NAD83
El Paso County, Colorado, Hydrologic Unit 11020003
Drainage area: 7.15 square miles
Datum of gage: 7,216 feet above NAVD88. July 1, 2013: 0.41”

USGS 07103703 CAMP CREEK AT GARDEN OF THE GODS, CO
Latitude 38°52'37", Longitude 104°52'20" NAD27
El Paso County, Colorado, Hydrologic Unit 11020003
Drainage area: 9.38 square miles
Datum of gage: 6,310 feet above NGVD29. July 1, 2013: 0.19”

USGS 07103700 FOUNTAIN CREEK NEAR COLORADO SPRINGS, CO
Latitude 38°51'17", Longitude 104°52'39" NAD27
El Paso County, Colorado, Hydrologic Unit 11020003
Drainage area: 102 square miles
Datum of gage: 6,110.00 feet above NGVD29. Stream gage only, no precipitation







201308092302 =
5:02 PM MDT

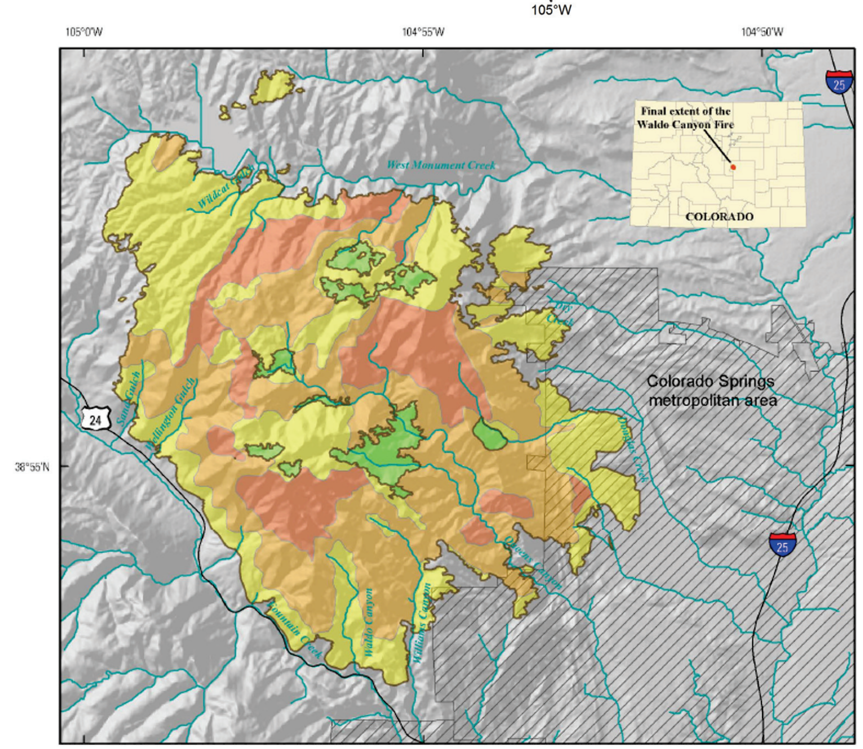
201308092307 =
5:07 PM MDT

201308092316 =
5:16 PM MDT

Source: NEXRAD Website; Pueblo, CO
Data for Waldo Canyon Burn area
YYYYMMDDHHMM Universal time
MDT denotes Mountain Daylight Time

NEXRAD Radar Reflectivity dbZ	Approximate Rainfall Intensity in/hr	mm/hr
15	0.01	0.25
20	0.03	0.75
25	0.06	1.5
30	0.12	3
35	0.24	6
40	0.48	12
45	0.96	24
50	1.95	50
55	4	100
60	8	200
65	16	400
70	32	800

Source: http://www.srh.noaa.gov/radar/radinfo/radinfo.html



EXPLANATION

Burn Severity

- **High**
- **Moderate**
- **Low**
- **Unburned**

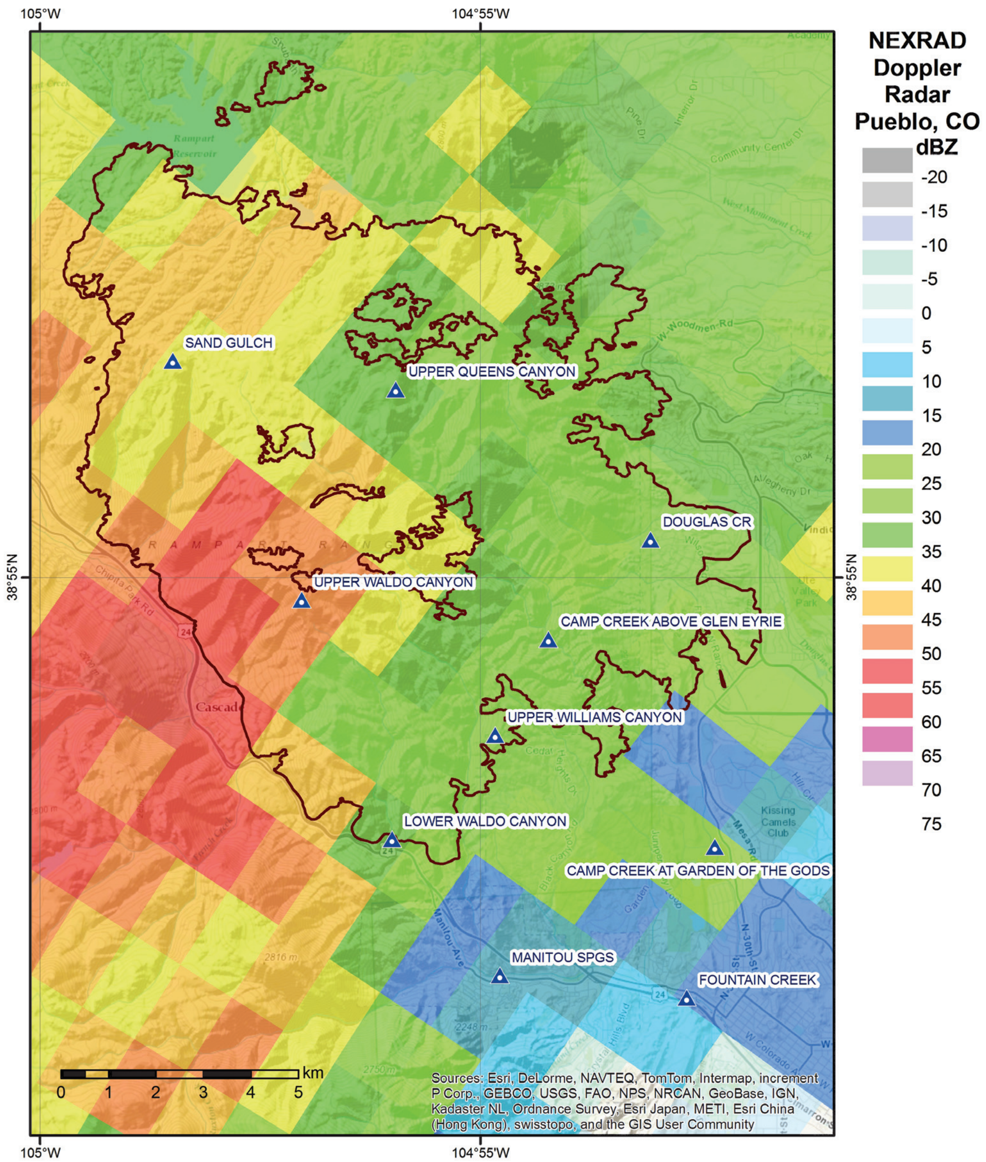
Final extent of Waldo Canyon Fire

Urbanized area

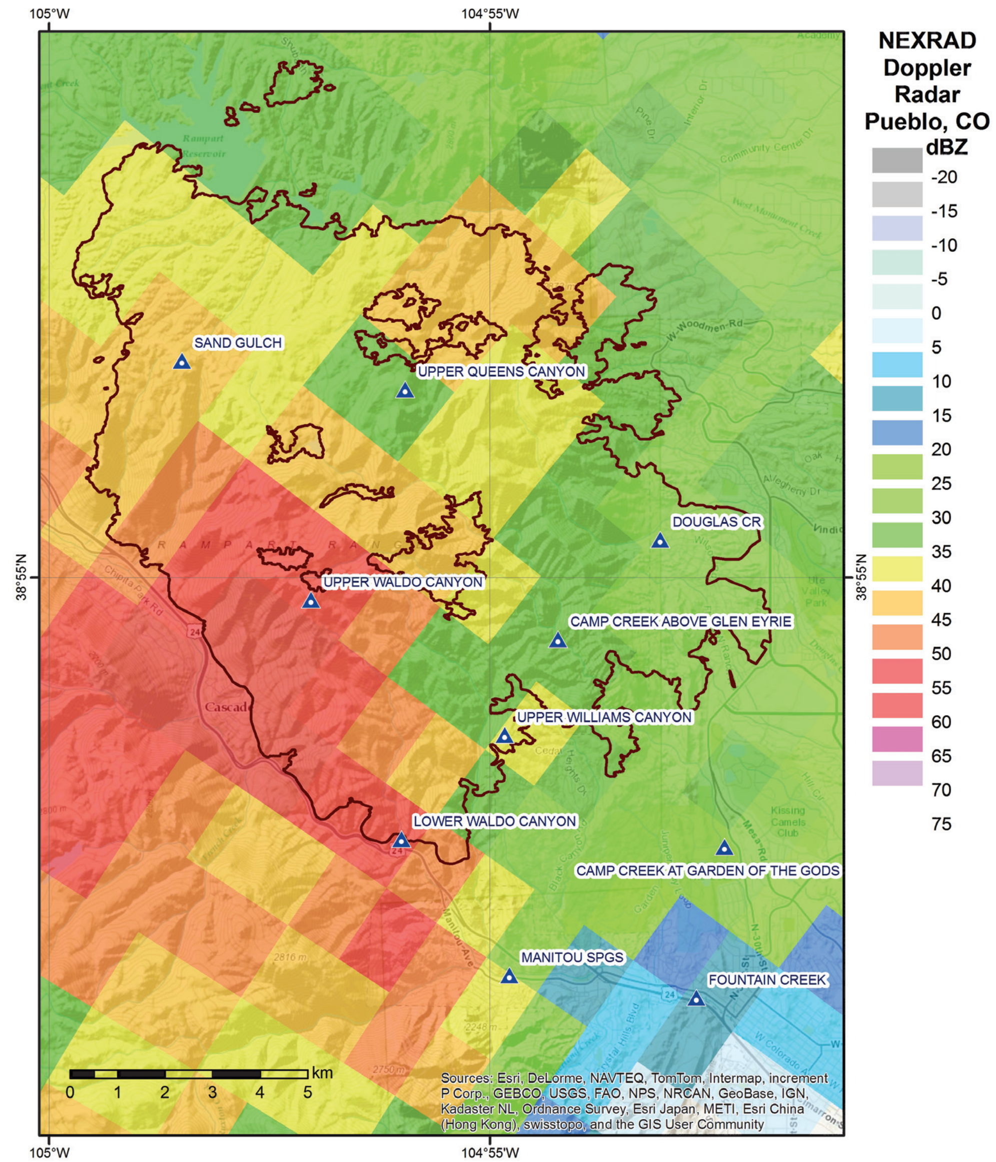
Source: USGS OFR 2012-1158

Figure 3.1.1A
5:02, 5:07, and 5:16 PM MDT

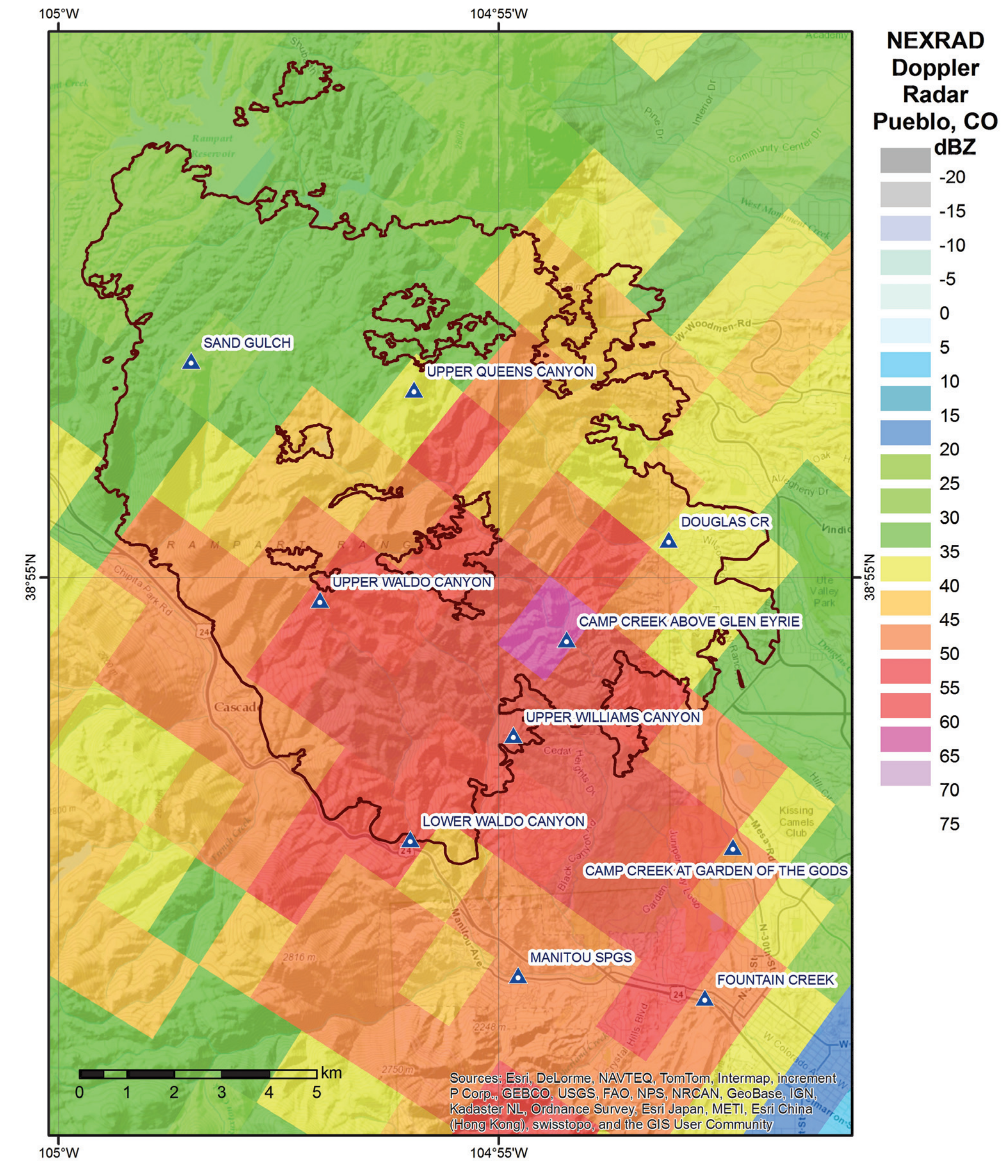
NEXRAD Doppler Radar
Reflectivity of the August 9, 2013
Storm over the Waldo Canyon Burn



201308092320 =
5:20 PM MDT



201308092325 =
5:25 PM MDT

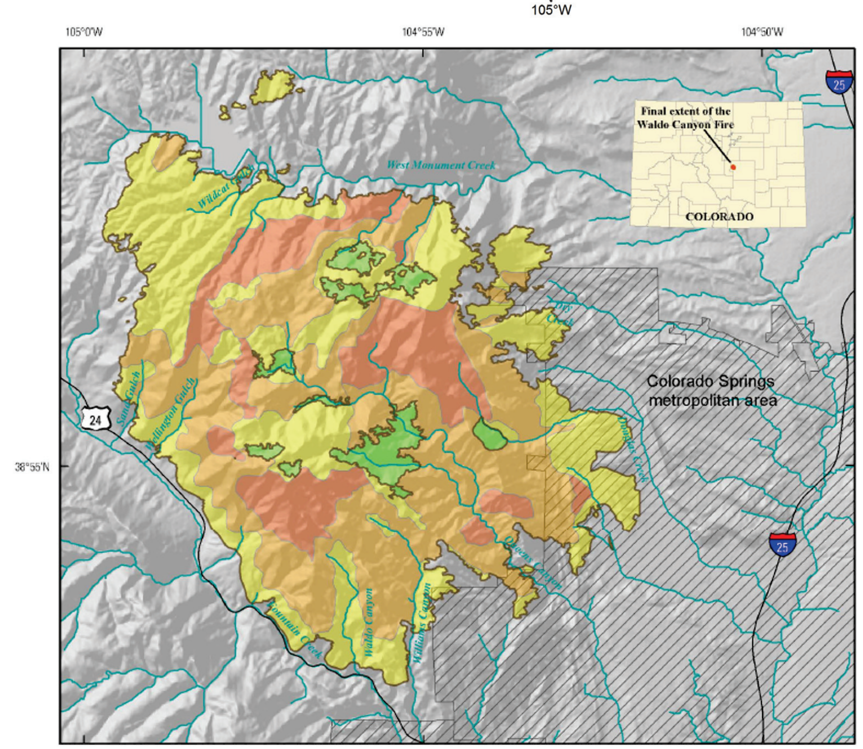


201308092334 =
5:34 PM MDT

Source: NEXRAD Website; Pueblo, CO
Data for Waldo Canyon Burn area
YYYYMMDDHHMM Universal time
MDT denotes Mountain Daylight Time

NEXRAD Radar Reflectivity	Approximate Rainfall Intensity	
dbZ	in/hr	mm/hr
15	0.01	0.25
20	0.03	0.75
25	0.06	1.5
30	0.12	3
35	0.24	6
40	0.48	12
45	0.96	24
50	1.95	50
55	4	100
60	8	200
65	16	400
70	32	800

Source: http://www.srh.noaa.gov/radar/radinfo/radinfo.html



EXPLANATION

Burn Severity

- **High**
- **Moderate**
- **Low**
- **Unburned**

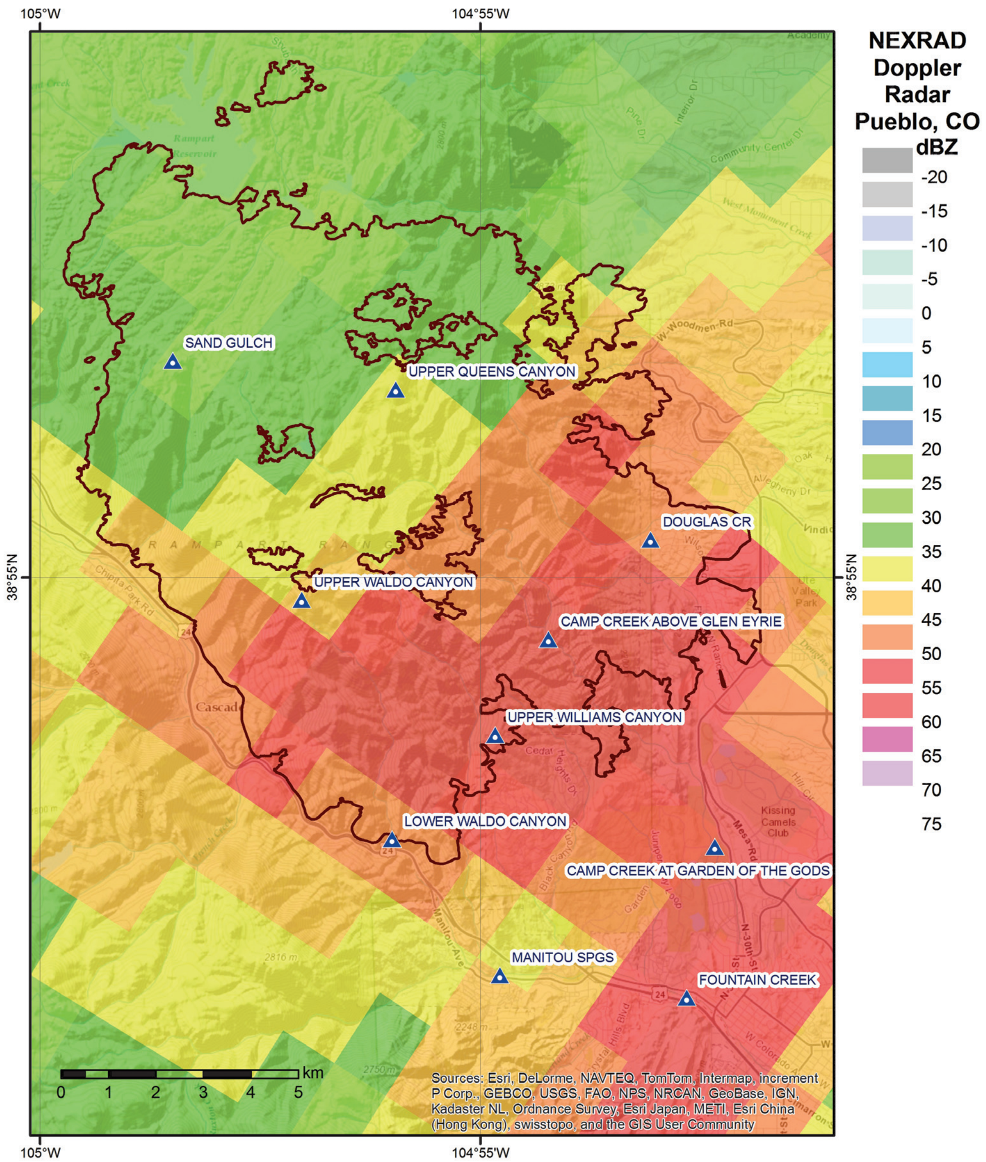
Final extent of Waldo Canyon Fire

Urbanized area

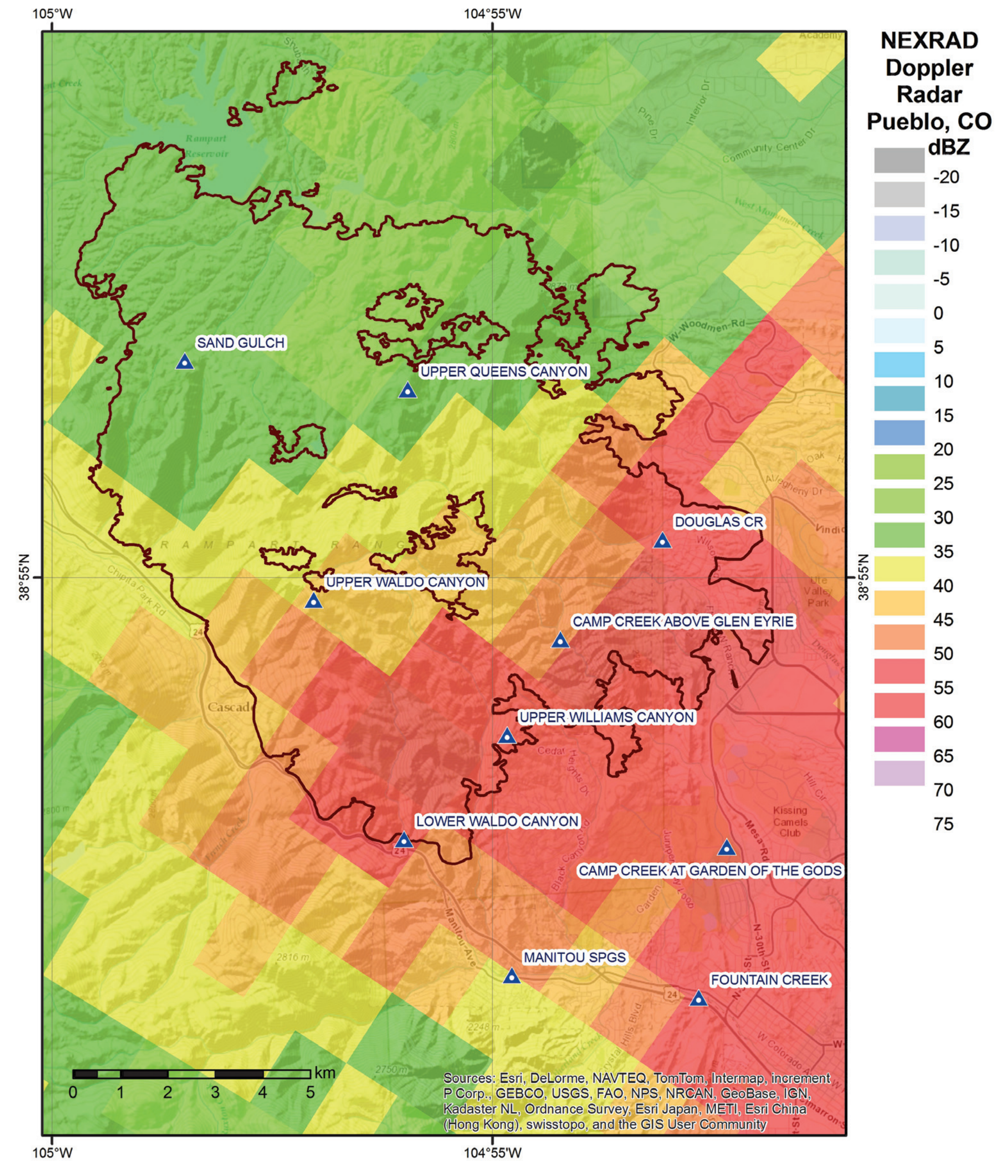
Source: USGS OFR 2012-1158

Figure 3.1.1B
5:20, 5:25, and 5:34 PM MDT

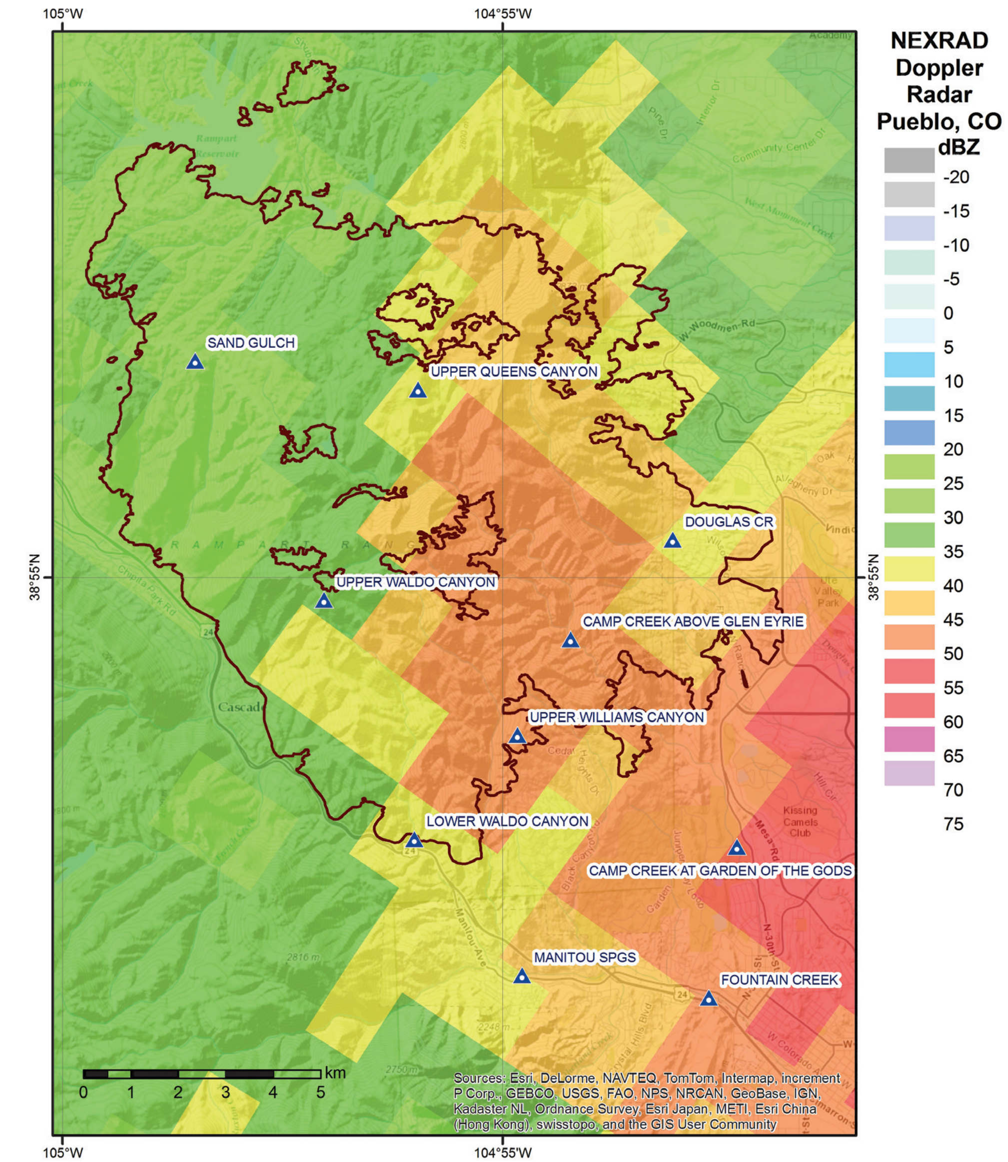
NEXRAD Doppler Radar Reflectivity of the August 9, 2013 Storm over the Waldo Canyon Burn



201308092339 =
5:39 PM MDT



201308092343 =
5:43 PM MDT

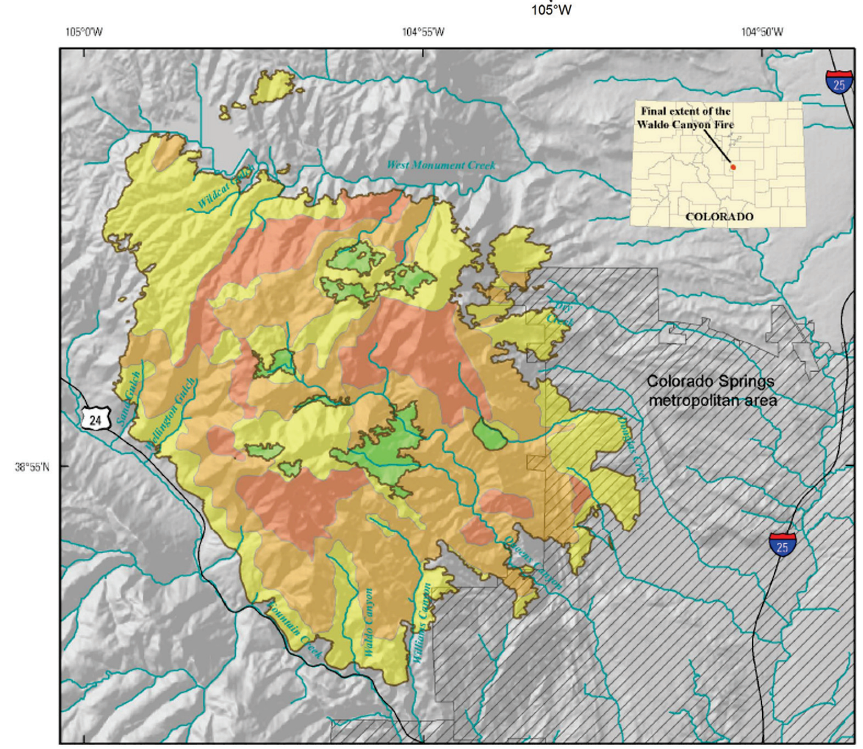


201308092353 =
5:53 PM MDT

Source: NEXRAD Website; Pueblo, CO
Data for Waldo Canyon Burn area
YYYYMMDDHHMM Universal time
MDT denotes Mountain Daylight Time

NEXRAD Radar Reflectivity	Approximate Rainfall Intensity	
dbZ	in/hr	mm/hr
15	0.01	0.25
20	0.03	0.75
25	0.06	1.5
30	0.12	3
35	0.24	6
40	0.48	12
45	0.96	24
50	1.95	50
55	4	100
60	8	200
65	16	400
70	32	800

Source: http://www.srh.noaa.gov/radar/radinfo/radinfo.html



EXPLANATION

Burn Severity
- High
- Moderate
- Low
- Unburned

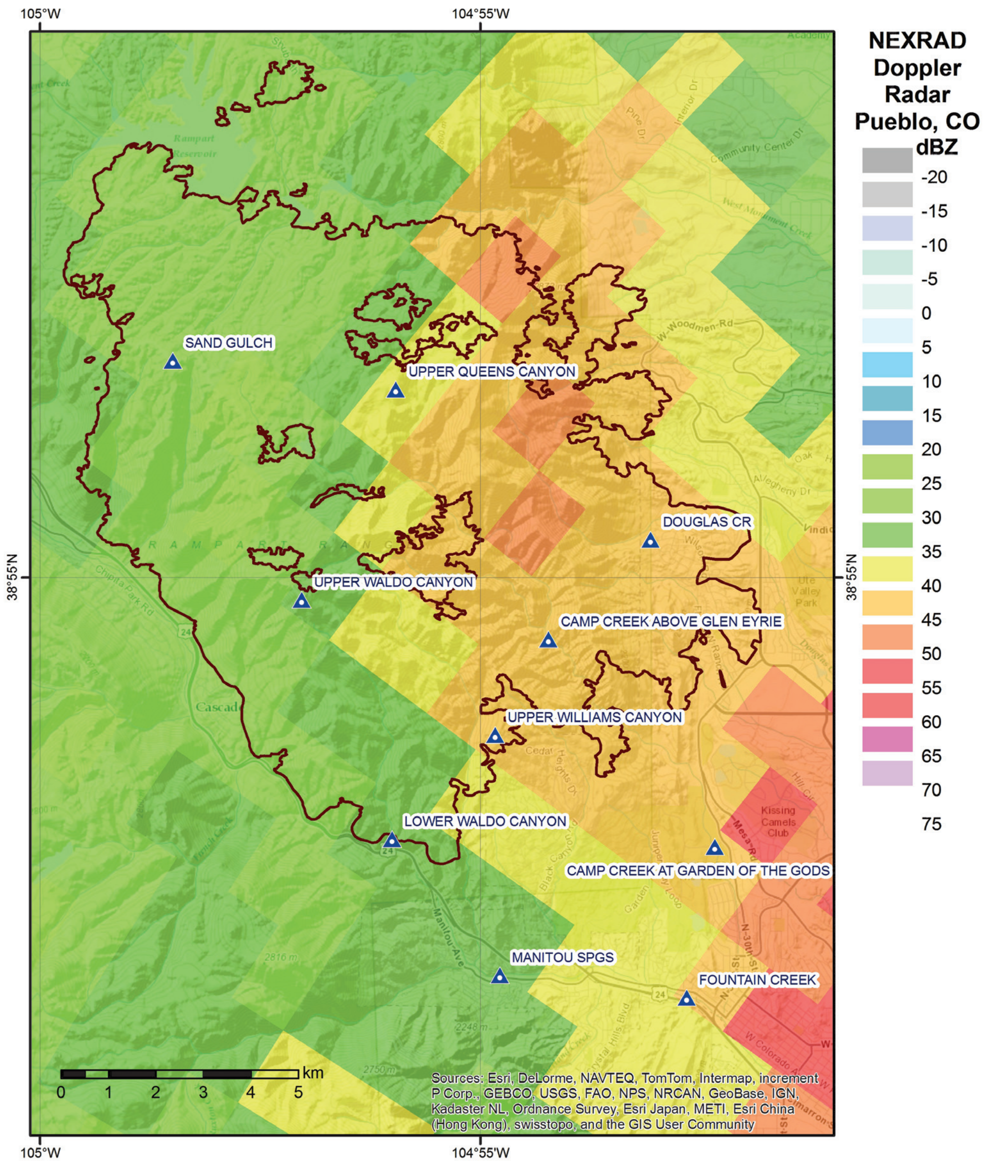
Final extent of Waldo Canyon Fire

Urbanized area

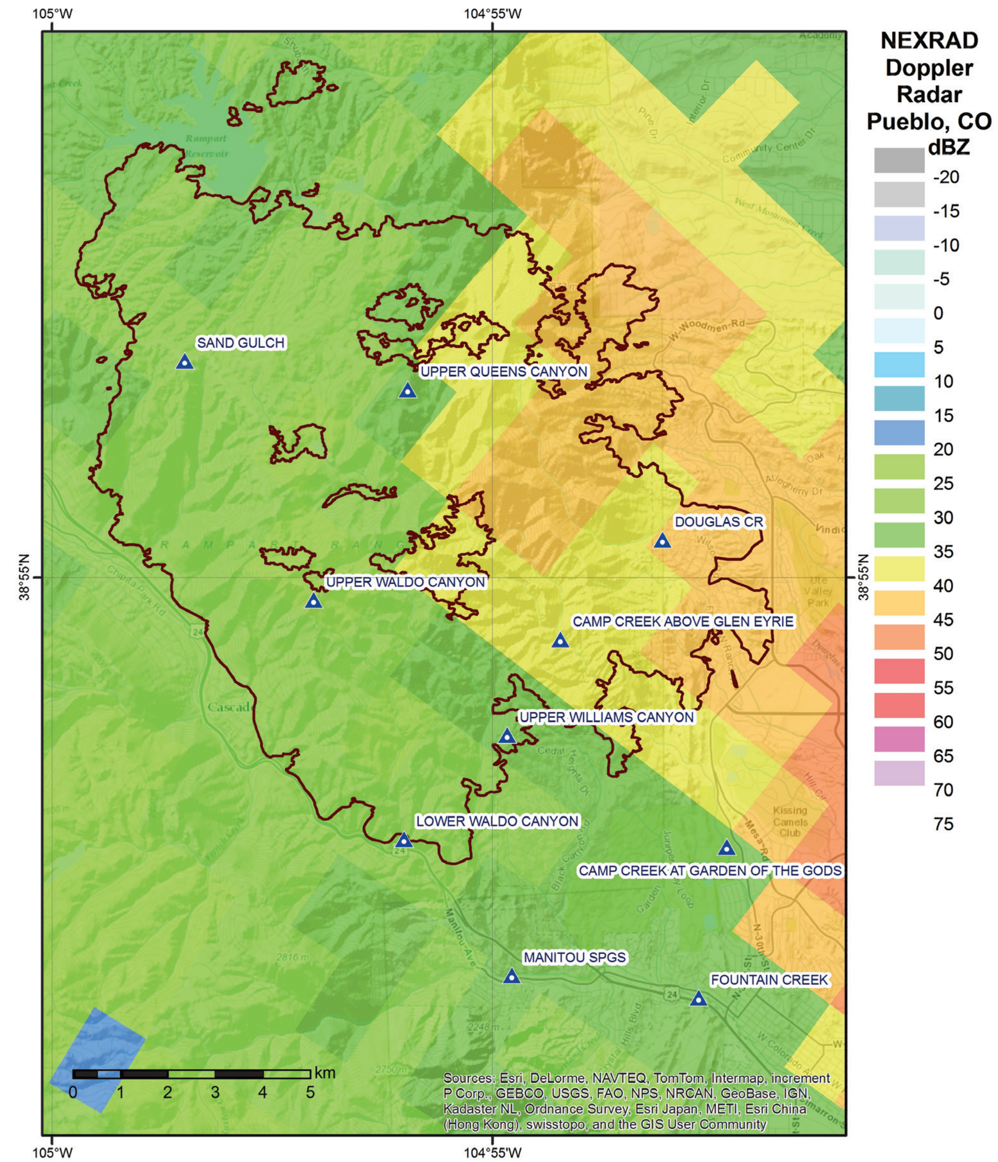
Source: USGS OFR 2012-1158

Figure 3.1.1C
5:39, 5:43, and 5:53 PM MDT

NEXRAD Doppler Radar Reflectivity of the August 9, 2013 Storm over the Waldo Canyon Burn



201308092357 =
5:57 PM MDT

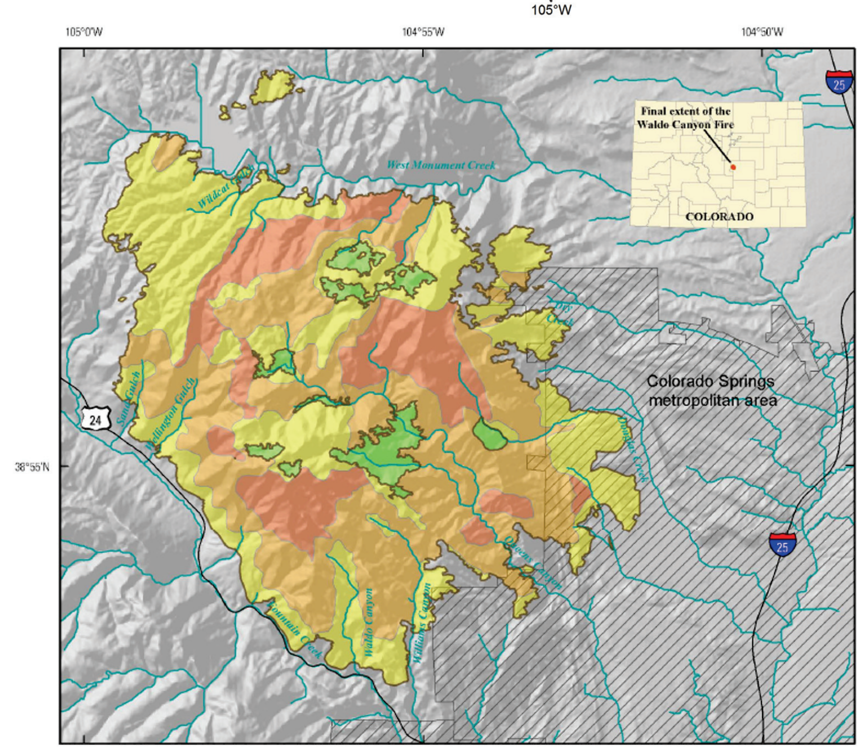


201308100002 =
6:02 PM MDT

Source: NEXRAD Website; Pueblo, CO
Data for Waldo Canyon Burn area
YYYYMMDDHHMM Universal time
MDT denotes Mountain Daylight Time

NEXRAD Radar Reflectivity dbZ	Approximate Rainfall Intensity in/hr	mm/hr
15	0.01	0.25
20	0.03	0.75
25	0.06	1.5
30	0.12	3
35	0.24	6
40	0.48	12
45	0.96	24
50	1.95	50
55	4	100
60	8	200
65	16	400
70	32	800

Source: http://www.srh.noaa.gov/radar/radinfo/radinfo.html



EXPLANATION

Burn Severity
- **High**
- **Moderate**
- **Low**
- **Unburned**

Final extent of Waldo Canyon Fire

Urbanized area

Source: USGS OFR 2012-1158

Figure 3.1.1D
5:57 and 6:02 PM MDT

NEXRAD Doppler Radar
Reflectivity of the August 9, 2013
Storm over the Waldo Canyon Burn

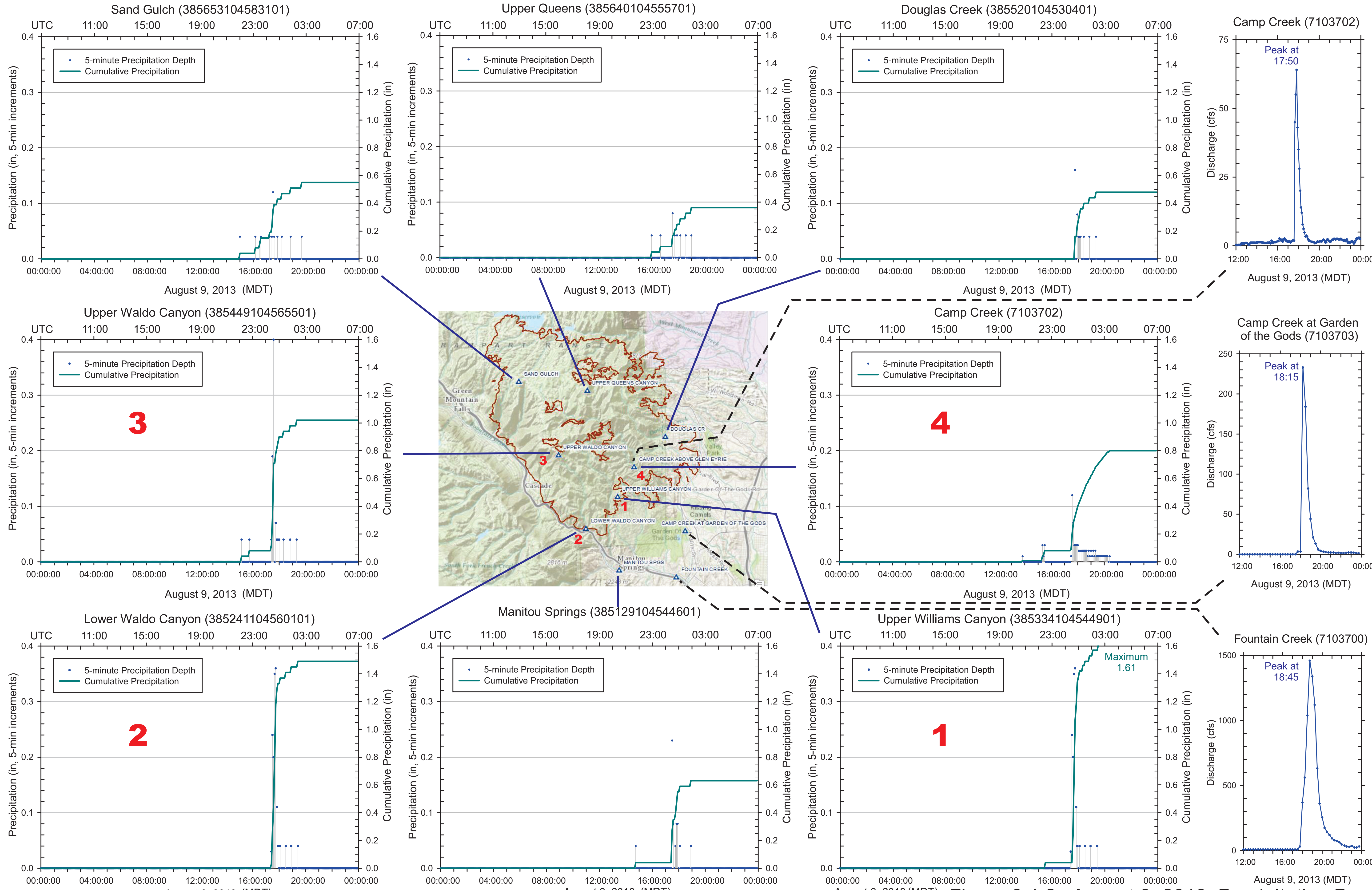


Figure 3.1.2. August 9, 2013, Precipitation Depths and Stream Discharge Near Waldo Canyon Burn Area

Source: http://waterdata.usgs.gov/co/nwis/current

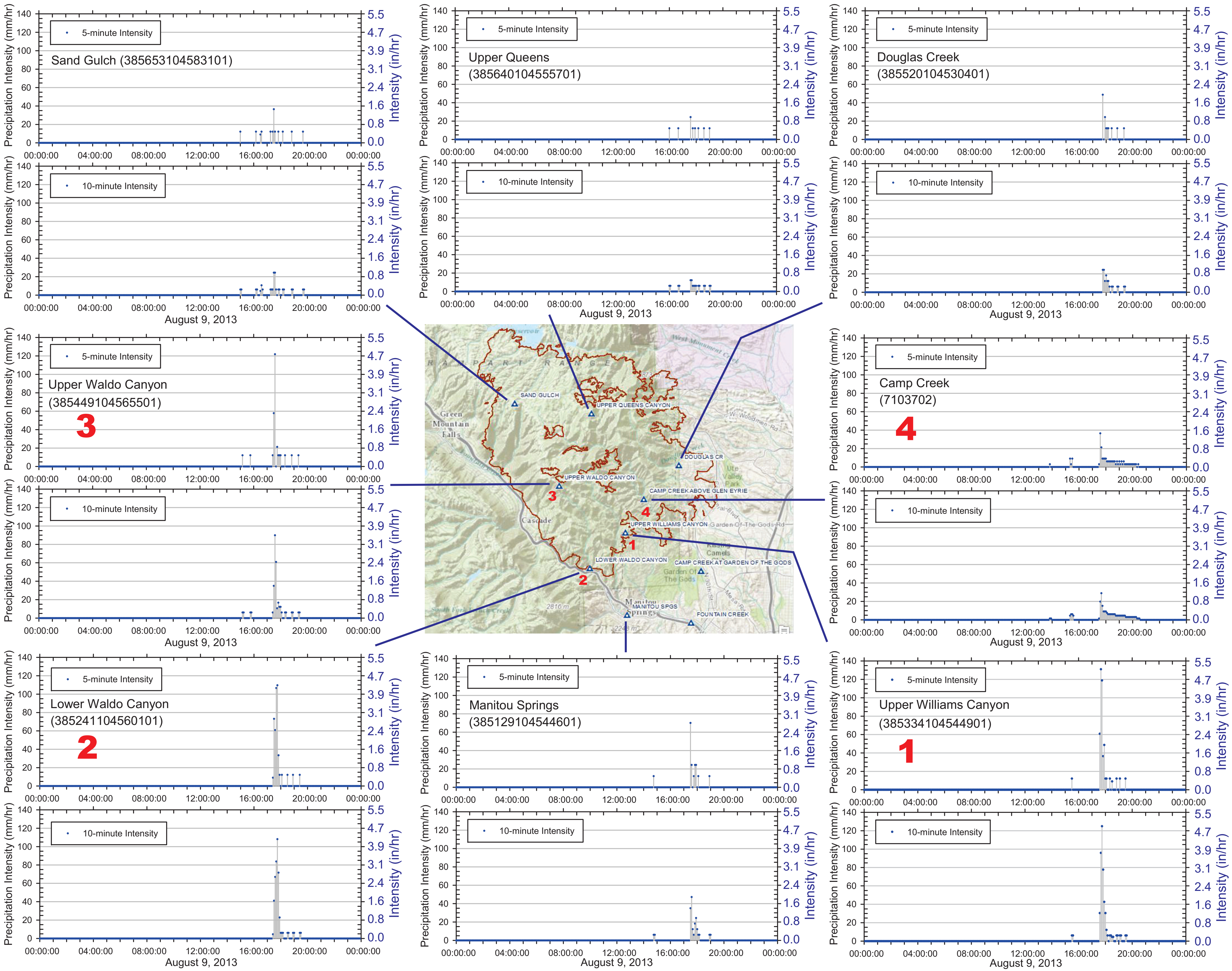


Figure 3.1.3
Five- and Ten-minute Rainfall Intensities for August 9, 2013, Storm Event

3.2 Observations of the Waldo Canyon Flood on US 24

U.S. Highway 24 is an east-west highway that travels along Fountain Creek and the Ute Pass fault (Figure 2.1) west of Manitou Springs. The reconnaissance team made observations between Manitou Springs and a few kilometers northwest of the town of Cascade (Figure 2.10). In this area the highway is divided, with two lanes in each direction, separated by guardrail and median or concrete K-rail. The burn area, Waldo Canyon and the basins that generated the flooding and debris flows are to the north of the highway (Figures 1.1 and 2.3).

This report section presents observations from our field reconnaissance on August 16 – 18, 2013, and from online images and videos we viewed at that time, for the section of highway from Waldo Canyon, eastward to the junction with old Highway 24 (Manitou Avenue), and along Manitou Avenue to the intersection with Serpentine Drive at the western edge of town. This area is where the impacts were greatest; additional observations made further west along Highway 24 are presented in Sections 3.5 and 3.6.

Waldo Canyon has a narrow, bedrock controlled outlet where it intersects US 24 and the Fountain Creek valley. Waldo Canyon has a drainage basin area of about 4.6 km^2 (1.78 mi^2; Verdin et al., 2012) upslope of US 24. Its location is marked on Figures 2.5 and 2.6. Drainage from the canyon are passed obliquely beneath the highway and into Fountain Creek via an approximately 72-inch-diameter culvert (Figure 3.2.1). Field observations near the junction of Waldo Canyon and US 24 were as follows:

1. The culvert was half full of sand and gravel and was passing a clear-water flow estimated to be less than 1 ft^3/sec at the time of our reconnaissance (Figure 3.2.1 (left)).
2. Waldo Canyon widens a few hundred feet from its intersection with US 24 (Figure 3.2.2).

3. The canyon mouth had been cleared of storm debris and an access road had been graded to the wider part of the basin to allow construction of debris basins; construction was in progress at the time of our reconnaissance.
4. The rock-bed channel of Waldo Canyon and the canyon walls preserved the high-water mark of the August 9, 2013, flood event (Figure 3.2.3).
5. Deposits exposed in the Waldo Canyon channel show both matrix-supported debris flow and clast-supported hyperconcentrated sediment flow processes (Figure 3.2.4).
6. A rockfall catchment fence is located immediately east (downhill) of the Waldo Canyon on US 24 (Figure 3.2.5). Boulders and K-rail barriers are present at the west end of the opening behind the fence probably to prevent vehicles from entering. The boulders and K-rail barriers tend to divert flood discharge from Waldo Canyon onto US 24. Storm debris trapped by the fence (Figure 3.2.5 (right)) indicates that the direction of flow during the flood was from the roadway towards the slope.
7. The highway at Waldo Canyon is divided by concrete K-rail whereas steel guardrail and posts are used farther west on US 24 (labeled in Figure 3.2.2). It appears this difference is coincidental and due to highway design needs, and is not related to drainage or flood management.
8. Nearly all storm debris had been cleaned before our visit; however, sediment and woody debris was present in many places on the shoulder of the westbound lanes of US 24, and in a few places on the eastbound lanes (Figure 3.2.6). Some sediment and woody debris was observed on the K-rail and along the guardrail of the eastbound lanes.

Videos posted on YouTube and viewed by the team show eyewitness perspectives of people stopped in the westbound lanes, driving in the eastbound lanes early in the event, and walking in the eastbound lanes later in the event after eastbound traffic had been stopped. Links to two of these videos are as follows:

A 00:10:36-long video by Tj Omara has some rough language in it, but it apparently captures the peak of the hydrograph and the narrator mentions surges of rocky flow as it is flowed from Waldo Canyon and down the westbound lanes. The video was taken from a vehicle behind a Sport Utility Vehicle (SUV) which appears to be behind an 18-wheel highway truck and trailer. Three screenshots from this video are presented on Figure 3.2.7; the three screenshots from video time 2:10, 4:22, and 5:23 show the flow rising relative to the K-rail barrier. a short distance below Waldo Canyon where the flood entered US 24.

YouTube video URL: http://www.youtube.com/watch?v=575Czr6HP00

A 00:01:06 video with CNN Breaking News logo gives credit to Carrie Young (0:00 to 0:21) and to Ed Flanagan, Manitou Motion Pictures (0:22 to 1:06). The first part shows cars being carried down the westbound onramp by turbid discharge from Waldo Canyon. The second part shows turbid discharge from Waldo Canyon overtopping the center K-rail barrier with the rock fall fence in view (Figure 3.2.1 (right)). Two screenshots from this video (Figure 3.2.8) show the red SUV that is visible in Figure 3.2.7 and the truck behind it from which the Tj Omara video was taken and the truck and trailer that is in front of the SUV. Water and sediment are visible in Figure 3.2.8 overtopping the K-rail and flowing across the eastbound lanes of US 24 to Fountain Creek. YouTube video URL: http://www.youtube.com/watch?v=Q_iMDHqRV4U

These video links and others viewed show that after less than a minute, what may have begun as a debris flow had become a sediment-laden flood that lasted for more than approximately 20 minutes. The US 24 shoulder and roadside ditch are uncharacteristically wide downstream of the junction with Waldo Canyon (Figures 3.2.9 and 3.2.10) and this allowed the flood waters to spread out over a width of 50 feet or more.

The eastbound off-ramp of US 24 (Figure 3.2.11) was observed to be free of significant sediment or debris, so it is clear that the discharge from Waldo Canyon that overtopped the K-rail barrier flowed across the eastbound lanes and entered Fountain Creek. Therefore, the discharge confined in the westbound lanes flowed to and down the westbound on-ramp. The highway grades, K-rail barriers, and super-elevation probably contributed to this flow path. At least where observed on the eastbound off-ramp (Figure 3.2.11) and at the curve between Waldo Canyon and the off-ramp (Figure 3.2.6B), no K-rail or other barrier is present to divert flows from entering the Fountain Creek channel. It also appears that the majority of water, sediment, and debris was contained in the westbound lanes; therefore, only a modest to minor amount of water, sediment and debris from Waldo Canyon made it into the eastbound lanes and into Fountain Creek.

In contrast to the eastbound off-ramp, the US 24 westbound on-ramp at the time of the GEER reconnaissance still had piles of debris along the paved surface, knocked-over light poles, and other signs of high velocity flow(Figure 3.2.12). In fact, many YouTube videos showed vehicles being washed toward and down this on-ramp (e.g., the first 0:21 of http://www.youtube.com/watch?v=Q_iMDHqRV4U).

Piers along the southeast abutment of the US 24 overpass of Manitou Avenue just before the on-ramp to westbound US 24 show muddy water marks and effects of the flood flow splash (Figure 3.2.13). The southeast pier has splash marks to its top, suggesting that some flood discharge may have come from the westbound shoulder of US 24. A 00:00:35-long YouTube video by MMaksimow taken from a passing eastbound vehicle shows clearly the discharge of a small tributary canyon down a rock-wedge shaped portion of the road cut face and onto the shoulder of the US 24 westbound lanes (http://www.youtube.com/watch?v=PaUmFV30lK0/) essentially at the east end of the underpass for the westbound on-ramp (Figure 3.2.14). This tributary basin can be identified on Google Maps and from photographs taken during an aerial reconnaissance as shown in Figure 3.2.15. The burn severity maps show that the upper part of this basin is of low to moderate burn severity and no soil burn severity (Figures 2.3 and 2.4, respectively). The MMaksimow video captures dark water discharge that probably represents ashy, carbon-rich flow, and it shows this from a car driving eastbound, which must have been early in the flood before eastbound traffic was stopped. This water probably helped move sediment and debris trough the underpass, which is at a gentler grade than the off-ramp. The aerial photo in Figure 3.2.15 suggests that some flow from the tributary canyon is conveyed southeast along the westbound shoulder; however, the dark water marks in Figure 3.2.14 indicate a split, with the left branch having no flow at the time of the video. The split flow could have occurred during peak discharge, some of which, at least, could have flowed northwest to the bridge abutment. It appears that some of the flow that passed under US 24 on Manitou Avenue may have entered Fountain Creek at the base of the eastbound off-ramp (Figure 3.2.11). However, the majority of flow turned southeast on Manitou Avenue and continued across the Fountain Creek Bridge. Little debris was observed on the banks of Fountain Creek (Figure 3.2.16) or on the bridge (Figure 3.2.17); the reconnaissance team members it did not observe features that led them to believe sediment and woody debris had been removed in the week between the flood event and the reconnaissance observations.

The flow crossed the bridge, continued through a short roadway cut section (visible in the distance of the top left photo in Figure 3.2.17 and identified in Figure 3.2.18), and then entered an embankment section where the super-elevation of the road directed it towards the slope. The flow passed under the steel guardrail until it became clogged by rocky debris (Figure 3.2.19) and forced the flow farther along the guardrail where it could spill through. Just beyond the people visible in Figure 3.2.19, a drainage detail consisting of asphalt curb and 2-in x 6-in wood flashing was added to the guardrail. This curb and flashing was interrupted intermittently every couple hundred feet to direct collected water over short pieces of asphalt apron and down the embankment to Fountain Creek. Examples of this drainage detail at the embankment crest along Manitou Avenue are shown in Figure 3.2.20.

The Manitou Avenue embankment was partially washed out at two locations by flow from the August 9, 2013, flood (Figures 3.2.18 and 3.2.21). Contributing factors to these washouts included the combination of conditions that routed the Waldo Canyon flood flows down the westbound lanes of US 24 to the Manitou Avenue on-ramp, around the curve to Manitou Avenue, and across the Fountain Creek bridge, as well as the drainage details on the shoulder of the westbound lane that allowed discharge over the crest of the fill embankment. A tributary canyon to Fountain Creek located to the west of the embankment section (Figure 3.2.18) had water ponded against the road fill at the time of the reconnaissance. This ponded water also is visible in the bottom photo of Figure 3.2.20 and photos A, B, and C in Figure 3.2.21. The details of the flood event on Manitou Avenue are not known completely. However, it appears that storm water flowed down Manitou Avenue and into the tributary canyon at the position of photo C in Figure 3.2.21. Observations made in the lower part of the tributary canyon above the pond indicate than little runoff occurred in this canyon. The NEXRAD Doppler radar (Figure 3.1.1) scenes are consistent with an interpretation that this canyon was mostly outside the area of major precipitation. Water marks on the north-facing wall of this canyon indicate that water flowed onto Manitou Avenue. A cross culvert was not observed at this location; the amount of ponded water remaining behind the road embankment would have concealed a culvert that is expected to have been in place.

The influence of water from the pond on the large and small washouts is unknown. Seepage through the embankment, as well as flow through the culvert discharging onto the embankment slope, certainly would have contributed to the washouts. Seepage may have been an historical phenomenon that needed to be managed at the small washout because a perforated corrugated steel pipe was observed on the embankment slope (Figure 3.2.21D). It is clear that this pipe was party buried at one time because of the brown color at one end and bright galvanized steel at the other. The pipe diameter was not measured, but it appears to be too large for a normal sub-drain.

It is likely the large washout (Figure 3.2.21A) occurred first, followed by the small one, because in their final form, either of the washouts appears to have the capacity to capture most of the flow. Therefore, it is likely that flow on Manitou Avenue left the highway at each of the drainage interruptions and flowed down the embankment and into Fountain Creek. Once the pond on the west side of Manitou Avenue filled to a point where it overtopped the highway, the large washout increased in size and captured most of the flow that would have traveled farther down the road. Meanwhile, the small washout continued to enlarge until the flood peaked and waned. The trailing limb of the flood hydrograph on the road would have been very steep because of the captured flow and this could explain how the lower roadway has essentially only woody debris. Much of it is arranged in features similar to small levees, as shown in Figure 3.2.22 and the top right photo in Figure 3.2.20, which also shows a car bumper and the lowest extent of significant debris on the road.

Construction by Colorado Department of Transportation (CDOT) to support the eastbound embankment slope using geogrid reinforcement and a shotcrete/chain-link facing (Figure 3.2.23), and to protect its toe using large riprap. Footage in YouTube videos indicates that at least the geogrids reinforcement work was underway on August 9 and during the flood. Because a lot of the flood water, sediment and debris was captured and diverted by the westbound onramp to Manitou Avenue, it seems unlikely that substantial discharge flowed past the riprap at the toe of the slope. Rilling is visible on the slope and riprap is visible at the toe of the slope (top left and bottom photo in Figure 3.2.23); the chain-link reinforcement is shown in the top right photo in Figure 3.2.16 at the end of the day on August 16. It is expected that the condition of this slope and the construction of measures to stabilize it and the US 24 roadway above pre-date the flooding on August 9.

Figure 3.2.1. Mouth of Waldo Canyon at US Highway 24; Waldo Canyon culvert inlet on August 16, 2013, half full of sediment at inlet (left); screenshot of YouTube video by Ed Flanagan taken on August 9, 2013 (right). Left: View toward southeast from +38.887°N, -104.932°W, approximate elevation 6767 feet. Right: View from eastbound lanes showing the center K-rail barrier on US 24 being overtopped by water and sediment discharge from Waldo Canyon apparently after filling the westbound lanes (http://www.youtube.com/watch?v=Q_iMDHqRV4U); rock fall fence adjacent to east side of Waldo Canyon is visible.

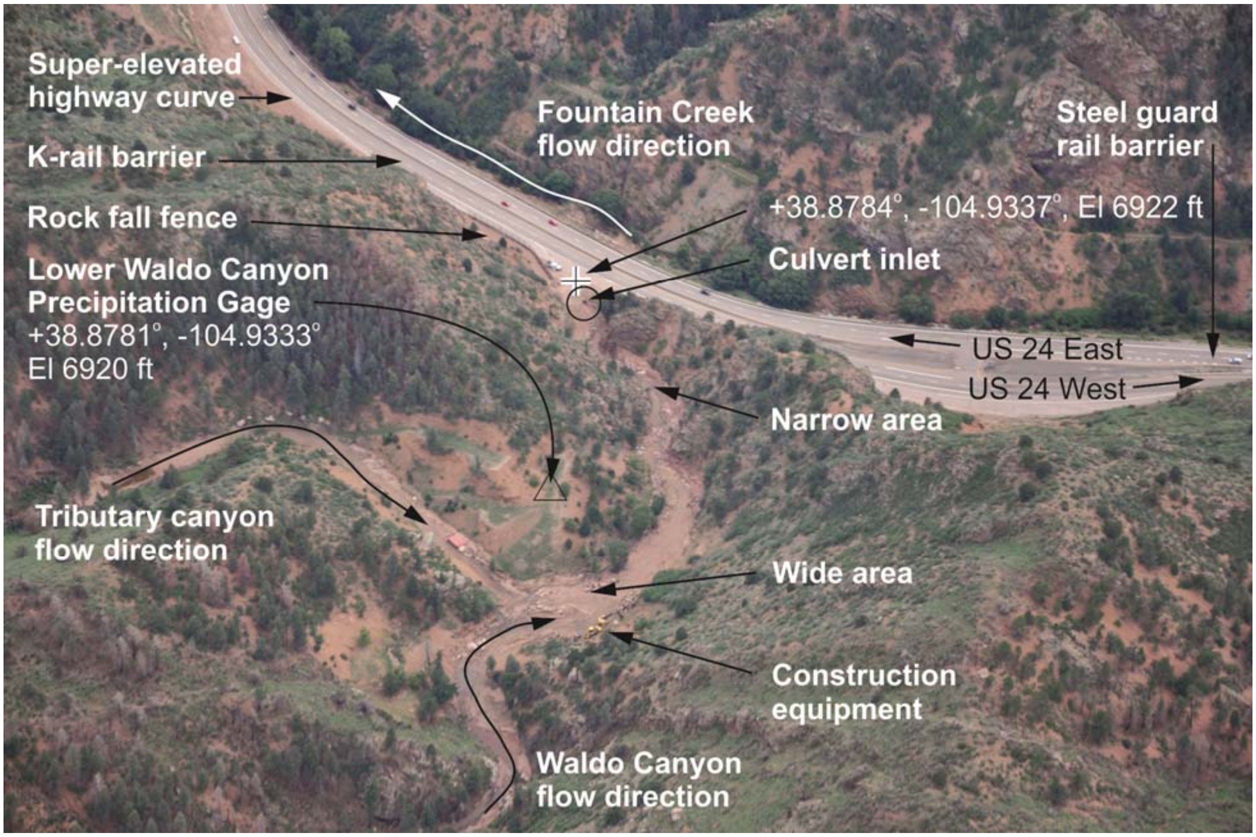


Figure 3.2.2. Aerial oblique photograph showing the lower part of Waldo Canyon and US Highway 24. Photo taken August 17, 2013, as part of the GEER reconnaissance. Location of Lower Waldo Canyon Precipitation Gage (marked by open black triangle) is 38.8781°N, -104.9333°W, elevation 6920 ft. Photo view is toward the south-southeast.

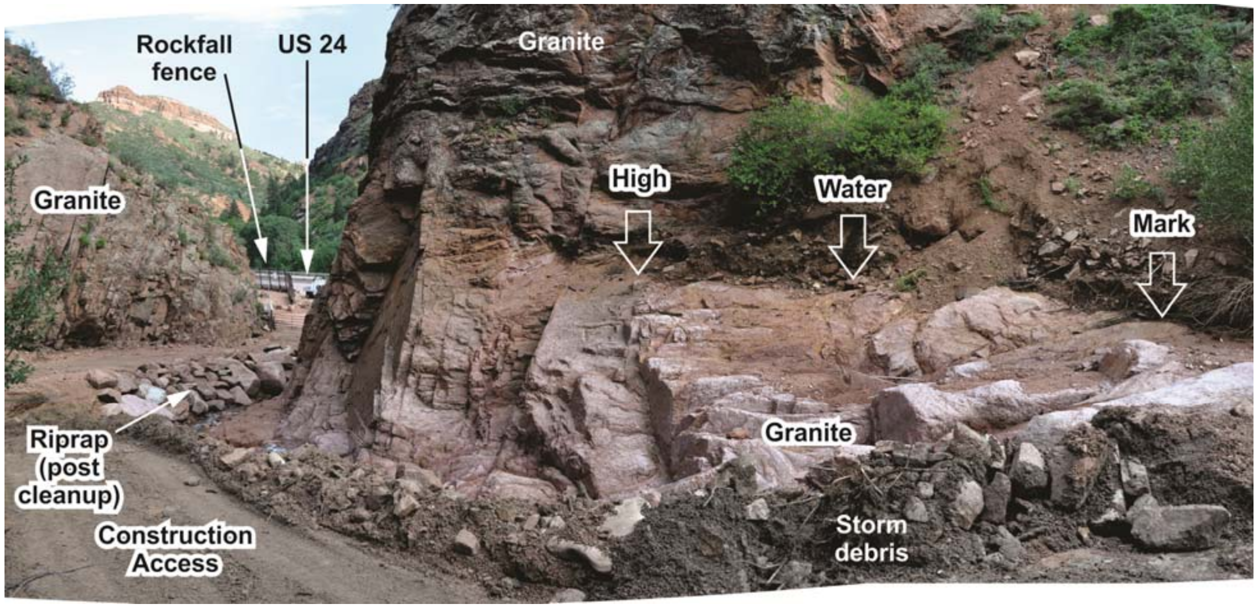


Figure 3.2.3. Lower stretch of Waldo Canyon showing rock-bed channel and high-water mark of August 9, 2013, flood. US 24 and the rockfall fence also are visible. Location is in Narrow area in Figure 3.2.2; 38.8771° N, -104.9331° W, elevation 6796 ft; view azimuth is 155° (SE).

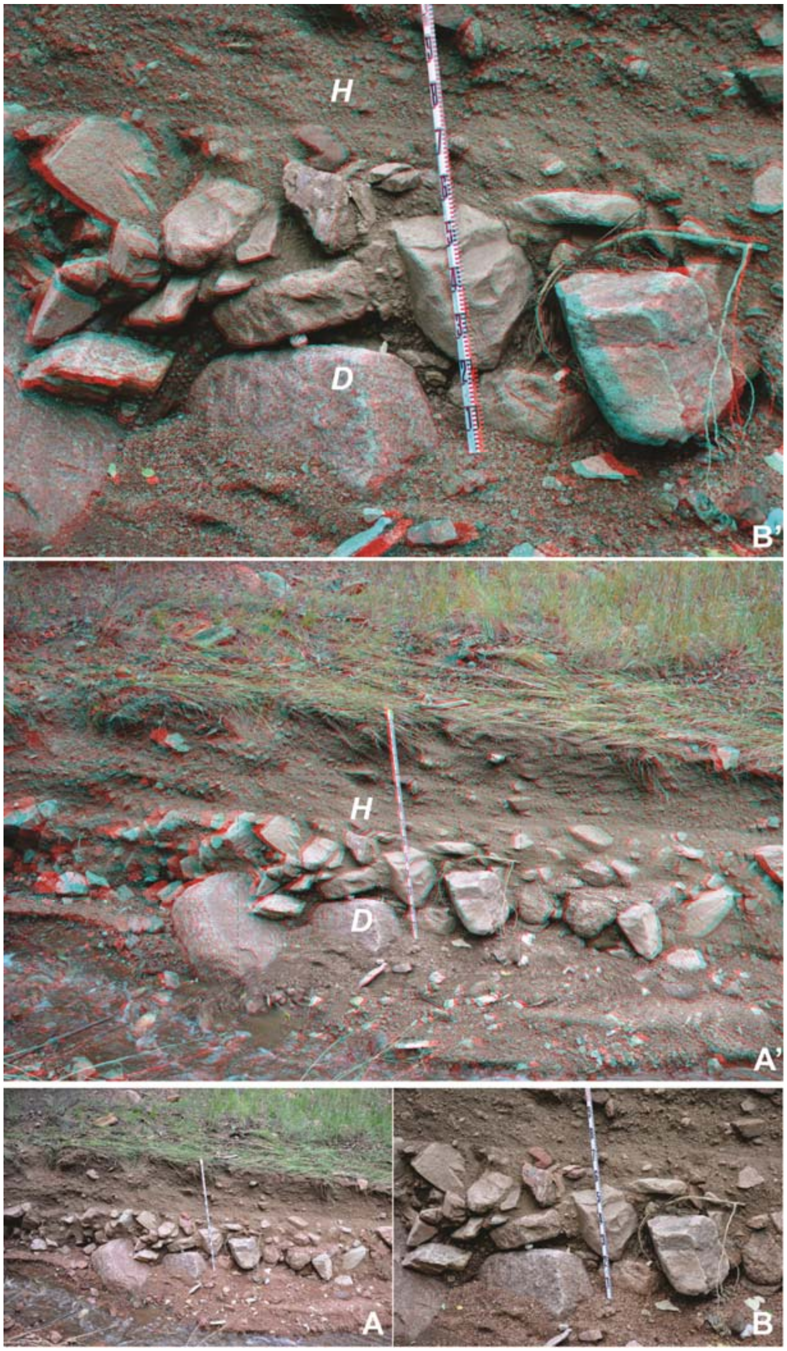


Figure 3.2.4. Pre-August 9, 2013, debris flow (D) and hyperconcentrated sediment flow (H) deposits exposed in channel of Waldo Canyon. A and B are photographs; A' and B' are red-cyan anaglyphs made with StereoPhotoMaker v. 4.41. Ruler numbers are decimeters. Location is a short distance above Narrow area in Figure 3.2.2; 38.8778° N, -104.9337° W, elevation 6846 ft.

Figure 3.2.5. The rockfall fence adjacent to the mouth of Waldo Canyon. Left: the K-rail barrier and the super-elevation of the highway east of where Waldo Canyon meets US 24 also are visible. View is east-southeast from +38.877° N, -104.932° W, approximate elevation 6765 feet. Right: view of August 9, 2013, storm debris trapped by rockfall fence on the highway side of the fence.

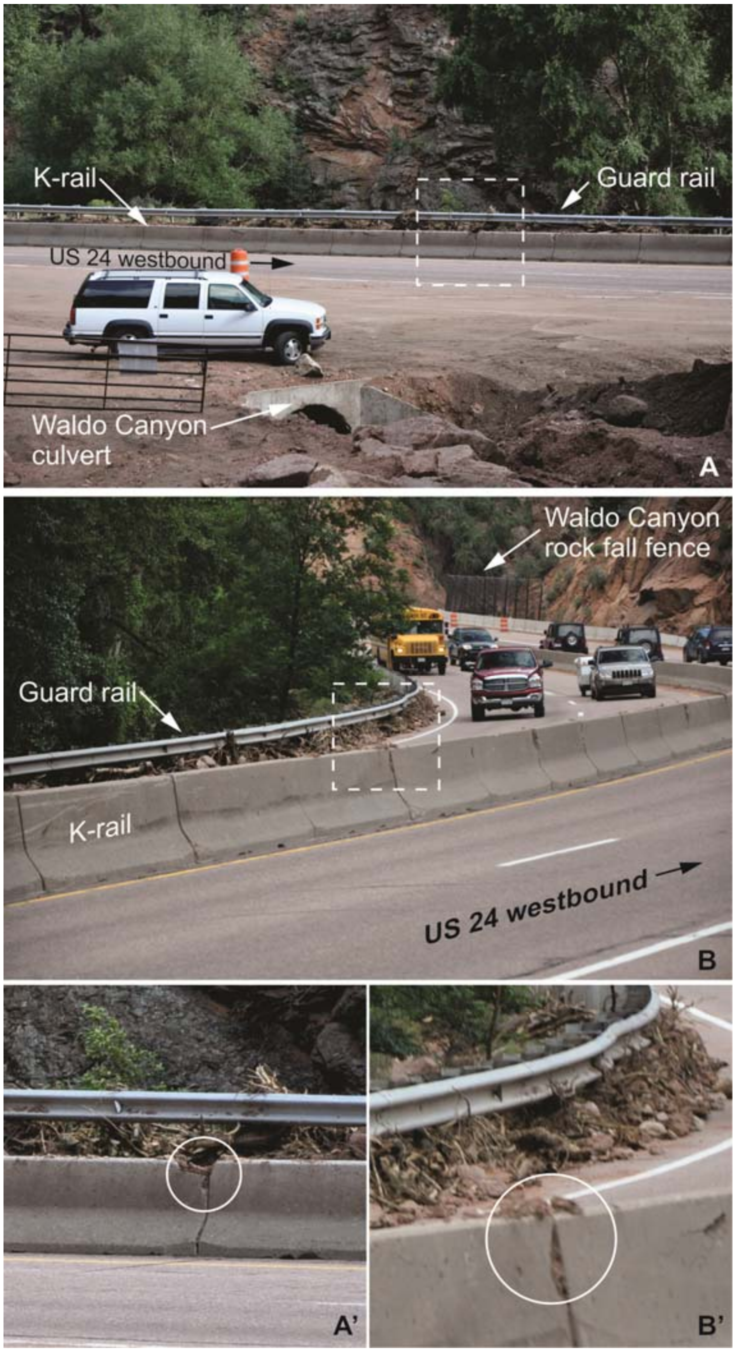


Figure 3.2.6. Rock and woody debris on K-rail and under guard rail on eastbound US 24. A. view from mouth of Waldo Canyon (38.877° N, -104.932° W); B. view from wide shoulder on westbound US 24 (38.8754° N, -104.9292° W). A' and B' are inset photos for A and B, respectively; soil on K-rails marked by open white circles.

Figure 3.2.7. Screenshots from YouTube video by Tj Omara at three times during its 10:36 duration. The vehicle from which the video was taken was located in the westbound lanes of US 24 about 0.1 mi (0.18 km) east of Waldo Canyon at about 38.8761° N, -104.9303° W.

Figure 3.2.8. Screenshots from YouTube video by Breaking News attributed to Ed Flanagan, Manitou Motion Pictures, at two times during its 1:06 duration. Upper (video time 0:34): the vehicle from which the video by Tj Omara was taken is in the center of this screenshot; the red SUV in Figure 3.2.7 is labeled; view toward the east over K-rail barrier from eastbound lanes of US 24 showing that the westbound lanes are choked with sediment up to the top of the K-rail barrier. Lower (video time 0:41): the truck and trailer ahead of the red SUV in Figure 3.2.7 are labeled; storm debris on eastbound lanes is visible; Fountain Creek is just off the right edge of the photo.

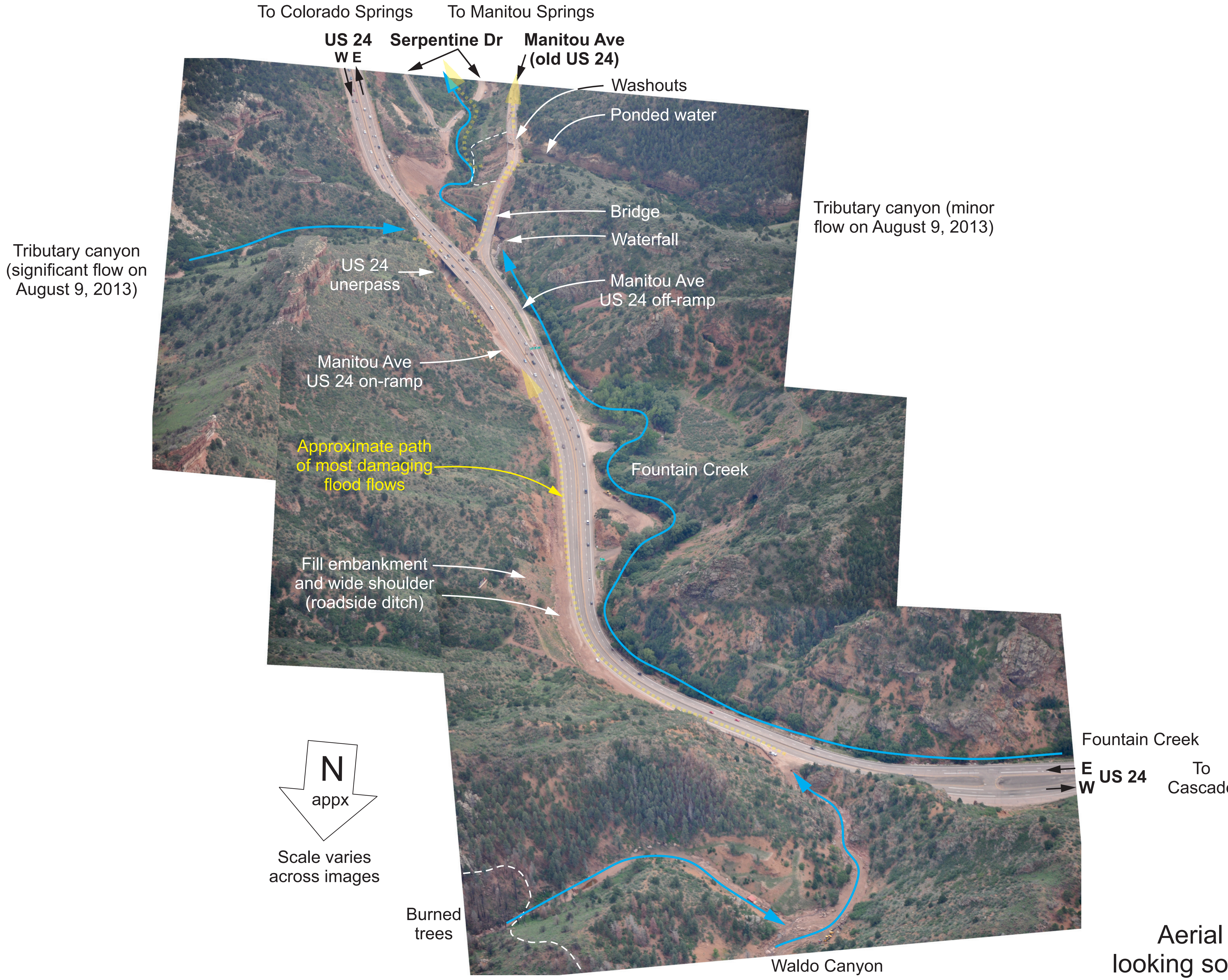


Figure 3.2.9
Aerial oblique photo mosaic
looking south at US 24 from west of
Manitou Springs to Waldo Canyon

Figure 3.2.10. Looking northwest (left) and southeast (right) from relative high ground along shoulder of westbound US 24. US 24 super-elevation is visible to the left in the left image. Wide shoulder is visible in both images. Camera location: +38.8757° N, -104.9295° W, approximate elevation 6686 feet. Waldo Canyon is in the distance above car on highway in left image. The earth embankment toe visible in the foreground on the right side of the left image is a placed earth fill of uncertain purpose (see Figure 3.2.9 for aerial oblique view); it could be a stockpile in a material site and may indicate wider DOT Right of Way. Right image shows flattening of highway grade, wide shoulder, and the earth fill embankment toe. The westbound on-ramp is at steeper grade and just beyond the person. The eastbound off-ramp is near the cars and highway sign on the right side of right image.

Figure 3.2.11. View of the US 24 eastbound off-ramp. Top: view northwest up the off-ramp; the US 24 underpass to the on-ramp is to the left of the camera position; Fountain Creek is located to the right of the guardrail. Middle: panorama view to the east and southeast from a point part way down the off-ramp; underpass is visible on the left; Fountain Creek is located to the right of the guardrail. Bottom: view southwest of base of off-ramp; camera position is on access road connecting Manitou Avenue to US 24 westbound on-ramp; tree in middle of view is the same tree that is visible left of center in the middle photo. Note that only woody debris is present on

the off-ramp visible and that it extends only to where the person is walking (top photo); the remainder of the ramp is clear of debris and it appears that the woody debris may have been deposited by water flowing under the guardrail on the left side of the bottom photo. Camera position for the top photo is +38.8708° N, -104.9261° W, approximate elevation 6592 feet.

Figure 3.2.12. View of the US 24 westbound on-ramp. Top: view southeast down the westbound on-ramp; some of the sediment cleared from on-ramp is visible on the shoulder between westbound US 24 and the on-ramp. Bottom: panoramic view toward southwest (left) and northwest (right); woody debris around the wood posts of the guardrail may be a suggestion of the flood level in the westbound lanes. Camera position for top photo is +38.8719° N, -104.9265° W, approximate elevation 6670 feet.

Figure 3.2.13. Southeast abutment of US 24 overpass of Manitou Avenue just before the on-ramp to westbound US 24. Left: view from the east side; note that splash marks go clear to the top of the closest bridge pier and that the flow line itself can be seen about mid-height, and decreasing at subsequent piers farther west. Right: view from the west side; the muddy water mark is easier to see on the cut slope behind the piers; splash marks on the east sides of the piers and the shape of the water mark on the west sides suggests that the water flow was high velocity. Camera position for left photo is +38.8711° N, -104.9257° W, approximate elevation 6651 feet.

Figure 3.2.14. Screenshots from YouTube video by MMaksimow at two times during its 0:35 duration. Upper (video time 0:03): dark water discharge over cut slope on westbound US 24 shoulder just southeast of overpass on Manitou Avenue where it becomes the westbound on-ramp; view toward the northeast over K-rail barrier from eastbound lanes of US 24 showing the transition from steel guard rail to bridge guard rail. Lower (video time 0:06): same view as upper screenshot with rock wedge more clearly visible.

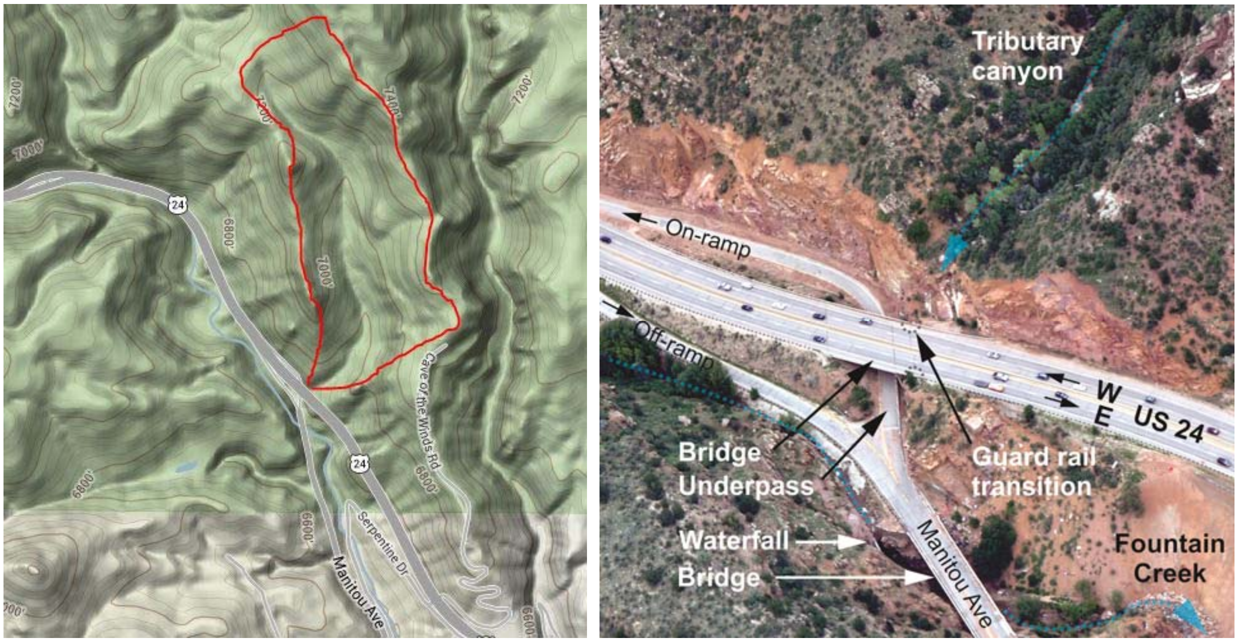


Figure 3.2.15. Tributary canyon draining onto cut slope on US 24 westbound shoulder at bridge abutment with dark water flood discharge captured in YouTube video by MMaksimow (Figure 3.2.14. Left: shaded relief topographic map from Google Maps with drainage basin outlined. Right: aerial oblique photograph taken August 17, 2013, showing details of the US 24 overpass of Manitou Avenue.

Figure 3.2.16. Fountain Creek adjacent to the junction of the eastbound off-ramp and Manitou Avenue where some of the Waldo Canyon flood water entered it. This part of the channel appears to have had little sediment or woody debris in it from the August 9,2013, storm. View north from +38.8702° N, -104.9259° W, approximate elevation 6598.

Figure 3.2.17. Fountain Creek Bridge on Manitou Avenue (old US 24). Top left: looking downslope to the south-southeast, towards Manitou Springs; storm debris visible on bridge, particularly against the left (east) guard rail. Top right: State of Colorado Highway Department plaque on Fountain Creek Bridge from 1932. Bottom: mosaic photo of Fountain Creek Bridge from west side of guard rail north of north abutment; Fountain Creek at the waterfall is visible in the lower right corner of the mosaic photo at the base of the rock wall below the man. Camera position for top left photo: +38.8702°N, -104.9258° W, approximate elevation 6589.

Figure 3.2.18. Aerial oblique photo of Manitou Avenue showing selected features, including two washout areas. Aerial oblique photograph taken August 17, 2013, as part of the GEER reconnaissance.

Figure 3.2.19. Debris-clogged guardrail on Manitou Avenue (old US 24). View south from +38.8691° N, -104.9255° W, approximate elevation 6573.

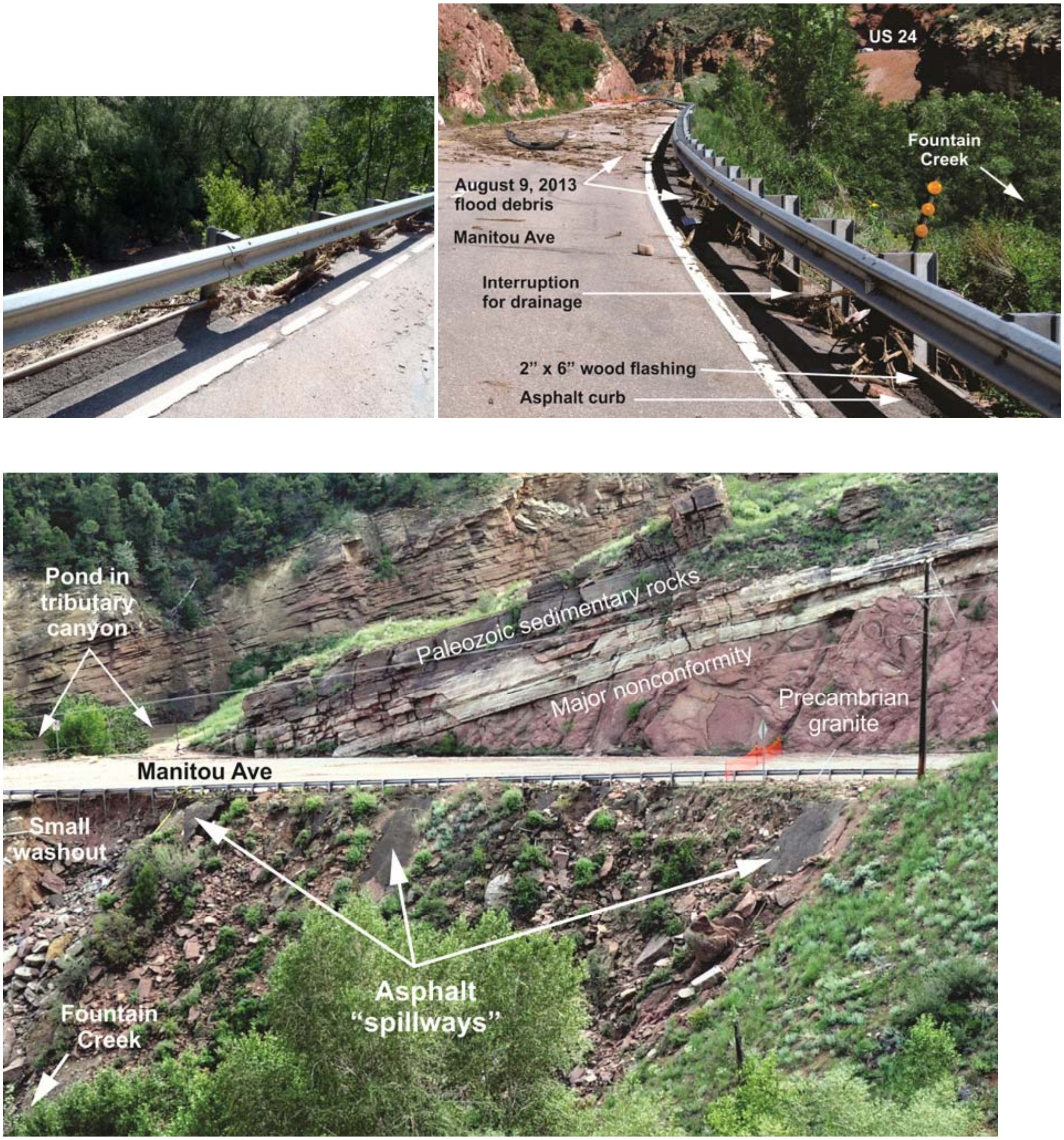
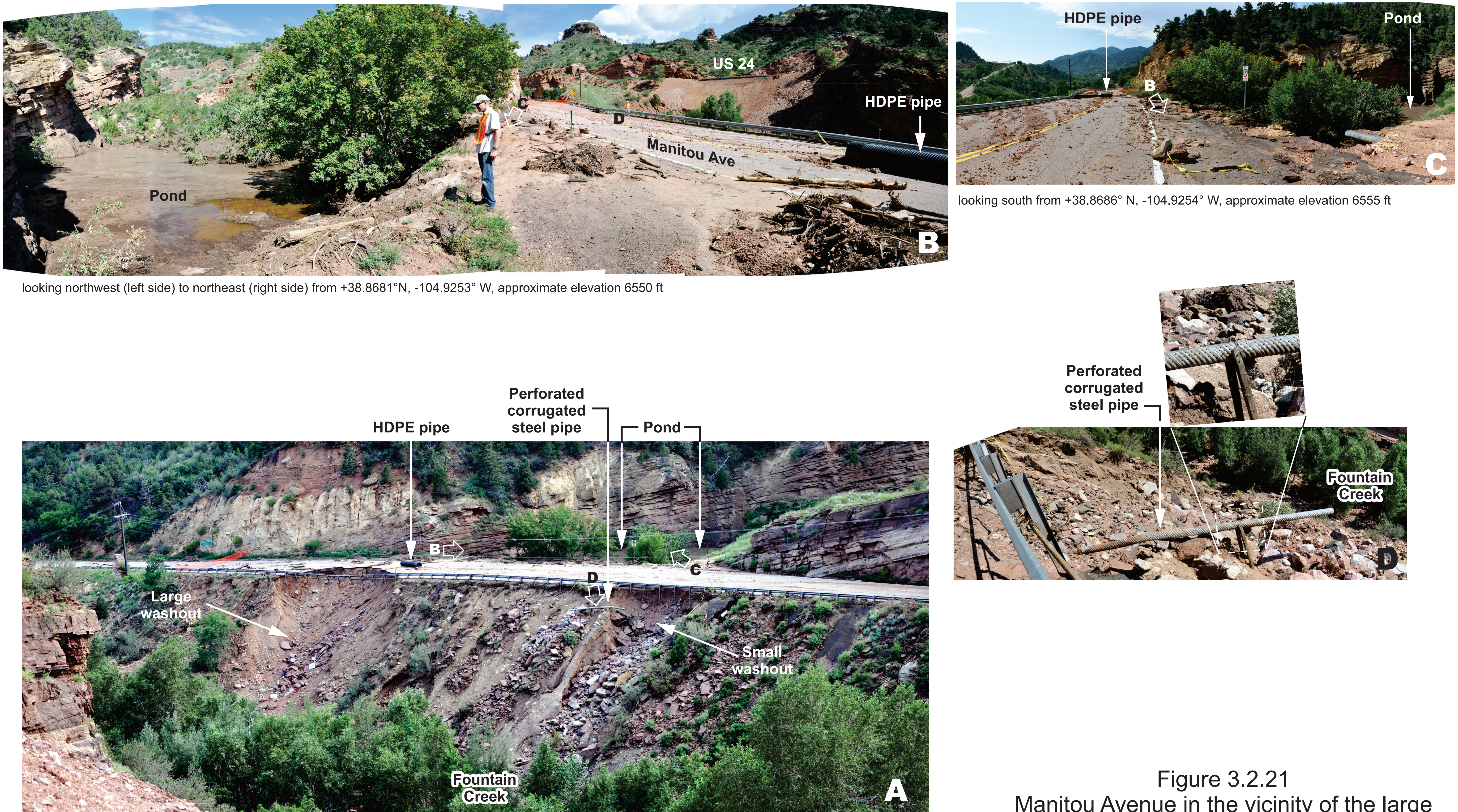


Figure 3.2.20. Designed interruptions in asphalt curb and asphalt "spillways" located along Manitou Avenue embankment crest above Fountain Creek. Camera positions: top left, looking south from +38.8652° N, -104.9234° W, approximate elevation 6431 ft; top right, looking northwest (336° azm) from +38.8662° N, -104.9243° W, approximate elevation 6481 ft; bottom, looking southwest (238° azm) from +38.8695°N, -104.9244° W, approximate elevation 6565 ft.



looking northwest (left side) to northeast (right side) from +38.8681°N, -104.9253° W, approximate elevation 6550 ft

looking south from +38.8686° N, -104.9254° W, approximate elevation 6555 ft

looking southwest (238° azm) from +38.8695°N, -104.9244° W, approximate elevation 6565 ft

Figure 3.2.21
Manitou Avenue in the vicinity of the large and small washouts on the embankment

Figure 3.2.22. Manitou Avenue below large washout with woody debris but not much sediment. Woody debris from side canyon is also visible. Car bumper is a distinctive feature visible in top right photo in Figure 3.2.20. View south-southeast from 38.8667° N, -104.9245° W, approximate elevation 6486 ft.

Figure 3.2.23. Riprap and rilling on eastbound US 24 embankment, and Geogrid reinforcement with shotcrete and chain-link facing at crest of embankment. Top left: view to the northwest from +38.8695° N, -104.9245° W, approximate elevation 6583 feet; Fountain Creek Bridge that carried flood and debris from Waldo Canyon is in the background. Top right: view to the north from +38.8695° N, -104.9245° W, approximate elevation 6583 feet. Bottom: view to the east from 38.8695° N, -104.9250° W, approximate elevation 6564 feet; the small green soil compactor visible in the top right photo also is visible in the bottom photo.

3.3 Observations of the Williams Canyon Flood

Williams Canyon drains directly into the City of Manitou Springs. It has an area of 6.8 km^2 (2.65 mi^2) above its intersection with US 24 (Table 2.1; Figures 2.5 and 2.6). It is the major canyon east of Waldo Canyon and it shares its western drainage divide with the small canyon shown in Figure 3.2.15. An aerial photo mosaic of the lower part of Williams Canyon and the City of Manitou Springs is shown in Figure 3.3.1. Locations of figures referenced in this section of the report are identified in Figure 3.3.1, as are the channel traces of Williams Canyon and Fountain Creek. Of importance to the flood effects is the nature of the open-channel and culvert sections of the drainage channels. The GEER team visited this area on August 16, 2013, one week after the flood; the observations presented here are from that reconnaissance and subsequent viewing of available YouTube videos taken during the flood on August 9 by eyewitness observers. The observations are presented in an order following the path of the flood, from upstream to downstream.

The upper part of Williams Canyon has private gated access belonging to the Cave of the Winds and was not visited by members of the GEER team. Below this gate (Figure 3.3.2), Cañon Avenue follows the canyon bottom approximately 0.2 miles, passing under US 24 and entering the north edge of the residential part of the City of Manitou Springs. The Williams Canyon channel upslope of US 24 is on the west (left) side of the canyon bottom. At the Cave of the Winds gate (Figure 3.3.2), the narrow, steep-walled character of the canyon is evident; the channel appears to have been separated from the exit road by a stone-and-mortar wall prior to the August 9, 2013, storm event. A corrugated metal pipe that was carried by the flood was wrapped around a gate post (under the "E" in EXIT on the sign in Figure 3.3.2). It appeared that the maximum flood height was close to reaching the lowest part of the hanging overhead sign.

A short distance south of the gate in Figure 3.3.2, the channel was grouted riprap (Figures 3.3.3 and 3.3.4) suggesting that erosion may have been an historical problem. A steel light pole near the gate was leaning (Figure 3.3.3) and had a tree branch hanging on it; above the tree branch the pole was smooth steel; however, below the tree branch, dents are in the pole are visible providing additional indication of maximum flood depth. Furthermore, the character of the light pole and the fact that it remains after the flood is an indication that the discharge probably was essentially water with floating debris and sediment, rather than debris flow. A relatively narrow, gabion-lined channel with stepped geometry begins adjacent to the white truck in Figures 3.3.3 and 3.3.4, and extends to a circular steel pipe culvert estimated to be approximately 54 inches in diameter (Figure 3.3.5). The gabion baskets appeared to have performed well and to require no specific maintenance caused by flood damage. The circular culvert inlet is located a short distance north of the US 24 bridge.

Debris on the left side of the photo in Figure 3.3.5 at about shoulder height where the man is pointing (inset photo in Figure 3.3.5) was inspected to determine if it was deposited by debris flow or flood flow processes, or if it had been dumped during clean up; the elevation in the canyon bottom appeared to be reasonable for a maximum flood depth. The material was unsorted, unstratified, and contained boulder-sized rock fragments surrounded by finer-grained matrix; however, it did not have lateral continuity that would be expected of a levee from a bouldery debris-flow snout. Furthermore, the nature of damage to the gate and light pole at the Cave of the Winds exit were consistent with flood flow, but not with boulder debris flow. Flow characteristics captured in YouTube videos taken from a path above the culvert in Figure 3.3.5 clearly indicate turbulent flood flow, but that observation by itself does not rule out the possibility of processes meeting the definition of debris-flow occurring earlier in the hydrograph.

Sediment concentrations by volume ranging from 0.4 to 0.8 are reported by Iverson (1997) as typical for debris-flow mixtures; a fluid slurry with this range of sediment concentration would have a unit weight of 103.6 to 124.4 lb/ft^3 (16.3 to 19.5 kN/m^3) if all solid grains had the specific gravity of quartz (2.65). The narrow character of the Williams Canyon bottom (Figure 3.3.5) indicates that any substantial debris flow mass would have been channelized at this point in the flow path and damage consistent with channelized bouldery debris flow processes was not observed at any location in Williams Canyon; damage observed and documented in this GEER report is consistent with flood flows carrying sediment but not at concentrations beyond the range of normal flood flows.

A stone-and-mortar residence built into the east side of Williams Canyon (Figure 3.3.6) was the first structure impacted by the flood in Williams Canyon and also the farthest upstream of any YouTube video that was viewed by GEER team members. Two YouTube videos include images taken from a path under the US 24 bridge on the west side of Williams Canyon and clearly show the depth and velocity of flow along this part of Cañon Avenue at one point in the flood. Posted YouTube videos of the August 9, 2013, flood in Williams Canyon are at these links: 00:10:51-long video by JS4IV: http://www.youtube.com/watch?v=RcauQ_UMx08
00:02:46-long video by Dave McCrary: http://www.youtube.com/watch?v=pEEW0czt0Sg
(labeled Video 1 in Figure 3.3.1).

Two screenshots from the 02:46-long YouTube video by Dave McCrary are included in Figure 3.3.6 adjacent to photos taken on August 16, 2013, during the GEER reconnaissance. Distinctive windows and doors on the stone residence make it possible to infer flow depths from the video images. The water in the screenshots in Figure 3.3.6 is dark brown and probably at least five feet (1.5 m) deep. The velocity of the water cannot be deduced from screenshots, but it is clear on the video that it is flowing swiftly, probably several feet per second (>3 feet or >1 m per second).

The YouTube videos of the flood in Williams Canyon below the US 24 bridge can be interpreted to show that the flood volume was much greater than could have been carried by the culvert (Figure 3.3.5) and much of it was flowing down Cañon Avenue. Immediately south of US 24 on Cañon Avenue, the homes directly impacted by the flood (Figure 3.3.7) were adjacent to the Williams Canyon drainage culvert outlet (Figure 3.3.8). Most of the flood water went between these two structures into the deeper gabion-lined open channel, but a substantial amount of water continued down Canñon Avenue. Figure 3.3.7 includes a photo taken on August 13, 2013, that shows the extent of debris remaining three days after the flood event.

The gabion-lined open channel extends southward from the area shown in Figure 3.3.8 to a concrete box culvert beneath Narrows Road west of Canon Avenue (Figure 3.3.9), at some point making a transition to a rock- or slab-lined open channel. Narrows Road is covered by earth material presumably from flood-damage cleanup. Figure 3.3.9 shows two photos of essentially the same view; the top photo was taken by the GEER team on August 16, 2013, whereas the bottom photo was taken by Jason Kean, US Geological Survey, on August 13.

South of the concrete box culvert under Narrows Road, the Williams Canyon drainage is a concrete-lined, rectangular, open channel (Figure 3.3.10). The flood discharge exceeded the capacity of these hydraulic structures and flowed above the channel, along streets, and between structures. Two nearly identical views are displayed in Figure 3.3.10; the top photo was taken by the GEER team on August 16, 2013, whereas the bottom photo was taken by Jason Kean, US Geological Survey, on August 13. The top photo shows what appears to be a mud line on the left wall of the concrete channel adjacent to the structure that is overhanging it. It is clear in the bottom photo that this mud line was the surface of deposited flood sediment about 3-feet (1-m) deep on August 13 that had been excavated by the time of the GEER team visit.

The concrete-lined, rectangular, open channel curves to the left south of Narrows Road and enters a deeper section which becomes the inlet to a culvert under Cañon Avenue (Figures 3.3.11 and 3.3.12) that carries the Williams Canyon flow the rest of the way to Fountain Creek. During the August 9, 2013, flood, the culvert was overwhelmed and water flowed down Cañon Avenue, as is documented in a YouTube video by Dave McCrary (bottom photo in Figure 3.3.12) (http://www.youtube.com/watch?v=4Y5U_Zo18cM) taken looking north up Cañon Avenue from the intersection with Spencer Avenue (labeled Video 2 in Figure 3.3.1).

Cañon Avenue makes a left turn before reaching the main Manitou Springs business district and Fountain Creek; this left turn is at the intersection with Park Avenue. A view west along Park Avenue during the GEER reconnaissance (Figure 3.3.13) shows sandbags that appear to be staged for a future flood event. A YouTube video by JS4VI (bottom photo in Figure 3.3.13) (http://www.youtube.com/watch?v=RcauQ_UMx08) taken from the Post Office building on Cañon Avenue (labeled Video 3 in Figure 3.3.1) shows the intersection with Park Avenue with thin flood discharge that appears to extend completely across Cañon Avenue. A prominent feature in the screenshot from this video (Figure 3.3.13) is the geyser shooting from the street that represents pressure flow in the Williams Canyon drainage culvert; the top of the geyser appears to be at least 10 feet (3 m) above the street.

The video by JS4VI also shows the flood flow where it turns west from Cañon Avenue onto Park Avenue (Figure 3.3.13); most of the flood flow passes the building on the left in the upper photo of Figure 3.3.13, turns left across a park area, and enters the open channel of Fountain Creek. Even without the video documentation, this flow path was evident to the GEER team.

What was not evident, however, was how much flood water and debris passed through the businesses on the ground floor of this building and had been cleaned up within the one-week period since the flood.

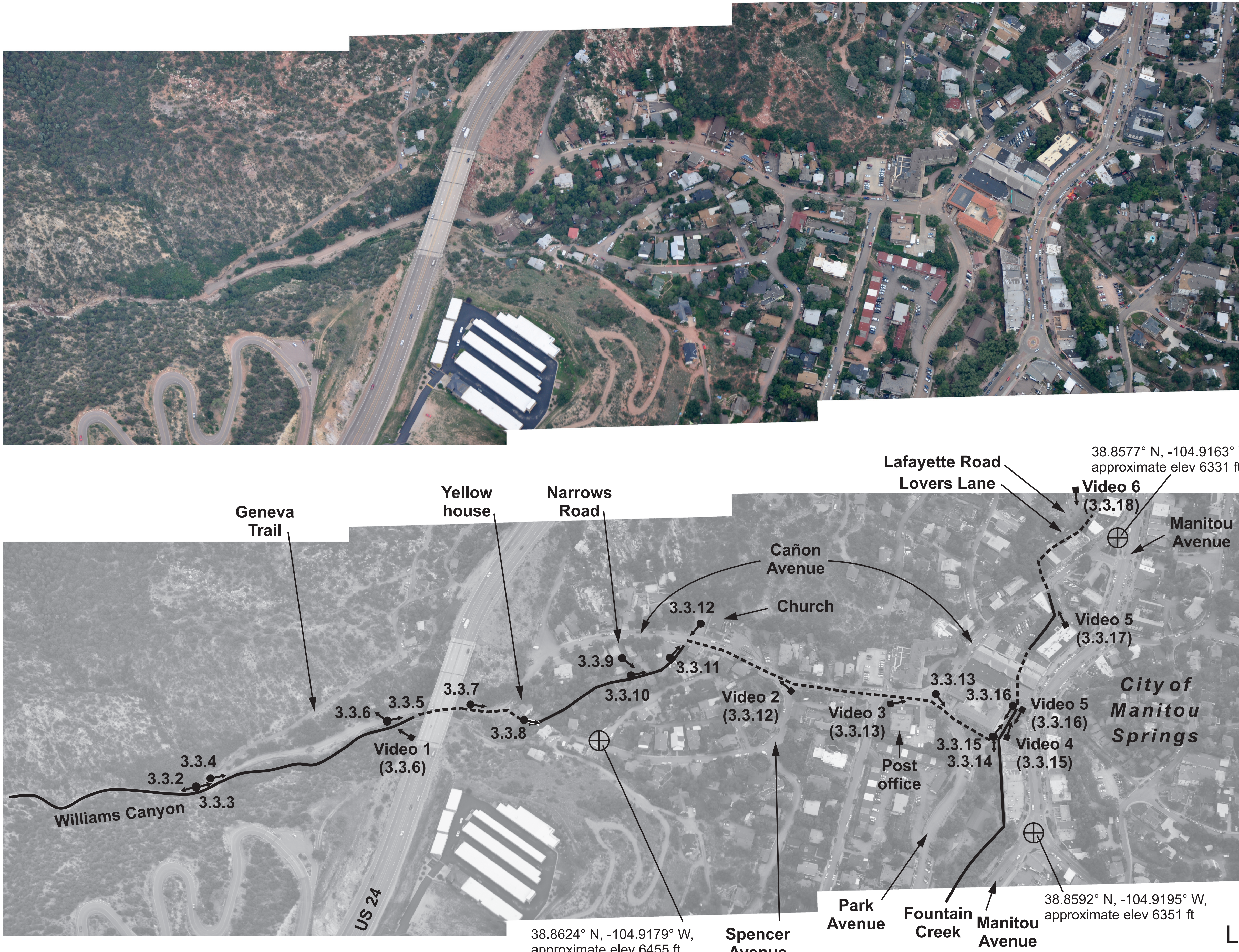
The outlet of the Williams Canyon drainage culvert at Fountain Creek (Figure 3.3.14) was essentially clear of large debris at the time of the GEER reconnaissance. A metal fence at the top of the culvert was the part of the boundary fence of a city park; the fence had been pushed over by water and debris flowing into Fountain Creek. The retail shops facing Manitou Avenue at this location have their backs overhanging the Fountain Creek channel (Figure 3.3.14). The apparently undamaged angle bracing for the businesses suggest little if any flood water reached that height; at this location, the flow in Fountain Creek would include Waldo Canyon discharge and backwater from the Williams Canyon culvert, as well as overland flow from Williams Canyon. For reference, the drainage area of Fountain Creek is 106 square miles (275 km^2) above the stream gage located about 2 miles downstream from Manitou Springs (USGS 07103700).

The building in Figure 3.3.13 borders on Fountain Creek. The south side of the building is a café with creek-side patio seating (Figure 3.3.15). The top photo in Figure 3.3.15 was taken by the GEER team on August 16, 2013, whereas the bottom photo is a screenshot from a YouTube video by Thom Vincent taken on August 9 (http://www.youtube.com/watch?v=ZBs-7siS86c) (labeled Video 4 in Figure 3.3.1). The damaged fence is the primary indication of the flood remaining on the patio after the week of cleanup activities. Views of Fountain Creek looking upstream from the footbridge visible in Figure 3.3.15 are shown in Figure 3.3.16. The water level in the video by Apeakrunner taken on August 9 (labeled Video 5 in Figure 3.3.1) (http://www.youtube.com/watch?v=DWu5lizAPKY) appears to be lower, hence later in the flood, than the water level in the video by Thom Vincent.

The flood along Fountain Creek in Manitou Springs was captured by video from two additional locations: just west of Cañon Avenue (Figure 3.3.17, labeled Video 5 in Figure 3.3.1) and along and just east of Lovers Lane (Figure 3.3.18, labeled Video 6 in Figure 3.3.1). Three screenshots of a video by Apeakrunner (http://www.youtube.com/watch?v=DWu5lizAPKY) (Figure 3.3.17) appear to be in real time and capture the rising limb of the hydrograph. Cañon Avenue is visible in the upper part of the video frames and crosses Fountain Creek where it is in a culvert.

On the east side of Cañon Avenue, the Fountain Creek channel is a quasi-culvert and open-channel section; buildings have been constructed over the channel but openings at street level, as can be seen in Figure 3.3.18 at the intersection of Lovers Lane and Lafayette Road (video by growmotionvideo http://www.youtube.com/watch?v=_ncHXBdqk7o). The dark band at the base of the building behind the stop sign in the screenshot at video time 00:37 marks openings along the Fountain Creek channel. Lafayette Road crosses Fountain Creek with a conventional culvert, but the channel upstream of Lafayette Road is essentially concrete, rectangular, open-channel section with only a few feet of vertical space to the bottoms of overhanging buildings. Downstream of Lafayette Road, the Fountain Creek channel is a rectangular open channel.

The GEER team did not visit this location during the reconnaissance; it was in the systematic viewing YouTube videos that the potential value of the information documented by eyewitness accounts became evident. In many cases, the GEER team members were sufficiently familiar with the layout of Manitou Springs that the locations of the videos were recognizable. However, in the case of the video by growmotionvideo, a few minutes of searching Google Maps with the Street View utility provided clear indication of the location of the view, as well as the nature of the channel.



List of YouTube Videos Identified on This Figure

Video 1 by Dave McCrary
http://www.youtube.com/watch?v=pEEW0czt0Sg

Video 2 by Dave McCrary
http://www.youtube.com/watch?v=4Y5U_Zo18cM

Video 3 by JS4IV
http://www.youtube.com/watch?v=RcauQ_UMx08

Video 4 by Thom Vincent
http://www.youtube.com/watch?v=ZBs-7siS86c

Video 5 by Apeakrunner
http://www.youtube.com/watch?v=DWu5lizAPKY

Video 6 by growmotionvideo
http://www.youtube.com/watch?v=_ncHXBdqk7o

Figure 3.3.1
Aerial photo mosaic of Lower Williams Canyon and the City of Manitou Springs

Figure 3.3.2. View looking north (upstream) from the bottom of Williams Canyon at the end of Cañon Avenue at Geneva Trail. The pre-flood channel appears to be the narrow space between the rock cliff and the stone-and-mortar wall; the wider eroded strip appears to be the exit road from Cave of the Winds. Camera location: +38.8655° N, -104.9178° W, elevation 6522 ft.

Figure 3.3.3. View looking south (downstream) from the bottom of Williams Canyon near the end of Cañon Avenue at Geneva Trail. Vehicles are parked on Cañon Avenue. Leaning metal feature is a light pole that has a tree branch hanging on it; above the tree branch is smooth steel, whereas dents are present in the pole below the tree branch providing an indication of maximum flood depth. Grouted riprap is visible in the middle-right part of the photo, and gabion baskets are visible at the end of the grouted riprap to the right of the vehicles. Camera location: +38.8655^{o} N, -104.9178^{o} W, elevation 6522 ft.

Figure 3.3.4. View looking south along Cañon Avenue at the transition from grouted riprap to gabion baskets lining the channel of Williams Canyon. The US 24 bridge over Williams Canyon is visible in the top center of the photo. Camera location: +38.9320^{o} N, -104.9178^{o} W, elevation 6515 ft.

Figure 3.3.5. View looking south along Cañon Avenue at the transition from gabion-lined open channel to a culvert estimated to be 54 inches in diameter. US 24 bridge over Williams Canyon is visible. Steel pipe next to bridge pier discharges into an inlet to the culvert. The narrow bottom of Williams Canyon is evident in this photo. Northernmost residence in Williams Canyon is adjacent to the left side of this photo; see Figure 3.3.6. Inset photo is a view of debris on east side of canyon between the two vehicles where the man is pointing. Camera location: +38.8641° N, -104.9173° W, elevation 6472 ft.

Figure 3.3.6. Stone-and-mortar residence in Williams Canyon north of US 24. Top left and bottom left: photos of residence taken on August 16, 2013. Top right and bottom right: screenshots of YouTube video by Dave McCrary taken on August 9, 2013; Video 1 in Figure 3.3.1. Flood flow is partway up the wall of the residence. Top: door and boarded window in left photo correspond to door and window with white trim in right photo; flow appears to be below the middle of the window. Bottom: distinctive white-trimmed windows and white door above horizontal dark line in left photo are visible in right photo; flow appears to be about the level of the boarded doors in the left photo. Camera location: +38.8641° N, -104.9173° W, elevation 6472 ft.

Figure 3.3.7. View looking south along Cañon Avenue and the buried culvert for Williams Canyon drainage. Most of the flood flow passed to the right of the two-story yellow house, but substantial flow also went to the left down Cañon Avenue. Top: photo by GEER team members taken on August 16, 2013. Bottom: photo by Jason Kean, US Geological Survey, taken on August 13, 2013. Camera location: +38.8633° N, -104.9173° W, elevation 6453 ft.

Figure 3.3.8. View looking south from the culvert outlet at the gabion-lined channel in the northern part of Manitou Springs residential area south of US 24. The concrete wall visible in the lower center of the photo is the culvert outlet. The main part of the flood passed through the area shown in this photograph. Substantial flood flows also went around the left side of the yellow house. Camera location: +38.8630^{o} N, -104.9174^{o} W, elevation 6432 ft.

Figure 3.3.9. Views west along Narrows Road at concrete-lined open-channel section of Williams Canyon drainage and south at box culvert under Narrows Road. Top: photos by GEER team on August 16, 2013. Bottom: photo by Jason Kean, US Geological Survey, taken on August 13, 2013. Camera location: +38.8620^{o} N, -104.9170^{o} W, elevation 6401 ft.

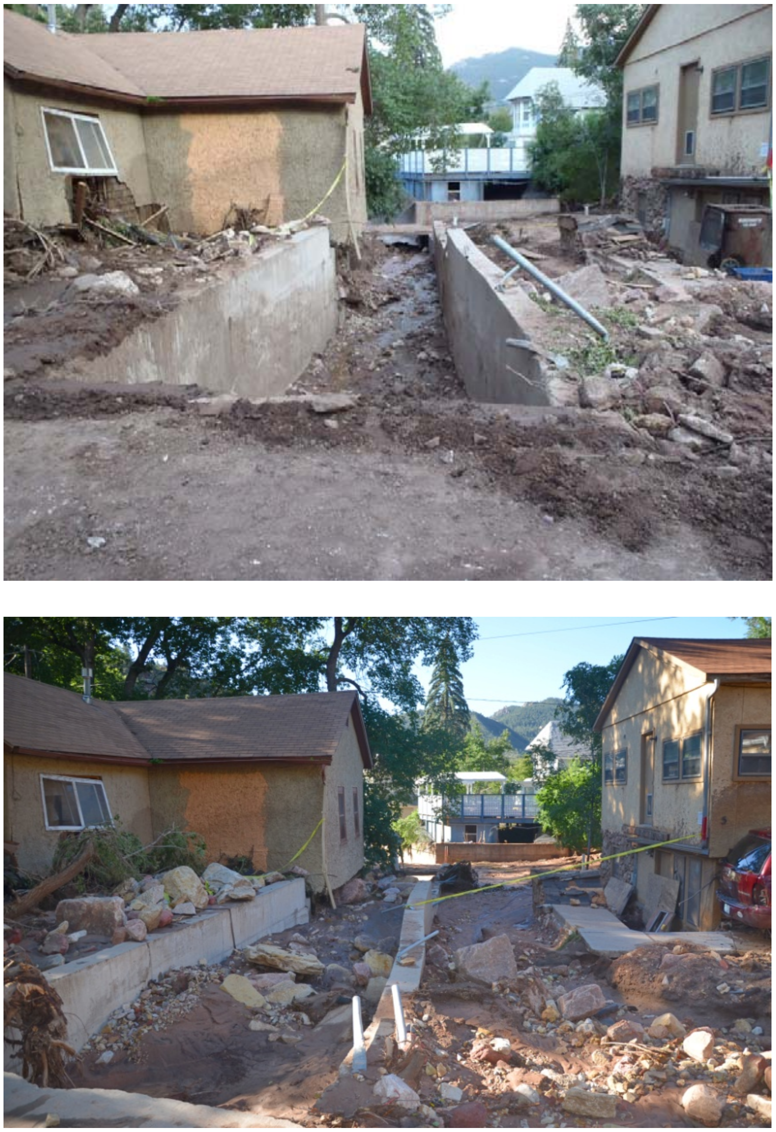


Figure 3.3.10. View south from Narrows Road along concrete-lined open-channel section of Williams Canyon drainage. Top: photo by GEER team on August 16, 2013. Bottom: photo by Jason Kean, US Geological Survey, taken on August 13, 2013. Camera location: +38.8620^{o} N, -104.9171^{o} W, elevation 6407 ft.

Figure 3.3.11. Views of deep rectangular channel and inlet to box culvert at Cañon Avenue. Left: view to southeast; Cañon Avenue and church at top of photo. Right: view northwest at grade transition from open-channel section to box culvert section. It is difficult to appreciate from these photos that a major flood event occurred one week prior to the date they were taken. Camera location: +38.8616° N, -104.9169° W, elevation 6405 ft.

Figure 3.3.12. Views of Cañon Avenue near the culvert inlet that carries Williams Canyon drainage to Fountain Creek. Top: view to the northwest from the church visible in Figure 3.3.11 across Cañon Avenue to the culvert inlet that carries Williams Canyon drainage to Fountain Creek. Bottom: screenshot of YouTube video by Dave McCrary taken on August 9, 2013, looking north up Cañon Avenue at flood flow; Video 2 in Figure 3.3.1. Camera location: +38.8613^{o} N, -104.9167^{o} W, elevation 6391 ft.

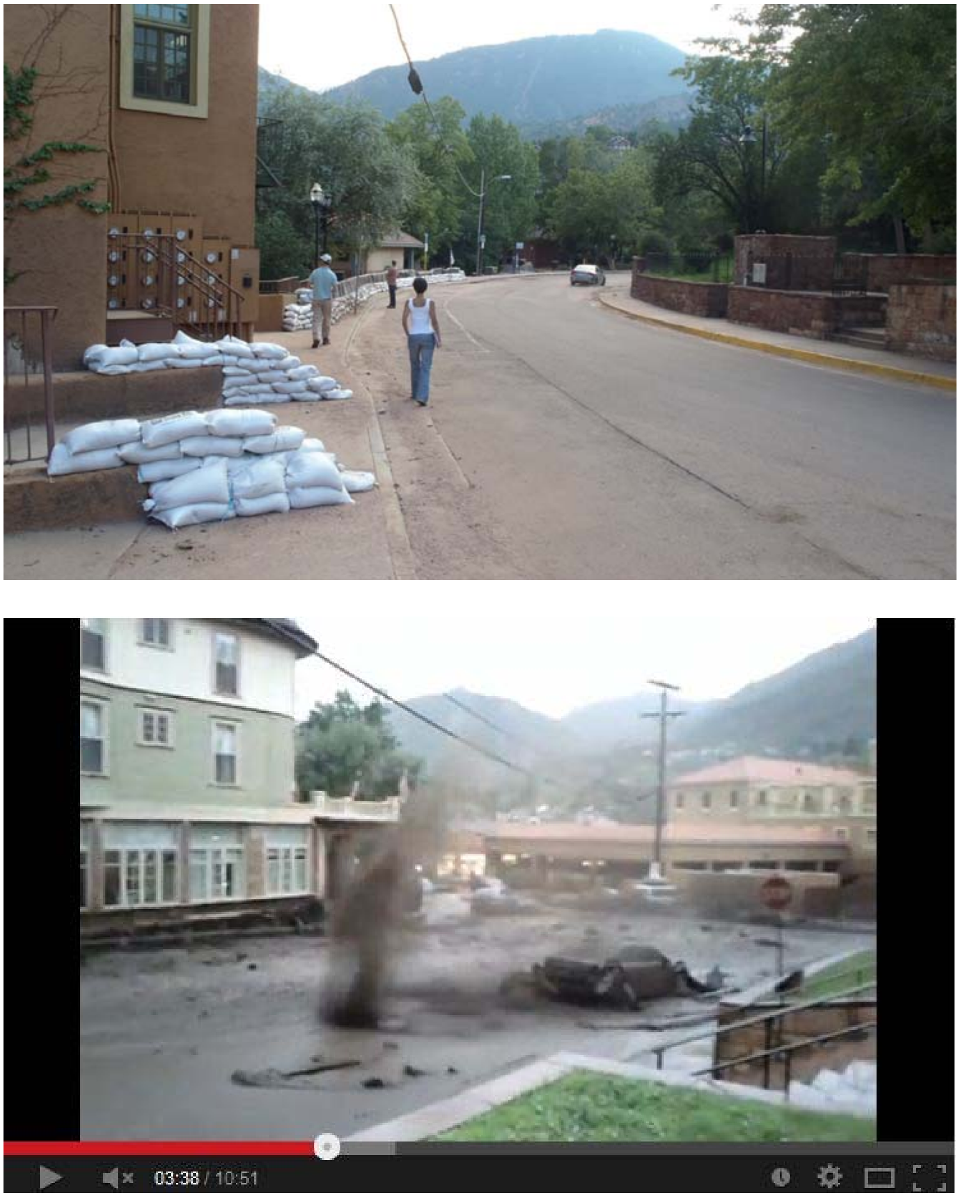


Figure 3.3.13. Views near intersection of Park Avenue and Canon Avenue. Top: view west along Park Avenue after cleanup. Bottom: screenshot of YouTube video by JS4VI taken on August 9, 2013, looking southeast down Cañon Avenue from Post Office building at flood flow with pressure discharge from service hole on Williams Canyon drainage culvert; Video 3 in Figure 3.3.1. Intersection of Cañon Avenue and Park Avenue is just to the right of the stop sign. Camera location: +38.8596° N, -104.9178° W, elevation 6354 ft.

Figure 3.3.14. Outlet of the Williams Canyon drainage culvert at Fountain Creek. Top: view to the west (upstream) along Fountain Creek showing backs of retail stores to the left of the creek and flood damage to the right; culvert outlet is in the lower right of photo. Bottom: view to the north of Williams Canyon drainage culvert outlet. Camera location: +38.8592^{o} N, -104.9184^{o} W, elevation 6344 ft.

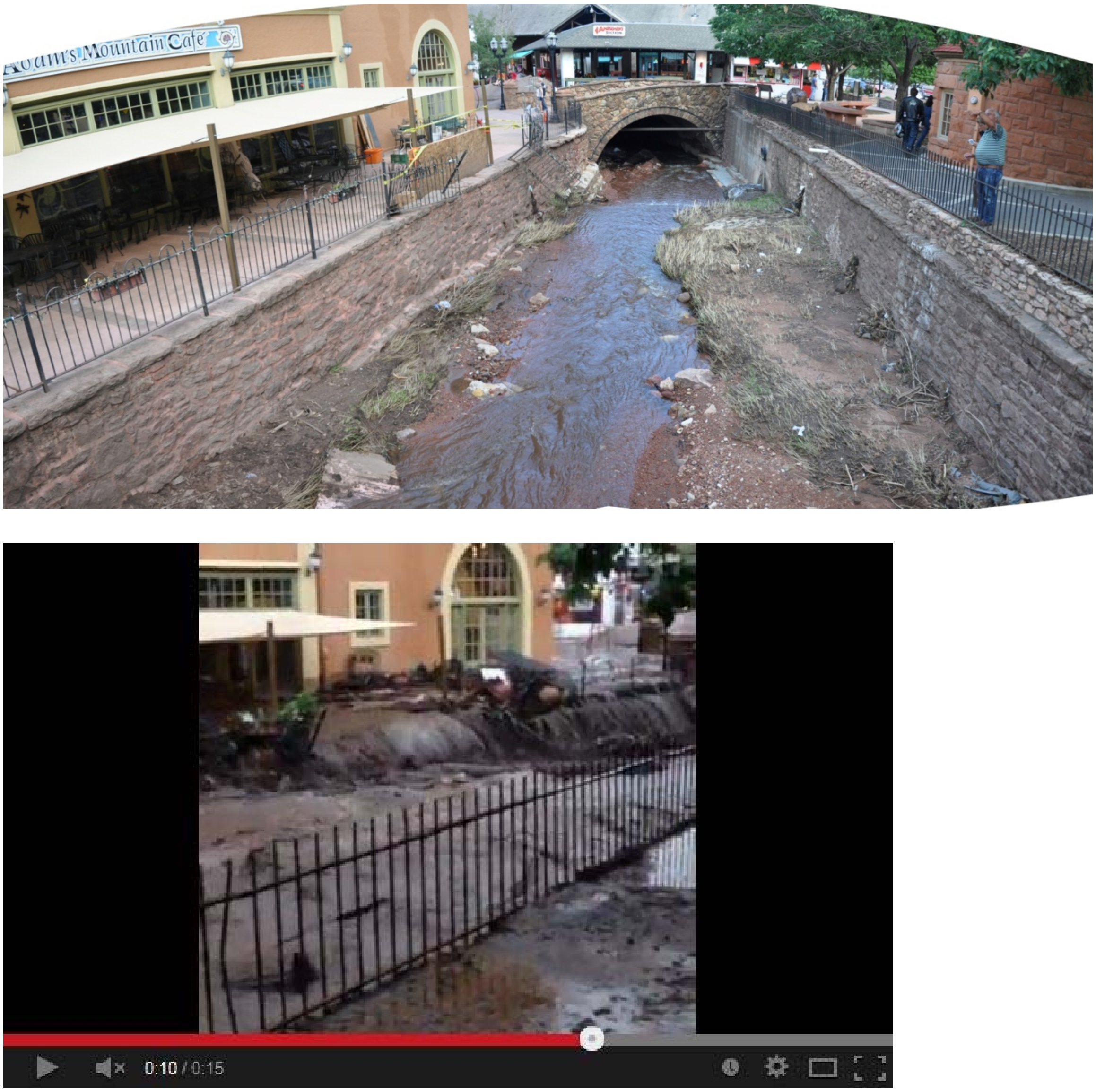


Figure 3.3.15. View looking downstream of Fountain Creek downstream from the Williams Canyon drainage culvert inlet. Top: view looking east from footbridge visible in Figure 3.3.16 taken by GEER team on August 16, 2013; note fence damage on left near end of the awning. Bottom: screenshot of YouTube video by Thom Vincent taken on August 9, 2013; Video 4 in Figure 3.3.1. Camera location: +38.8592^{o} N, -104.9184^{o} W, elevation 6344 ft.

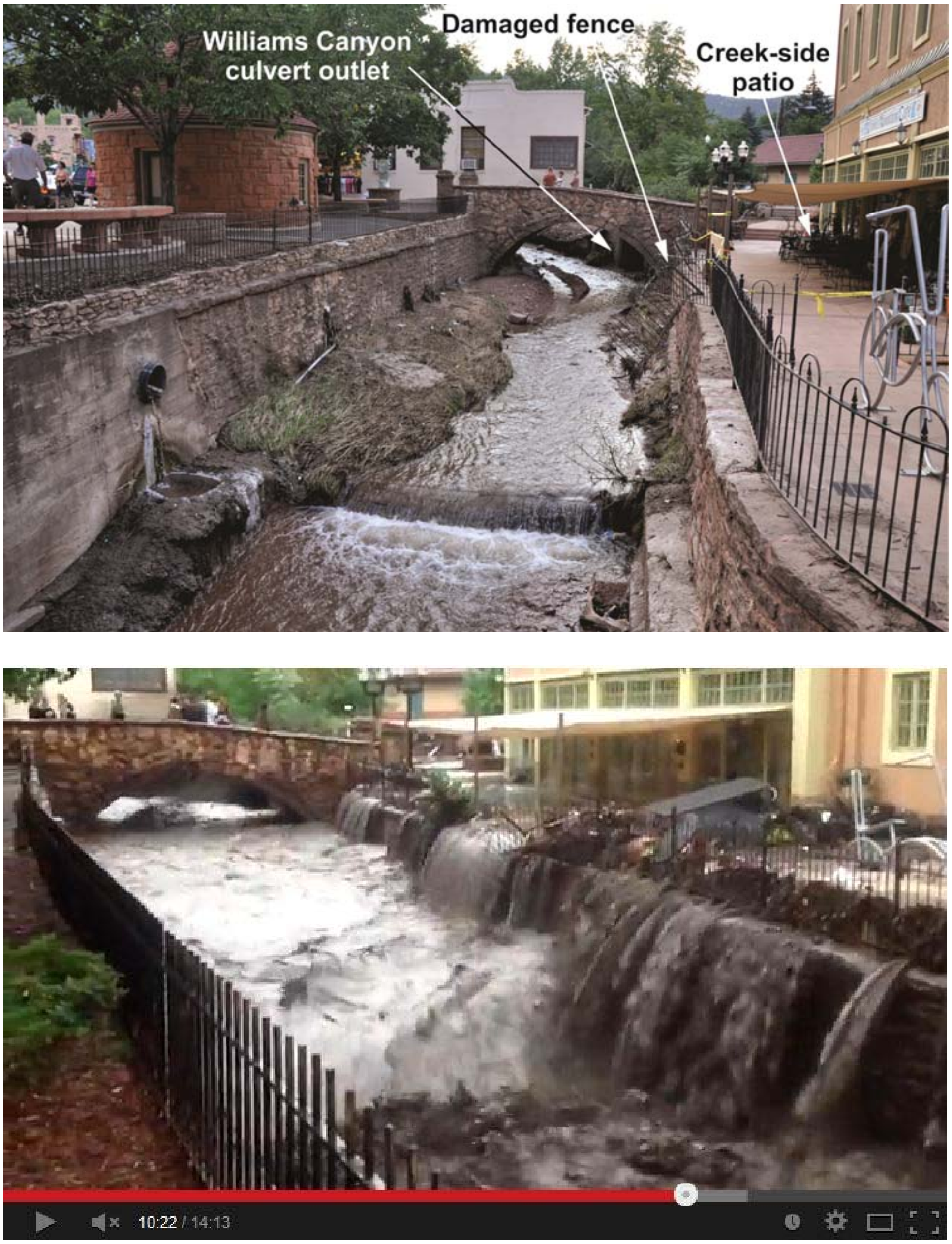


Figure 3.3.16. View looking upstream of Fountain Creek downstream from the Williams Canyon drainage culvert outlet. Top: view looking west from footbridge visible in Figure 3.3.15 taken by GEER team on August 16, 2013; Williams Canyon culvert outlet is visible under arch of footbridge. Bottom: screenshot of YouTube video by Apeakrunner taken on August 9, 2013; Video 5 in Figure 3.3.1. Camera location: 38.8590° N, -104.9181° W, elevation 6340 ft

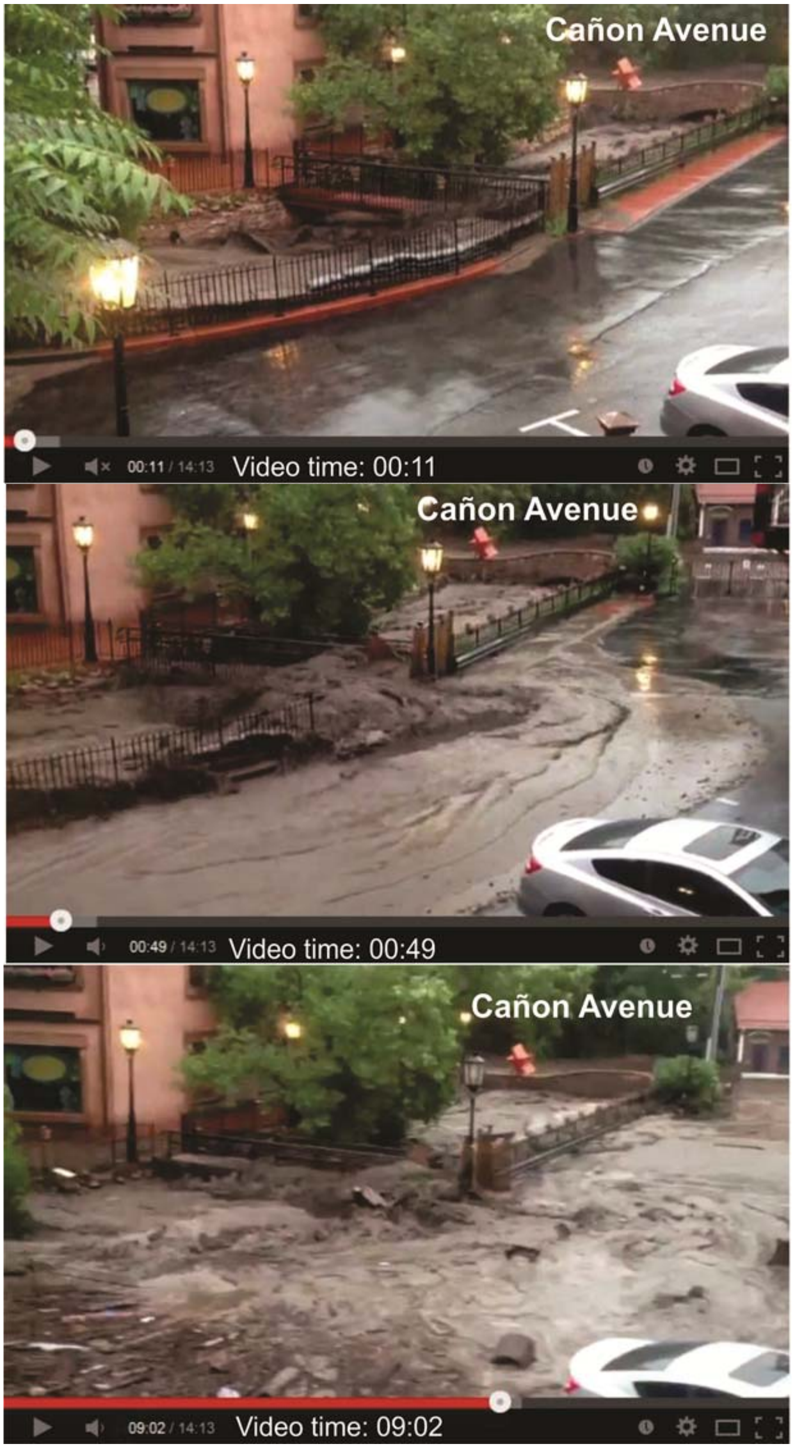


Figure 3.3.17. Flooding in Fountain Creek just west of Cañon Avenue. Three screenshots of YouTube video by Apeakrunner taken on August 9, 2013, at video times 00:11, 00:49, and 09:02; Video 5 in Figure 3.1.1. Camera location: 38.8583° N, -104.9170° W, elevation 6345 ft.

Figure 3.3.18. Flooding in Fountain Creek at intersection of Lovers Lane and Lafayette Road. Three screenshots of YouTube video by growmotionvideo taken on August 9, 2013, at video times 00:37, 01:16, and 01:49 (video has gaps created by editing); Video 6 in Figure 3.1.1. Camera location: 38.8583° N, -104.9170° W, elevation 6345 ft.

3.4 Observations in Other Canyons

The main effects of the August 9, 2013, storm were on US 24 and Manitou Avenue below Waldo Canyon (Section 3.2) and in the City of Manitou Springs below Williams Canyon (Section 3.3). The GEER team visited five other drainage basins; observations made at those locations are described in this section. Several erosion control structures and sediment management facilities were observed in the vicinity of Manitou Springs, most of which appear to have been constructed in response to the Waldo Canyon Fire and anticipation of enhanced flooding. Observations at one location (Section 3.4.1) involve an existing drainage culvert, whereas the other examples (Sections 3.4.2 to 3.4.5) are in-channel mitigation measures meant to control or capture debris and eroded sediment or to reduce the erosive power of channelized runoff. Mitigation measures to reduce sheetflow and hillslope erosion across drainage basin slopes were not observed during the GEER reconnaissance.

3.4.1 Unnamed Creek 1 (Existing Culvert under US 24)

Unnamed Creek 1 (Figures 2.5 and 2.6) is located approximately 1.5 miles northwest of Waldo Canyon on US 24. The drainage basin area is 1.4 km^2 (0.54 mi^2; Table 2.1, Verdin et al. 2012) above US 24, and is underlain entirely by granite bedrock (Figure 2.1). The creek crosses US 24 (Figure 3.4.1) in a concrete culvert that was buried by coarse sand and gravel-sized fragments of granite (Figure 3.4.2). The flow in Unnamed Creek 1 did not overtop US 24 despite the culvert being buried and evidence of substantial flows in the creek (Figure 3.4.3).

A trickle of water (<< 1 cubic foot per second) flowing in Unnamed Creek 1 at the time of the GEER visit was infiltrating into the coarse sand and gravel sediment that had been deposited in the channel. The free-draining nature of the sediment probably was a major factor in the flood flow not overtopping the US 24 embankment. The culvert outlet at Fountain Creek is in the US 24 median and was filled half way with the coarse sand and gravel sediment (Figure 3.4.4). The coarse sand and gravel sediment apparently was so free draining that after the culvert inlet was buried, sufficient water was discharging from the outlet that it could erode the previously deposited sand and gravel to create a channel from the culvert to Fountain Creek (Figure 3.4.4, bottom).

The position of the Unnamed Creek 1 culvert is approximately 2 km southwest of the midpoint of a line extending between the precipitation gages at Upper Waldo Canyon and Lower Waldo Canyon (Figure 3.1.2). The NEXRAD Doppler radar images (Figure 3.1.1 series) show that the storm passed over the Unnamed Creek 1 drainage basin with the same or similar intensity to Waldo Canyon. The burn intensity was moderate across most of the Unnamed Creek 1 basin. It is unclear why the sediment that accumulated in the mouth of Unnamed Creek 1 was so free-draining; however, it seems likely that, if the sediment had higher silt content, the buried culvert inlet would have backed up the water discharge leading to overtopping of the US 24 embankment. Such overtopping would have had the potential to breach the embankment and cause significant damage to the westbound lanes of US 24.

3.4.2 Unnamed Creek 3 (Town of Cascade)

Unnamed Creek 3 (Figures 2.5 and 2.6) is located at the town of Cascade, approximately 2.5 miles northwest of Waldo Canyon on US 24. The drainage basin area is 2.0 km^2 (0.77 mi^2; Table 2.1, Verdin et al. 2012) above US 24, and is underlain entirely by granite bedrock (Figure 2.1); however, the town of Cascade is located on a well-developed alluvial fan. The creek flows southwest across the Town of Cascade (Figure 3.4.5) as an unlined open channel with one concrete channel section connected to a metal pipe culvert (Figure 3.4.6) under Hagerman Road; the concrete channel section appears to have been added after the metal pipe culvert was in place, probably because erosion at the culvert outfall was similar to the current erosion visible at the end of the concrete channel section. The Hagerman Road embankment visible above the culvert in Figure 3.4.6 was not overtopped by the August 9, 2013, flood, as can be seen in views from the road embankment in both downstream and upstream directions (Figure 3.4.7). It is clear from the photo of the channel upstream of the Hagerman Road culvert that no substantial debris flows or hyperconcentrated sediment flows moved through this section of the Unnamed Creek 3 channel on August 9, 2013, one week prior to the date that the photos were taken.

The August 9, 2013, storms caused erosion of the channel and deposition at and below the intersection point near the distal end of the alluvial fan (Figure 3.4.8). Boulders visible in the lower right part of the top photo in Figure 3.4.8 appear to be anomalous based on the channel conditions documented in Figure 3.4.7. The corrugated metal pipe and low concrete wall visible in both photos in Figure 3.4.8 mark the position of a driveway from Severy Road to a private residential garage.

The channel of Unnamed Creek 3 is adjacent to the Ute Pass Branch Library (Figure 3.4.9). At the time of the GEER reconnaissance visit, earth-filled fabric bags similar to saddle bags had been placed on the in a line resembling a levee between the library building and the channel of Unnamed Creek 3. Vegetation growing on the earth filling these bags could not have become established in a period of one week; therefore, these earth-filled fabric bags must have been placed prior to August 9, 2013, in response to or anticipation of a previous flood event – most likely the July 1, 2013, event. The appearance of the channel adjacent to the fabric bags (Figure 3.4.9) suggests that eroding water flow occurred at this location, but not discharges of sediment-laden debris flows or hyperconcentrated sediment flows.

Erosion of the Unnamed Creek 3 channel below the Hagerman Road culvert created an exposure of the stratigraphy of the Cascade alluvial fan about 6 feet (2 m) high (Figure 3.4.10). The general appearance of the exposure is stratified and sandy with gravel and a few isolated small boulders. The upper part of the exposure below the ground surface contains brighter red-brown color indicative of incipient soil profile development on a landform that is relatively young (i.e., mid-Holocene). Closer examination of the exposure reveals thin beds of sand with plane sedimentary structure and thicker massive beds of sand and gravel, some of which appear to be at least in part matrix supported. Samples from this exposure were not collected for laboratory testing; therefore, estimates of sediment concentration of the fluid slurry have not been developed. Iverson (1997) reports sediment concentrations by volume ranging from 0.4 to 0.8 for typical debris-flow mixtures. Pierson and Costa (1987) note that the sediment concentration by volume marking rheological transition boundaries shift based on particle-size distribution and composition of the fluid slurry. Acquisition of yield strength marks the transition from normal streamflow to plastic hyperconcentrated streamflow. An abrupt increase in yield strength coincides with the onset of liquefaction behavior marks the transition from hyperconcentrated streamflow to slurry flow. Loss of the ability to liquefy marks the transition from slurry flow to granular flow. Pierson and Costa (1987) advise caution in inferring processes from deposits because of the number of unknown factors, including deformation rate (flow velocity) which affects grain-support mechanisms differentially depending on level of energy (buoyancy, cohesion, and grain contact at low energy and turbulence, dispersive stress, and fluidization at higher energy).

Boulders were deposited near the apex of the alluvial fan (Figure 3.4.11, top and bottom left images), but apparently not in the middle or lower parts of the fan (Figures 3.4.7 and 3.4.9). The residence in Cascade located near the apex of the fan had boulders deposited on the concrete slab of a carport under a deck (Figure 3.4.11, bottom left image). The boulders seem to form somewhat of a line that resembles a debris-flow levee; however, the boulders appeared to have little finer sediment that would be expected in a debris-flow deposit and the wooden posts supporting the deck were undamaged. Furthermore, boulders were conspicuously absent in the channel of Unnamed Creek 3 upstream of Pyramid Mountain Road. The character of the August 9, 2013, flood at the apex of the fan would be expected to include all grain sizes available from the drainage basin. Perhaps the August 9, 2013, flood redistributed boulders used for landscaping.

The absence of boulders in the channel upstream of Pyramid Mountain Road (Figure 3.4.11, bottom right image) further suggests that boulders were not transported by the July 1, 2013, flood, either. The apparent impact of the July 1, 2013, flood was evident in the region during the GEER reconnaissance as can be inferred from a poster stapled to a utility pole on Pyramid Mountain Road near its intersection with US 24 (Figure 3.4.12) announcing that sandbags would be available free of charge on August 3, six days prior to the August 9, 2013, storm and flash flood.

3.4.3 Unnamed Creek 6 (Partially Grouted Riprap Spillway)

The mouth of Unnamed Creek 6 (Figures 2.5 and 2.6) is located approximately 1.5 miles northwest of town of Cascade US 24. The drainage basin area is 0.9 km^2 (0.35 mi^2; Table 2.1, Verdin et al. 2012) above US 24, and is underlain entirely by granite bedrock (Figure 2.1). The setting of the mouth of Unnamed Creek 6 on the north side of US 24 consists of a road cut in sandy colluvial deposits (Figure 3.4.13).

At the time of the GEER reconnaissance visit, two pieces of construction equipment were parked at the toe of the slope and a partially grouted riprap spillway was nearly completed (Figure 3.4.14). The riprap slope serves as a spillway for local drainage from Unnamed Creek 6. The riprap was grouted in a manner that holds the rock blocks together while allowing free drainage; geofabric was used to prevent migration of soil particles from the foundation into the large voids within the riprap (Figure 3.4.15). This structure is intended to pass water flow while controlling the grade line of the channel. Since the road cut created an over-steepened section, aggressive erosion must have been a persistent problem.

Construction of the partially grouted riprap spillway was nearly completed one week after the August 9, 2013, storm and flash flood. Undoubtedly, the riprap spillway had been designed long before the August 9 storm. Google Earth Pro images of this location were reviewed to understand what the slope looked like prior to the summer of 2013. Imagery dated October 22, 2011, showed the cut along US 24 with a narrow ribbon-like feature interpreted to be a concrete or riprap drainage device. A slender, light-colored line connected the top of the ribbon-like feature to what probably was drainage collection ditch parallel to the crest of the cut slope and adjacent to an unsurfaced road providing access to a small structure; the small structure is visible above and to the right of the spillway in the oblique aerial photo shown on the bottom of Figure 3.4.13. Thus, it seemed logical that the need for the riprap spillway must have been poor performance in the July 1, 2013, storm. However, it was the Street View utility in Google Maps that provided clear indication that this part of the slope had a substantial erosion gully adjacent to the ribbon-like concrete drainage device. Google Earth Pro and the so-called Earth option in Google Maps both use October 22, 2011 images as a base with the best resolution. The slope is a uniform cut slope with a narrow drainage structure that probably is concrete or grouted stones. Earlier historical images back to 1999 have poor resolution and did not appear to show conditions much different from October 2011.

However, Google Maps Street View utility provided impressive and useful information. The viewer was navigated into position across US 24 from the slope with the narrow drainage device; the Street View was from July 2012 and showed that the toe of the slope had a relatively fresh nearly vertical excavation and a major erosion gully existed on the slope a short distance to the northwest of the concrete drainage device. In an attempt to move the viewer a little closer to the toe of the slope, the viewer crossed from the eastbound lane to the westbound lane and the Street View image shifted to September 2012. Erosion gullies were visible on the slope to the southeast of the narrow drainage device and the excavation at the toe of the cut slope was much larger. The Waldo Canyon fire occurred in late June 2012, so both Street View images were after the fire was over. An unsurfaced road visible in the oblique aerial photos (Figure 3.4.13) may have been a fire road graded rapidly during the burn to provide access for fighting the fire.

3.4.4 Wellington Gulch (Sediment Basin and Debris Rack)

The mouth of Wellington Gulch (Figures 2.5 and 2.6) is located approximately 2.5 miles northwest of town of Cascade US 24. The drainage basin area is 4.5 km^2 (1.74 mi^2; Table 2.1, Verdin et al. 2012) above US 24, and is underlain entirely by granite bedrock (Figure 2.1). The setting of the mouth of Wellington Gulch on the north side of US 24 consists of a relatively broad, gently sloping area (Figure 3.4.16).

A debris rack and a sediment basin were under construction in the mouth of Wellington Gulch south of Wellington Road to protect US 24 and the downstream area from debris flows and floods (Figures 3.4.17 and 3.4.18). The debris rack is constructed of welded steel I-beams grouted into the ground, with a series of diagonal braces to provide resistance against impact forces. It is on the order of 100 m long and 1.5 m high. The rack is intended to capture the largest boulders, logs, and other vegetation carried by flows and floods. In turn, this will reduce the volume, velocity, and destructive energy of a flood event. Downstream of the rack, a shallow debris stilling basin is being excavated to provide additional storage and further reduce flow volume. The basin outlet is the pre-existing drop inlet (Figure 3.4.19) that will serve as a spillway and outlet for overflow and watery and muddy components of future flow events.

3.4.5. Queens Canyon (Ring-net Debris Fence)

Queens Canyon is adjacent to Williams Canyon on the east side (Figures 2.5 and 2.6). It has a drainage basin area of 20.6 km^2 (7.95 mi^2; Table 2.1, Verdin et al. 2012) above the Glen Eyrie facility near Garden of the Gods. The drainage basin is underlain by granite bedrock in its upper and middle areas, and by gneiss and sedimentary bedrock in its lower area (Figure 2.1). Two ring-net debris fences were constructed in Queens

Canyon to protect the Glen Eyrie Castle, conference center and surrounding grounds located directly west of the Garden of the Gods; the lower debris fence in the mouth of Queens Canyon (Figures 3.4.20 and 3.4.21) was visited by some of the GEER team members. The upper similar fence is located a few hundred meters upstream and was not visited during the GEER reconnaissance. These ring-net debris fences were designed and constructed by private funds well before the August 9, 2013, flood. The GEER team suspects that they were constructed shortly after the Waldo Canyon fire in anticipation of future enhanced sediment discharge from the canyon.

The lower debris fence is approximately 10 m high and 20 m wide at the top. The fence consists of approximately 30-cm-diameter interlocking rings, backed by single twist chain link to catch smaller particles. Support cables include numerous circular friction brakes. The fence was constructed in two parts: a larger upper portion that terminates approximately 1 m above the base of the channel, and a second smaller portion located approximately 1 m downstream and extending from the base of the channel to the bottom of the upper fence. The fence shape is supported by two H-beam support posts bolted to a concrete foundation pad, and the sides of the fence are anchored to rock at the abutments. The channel is protected by stepped, rock-filled gabion-basket walls on both abutments. The bases of these walls are protected by grouted riprap. An access road over the left abutment was constructed to allow sediment accumulation in the basin to be cleaned out.

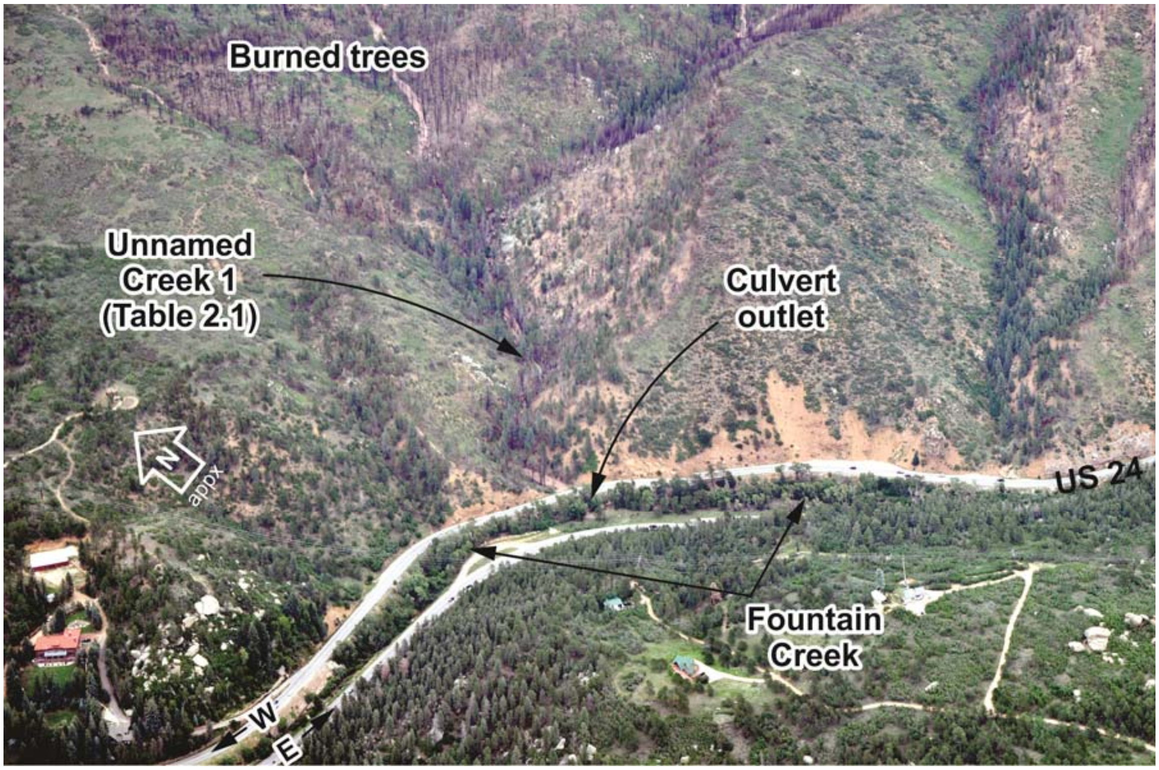


Figure 3.4.1. Aerial oblique photograph of Unnamed Creek 1 showing US 24, Fountain Creek, and the culvert outlet location. The culvert inlet location at westbound US 24 38.8900° N, -104.9586° W, approximate elevation 7195 ft.

Figure 3.4.2. Unnamed Creek 1 where it enters a culvert under US 24 that was buried by sediment in the August 9, 2013, storm. Top: view looking west across the mouth of Unnamed Creek 1 at US 24. Bottom: view looking south at embankment of US 24 where the culvert inlet has been buried. Location of culvert inlet at westbound US 24: 38.8900° N, -104.9586° W, approximate elevation 7195 ft.

Figure 3.4.3. Woody debris trapped on the upstream side of a tree in Unnamed Creek 1. View looking north-northeast; ruler is 1.5 m long. Trickle of water to the right of the leaning tree trunk was infiltrating into the clean, coarse sand and gravel that had been deposited by the August 9, 2013, flood. Camera location is 38.8909° N, -104.9584° W, approximate elevation 7259 ft.

Figure 3.4.4. Unnamed Creek 1 culvert outlet on US 24 median at Fountain Creek. Top: view to north at culvert outlet at base of westbound US 24 embankment. Bottom: panoramic view to southeast at culvert outlet and sand and gravel deposit adjacent to north side of Fountain Creek; ruler is 0.7 m long. Both views from 38.8898° N, -104.9587° W, approximate elevation 7187 ft.

Figure 3.4.5. Oblique aerial photograph of the alluvial fan at Cascade on Unnamed Creek 3. Short circle-and-arrow symbols point in view direction of photographs corresponding to figure numbers.

Figure 3.4.6. Concrete open-channel section and metal pipe culvert outlet on west side of Hagerman Road, Town of Cascade. Concrete channel appears to have been constructed after the culvert, probably because of erosion at the culvert outfall similar to the erosion at the end of the concrete channel section. Bare concrete at end of concrete section probably is related to discharge from the 12-inch-diameter corrugated metal pipe at shoulder height across from man standing on the concrete. View looking northeast from 38.8972° N, -104.9695° W, approximate elevation 7421 ft.

Figure 3.4.7. Unnamed Creek 3 downstream and upstream from Hagerman Road. Top: view looking downstream (southwest) at the concrete channel. Bottom left: view looking upstream (northeast) at the unlined channel. Bottom right: view looking south at the inlet to the metal pipe culvert under Hagerman Road. All views from approximately 38.8971° N, -104.9695° W, approximate elevation 7426 ft.

Figure 3.4.8. Unnamed Creek 3 at its intersection point in the lower part of the alluvial fan in the Town of Cascade. Top: panorama view looking northeast (left side) to southeast (right side) from a point near Ute Pass Avenue and Severy Road. Bottom: view looking southwest at exposed concrete wall and oval corrugated metal pipe culvert at a driveway from Severy Road (white truck) to the right side of photo. Camera location for top view 38.8965° N, -104.9705° W, approximate elevation 7367 ft; camera location for bottom view 38.8968° N, -104.9702° W, approximate elevation 7405 ft.

Figure 3.4.9. Unnamed Creek 3 in the lower part of the alluvial fan adjacent to the Ute Pass Branch Library in the Town of Cascade. Panorama view looking northeast; white objects lining the channel are fabric bulk handling bags that are somewhat similar to saddle bags that are able to straddle a ridge or cable. Vegetation growing on soil filling the bags indicates that these bags were in place at the time of the August 9, 2013, flood. This location is just above the intersection point on the Cascade alluvial fan. View from 38.8968° N, -104.9702° W, approximate elevation 7405 ft

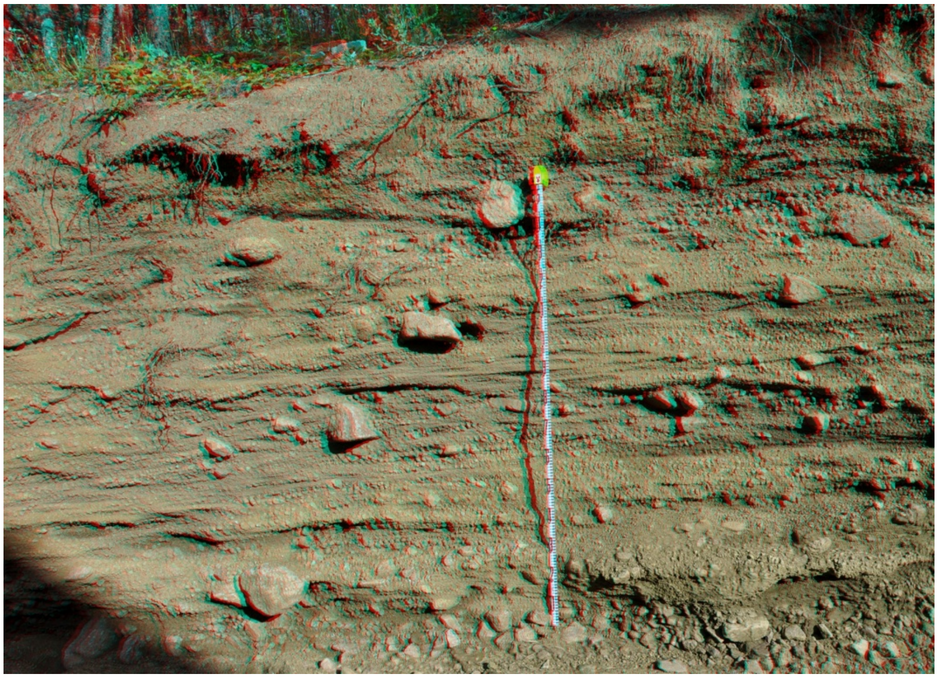


Figure 3.4.10. Exposure of Cascade alluvial fan stratigraphy. Top: view looking northwest; red-cyan anaglyph made with StereoPhotoMaker v. 4.41. Bottom: pair of photos arranged for

stereoscopic viewing. Ruler is 1.57 m long. Note brighter red-brown color above the top of the ruler (Bw soil horizon). View from 38.8971° N, -104.9699° W, approximate elevation 7405 ft.

Figure 3.4.11. Flood effects near the apex of the alluvial fan at Cascade. Top: panoramic view looking southwest at Unnamed Creek 3 from Pyramid Mountain Road. Bottom left: detail of carport area in top photo showing boulders on the concrete slab. Bottom right: view looking northeast up Unnamed Creek 3 from Pyramid Mountain Road; absence of boulders is conspicuous. Views from 38.8996° N, -104.9635° W, approximate elevation 7599 ft.

Figure 3.4.12. “Free sandbags” poster stapled to a utility pole on Pyramid Mountain Road near US 24. Granite sand exposed behind utility pole is in a road cut in alluvial and colluvial deposits. View looking south from 38.9053° N, -104.9694° W, approximate elevation 7505 ft.

Figure 3.4.13. Aerial oblique views of the mouth of Unnamed Creek 6 located about 1.5 miles northwest of Cascade. Inclined rectangle is a partially grouted riprap panel that was under construction at the time of the GEER reconnaissance (August 17, 2013). The toe of the riprap is located at 38.9123° N, -104.9769° W, approximate elevation 7552 ft.

Figure 3.4.14. Partially grouted riprap spillway west of Cascade on US 24. Top: view looking northeast from the shoulder of US 24; camera position was 38.9123° N, -104.9769° W, approximate elevation 7552 ft. Bottom: view looking north from the crest of the riprap spillway; camera position was 38.9125° N, -104.9766° W, approximate elevation 7592 ft. Individual rock blocks are approximately 1 m across; note minimal freeboard between the top of the spillway in the center of the photograph and the natural drainage channel to the right.

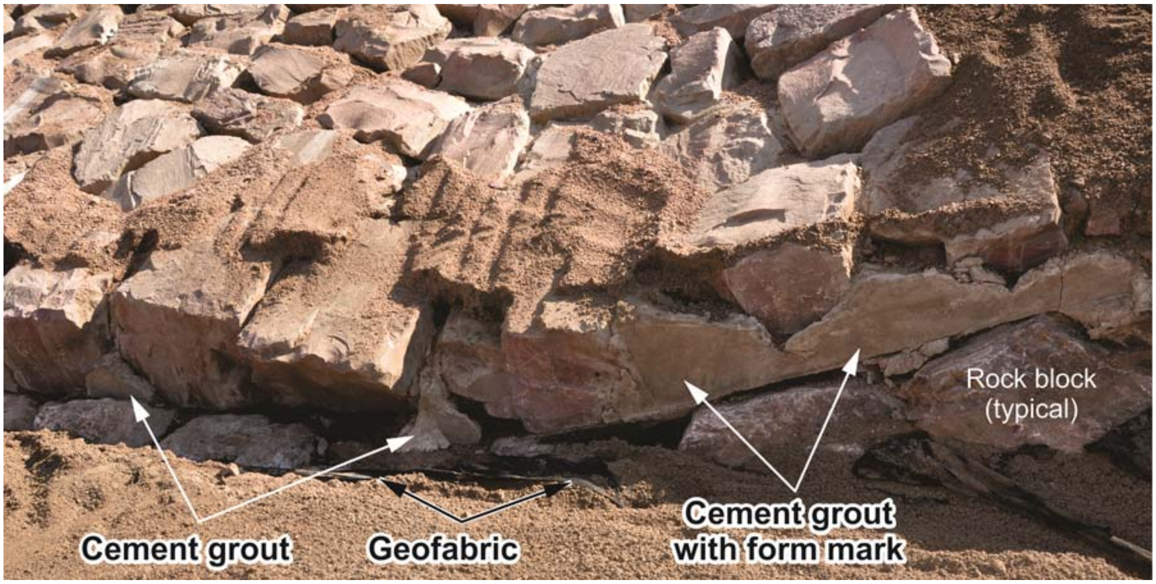


Figure 3.4.15. Detailed view of partially grouted riprap. View looking northeast from the toe of the riprap spillway; geofabric and cement grout are indicated with annotations. The purpose of partial grouting is to hold the durable rock blocks together while allowing unrestricted drainage of subsurface water. Camera position was approximately 38.9123° N, -104.9769° W, elevation 7552 ft.

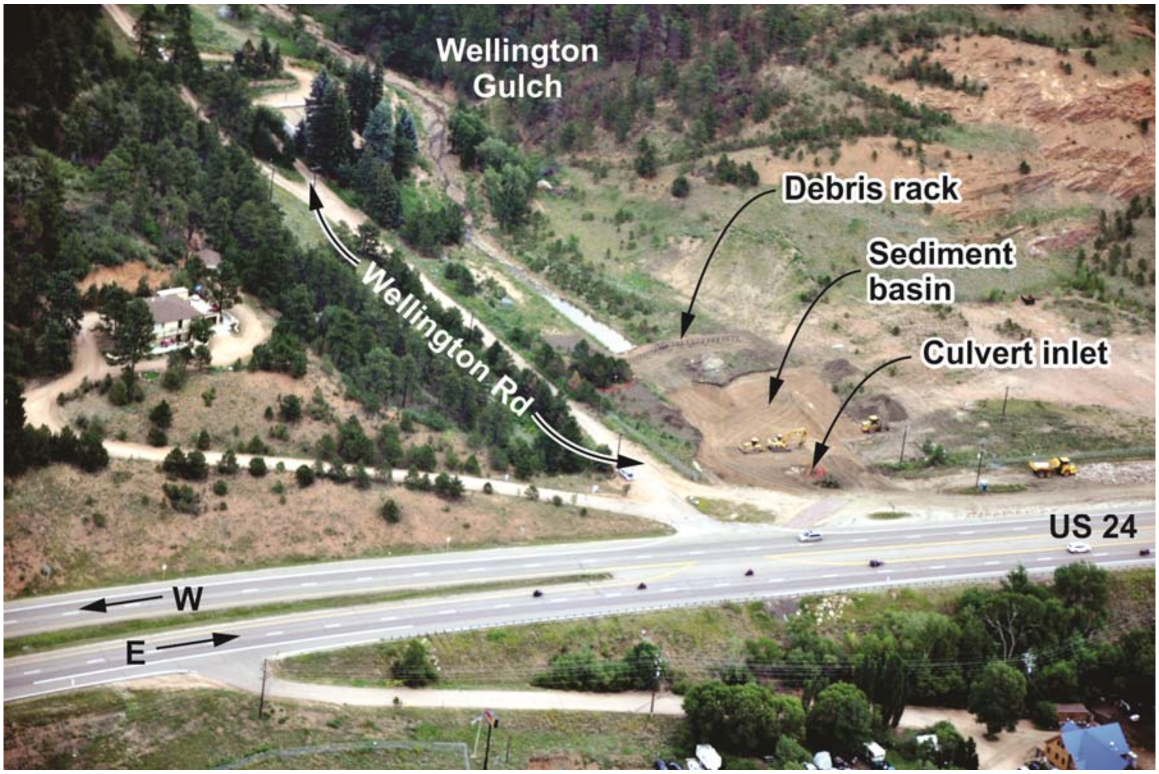


Figure 3.4.16. Oblique aerial view of the mouth of Wellington Gulch showing position of a sediment basin and a debris rack. View to the east; location of intersection of Wellington Road and westbound US 24: 38.9185° N, -104.9843° W, approximate elevation 7590 ft.

Figure 3.4.17. Debris rack under construction in the mouth of Wellington Gulch south of Wellington Road. Note Sonotubes for grouting of foundation footings, the diagonal support braces, and the welded joints. The rack is oriented perpendicular to the flow direction. View looking north from 38.918603° N, -104.983124° W, approximate elevation 7611 ft.

Figure 3.4.18. Sediment basin excavation downstream of debris rack. This basin is not intended as a large capacity storage area, but more as a stilling basin to allow debris and larger particles to drop out in a controlled manner without clogging the drainage culvert inlet. View toward east from 38.9185° N, -104.9840° W, approximate elevation 7597 ft.

Figure 3.4.19. Inlet to existing corrugated metal pipe culvert at Wellington Gulch. View toward the southwest at US 24 from 38.9185° N, -104.9838° W, approximate elevation 7597 ft.

Figure 3.4.20. Ring-net debris fence constructed in the mouth of Queens Canyon above the Glen Eyrie Castle and conference center. View to the west from 38.8937° N, -104.8872° W, approximate elevation 6571 ft. Note gabion walls and grouted riprap protecting the abutments and channel from erosion, the use of two separate fences in the design, and the accumulation of a small amount of mostly gravelly sediment and logs in the lower fence. Prominent circles are loops on cables that are friction brakes to convert mechanical energy into heat and minimize damage to the fence while stopping debris.

Figure 3.4.21. Ring-net debris fence in Queens Canyon above Glen Eyrie conference center.

View to the south from 38.8938° N, -104.8873° W, approximate elevation 6569 ft.

4.0 DISCUSSION AND CONCLUSIONS

The observations made by the GEER team in the vicinity of Manitou Springs, Colorado, on August 16, 17, and 18, 2013, are described in Section 3 of this reconnaissance report. A brief listing of key points is provided as a summary of the reconnaissance observations.

1. Waldo Canyon fire in June 2012 prepared slopes and watersheds for enhanced runoff of water and sediment.
2. Following the fire, USGS installed rain gages at five locations within and adjacent to the burn area.
3. The August 9, 2013, storm was a fast-moving (about 37 km/hr [23 mi/hr]) , west-to-east, localized cloudburst event that dropped as much as 1.61 inches in about 35 minutes with 5- and 10-minute intensities as large as 131 mm/hr (5.16 in/hr) and 125 mm/hr (4.92 in/hr), respectively.
4. The heaviest precipitation was recorded in Waldo and Williams canyons and is consistent with NEXRAD data.
5. Waldo Canyon discharge overwhelmed the drainage culvert at its mouth; flowed onto westbound lanes, and was prevented from crossing the eastbound lanes by the concrete K-rail barrier in the median of US 24.
6. The Waldo Canyon discharge entered Fountain Creek in a series of cascades over the crest of the fill embankment from Manitou Avenue because the discharge flowed southeast in the westbound lanes of US 24, down the westbound onramp, under the US 24 overcrossing, and onto Manitou Avenue, where it crossed Fountain Creek on a concrete bridge that acted as an elevated canal section for the Waldo Canyon discharge. The discharge over the fill crest occurred at gaps in the asphalt curb-and-wood flashing

drainage-control system on Manitou Avenue; two gullies formed by erosion of the embankment at gaps in the drainage-control system.

7. Williams Canyon discharge exceeded the capacity of a gabion-lined open channel and culvert system adjacent to the US 24 overcrossing, and flowed down Cañon Avenue in a narrow section of Williams Canyon immediately upstream from a residential neighborhood of Manitou Springs. YouTube videos taken by eyewitnesses provided the basis for estimating the flood depth to be at least 1.5 m (5 ft) just upstream of the US 24 overcrossing.
8. The Williams Canyon discharge flowed, in part, down Cañon Avenue and, in part, down the channel of Williams Canyon where it was gabion-or concrete-lined . The discharge overwhelmed the drainage control system basically everywhere, especially where it was conveyed in culverts.
9. The flood discharge through Manitou Springs overwhelmed the concrete-lined channel and culvert sections of Fountain Creek; in some places, commercial development has been built over the channel of Fountain Creek. Sediment was deposited in response to slower flow velocities, but no other geotechnical effects were observed. Eyewitness videos posted on YouTube documented the rate of the rising limb of the hydrograph and the effects of vehicles acting as debris to spread flows away from the main channel.
10. Coarse sand and gravel sized fragments of granite in the drainage collection basin of Unnamed Creek 1 at US 24 was sufficiently free-draining that water did not overtop the basin even though the culvert inlet was buried.
11. The presence of boulders in flood deposits in the Town of Cascade seemed to be inconsistent. Boulders were observed adjacent to Severy Road near US 24 and southwest

(downstream) of Pyramid Mountain Road at the apex of the alluvial fan. However, boulders were absent from the channel between these two locations and also absent from the flood deposits northeast (upstream) of Pyramid Mountain Road.

12. Soil-filled fabric saddle bags along an eroded section of the stream channel in Cascade appeared to have been in place for several weeks and probably were placed following the July 1, 2013, storm.
13. A partially grouted riprap spillway for erosion control at Unnamed Creek 6 had been under construction since before the August 9, 2013, storm. Google Maps with the Street View utility revealed erosion gullies existed on this slope in July 2012, and that substantially enlarged gullies and new erosion features were present in September 2012. Therefore, flood response at this location was not related to the August 9, 2013, storm.
14. A debris rack had been installed at Wellington Canyon and excavation was underway for a sediment basin. These flood-control measures may have been initiated in response to the July 1, 2013, storm unless the debris rack was a typical design that could be constructed within the period of one week.
15. The debris-flow countermeasure ring-net fences across the Queens Canyon channel at Glen Eyrie Castle and conference center must have been designed and constructed following the Waldo Canyon fire in anticipation of, and not in response to, a flood event.
16. Flood effects observed by the GEER team in the vicinity of Manitou Springs appeared to be related to water discharge in drainage features that were designed to pass smaller flows.
17. YouTube videos by eyewitnesses documented several aspects of the August 9, 2013, flood, specifically sediment accumulation in the westbound lanes of US 24, the flow-

control effect of the concrete K-rail barrier in the median of US 24, the fluid character of flood discharge, and the debris effect of floating vehicles on flood flows.

The primary conclusions of the GEER observations are listed below:

YouTube videos of eyewitness accounts were invaluable. Google Maps and the Street View utility proved to be valuable for post-observation analyses. The Street View utility was available for most streets in Manitou Springs and on US 24; it was not available for Lovers Lane or Layafette Road between Lovers Lane and Cañon Avenue where it would have added detail about the nature of the Fountain Creek channel.

Social media, primarily Tweets that are geo-tagged, may be a useful tool in the future. Keyword search and plotting with GIS may aid in understanding the distribution of geotechnical effects in future extreme events. Researchers at the University of Colorado at Boulder were working with two members of the GEER team to evaluate the utility of this information.

Cleanup efforts removed important evidence very quickly. A simple way to capture some useful information would be to publicize to cleanup crews and agencies the importance of information such as sediment deposits and debris volumes. Smartphones with cameras are common and cleanup crew members probably have them; simple photos at the beginning of the cleanup campaign would document some information that will be lost immediately as the cleanup begins.

For weather- or climate-driven extreme events, precipitation and stream gage data are the equivalent of “strong ground motion” for earthquake reconnaissance missions. GEER teams need to include members who have access to automated procedures for synthesizing precipitation gage data. The GEER Steering Committee needs to have an understanding of the availability of precipitation data in evaluating the potential value of mobilizing a GEER team.

Reconnaissance report sections should be standalone pieces written by individual members of the GEER team to facilitate rapid completion of meaningful GEER reports. Earthquake reports tend to be done in well-established pieces with subdivision of effort that facilitates uploading to information and report sections to the GEER website. A similar identification of subdivisions is needed for weather-related processes.

The GEER Steering Committee should review its process for learning details about the nature of the effects from flood events to enhance its decision capabilities for mobilizing GEER teams to document geotechnical effects.

The aerial reconnaissance provided some very useful images to support the ground-based observations and photos. The cost for the fixed-wing reconnaissance was about $140 for 0.9 hours of flight time.

5.0 ACKNOWLEDGMENTS

The Geotechnical Extreme Events Reconnaissance (GEER) Association is supported by the U.S. National Science Foundation to organize the response of the geoengineering professional community to earthquakes and other natural disasters. This support is gratefully acknowledged.

The United States Geological Survey provided key information and logistical support for the GEER team. Specifically, Jason Kean and Joe Gartner participated in discussions with the GEER Steering Committee during the process of evaluating the event for the potential to mobilize a GEER team. Jason Kean uploaded photographs and other key information to assist the team. Joe Gartner participated in the GEER observations in the afternoon of August 16 and morning of August 17, leading the GEER team members to Waldo Canyon, Williams Canyon, Unnamed Creek 1, Unnamed Creek 3 at Cascade, Unnamed Creek 6, and Wellington Gulch, as well as to the ring-net debris fence at Glen Eyre Castle and conference center. This assistance was very valuable to the GEER team and is gratefully acknowledged.

Individuals employed by the U.S. Department of Agriculture Forest Service, Colorado Department of Transportation, and Colorado Geological Survey communicated with members of the GEER team, providing information about schedules for cleanup and the nature of the features that they observed. The information provided by these agencies is gratefully acknowledged.

Al Mathews at Peak Aviation in Colorado Springs volunteered his time as pilot for the fixed-wing aerial reconnaissance flight on the afternoon of August 17, 2013, enabling useful observations and acquisition of oblique photos that enhanced the GEER team's understanding of the August 9, 2013, flood effects and the GEER report. Al Mathews' support of the GEER team is gratefully acknowledged.

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