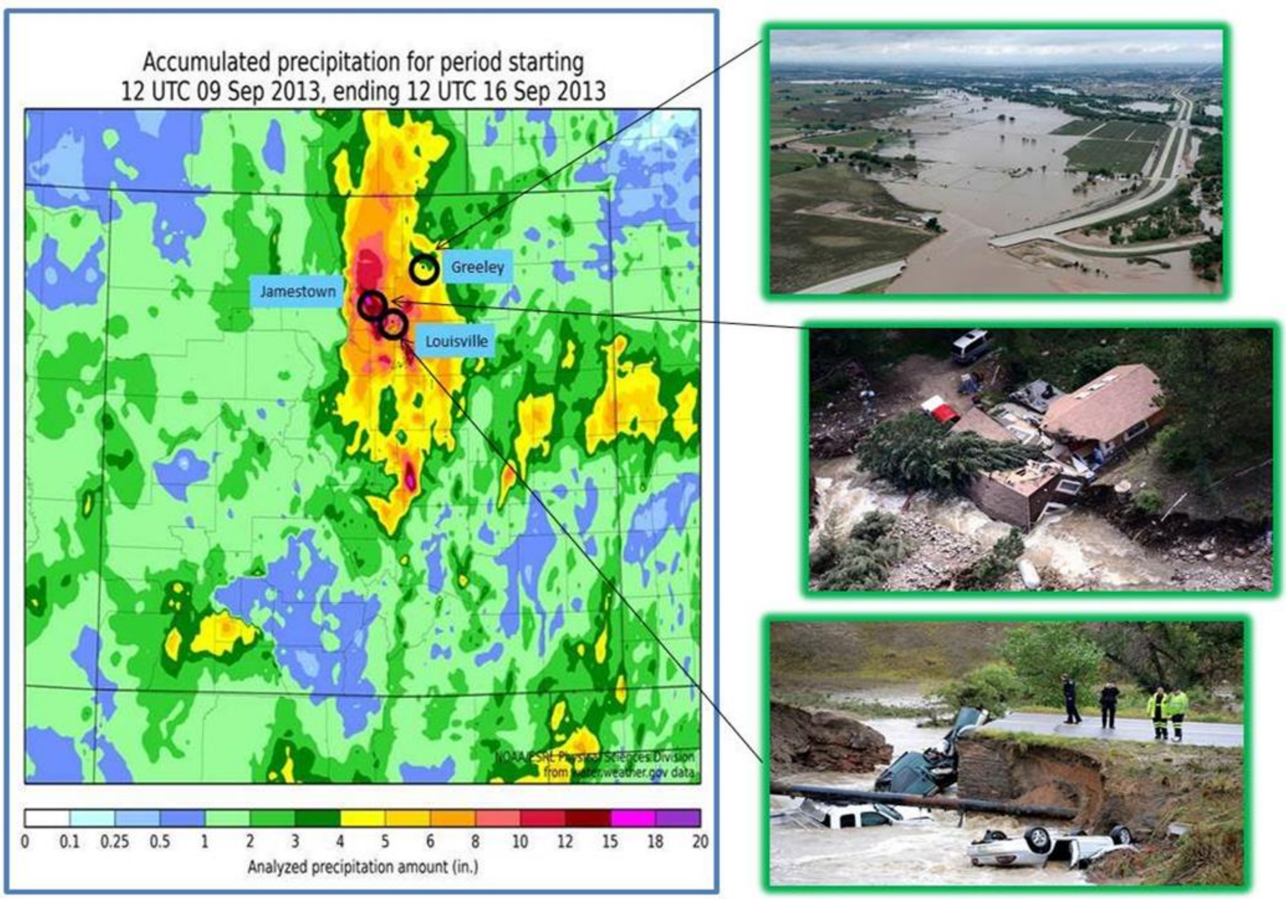
Service Assessment

The Record Front Range and Eastern Colorado Floods of September 11–17, 2013



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

Cover Photograph:

Left Image	Map of event total rainfall for the period Sep. 9–16 (NOAA/ESRL)
Upper Right	River flooding on the South Platte River at Highway 34 near Greely, CO (Huffington Post.com)
Middle Right	Flash flood damage in Jamestown, CO, along Left Hand Creek (M. Leffingwell, *Boulder Daily Camera*)
Lower Right	Flash Flood damage on Rock Creek at Dillon Road and Highway 287, Louisville, CO (M. Leffingwell, *Boulder Daily Camera*)

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June 2014

National Weather Service
Louis W. Uccellini
Assistant Administrator for Weather Services

Preface

Copious amounts of tropical moisture flowed northward from the Pacific Ocean and Gulf of Mexico into eastern Colorado on September 9–16, 2013. The combination of a slow moving upper-level system over the Great Basin region, favorable upslope easterly flow along the Front Range, and the presence of a stalled frontal system resulted in several episodes of torrential rainfall. The heaviest rain fell on the evenings of September 11–12. By week's end, a swath of 8–17 inches of rain resulted in widespread, devastating flash flooding in the South Platte River Basin from Denver downstream to western Nebraska and in the upper Arkansas River Basin along the upper Fountain Creek. There were eight fatalities directly attributed to the flooding.

Because of the significant impacts of the event, the National Oceanic and Atmospheric Administration's National Weather Service formed a service assessment team to evaluate its performance before and during the record flooding. The findings and recommendations from this assessment will be factored into the 2015 Annual Operating Plan to improve the quality of operational National Weather Service products and services and enhance its ability to provide an increase in public education and awareness materials relating to flash flooding, areal flooding, and river flooding. The ultimate goal of this report is to help the National Weather Service meet its mission of protecting lives and property and enhancing the national economy.

[redacted]
Assistant Administrator
for Weather Services

June 2014

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Service Assessment Team

The following people participated as members of the Service Assessment Team:

David Vallee	Hydrologist in Charge, Northeast River Forecast Center, Taunton, MA (Co-Team Lead)
Robert Kimbrough	Associate Director, USGS Colorado Water Science Center, Denver, CO (Co-Team Lead)
Chris Darden	Meteorologist in Charge, Weather Forecast Office (WFO) Huntsville, AL
Michael DeWeese	Development and Operations Hydrologist, North Central River Forecast Center, Chanhassen, MN
Tom Frieders	Warning Coordination Meteorologist, WFO Billings, Montana
Peter Gabrielsen	Chief, System Operations Division, Eastern Region Headquarters, Bohemia, NY
Tom Hamill	Meteorologist, NOAA Earth System Research Lab, Physical Sciences Division, Boulder, CO
Wallace Hogsett	Science and Operations Officer, Weather Prediction Center, College Park, MD
Ken Weidner	Director of Emergency Management, Sumner County, TN

Subject-Matter Experts/Consultants:

Kate Abshire	Physical Scientist, Office of Hydrologic Development, Silver Spring, MD
Julie Demuth	Associate Scientist III, NCAR, Boulder, CO
Eve Gruntfest	Research Scientist, Trauma, Health and Hazards Center University of Colorado, Colorado Springs, CO
Rebecca Morss	Scientist III, National Center for Atmospheric Research (NCAR), Boulder, CO

Other Valuable Contributors:

Melody Magnus	Technical Editor, Innovim, Inc., OCWWS, Silver Spring, MD
Salvatore Romano	Evaluation Meteorologist, OCWWS Performance Branch, Silver Spring, MD
Christopher Strager	Acting Director, Office of Climate, Water, and Weather Services (OCWWS), Silver Spring, MD
Cindy Woods	Chief, Performance and Awareness Division, Silver Spring, MD
Douglas Young	Chief, OCWWS Performance Branch, Silver Spring, MD

Executive Summary

On September 11–17, 2013, devastating and widespread flash flooding occurred along much of the Front Range of the Rocky Mountains in eastern Colorado from Colorado Springs to Fort Collins. Flash flooding in tributary streams would later evolve into major river flooding on the lower main stem South Platte River, eventually reaching the Platte River in western Nebraska. Eight people lost their lives as a direct result of the flooding. Most of these fatalities occurred during the height of flash floods on the evenings of September 11 and 12. Local authorities evacuated more than 18,000 people. Approximately 19,000 homes and commercial buildings were damaged with more than 1,500 destroyed. Authorities estimate the flooding damaged or destroyed almost 485 miles of roads and 50 bridges in the impacted counties.

The event began on September 9 as a large, slow-moving upper-level circulation that became nearly stationary over the Great Basin of the southwest United States. The broad flow around this system pulled plumes of tropical moisture northward from the Pacific Ocean off the western coast of Mexico and the western Gulf of Mexico. A frontal system became stationary along the Front Range of the Rockies while upslope easterly flow became established. Three episodes of torrential rainfall struck the Front Range from Fort Collins southward to Colorado Springs and east to Denver and Aurora, CO. The most intense events occurred on the nights of September 11–12, and September 15. Rainfall totals far exceeded existing records. In Boulder, 24-hour amounts exceeded 9 inches by the morning of September 12, nearly doubling the previous record. Event rainfall totals exceeded 17 inches in the climatologically favored upslope areas of the Front Range with a large area in eastern Colorado measuring 8–17 inches of precipitation.

This region of Colorado is no stranger to devastating flash floods. One of the worst floods of record occurred in the Big Thompson Canyon in the summer of 1976, claiming 144 lives; however, that rainfall event was small in areal and temporal coverage. The footprint of the September 2013 event was vast, covering most of the Front Range of the Rocky Mountains of Colorado.

People in many parts of the Front Range had become more aware of flash flooding during the 4 years before this event, primarily due to major wildfires that had left behind significant burn scars. The public was made aware that the flood threat increases when there is heavy rain on recent burn scars. The most significant burn scars included those associated with the Waldo Canyon Fire above Manitou Springs, the Black Forest Fire north of Colorado Springs, the High Park Fire west of Fort Collins, and the Fourmile Canyon Fire west of Boulder. Because of these burn scars, there had been considerable collaboration between county and local Emergency Management Agency (EMA) officials and Weather Forecast Offices (WFO) Pueblo and Boulder during the previous 2 years. These strong relationships paid great dividends as flash flooding developed during this event.

The NOAA Climate Prediction Center identified atmospheric ingredients necessary for potential heavy rainfall more than a week in advance, as highlighted in its 6–10 and 8–14 day outlooks, which forecast the establishment of a wetter than normal pattern. As early as 5 days in advance, the NWS Weather Prediction Center (WPC) began issuing 48–72 hour forecasts indicating the potential for 2–4 inches of rainfall for portions of the Front Range. WPC refined these forecasts as the event approached and highlighted areas of slight and moderate risk for excessive rainfall capable of producing flash flooding. Similarly, WFOs Pueblo and Boulder indicated correctly, as much as 5 days in advance, the potential for locally heavy rainfall in Area Forecast Discussions and Hazardous Weather Outlooks.

As the start of the event approached, deterministic model guidance displayed considerable variability for timing, location, and magnitude of heavy rainfall. One of the most useful tools was the Short Range Ensemble Forecast System (SREF), which was more consistent in magnitude, showing event total rainfall of 8 inches, though the location and timing of the heaviest rain was not consistent. Model output from individual SREF members is not readily available to WFO forecasters. Given the shifting deterministic model guidance, WFOs Boulder and Pueblo could not accurately anticipate and predict the timing, magnitude, and extent of heavy rainfall that struck the Front Range.

Although only a portion of the impacted Front Range was under a Flash Flood Watch before the first round of torrential rains on the evening of September 11, WFO Pueblo and WFO Boulder both reacted quickly by collectively issuing 78 Flash Flood Warnings. The average Probability of Detection was quite high, 94 percent. The average weighted lead time for all flash flood warnings issued was 69 minutes, which is above the national goal of 58 minutes.

The inability to anticipate accurately the precise location and magnitude of heavy rainfall affected river forecasts provided by the Missouri Basin and the Arkansas–Red River Basin River Forecast Centers (RFC). A significant number of streamflow gages failed in the impacted river basins, limiting the ability of local WFOs and RFCs to capture the rate of rise and the magnitudes of some of the initial rises. Complicating matters further for the Missouri Basin RFC (MBRFC) was the loss of Automated Local Evaluation in Real Time (ALERT) rain gage data as the result of a recent installation of the Advanced Weather Interactive Processing System II (AWIPS II). Unfortunately, the RFC did not realize it had lost this data until after the flooding. Forecasting the propagation of the flood wave down the South Platte River was especially challenging for the Missouri Basin RFC due to the presence of braided river channels, which existing RFC hydrologic and hydraulic models do not handle adequately.

Despite obstacles, most partners were satisfied with the level of services NWS provided. The Boulder County EMA said that WFO Boulder helped them save hundreds of lives. At times, the WFOs found it extremely challenging to deliver effective decision support services (DSS) given the complexity and magnitude of the event. This Service Assessment highlights opportunities for improvements to DSS provision, partner outreach, and communication.

Complicating matters for the impacted WFOs was the loss of a critical fiber optics cable in central Colorado. This loss of telecommunications affected offices in the southwestern United States and impacted AWIPS, NWR, and WSR-88D communications. NWS Central Region Headquarters coordinated the dispatch of the Very Small Aperture Satellite Communications Terminal (VSAT) system to WFO Grand Junction, but the process to deploy and deliver VSAT failed to bring the office online. At one point during the event, rainwater leaked into the NOAA facility that houses WFO Boulder, raising concerns about the potential for having to invoke extended service backup. Central Region Headquarters had to develop a tertiary backup solution in preparation for this possibility.

The Missouri Basin and Arkansas-Red River Basin RFCs had worked with the WFOs over the previous year to define specific burn scar basins within the Flash Flood Monitoring and Prediction System. The identification of burn scar basins within the Flash Flood Monitoring and Prediction System improved forecaster situational awareness about flash flooding potential in these small burn scarred areas.

Findings and recommendations of this service assessment touch aspects of field operations, decision support services, science, and training. Key findings and recommendations follow:

- There was limited direct coordination between WPC and the impacted WFOs and RFCs before and during this event regarding rainfall and flash flooding potential. WPC and the WFOs and RFCs should replicate the successful winter-weather coordination model for significant hydrologic events.
- The NWS does not have a policy defining and describing DSS. As a result, DSS content and delivery vary greatly between offices. The NWS should implement a formal policy for DSS, as outlined in its Annual Operating Plan. The policy should capitalize on the Weather-Ready Nation Roadmap, and define DSS and its information formats, content, methods for dissemination and communication. The policy should also define recommended operational configurations for effective service delivery.
- The hydrologic product suite continues to be complex and cumbersome and often lacks the level of detail and specificity sought by partners. The NWS should move from a product-driven framework to a hazards information-driven framework. The NWS also should enhance the tools and techniques that provide objective characterization of flooding at ungaged locations so hazard information leverages Common Alerting Protocol to articulate clearly the severity, urgency, and certainty for a given hazardous situation.
- Medium-range and short-range forecast models significantly underestimated the magnitude of rainfall. NOAA does not have a coordinated, visible, well-funded program to evaluate and improve model Quantitative Precipitation Forecasts (QPF) similar to the hurricane forecast improvement program. NOAA should execute a sustained, collaborative research and development program that engages academic and federal partners to improve QPF and substantially increase its skill in detecting extreme precipitation events.
- Bandwidth limitations made it difficult to maintain situational awareness and provide timely service delivery. The slow Internet connection diminished the effectiveness of DSS. NWS should identify the resources needed to meet bandwidth requirements necessary to support operations during high-impact events and during service backup.
- Continued budgetary stresses and travel restrictions has significantly reduced hydrometeorological in-residence training and conference attendance while the availability of self-paced and distance learning courses have increased. The NWS training program should formulate a balanced approach to training, leveraging a combination of in-residence, distance learning, and self-paced training opportunities in concert with the established Hydrologic Professional Development Series (PDS) to satisfy training requirements. The NWS training program should develop a catalogue of all available training courses, and identify and update outdated modules.

Service Assessment Report

1 Introduction

1.1 NWS Mission

The mission of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) is to protect life and property by providing weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters, and ocean areas. The NWS disseminates centrally produced data, weather products, and guidance to 122 Weather Forecast Offices (WFO) and 13 River Forecast Centers (RFC). The forecasters at the WFOs and RFCs issue all local forecasts and warnings to the public and interface with local emergency managers (EM) and state and local government to promote community awareness and understanding of local climates, forecasts, and weather events.

The NWS is organized into six regional headquarters and one national headquarters, which provide policy, guidance, and administrative support to the WFOs and RFCs. The National Centers for Environmental Prediction (NCEP), consisting of nine prediction centers, provide central guidance, outlooks, and hazardous weather watches and warnings to the NWS organization and the public.

1.2 Purpose of Assessment Report

The NWS may conduct service assessments of significant weather-related events that result in one or more of the following: multiple fatalities, numerous injuries requiring hospitalization, significant impact on the economy of a large area or population, extensive national public interest or media coverage, or an unusual level of attention to NWS operations (performance of systems or adequacy of warnings, watches, and forecasts) by media, the EM community, or elected officials. Service assessments evaluate the NWS performance and ensure the effectiveness of NWS products and services in meeting its mission. The goal of service assessments is to better protect life and property by implementing recommendations and best practices that improve NWS products and services.

This document presents findings and recommendations resulting from the evaluation of NWS performance during the heavy rains and subsequent river and flash flooding in eastern Colorado and western Nebraska on September 11–17, 2013. Heavy rainfall over several days produced widespread flash flooding and major to record river flooding. This event resulted in eight fatalities, considerable property loss, and significantly affected transportation and commerce.

The objectives of this assessment are to identify significant findings, issue recommendations, and best practices related to the following key areas:

- Timeliness, quality, accuracy, and usefulness of NWS forecasts and warning services
- Situational awareness of the affected field offices prior to and during this event
- Effectiveness of current hydrologic and numerical weather prediction modeling capabilities for this event
- Effectiveness of coordination and decision support services for federal partners and key

stakeholders prior to and during this event

- Effectiveness of NWS continuity of operations during a major communications failure and determination whether this process needs to be improved

1.3 Methodology

The NWS formed an assessment team on September 13, 2013, consisting of employees from NWS field offices, the Office of Climate, Water, and Weather Services (OCWWS) in the NWS Headquarters (NWSH), an Associate Director of a U.S. Geological Survey (USGS) Water Science Center, and a county EM Director. Several social scientists and other subject matter experts served as team consultants. The 10-member team completed the following:

- Performed an on-scene evaluation from November 3-8, 2013
- Conducted interviews with staff from WFOs Pueblo and Boulder, CO, as well as the Missouri Basin RFC and the Arkansas-Red RFC (ABRFC). These offices had primary responsibility for providing forecasts, warnings, and DSS to the residents and EMs of the affected areas
- Interviewed EMs, the media, and local and federal water partners in the impacted areas
- Evaluated products and services issued by the Climate Prediction Center, WPC, National Environmental Satellite, Data, and Information Service Satellite Analysis Branch, WFOs, and MBRFC
- Developed a list of significant findings and recommendations to improve the effectiveness of NWS products and services

After a series of internal reviews, the NOAA Assistant Administrator for Weather Services approved and signed the Service Assessment and issued it to the American public.

2 Hydrometeorological Overview

Devastating and widespread flash flooding occurred along much of the Front Range of the Rocky Mountains of Colorado on September 11–17, 2013. Flash flooding in tributary streams would later evolve into major river flooding in the South Platte River Basin, eventually reaching the main stem Platte River in western Nebraska. Eight people lost their lives as a direct result of the flooding; many of these deaths occurred during the height of the flash floods on the evenings of September 11–12. Local authorities evacuated nearly 18,000 people. Flooding damaged approximately 19,000 homes and commercial buildings, with over 1,500 completely destroyed. In addition, the flooding damaged approximately 485 miles of roads, including 50 bridges in the impacted counties.

2.1 Event Evolution

Historic rainfall occurred in northern Colorado from September 9 to September 16 and resulted in severe flash flooding along the northern Front Range of Colorado and subsequent river flooding downstream along the South Platte River and its tributaries (**Figure 1**). The heaviest rain fell along the Front Range northwest of Denver on September 11–12.

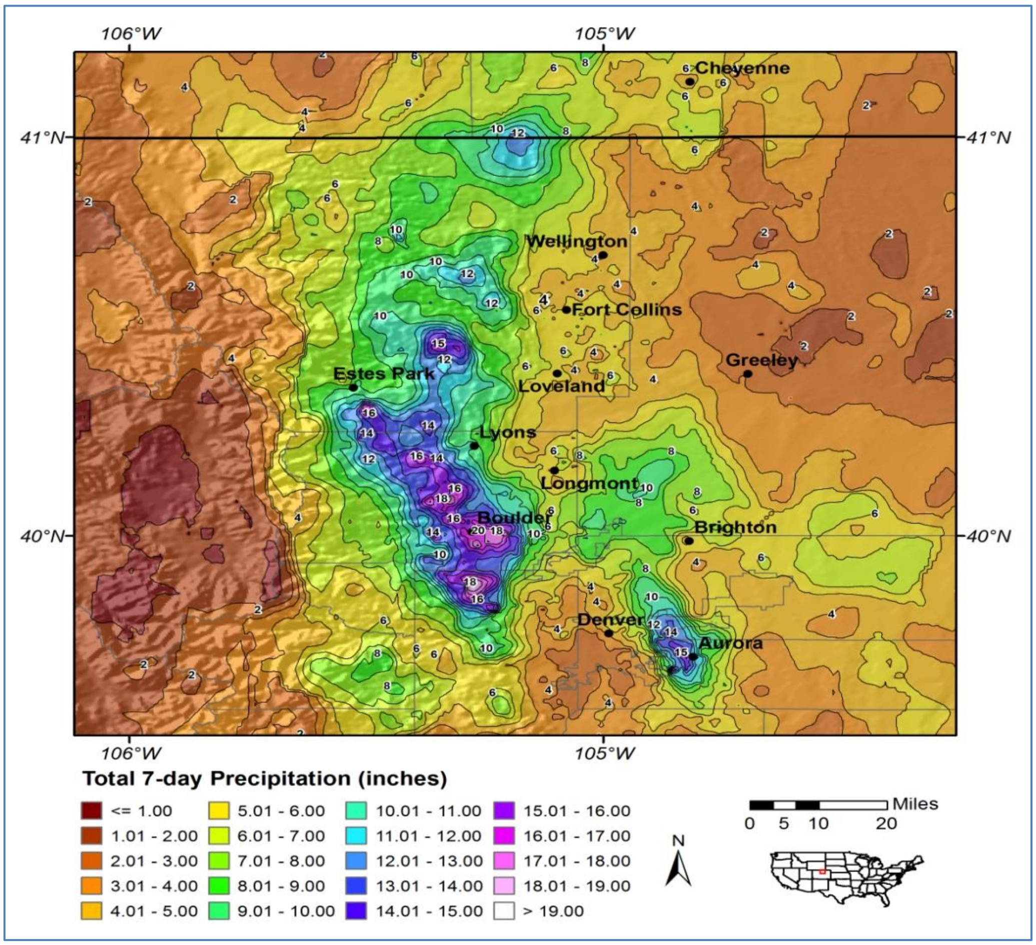

Figure 1: Rainfall analysis for September 9–16, 2013. Map created with the Storm Precipitation Analysis System through a collaborative effort by Applied Weather Associates, LLC, MetStat, Inc. and Colorado Climate Center (Colorado State University). Radar data supplied by Weather Decision Technologies, Inc.

Precipitation amounts were historically large for many locations due to the long duration and broad spatial extent of the event. During this same period, other significant heavy rainfalls occurred just east of Denver in Aurora, CO, southwest of Colorado Springs, CO, and through much of central and southern New Mexico. The precipitation event along the northern Front Range of Colorado is the primary focus of this assessment, given the large societal impact in this area.

In the days leading up to the event, several meteorological ingredients developed that are common precursors for heavy precipitation and flash flooding along the Front Range. These ingredients included relatively moist, unstable atmospheric conditions and easterly winds pushing the moisture up the face of the Rocky Mountains. One of the most notable aspects of this event was persistent record amounts of moisture present in the atmosphere as measured by the observed precipitable water (PW) values. Values of between 1.2 and 1.4 inches during the height of the heavy rainfall events exceeded the all-time observed maximum values for September (**Figure 2**). The combination of a stationary frontal system, instability, and persistent upslope easterly flow against the Front Range of the Rockies acted upon the deep tropical moisture plume.

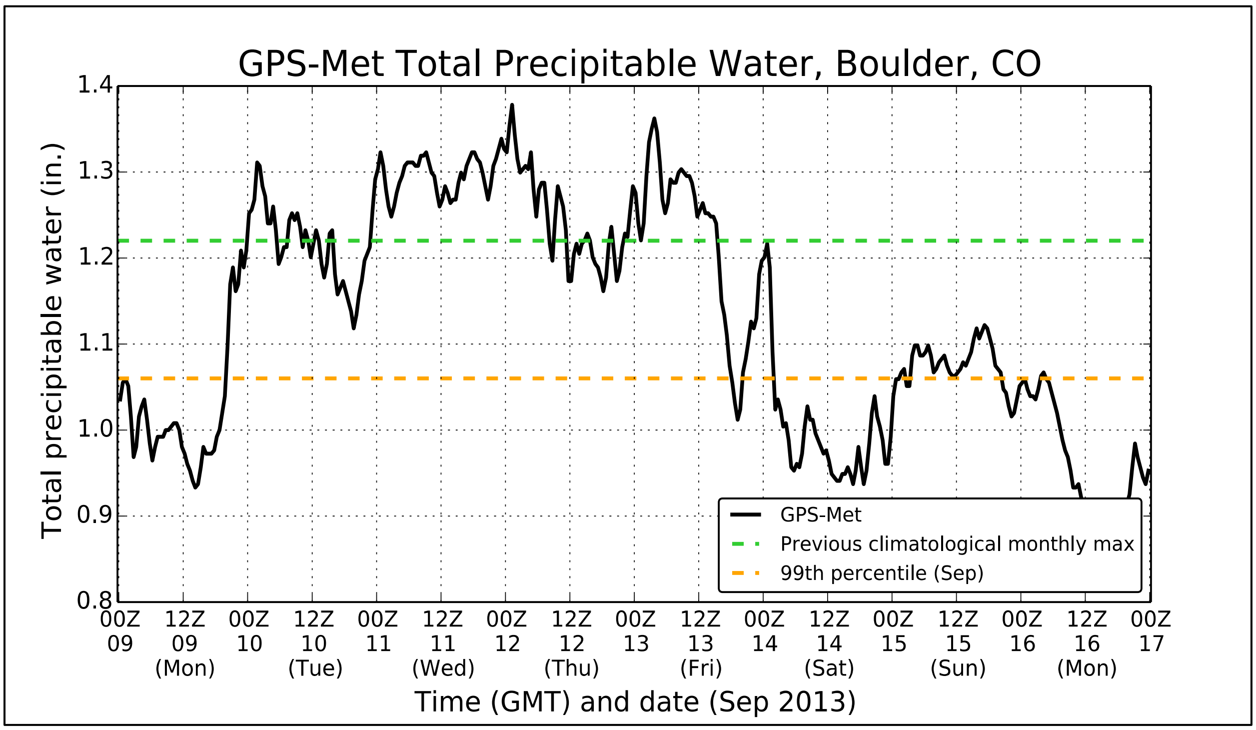

Figure 2: Shown is a time series of the PW in the atmosphere above Boulder, CO, during this heavy rainfall and flooding event. The green line denotes the previous maximum PW for September as determined from weather balloon data; the orange line denotes the 99th percentile of the water vapor climatology for September, also from weather balloon data.

The large-scale atmospheric wind pattern on September 11 was characterized by a near-stationary upper-level trough over the Desert Southwest and a ridge over the mid-Mississippi Valley. Between the two weather systems, deep southerly flow east of the Front Range brought anomalous moisture north from the Gulf of Mexico as depicted in satellite-derived Blended Total Precipitable Water (**Figure 3A**). Additionally, southwesterly flow east of the upper-level trough likely facilitated additional moisture transport northward from the tropical east Pacific Ocean.

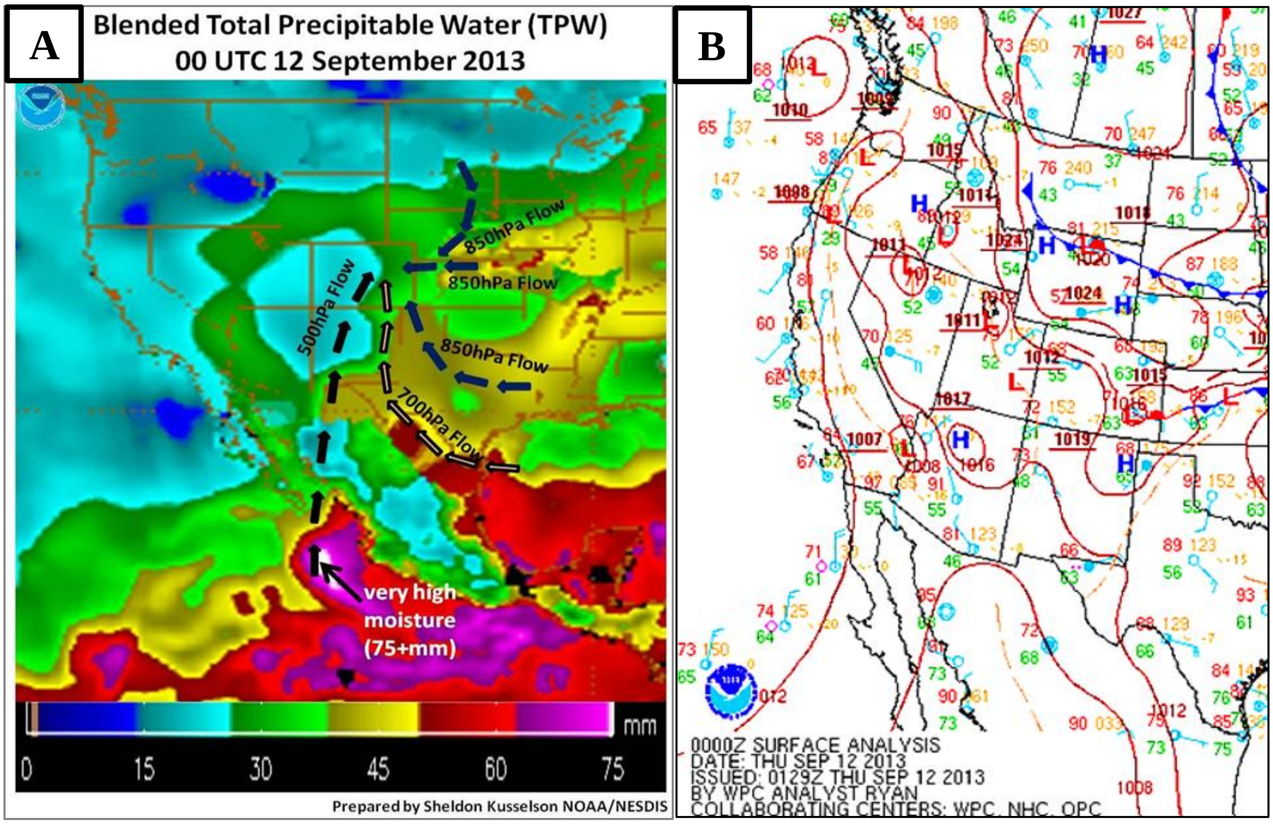

Figure 3: Blended Total Precipitable Water as derived from satellite observations (A), and Surface weather map analysis (B) valid September 11, 2013, 6 p.m. Mountain Daylight Time (MDT). For (A), superimposed arrows show atmospheric flow at 850 hPa, 700 hPa, and 500 hPa.

At the surface, a cold front moved slowly south and had become nearly stationary across east central Colorado by the evening of September 11(**Figure 3B**). As the cold front stalled, deep moisture continued to move into north-central Colorado resulting in scattered showers and thunderstorms on September 9–10, although the heaviest rain fell in New Mexico. During the evening hours of September 11, the first period of heavy rain began to develop in a west-east oriented band north of Denver, as well as northward parallel to the foothills. Individual cells within the band propagated westward toward the foothills. Because the flow in the lower atmosphere was directed toward the mountains, when the moisture-rich air reached the foothills, the upslope flow likely acted to enhance the precipitation rates near steep topography.

The rainfall processes were different from those that often occur in intense thunderstorms that extend to very high altitudes. The rainfall developed and fell mostly within the lower atmosphere, where temperatures were relatively warm. These “warm rain” processes are efficient in converting water vapor to liquid rain and are often associated with high rain rates.

Flash flooding started in the Boulder area during the early evening hours of September 11. Before midnight, the areal coverage of the rain increased markedly and became anchored along the foothills northwest of Denver **(Figure 4**). The event resulted in high rain rates given the high moisture content, slow movement, and topographic enhancement. Flash flooding became widespread overnight in the counties north and west of Denver. Over 8 inches of rainfall occurred in Boulder during the night of September 11.

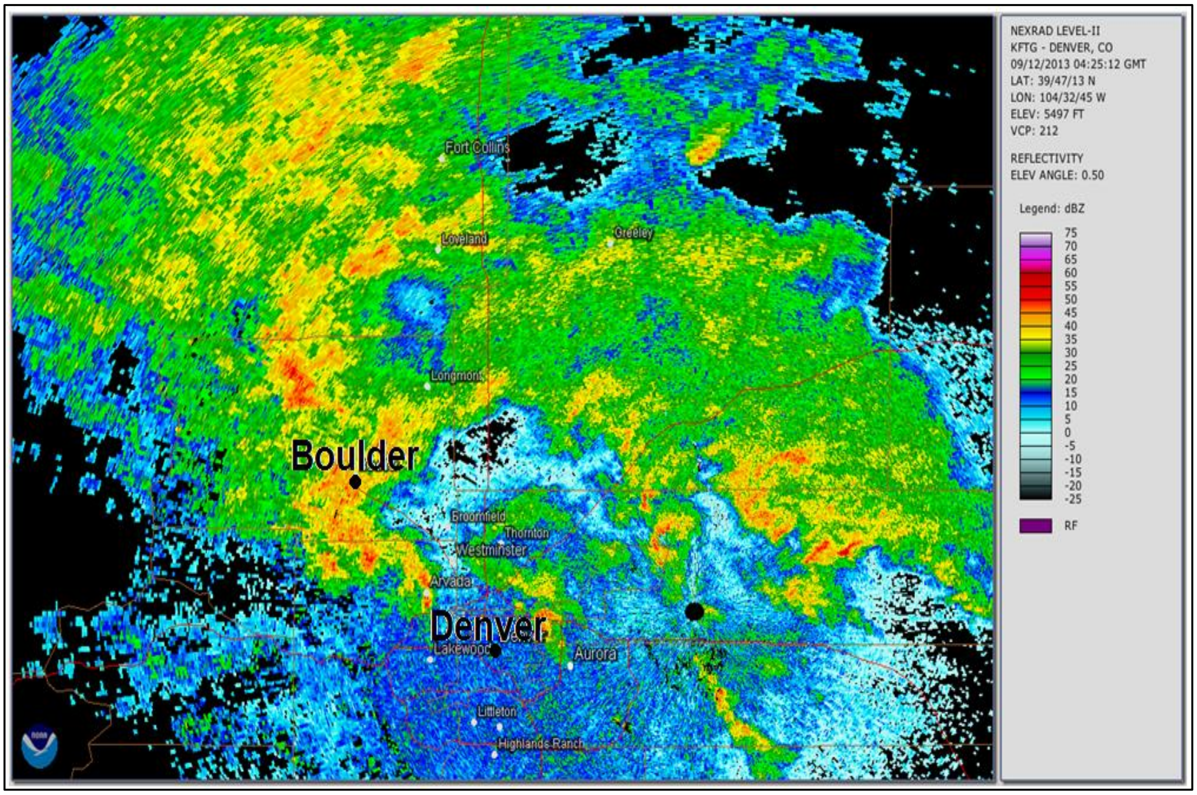

Figure 4: Radar image of base reflectivity showing heavy rainfall on Wednesday, September 11, at 10:25 p.m. MDT

The heavy rain continued throughout the morning hours of September 12 over an unusually large area from Fort Collins to Boulder extending southeast to Aurora before tapering off by midday. After only a brief lull, heavy rainfall began to redevelop over much of the same area impacted the night before. This second round of heavy rainfall continued throughout the night and finally began to taper on Friday morning, September 13. Sunday brought the third and final episode of heavy rain, but not nearly the intensity of September 11–12. **Figure 5** shows a timeline of accumulated rainfall for various locations impacted during this event.

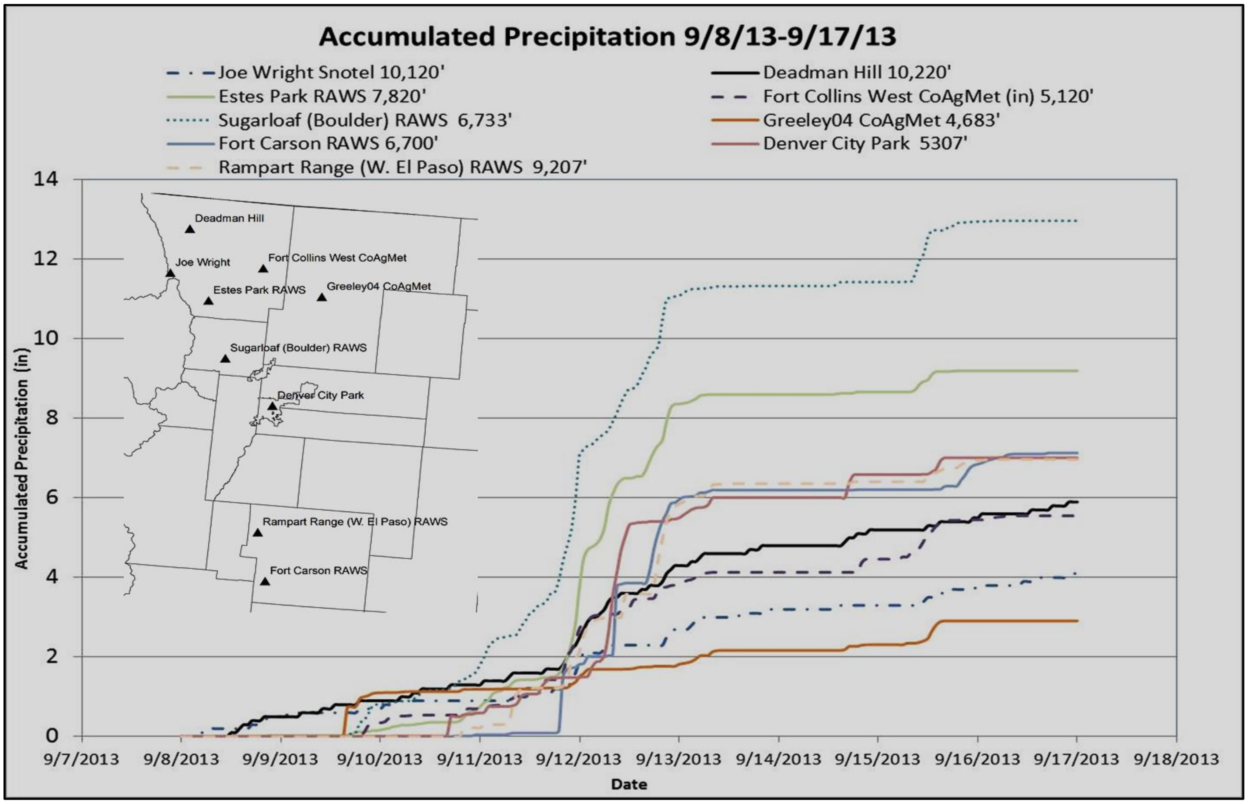

Figure 5: Timeline of rainfall accumulation at selected locations in north central Colorado.

The Front Range of Colorado is certainly no stranger to flash flooding. This event had a much larger footprint than other major floods such as the Big Thompson Canyon Flood of 1976 or the July 1997 Fort Collins flood. The September 2013 event covered most of the Front Range of eastern Colorado and produced record-breaking daily and multi-day rainfall. To put this event into climatological context, the annual exceedence probability for the 48-hour period encompassing the heaviest rainfall for this event exceeds 0.2 percent and in some areas approaches the 0.1 percent probability of occurrence (**Figure 6**). This event established a new state record for 24-hour rain of 11.85 inches in Fort Carson, CO. Boulder established a new 24-hour rainfall record of 9.08 inches, far exceeding the previous record of 4.80 inches set on July 31, 1919. Boulder also established a new monthly rainfall record of 18.16 inches, nearly doubling the previous record of 9.60 inches set in May 1995.

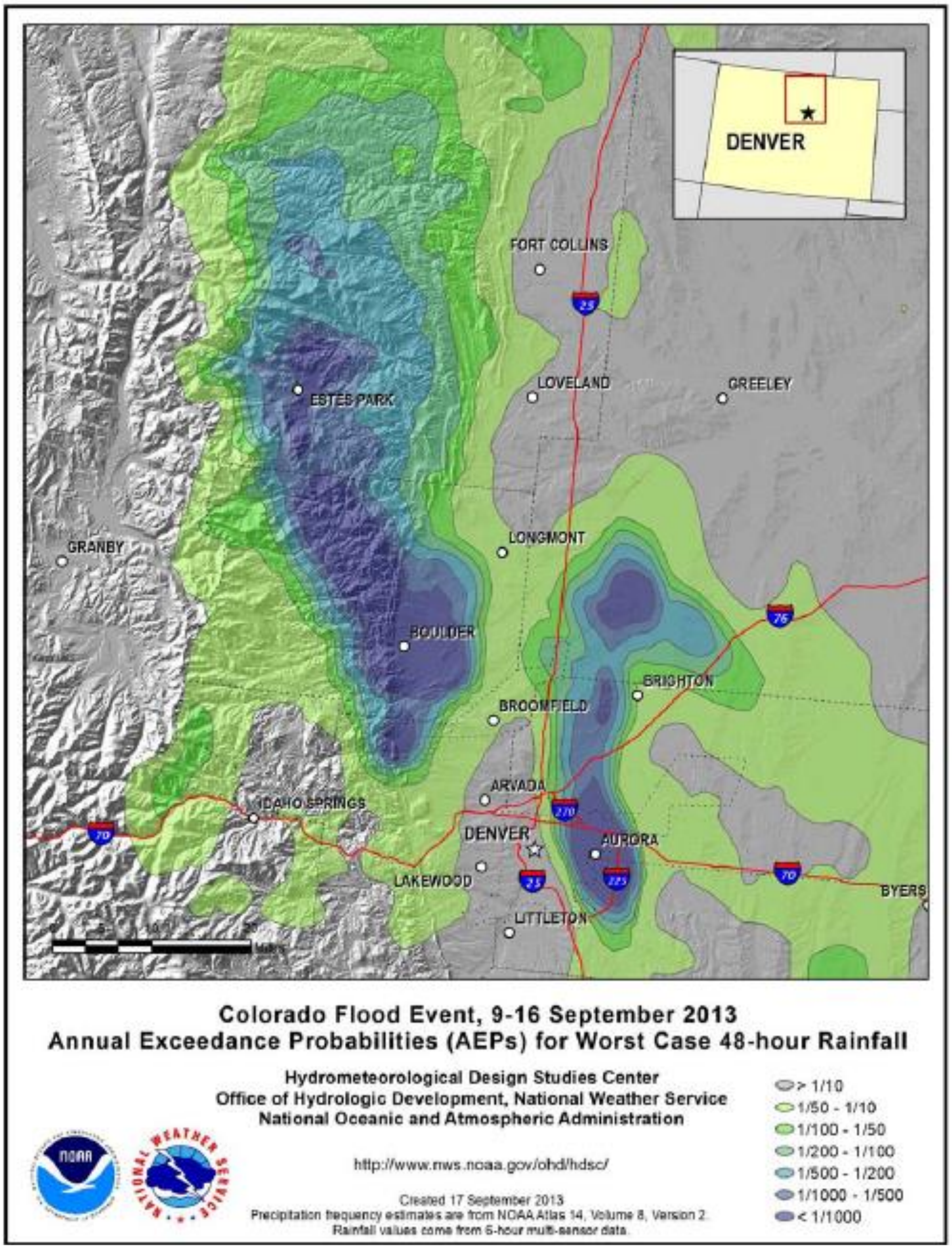

Figure 6: Annual exceedence probabilities for the worst case 48-hour rainfall

2.2 Hydrologic Perspective and Response

Eastern Colorado primarily resides in the South Platte River Basin in the north and the Arkansas River Basin in the south (**Figure 7**). Both river basins feature steep gradient headwater streams that drain from the east side of the Continental Divide in the Rocky Mountains from elevations as high as 14,000 feet. Exiting the foothills between 5,500 and 7,000 feet, streams flow across Colorado's Front Range Urban Corridor extending from Pueblo north to Fort Collins. This area encompasses 85 percent of the state's population. Downstream from the urban areas, the South Platte and Arkansas rivers flow through primarily agricultural areas before exiting the state at an elevation of about 3,500 feet.

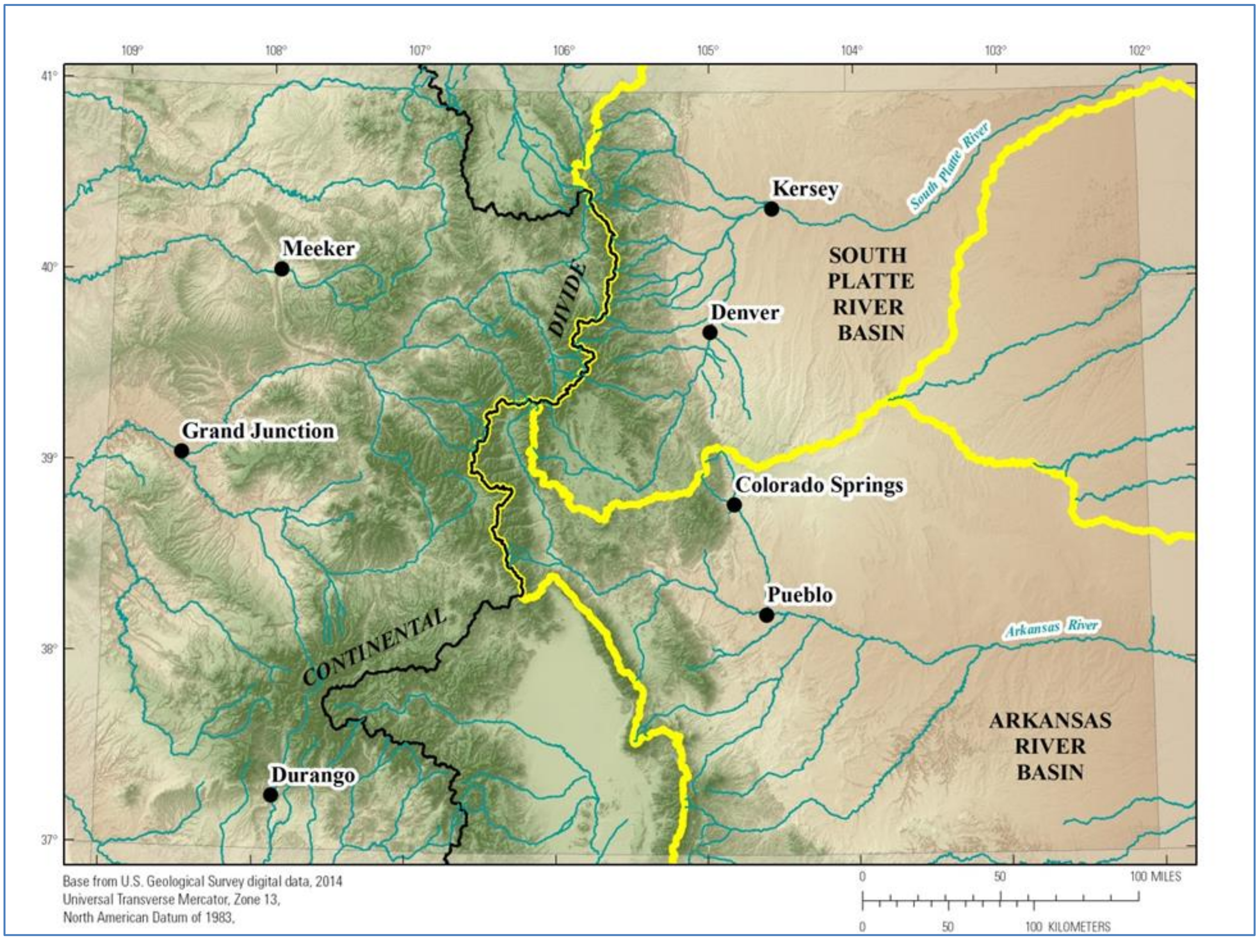

Figure 7: Map showing the Arkansas and South Platte River Basins

The hydrologic regime of eastern Colorado is characterized by high streamflow in May and June from annual spring snowmelt runoff, with flows continuing to recede throughout the summer and fall. Streamflow is relatively low throughout winter. Above normal snowpack can result in localized minor to moderate flooding in May and June. In late summer, more localized flooding infrequently occurs as a result of localized convective rainfall. The September 2013 event was extremely rare due to the widespread nature of intense rain, producing flooding over an extensive area. The anomalous nature of this event is evident in USGS flow duration hydrographs from gage locations across the area, including Boulder Creek near Boulder (**Figure 8**) and the South Platte River at Fort Morgan (**Figure 9**).

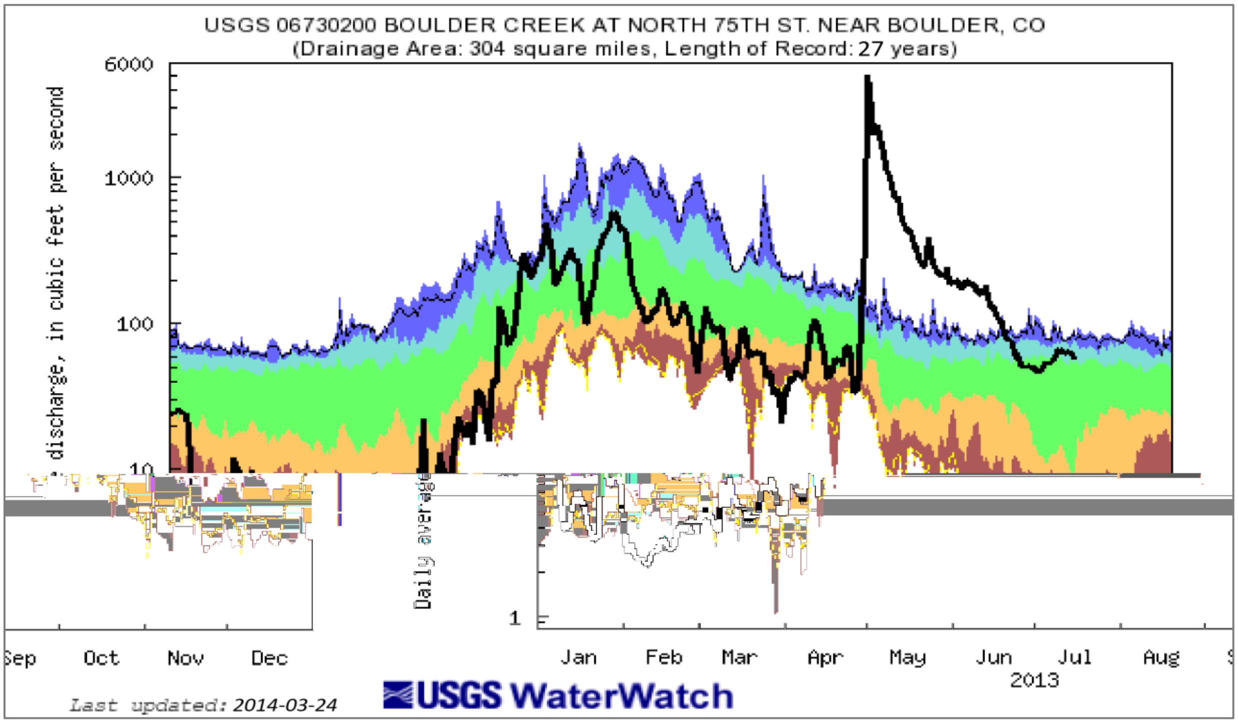

Figure 8: Flow duration hydrograph for Boulder Creek showing the magnitude of the September flood. The bluish-purple bar (top color) represents the 95 percentile to the maximum observed flow prior to 2013. The black line represents the observed flow from 2013.

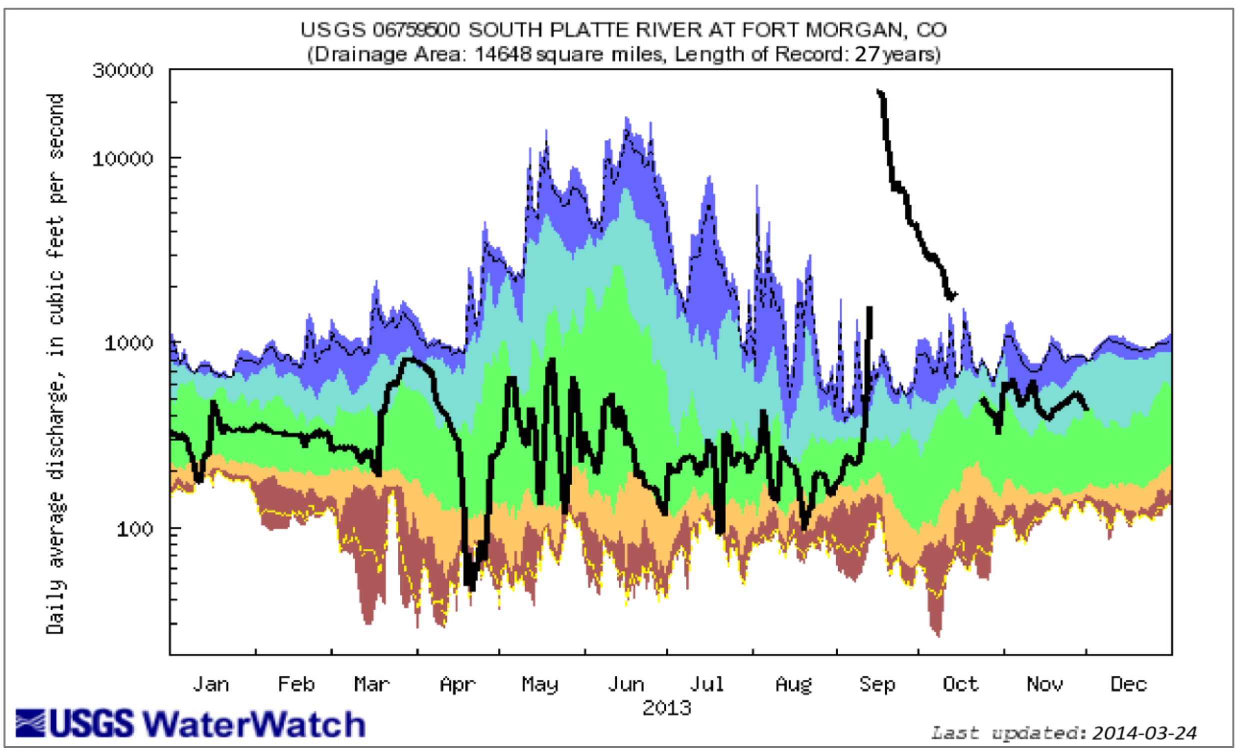

Figure 9: Flow duration hydrograph for the South Platte River showing the magnitude of the September flood. The bluish-purple (top color) represents the 95 percentile to the maximum observed flow prior to 2013. The solid black line represents the observed flow from 2013. The period of missing data leading up to the crest is due to gage damage from floodwaters.

In the South Platte Basin that September, there was frequent flash flooding along the entire Front Range and Foothills Region of eastern Colorado. Flooding occurred in the Denver metropolitan area, including the eastern suburb of Aurora, and in mountain streams that join the main stem South Platte between Denver and Kersey. The latter region includes the major mountain tributaries of Bear Creek, Clear Creek, Boulder Creek, St. Vrain Creek, Big Thompson River, and the Cache La Poudre River. Combined flow from the mountain tributaries and the Denver area resulted in flooding in the main stem South Platte River from Denver to the confluence with the Platte River east of North Platte, NE, and in the main stem Platte River downstream to Kearney, NE (**Figure 10**).

The U.S. Army Corps of Engineers operates three reservoirs to control flooding in the Denver metropolitan area: on the main stem South Platte just upstream of Denver; on the mountain tributary Bear Creek, which flows through west Denver; and on Cherry Creek, a plains stream that flows into downtown Denver. During the September 2013 flood event, only Bear Creek Reservoir captured significant flood flow because flooding was minor in the main stem South Platte River upstream of Denver and in Cherry Creek. On the Big Thompson River, the Bureau of Reclamation – Eastern Colorado Area Office had to respond quickly to the overwhelming increase in flows from the tremendous rainfall. The unexpected nature of the event made it challenging to mobilize staff overnight and to move people in position due to washed out roadways.

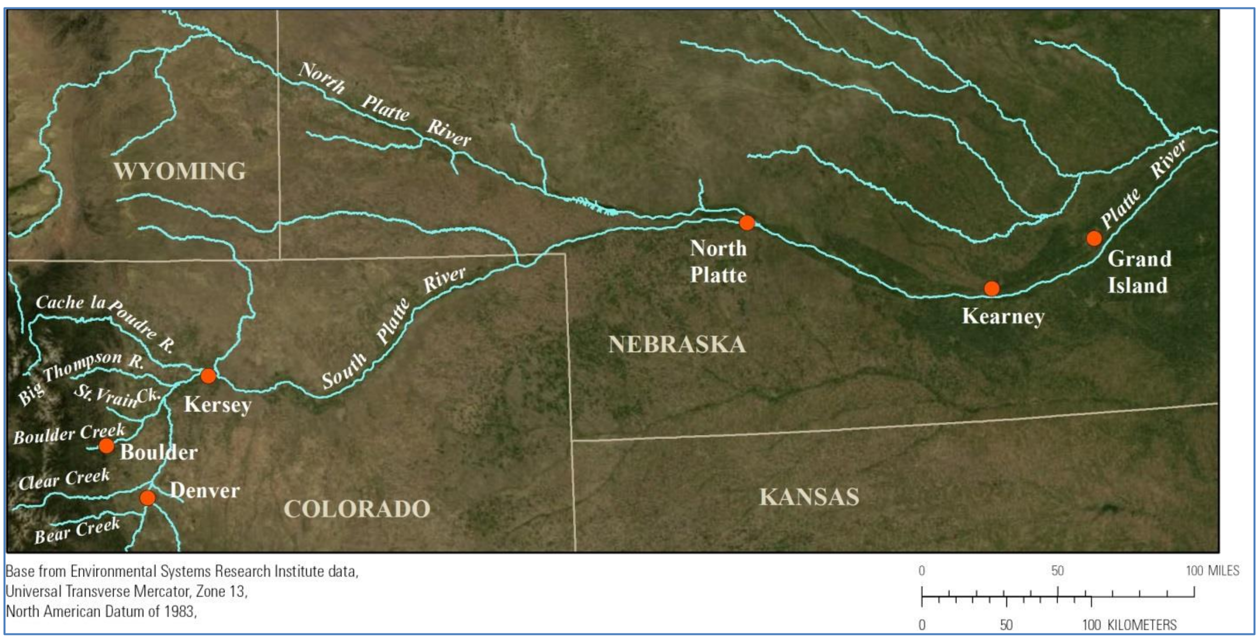

Figure 10: Flooding in the South Platte and Platte River Basins in September 2013 occurred from Denver, CO, to Kearney, NE

Small stream and headwater systems in the Front Range of Colorado are flashy and respond quickly to rainfall, with as little as a few tenths of an inch of runoff causing a rise of several feet in stage. Smaller streams experienced multiple crests from the repeated rainfall over the basin, typical of streams subject to flash flooding (**Figure 11**). Historically, flash floods in the region are isolated and usually caused by localized convective rainfall. As the storm system stalled on the night of September 11; however, numerous streams began to rise rapidly above flood stage almost simultaneously over a large area. The rain inundated roads and low-lying drainages with rushing water. As tributaries along the foothills crested and began to subside over the next 24–48 hours following the rain overnight on September 11–12, the flood wave concentrated in main stem rivers and traveled downstream continuing to cause record flooding.

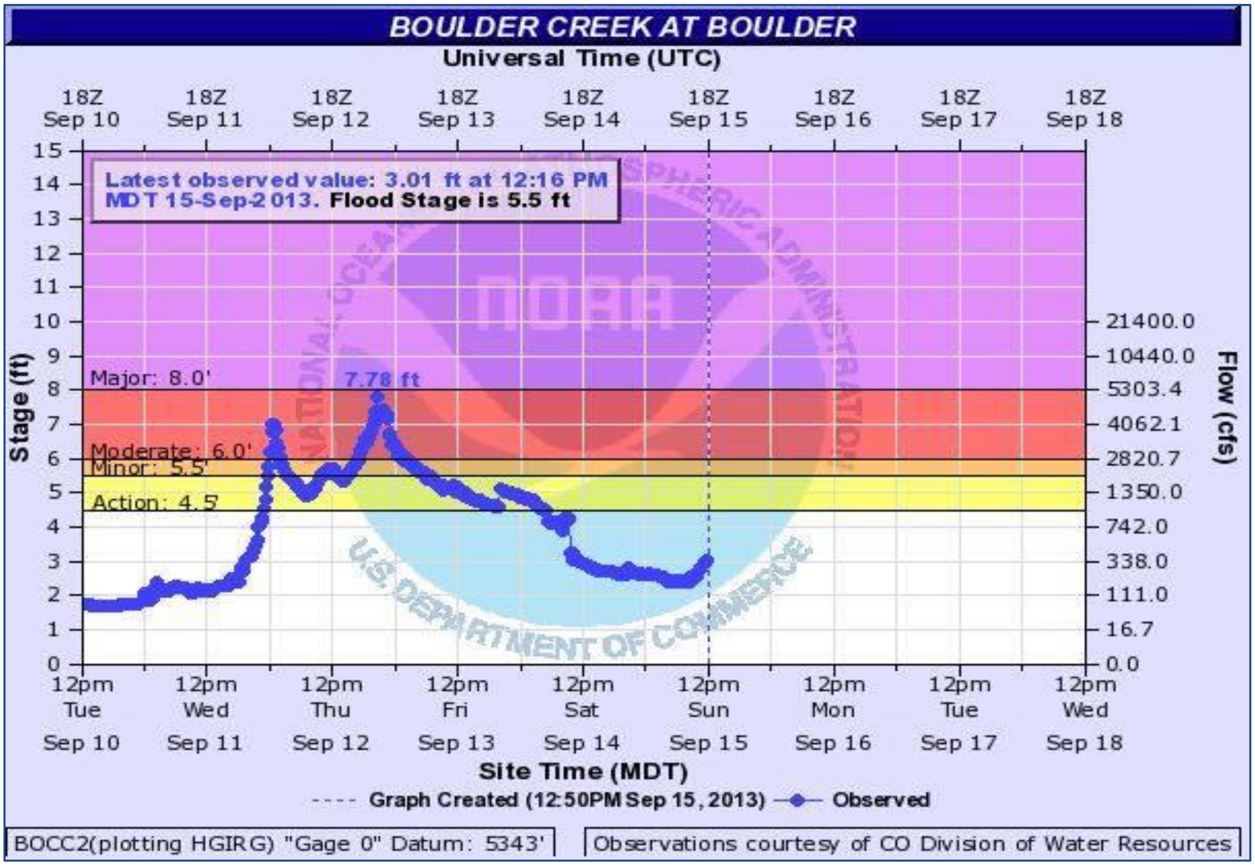

Figure 11: Observed hydrograph on Boulder Creek demonstrating the rapid rise and multiple crests. The initial rise increased from base flow to moderate flood level in just 6 hours.

In the Arkansas River Basin, flooding in September 2013 was primarily in the Fountain Creek Basin, which originates in the foothills northwest of Colorado Springs (**Figure 12**). After exiting the mountains near Manitou Springs, the creek flows through the Colorado Springs and continues south for 40 miles, where it joins the Arkansas River at Pueblo. Fountain Creek is extremely flashy and responds quickly to even modest rainfall totals. The upper part of the basin included burned areas from two major fires that had occurred in recent years, increasing flash flooding and debris flows. In 2012, the Waldo Canyon Fire burned about 18,000 acres in the foothills just west of Colorado Springs. In 2013, the Black Forest Fire burned 14,000 acres north of Colorado Springs. Although three significant flash flood events occurred off the Waldo burn scar in the summer of 2013, the most severe flooding in the Fountain Creek Basin in September 2013 occurred in non-burned areas draining the east flank of Pikes Pike, southwest of Colorado Springs.

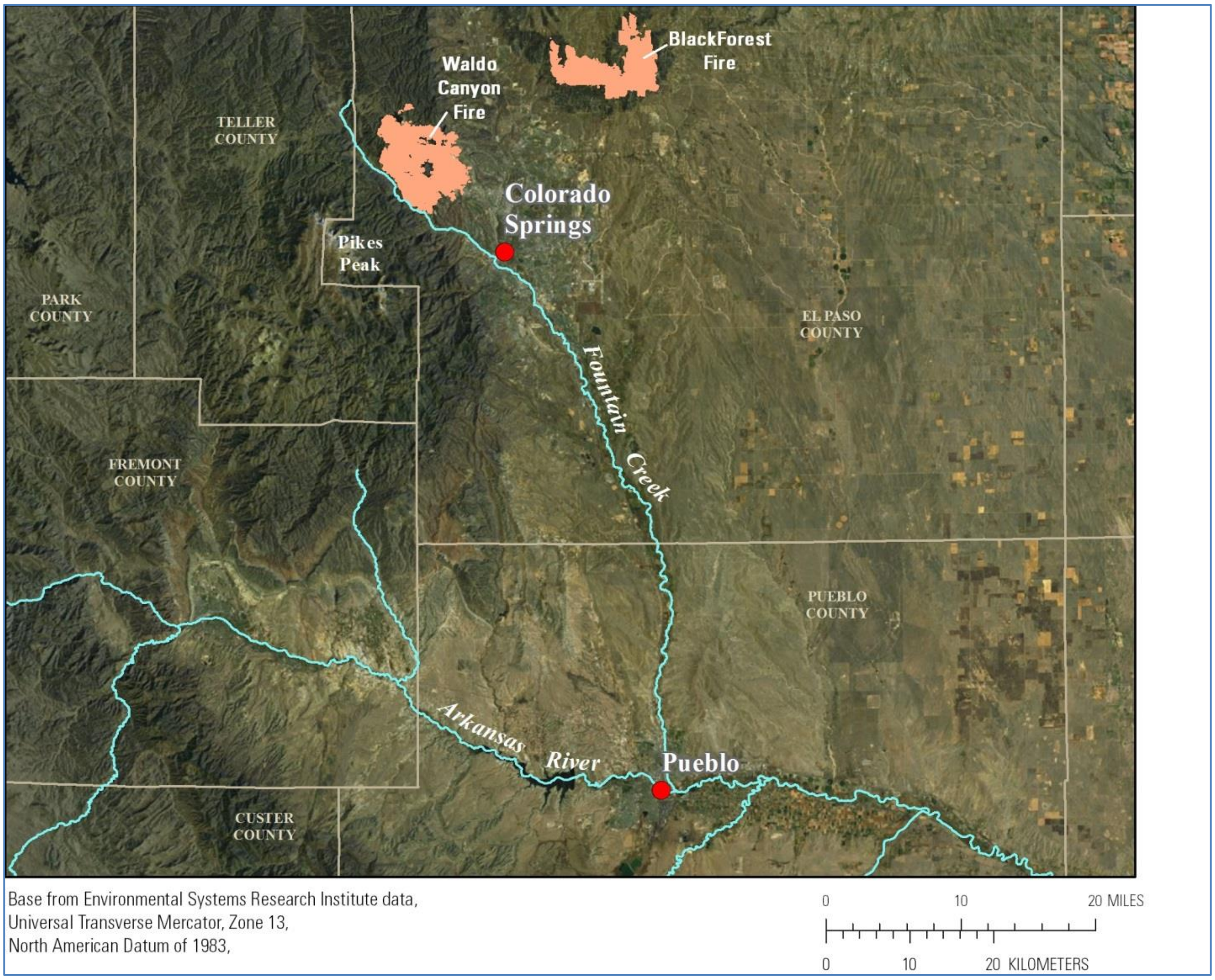

Figure 12: Flooding in the Arkansas Basin in September 2013 primarily occurred in parts of the Fountain Creek Basin.

2.3 Impacts

Damage from flash flooding and debris flows was extensive in numerous mountain tributaries of the South Platte River Basin including the Big Thompson River, Left Hand Creek, Little Thompson River, Cache la Poudre River, St. Vrain Creek, Coal Creek, Boulder Creek, and South Boulder Creek. Floodwaters also caused damage in the Sand Creek Basin, which drains the town of Aurora, a Denver suburb. During the height of the flash flooding along the Front Range, not only were stream channels rapidly overflowing, but many streets and urban drainages also became raging conduits of water, making these roadways impassable. The floodwaters then concentrated in the lower main stem South Platte River, impacting Weld, Morgan, Washington, and Logan counties in eastern Colorado. Farther south in the upper Arkansas Basin near Colorado Springs, flash flooding in Rock Creek, Cheyenne Creek, and Fountain Creek caused extensive damage in western El Paso County.

High waters resulted in flooded and washed out roadways and bridges, stranded vehicles and forced workplaces, universities, and many private and public schools to close from September 12 to September 17. Besides the 8 fatalities across the state, over 18,000 people were evacuated during and after the flood due to high waters and subsequent damage to infrastructure. At the height of the event, more than 1,200 people were listed as missing, most in Boulder and Larimer counties. The Boulder County EMA reported that at the height of the flooding, every road into the foothills in the entire county was impassable. Many foothills and mountain roads were also closed to the north and south. With vehicular access and telecommunications cut off, small mountain communities were isolated for several days. Once the rainfall diminished, emergency personnel conducted evacuation and search and rescue efforts using helictopters and on foot. The evacuation is believed to be the largest such effort since Hurricane Katrina. Direct and indirect losses from housing, infrastructure, and economic are estimate to be around $3 billion according to the *State of Colorado: Action Plan for Disaster Recovery*.

Based on FEMA information, the flooding destroyed more than 350 homes with over 19,000 homes and commercial buildings damaged, many of which were impossible to reach except on foot. Flooding resulted in a total of 485 miles of damaged roadway, destroyed 30 state highway bridges, and severely damaged another 20 bridges. During the height of the flooding, authorities were forced to close 36 state highways. Some highways could not be repaired for weeks or even months. In Larimer County, flooding damaged approximately 85 percent of the roads and bridges, cutting off several mountain communities, including a portion of Highway 34 bewteen Loveland and Estes Park. In all, FEMA Disaster Declarations for Colorado as of October 21, 2013 covered 16 counties (**Figure 13**).

The U.S. Forest Service reported significant flood related impacts in the Arapahoe and Roosevelt National Forests, including damage to 232 roads covering 380 miles, 4 bridges, 70 trails covering 236 miles, and impacts to 42 of its facilities.

The USGS mapped more than 1,300 landslides generated by the storm. The landslides occurred over a broad range of elevations, geology, and ecosystems and were directly responsible for the loss of three lives and considerable damage to property. Landslides and debris flows delivered considerable coarse-grained sediment to stream channels, which exacerbated the damage done by flooding in the mountain areas.

Railroad infrastructure was severly damaged: the flooding damaged 150 miles of track and toppled several railroad bridges. Union Pacific reported the loss of 20 miles of its line west of Denver and 19 miles of its line between Denver and Cheyenne, WY. This loss caused the diversion of rail traffic 600 miles north and west. BNSF Railway reported the loss of 1,200 feet of track in Loveland along the Big Thompson River, 3,000 feet of rail in Longmont along the St. Vrain River, and 2,000 feet of track in Boulder.

Flooding also significantly impacted Colorado’s dams. In all, 27 state dams sustained some degree of damage with a handful of low-hazard dams completely failing. Dozens of other small, low-hazard dams not subject to state inspection failed during the event.

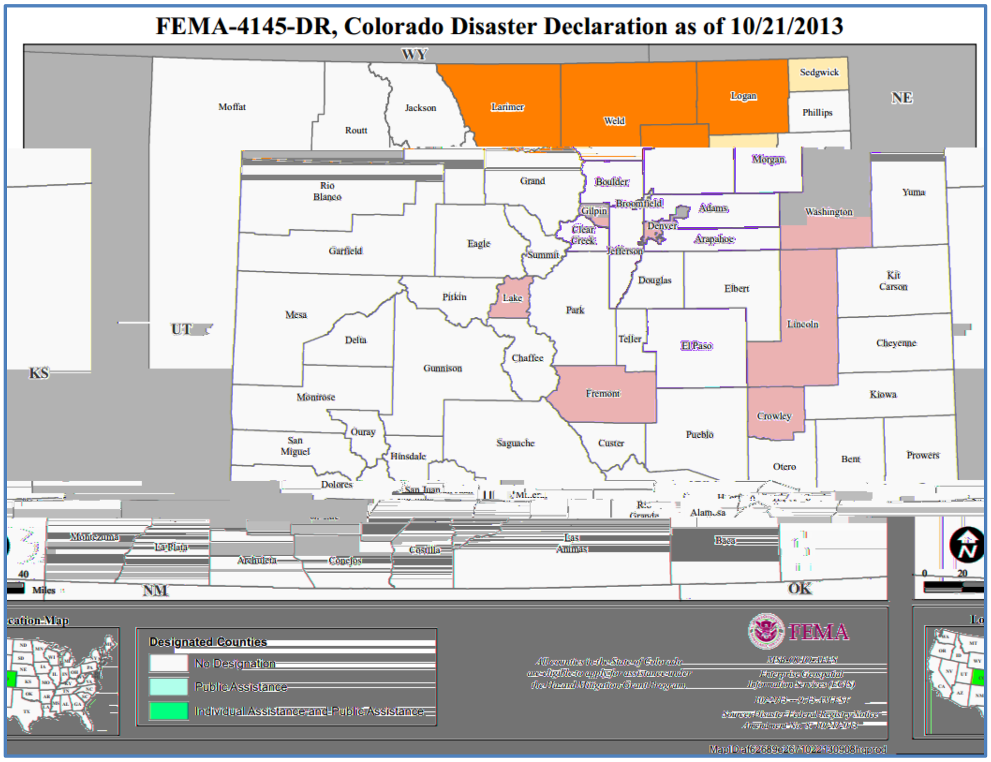

Figure 13: FEMA Disaster Declarations for Colorado as of October 21, 2013

NWS confirmed eight fatalities (**Table 1**) as a direct result of the flooding and debris flows across eastern Colorado. A majority of the flood victims were in canyon areas along the east slopes of the Colorado Rockies when floodwaters rose, rapidly innundating homes and roads. Two fatalities occurred along a foothills road when a car was stranded in high water and debris.

Table 1: Colorado flood fatalities during the September 2013 event

Flooding Fatalities				
Sex	Age	Date	Location	Cause of Death
M	72	9/11/13	Jamestown, CO James Canyon Boulder, County	Blunt force trauma when home caved in under 12 feet of rocks and mud
F	19	9/11/13	Boulder, CO Boulder County	Drowning while abandoning her stranded car in floodwaters
M	19	9/11/13	Boulder, CO Boulder County	Drowning while trying to rescue a fellow car passenger from floodwaters
M	80	9/12/13	Lyons, CO St Vrain River Boulder County	Drowning in floodwaters (returned after evacuating)
F	60	9/12/13	Cedar Cove, CO Big Thompson River Larimer County	Drowning as home washed away
F	79	9/12/13	Cedar Cove, CO Big Thompson River Larimer County	Drowning and blunt force trauma while trying to climb to higher ground (hit with water and debris)
M	54	9/12/13	Fountain Creek El Paso County	Drowning in floodwaters
M	47	9/15/13	Sand Creek El Paso County	Drowning in floodwaters

2.4 Flash Flood Verification

WFOs Pueblo and Boulder collectively issued 78 flash flood warnings from September 11 to September 15, 2013. Only WFO Pueblo had a Flash Flood Watch in effect before the initial round of flash flooding on the late afternoon and evening of September 11. The watch extended into the early morning hours of September 12.

Probability of detection was quite high, averaging nearly 94 percent with an average False Alarm Ratio below 11 percent (**Table 2** and **Table 3**). The average initial lead time for all warnings was 69 minutes, above the national goal of 58 minutes (**Table 3**). There were several warnings issued during the early morning of hours of September 12 that provided zero lead time. **Appendix D** provides a complete listing of watch and warning products.

Table 2: Flash Flood Warning statistics including False Alarm Ratio

Forecast Office	# of warnings	# of Warnings Verified	# of Warnings Unverified	False Alarm Ratio
Boulder	64	55	9	14.1%
Pueblo	14	13	1	7.1%
Total	78	68	10	10.6%

Table 3: Flash flood event statistics including average initial lead time and probability of detection.

Forecast Office	# of Events	# of Fully Warned Events	# of Partially Warned Events	Probability of Detection	Avg. Weighted Lead Time (mins.)
Boulder	63	36	27	93.6%	77
Pueblo	12	8	4	95.4%	24
Total	75	44	31	93.9%	69

2.5 River Flood Verification

The majority of river-related flooding affected the South Platte River Basin, including the main stem South Platte and many of its headwater streams in the WFO Boulder service area. Response times of the rivers and streams in the South Platte Basin range from fast-responding mountain streams, such as Boulder Creek, Big Thompson River, and the Saint Vrain Creek, to slower main stem river locations such as the South Platte River at Balzac and Julesburg. River flooding also occurred on Fountain Creek in WFO Pueblo's area and extended into a portion of the Arkansas River.

WFOs Boulder and Pueblo, with forecast support from MBRFC and ABRFC respectively, issued warnings with minimal lead time at several headwater locations on the nights of September 11–12. Lead times increased as the headwater flow moved downstream into the South Platte and Arkansas Rivers. **Table 4** provides a summary of river flood warning verification for WFOs Boulder and Pueblo. **Appendix D** provides a breakdown of MBRFC river forecast guidance lead times with respect to flood stage as a function of river response time.

Table 4: WFO River Flood Warning verification statistics

Forecast Office	Total Warnings	Verified Warnings	Non Verified Warnings	Total Events	Average Lead Time (hours)	False Alarm Ratio
Boulder	17	12	5	12	25.16	0.29%
Pueblo	12	10	2	10	3.46	0.17%
Total	29	22	9	22	14.31	0.23%

3 Facts, Findings, Recommendations, and Best Practices

3.1 Operations

Heavy rainfall and flash flooding evolved quickly along the Front Range of the Rocky Mountains of Colorado on the evening of September 11. While National Center forecasts indicated the potential for very heavy rainfall and at least a slight risk for rainfall to exceed flash flood guidance, significant variability in magnitude, timing, and location of the heaviest rainfall made it difficult for the WFOs to anticipate the rapid evolution of torrential rainfall and initial flash flooding. WFO and RFC staff responded quickly to the evolution of the flash and river flooding. Those offices referred to a flash flood emergency in products and civil emergency messages. NWS products included enhanced urgency wording to obtain immediate response to the event. The combination of these products and close collaboration with county EMs in the Pueblo and Boulder County Warning Areas (CWA) helped limit the number of fatalities.

3.1.1 NWS National Centers

More than a week in advance, the Climate Prediction Center's 6–10 day outlooks indicated a significant pattern shift across the western United States with a transition from a hot and humid regime to a cooler and wetter than normal pattern. By September 4, the Day 3–7 U.S. Hazards Outlook depicted an area of possible flooding stretching from the Front Range southward across western New Mexico and all of Arizona. The WPC 7-day deterministic forecasts indicated a large area in which 2–4 inches of rain was possible in this same region.

Three days before the event, WPC was forecasting an extensive slight risk area in which rainfall could exceed flash flood guidance (**Figure 14**). These probabilistic excessive rainfall forecasts continued through the onset of the event. WPC 24-hour probabilistic rainfall forecasts indicated the potential for 3–4 inches of rain over areas of the Front Range at the 95^{th} percentile, but confidence was highest that excessive rainfall would occur over portions of New Mexico. Forecasters and hydrologists use the probabilistic quantitative precipitation forecast (PQPF) guidance to estimate the probability of any rainfall amount at a given location. The 95^{th} percentile indicates a worst case—an amount of rain having a 5 percent chance of exceedence.

The WFOs and RFCs use WPC QPF and PQPF grids in a variety of ways. RFCs leverage WPC QPF for the purposes of hydrologic modeling. Hydrometeorological Analysis and Support Meteorologists at MBRFC and ABRFC start with WPC QPF and make adjustments typically for the first few forecast periods to account for timing and local topographic effects. These meteorologists may also incorporate local WFO QPF grids prior to generating the hydrologic forecasts. MBRFC and ABRFC use the 5 percent and 95 percent PQPF grids to generate additional streamflow simulations for planning purposes. These additional ensemble simulations are shared with partners such as the USACE and EMs.

WFOs utilize WPC grids as a guidance product and input to their forecast process. WFOs stated that the guidance often lacks the resolution necessary to resolve rainfall over complex terrain. WFOs will utilize local expertise and high-resolution Numerical Model Output to adjust the WPC QPF before publishing it to the National Digital Forecast Database. PQPF grids are used much less frequently and primarily for a subjective assessment of the flood or flash flood potential.

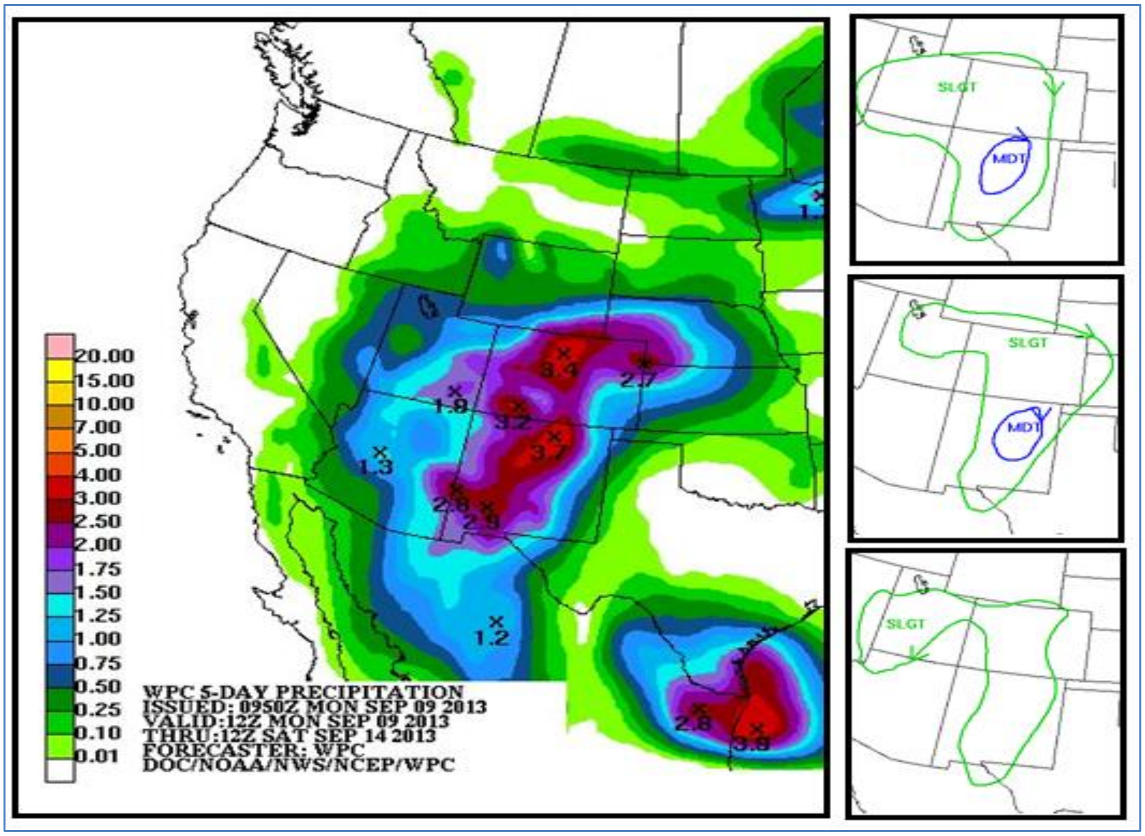

Figure 14: Shown are forecast rainfall amounts (left) and excessive rainfall outlooks (right) issued by the WPC prior to the event. WPC issued flash flood outlooks 3 days (top), 2 days (middle), and 1 day (bottom) prior to the peak of the event. Closed green contours indicate slight risk areas; closed blue contours show moderate risk areas.

Significant Numerical Weather Prediction (NWP) run-to-run variability in magnitude, timing, and location of potential heavy rainfall for this event made it difficult for WPC, WFO, and RFC forecasters to identify the location, timing, and magnitude of the potential heavy rainfall, as evident in forecast discussions. In spite of the potential for widespread heavy rainfall, other than routine technical discussions that accompany the QPF and probabilistic excessive rainfall forecasts, there was little direct coordination between WPC and the impacted WFOs and RFCs before the event. During major land-falling tropical cyclone events or significant winter storms, WPC and the WFOs collaborate through region-wide conference calls to discuss the forecast philosophy and to foster a collaborative approach, ensuring consistency in the forecast and messaging. A similar approach for significant convective and synoptic-scale heavy rainfall events could have improved forecast confidence, accuracy, and service delivery.

Finding 1: There was limited direct coordination regarding rainfall potential and flash flooding potential between WPC and the impacted WFOs and RFCs prior to this event.

Recommendation 1: WPC and the WFOs and RFCs should replicate the successful winter weather coordination model for significant hydrologic events by conducting coordination calls when the potential exists for widespread heavy rainfall and flash flooding.

3.1.2 Weather Forecast Offices

WFO Boulder had most of its staff available to assist with warning and forecast operations the week of September 9, with the exception of the Meteorologist in Charge (MIC), who was filling in as the Acting MIC at WFO Cheyenne, WY. In the absence of the MIC, the WFO Boulder Warning Coordination Meteorologist (WCM) was Acting MIC during the event. Washed out roads made it impossible for the WFO Boulder MIC to return to Boulder; however, the MIC maintained close contact with WFO Boulder and assisted in communication with Central Region Headquarters.

Forecasters in WFOs Boulder and Pueblo recognized that a much wetter regime was setting up over the region capable of producing at least localized heavy rainfall. For example, on September 9, WFO Boulder issued an Area Forecast Discussion citing an "abnormally wet period" for several days and potential for rainfall that could produce flash flooding. The WFO issued flash flood watches for September 9, but heavy rainfall and flash flooding did not develop.

On September 10–11, WFOs Boulder and Pueblo continued to discuss the potential for heavy rainfall. On the morning of September 11, Hazardous Weather Outlooks (HWO) highlighted the potential for heavy rain. The HWO stated the potential for rainfall rates in excess of 2 inches per hour and flash flooding, not just for the burn scar areas but also for urban areas. Significant NWP output variability in magnitude, timing, and location of potential heavy rainfall and the lack of flash flooding on September 9 contributed to WFO Boulder's decision not to issue a flash flood watch on September 11. Forecasters did not anticipate the large geographical coverage of heavy rainfall. QPFs provided by the WFOs did not predict the intense rainfall of September 11–12. The RFCs used these QPFs as input into their river forecasts, which contributed to the initial errors in river forecast timing and magnitude.

WFO Boulder had normal forecaster staffing levels the afternoon of September 11, including the WCM/Acting MIC and Senior Service Hydrologist (SSH). While showers had developed late in the afternoon over parts of the area, the duty forecast team determined the activity did not warrant additional overnight staffing. WFO Pueblo had augmented evening and overnight staffing on September 11–12 in anticipation of the heavy rainfall. WFO Pueblo issued flash flood watches for a large portion of its CWA on the morning of September 11.

The rainfall began to increase in intensity and areal coverage quickly on the evening of September 11, continuing into the overnight hours. Because of the unexpected onset of widespread flash flooding, WFO Boulder had not assigned a dedicated event coordinator beforehand. The WFO received the first reports of flash flooding by 7 p.m. MDT. The evening and overnight shift forecasters did a commendable job issuing flash flood warnings and statements, but they found it challenging to keep up with the combination of warning products and coordination with partners during the height of the flash flooding. The WFO Boulder SSH made numerous telephone calls from home to WFO Boulder during the evening to provide assistance. The SSH returned to the office to assist with operations at approximately midnight.

While WFO Boulder has a documented staffing model for severe weather operations, including appointing an event coordinator, the lack of anticipation for such an intense and widespread event resulted in less than adequate staffing at the onset of the event. By Thursday afternoon, WFO Boulder had arranged for augmented staffing to assist with operations and DSS through the weekend.

As the flood event unfolded late on September 11, the SSH assumed a significant amount of one-on-one coordination with the impacted counties, while forecasters focused on issuing flash flood warnings, statements, and social media postings. In spite of the SSH's best efforts, it became impossible to perform all the tasks necessary to maintain coordination with partners, issue river flood warnings and statements, and produce site-specific forecasts for defined service locations. WFO Boulder did not have a formal team defined for hydrologic services as recommended from previous service assessments. This lack of local hydrologic expertise significantly limited the office's ability to respond to such a widespread and multi-faceted flood event.

NWS generates site-specific forecasts using the Site Specific Hydrologic Predictor tool (SSHP). Forecasters generate deterministic stage forecasts for headwater and fast-responding streams and incorporate them into warning products for a series of pre-defined locations, using existing runoff relationships, as well as observed and forecast hourly rainfall amounts over each basin. The SSH contacted the MBRFC to request forecasts for many of the headwater locations either already in flood or expected to flood. MBRFC responded quickly and by 1:30 a.m. on September 12 was assisting WFO Boulder by providing small stream forecasts. WFO Boulder requested this assistance again on the afternoon and evening of September 12, as the second round of heavy rainfall and flash flooding developed.

Best Practice: MBRFC established site-specific capability for headwater streams in the WFO Boulder area, mirroring the capabilities at WFO Boulder. MBRFC leveraged this functionality to provide critical forecast support for headwater streams in the WFO Boulder hydrologic service area (HSA).

Finding 2: WFO Boulder did not have a defined hydrology team, which limited the office's ability to respond to such a widespread and multi-faceted flood event.

Recommendation 2: WFOs should establish hydrology teams and ensure that WFO forecasters have sufficient knowledge, skill, and ability to deliver hydrologic forecast and warning services.

When extensive flash flooding and flooding was unfolding across the WFO Boulder CWA, the Central Region Regional Operations Center (Central Region ROC) determined service backup might be necessary. WFO Pueblo is the primary backup office for WFO Boulder. Although WFO Pueblo was dealing with heavy rainfall and flash flooding, its operational staffing was augmented to back up WFO Boulder, if necessary. During the event, water began leaking into the facility that houses WFO Boulder. WFO Pueblo assumed back-up duties for an hour because of a fire alarm activation at WFO Boulder, likely related to the leak.

The CR ROC was concerned that, given the situation in WFO Boulder and with WFO Pueblo also dealing with flash flooding, WFO Boulder might need another service backup option. The CR ROC determined that WFO Dodge City was a logical candidate. The CR ROC and WFO Dodge City spent considerable time preparing for tertiary backup. For hydrologic services, a WFO can prepare only on an as-needed basis with assistance from the WFO Hydrologic Forecast System (WHFS) support group. More important, given the nature of the services that would be required to support Boulder, WFO Dodge City lacked several critical capabilities. As stated in the CR Supplement 02-2004, dated August 7, 2013, a tertiary backup office would not be able to do the following:

- Run SSHP for forecast points in the backed-up office's HSA
- View data for the office it is supporting in a Hydroview map display unless the backup WFO staff redefines its viewing area for Hydroview
- Use Multisensor Precipitation Estimates (MPE) for the backed-up office; MPE requires extensive configuration not feasible for a tertiary backup
- View the backed-up office's pre-defined groups in the Time Series application
- View the dam locations in the DamCREST application
- Use the predefined setting in RiverMon/PrecipMon

Fortunately, WFO Boulder did not require service backup for an extended duration. Had it been necessary, however, WFO Dodge City functionality would have been inadequate to deliver critical hydrologic services for WFO Boulder.

Finding 3: The potential activation of tertiary backup office for WFO Boulder was cumbersome and would have been inadequate for the delivery of vital hydrologic services.

Recommendation 3: The NWS should develop a dynamic service backup model that allows it to direct specified operations and services to less-impacted offices, and ensures all necessary hydrologic software applications are available for the backup office.

3.1.3 River Forecast Centers

The USGS and Colorado Department of Water Resources (CDWR) provide the NWS with 24 river observation points in the Arkansas River Basin in Colorado, including four on Fountain Creek. Except for brief data outages, most river gages in the Arkansas River Basin provided continuous stage and discharge data September 11–17. The USGS, CDWR, and the Nebraska Department of Natural Resources provide the NWS with 28 river observation points in the South Platte River Basin, including the 22 sites listed in **Table 5**. During the event, several river gages in the South Platte Basin stopped reporting discharge when the stage was above a station's stage-discharge rating curve, but continued to report stage. The stage-discharge rating defines the relation between the gage height and the amount of water flowing in a channel. The loss of these discharge data had a significant impact on WFO Boulder and MBRFC's ability to accurately forecast downstream river responses. The NWS relies on its partner agencies to share modifications to rating curves so NWS offices can incorporate rating curve data in real time into modeling operations. USGS gages, including those in Colorado and Nebraska, use an automated process that allows RFCs to access rating curve updates through the USGS Rating Depot. The state agencies that operate river gages in Nebraska do not have a similar mechanism for sharing rating curve updates.

Finding 4: State agencies that operate river gages, such as those in Nebraska, need an automated system for disseminating rating curve updates as they occur.

Recommendation 4: RFCs should work with state partners to develop an automated means for agencies to share changes in existing ratings.

During the event, several river gages in the South Platte Basin were either reporting erroneous data or stopped reporting data after floodwater damage. These gage issues also affected WFO Boulder and MBRFC's ability to predict river response accurately. Mountain tributary gages destroyed during the event include St. Vrain Creek at Lyons, North Fork Big Thompson River at Drake, and Big Thompson River at Canyon Mouth. The South Platte gage at Kersey was assumed to be reporting accurate stage data during the event, showing a peak of 18.79 feet on September 14; however, after the event, the Colorado Division of Water Resources determined the gage was reading about 3.7 feet too high on September 14. From Kersey downstream to the Colorado-Nebraska state line, none of the gages at river observation points provided complete or accurate data during the event.

Finding 5: Flooding damaged or destroyed a considerable number of river gages, significantly limiting the amount of real-time streamflow data available to the WFOs and RFCs.

Recommendation 5: RFCs and WFOs should work with their partners to document the upper operating limits of river gages and to establish alternate means for obtaining field observations and measurements near damaged gaging locations during significant flood events. This coordination could be accomplished through annual meetings that would identify key gages and reporting expectations for information during hydrologic events.

Table 5: Summary of preliminary peak discharge data and gage performance for selected NWS river observation points in the South Platte River Basin, September 11–18, 2013

NWS ID	Operating Agency	Station Name	Peak discharge				Comments on missing or erroneous data
			Date	Time (LST)	Gage Height (ft)	Discharge (ft^3/s)	
LOVC2	USGS	Plum Creek near Sedalia	9/14	18:30	8.87	1,260	
MRRC2	Colorado	Bear Creek at Morrison	9/13	9:30	9.05		No discharge 9/12 20:30–9/18 21:45
SHRC2	Colorado	Bear Creek at Sheridan	9/12	15:00	4.53	582	
DNVC2	Colorado	South Platte River at Denver	9/12	11:00	7.41	4,090	
DRBC2	Colorado	Clear Creek at Derby	9/13	4:15	5.29		No discharge 9/13 2:00–15:00
GLDC2	USGS	Clear Creek at Golden	9/13	4:00	6.83	1,530	
HNDC2	Colorado	South Platte River at Henderson	9/12	16:30	11.65	11,200	No data 9/11 11:00–20:30
MBNC2	Colorado	Middle Boulder Creek at Nederland	9/13	2:00	2.99	409	
OROC2	Colorado	Boulder Creek near Orodell	9/12	23:30	4.06	1,720	
BOCC2	Colorado	Boulder Creek at Boulder	9/12	21:15	7.78		Primarily no discharge 9/12 0:00-9/14 0:00
BELC2	Colorado	South Boulder Creek near Eldorado Springs	9/12	22:00	5.46		No discharge 9/11 22:30–9/12 3:00 and 9/12 18:00–9/13 3:15
LNSC2	Colorado	St. Vrain Creek at Lyons					GHt appears erroneous after about 9/12 6:00, no GHt after 9/12 21:15; no discharge after 9/11 23:00
ESSC2	Colorado	Big Thompson River. above Lake Estes	9/13	5:30	7.76	3,020	
DKKC2	Colorado	N. Fork Big Thompson River at Drake					GHt appears erroneous starting 9/13 0:30; no discharge after 9/12 6:15
BIMC2	Colorado	B. Thompson River at Canyon Mouth					GHt appears erroneous 9/12 8:30-11:30, no GHt after 9/12 12:30; no discharge after 9/12 5:45
FTDC2	Colorado	Cache La Poudre River Canyon Mouth	9/13	3:15	10.29		No discharge 9/12 22:15–9/13 11:15
POUC2	USGS	Cache La Poudre River at Fort Collins	9/13	14:15	10.79	8,120	
GRPC2	Colorado	Cache La Poudre River near Greeley					GHt appears erroneous 9/15 9:45–23:45; no discharge 9/14 11:15–9/15 12:45, erroneous discharge 9/15 13:00–22:30, no discharge 9/15 22:45–9/16 12:30
KERC2	Colorado	South Platte River near Kersey	9/14				Erroneous GHt 9/12 18:45–9/19 12:00
WNAC2	Colorado	South Platte River near Weldona					No GHt 9/14 18:00 - 9/17 10:30; no discharge 9/14 14:15–9/17 21:45
BZNC2	Colorado	South Platte River near Balzac	9/15	6:00	13.71		No data 9/13 1:45–11:45; No GHt 9/17 6:45–9/18 14:15; no discharge 9/15 4:15–9/19 9:30
JULC2	Colorado	South Platte River near Julesburg	9/18	12:00	10.74		Discharge appears erroneous starting on 9/18

3.2 Decision Support Services and Products

The Service Assessment Team interviewed stakeholders served by WFO Boulder, WFO Pueblo, ABRFC, and MBRFC. The stakeholders included county and city EMs, media, forestry officials, and other local emergency response officials. The WFOs and RFCs provided a variety of DSS and products before, during, and after the flooding event. Most partners were familiar with the basic product suite provided during the event, but many lacked knowledge of the additional support services that were available.

3.2.1 Services and Products for Local Partners and Users: *Outreach and Preparedness Activities*

The recent history of forest fires and hydrologically significant burn scars resulted in a tremendous amount of interagency coordination, outreach, and preparedness efforts by WFOs Boulder and Pueblo and the impacted counties. Recent wildfires in Boulder County (Fourmile Fire), Larimer County (High Park Fire), and El Paso County (Waldo Canyon and Black Forest Fires) served as catalysts for interagency meetings regarding the enhanced threat of flash flooding.

The Boulder County EMA, for example, noted that the post-fire community outreach and efforts were highly beneficial in enhancing community preparedness. The outreach and efforts helped members of isolated mountain communities provide services to each other when they became isolated for several days. During a series of town hall meetings, community officials from WFO Pueblo's CWA praised WFO Pueblo's outreach and collaboration efforts in the months leading up to the event. Several officials noted that an Integrated Warning Team Workshop led by WFO Pueblo in April 2013 served as a huge catalyst for enhanced partnerships and communication. At one of the town hall meetings, the chief meteorologist from KKTV (Colorado Springs) noted, "*the limited loss of life is a testament to what everyone has done.*"

An interagency group delineated burn scar areas and developed a rule of thumb to address the flash flood potential near a burn scar; officials agreed to use the measure of 3/4 inch of rain in 1 hour to initiate local evacuations. WFOs Pueblo and Boulder incorporated these delineated burn scar areas as shape files and map overlays into AWIPS/AWIPS II to assist forecast operations and DSS. WFO Pueblo also developed agreements to issue warnings over very small spatial scales better delineating flash flood threats due to the burn scars.

This rainfall rate-based rule of thumb played a key role in supporting county jurisdictions and the NWS's ability to respond to this type of high-impact hydrologic event. Counties covered by this agreement had emergency plans and were able to implement them quickly. EMs activated several Emergency Operations Centers early, mainly because of a local heavy rain threat that could potentially impact these burn areas.

Best Practice: Extensive interagency outreach and preparedness activities regarding the flash flood potential on burn scars greatly enhanced the level of threat awareness and resulted in communities having an emergency plan they could implement quickly.

3.2.2 Services and Products for Local Partners and Users: *Prior to the Event*

Most stakeholders interviewed indicated they rely on the NWS for information in advance of developing hazardous weather threatening their area, even when the information may have a high level of uncertainty. The feedback from partners was mostly positive for the DSS received prior to the event. Partners and stakeholders indicated the NWS was their source of information for potential high-impact events in their area. One partner in Colorado Springs described the NWS collaboration and coordination as the "*textbook case*" of how it should operate.

Partners and stakeholders agreed that early notification raised their situational awareness for planning and decision-making. Those counties impacted by burn scars were most prepared and received the majority of DSS provided before and during the event. As the event developed, stakeholders in northeast Colorado, including the broadcast meteorologists interviewed, indicated they did not consider this event unusual until NWS-issued warnings reported significant impacts.

WFO Pueblo uses a group email list to provide blast notifications of potential, high-impact weather updates to critical forecast information, and other DSS. The office also uses the list to coordinate and schedule conference calls for high-impact events. The system allows forecasters to send emails and set up webinars at any time. Local EMs mentioned these emails and heads-up webinars are crucial to their operations and assist them in pre-positioning spotters and rain gages. The EMs and media also stressed that the clear and consistent flow of information from the local partner WFO was vital to getting the message to their constituents.

In advance of this flood event, the WFO Pueblo MIC and WCM provided a face-to-face briefing on Monday, September 9, at the Waldo Canyon Regional Recovery Meeting highlighting the threat of substantial rainfall and a high-impact event for the upcoming week. In addition, WFO Pueblo added a special DSS web page to its website on Tuesday, September 10, and emailed briefings to over 80 key partners and stakeholders on the morning of September 10. For this event, WFO Boulder called select counties in its CWA, while other counties had little interaction with the WFO before the event. More formal communication and attendance on state-led conference calls began on the morning of September 12.

Best Practice: Group email blasts, notifications, and webinars are an effective way to reach many stakeholders and partners during an event without overly taxing the resources at WFOs.

Several NWS stakeholders indicated the WFOs *Weather Story,* often referred to as the Graphicast, is a beneficial service. NWS uses *Weather Stories* at various levels and conditions to increase visibility across the NWS. Partners found this product easy to ingest for situational awareness and planning. Many of the partners in the WFOs Boulder and Pueblo CWAs often look at *Weather Story* as a first review of short term expected weather (**Figure 15** and **Figure 16**).

Some staff members at WFOs Pueblo and Boulder mentioned they were unable to create *Weather Story* graphics for multiple days, events, or times, which hindered the usefulness of this product. Central Region uses software to create *Weather Story* that only allows staff to create and publish one image to the web page. This limit hinders an office's ability to discuss multiple threats or time periods simultaneously. Further, *Weather Story* is easy to miss. In Central

Region, it is in a thumbnail view in the middle of the WFO front page. Some partners interviewed were not aware of this product.

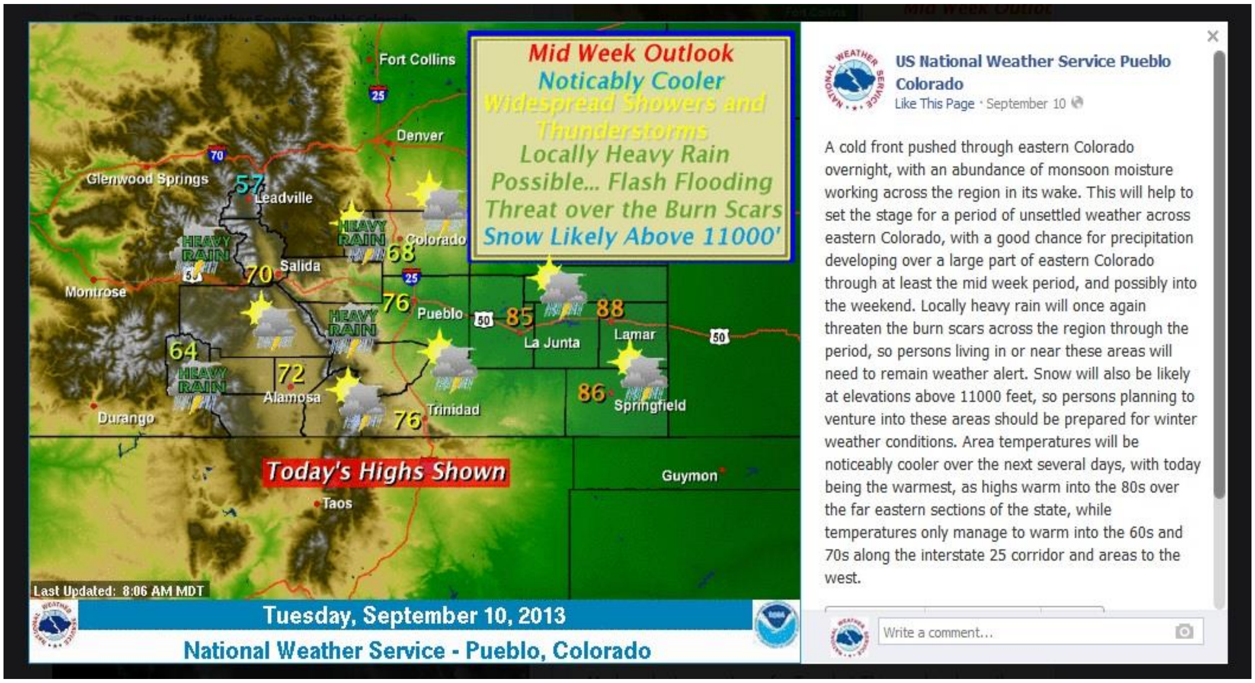

Figure 15: The *Weather Story* from WFO Pueblo for September 10 highlighting the potential for heavy rainfall across south central Colorado and especially the higher terrain

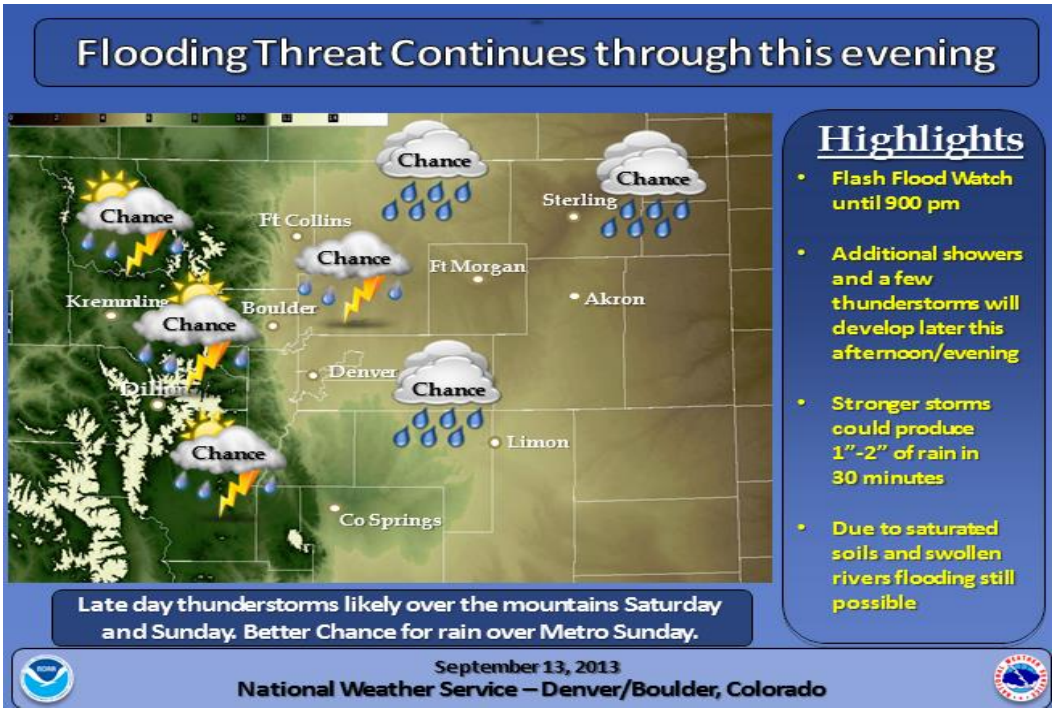

Figure 16: The *Weather Story* from WFO Boulder for September 13 highlighting the potential for locally heavy rainfall and continued flooding across the Front Range

Finding 6: Partners commented *Weather Story* is a beneficial graphic, but it lacks consistency in method of creation, format, content, and timeliness.

Recommendation 6: The NWS should continue enhancing *Weather Story*, increase its visibility, and standardize its implementation across the agency to meet the requirements of partners.

The HWO is a standard NWS text product that provides hazardous weather information in the forecast outlook period. Many partners interviewed said it was a valuable product. According to NWS policy, the HWO has strict rules for the order of date, but content and length is at the discretion of the individual office. This flexibility has led to differences in the message delivery.

Partners indicated that during their critical planning windows for events, their time is limited and NWS products must be concise. The HWO from WFO Boulder indicated a threat for heavy rainfall several days in advance: "*STRONGER STORMS WILL BE CAPABLE OF PRODUCING FROM 1 TO 2 INCHES OF RAIN.*" This information often was buried among less important weather threats or relegated to the end of the product. The placement of the information decreased its visibility and value to NWS partners.

WFO Pueblo was also highlighting heavy rainfall and a threat of flooding and flash flooding for much of the impacted period in its outlooks beginning as early as the evening of Sunday, September 8. Language in its HWOs included: *"SLOW STORM MOVEMENT WILL ADD TO THE HEAVY RAIN AND FLASH FLOOD THREAT."* and *"STAY TUNED TO THE FORECAST IN THE DAYS AHEAD AS THE WEATHER PATTERN IS ABOUT TO GET VERY ACTIVE AGAIN."* WFO Pueblo also placed this information farther down the HWO product because the forecast for heavy rain was in the extended forecast period: Days 2–7.

Fact: Partners indicated the importance of having concise and consistent information in advance of significant events to assist with event planning and decision-making.

Finding 7: The HWO conveys hazardous weather information in the outlook period of the forecast, but its effectiveness often is reduced by its length and format.

Recommendation 7: NWS should simplify the HWO into a bulleted format similar to other NWS products. The redesign should allow more flexibility in content at the WFO level.

The delivery of DSS before this event varied considerably, within and between WFOs. DSS consisted of conference calls, webinars, emails, web page graphics, and other resources. Partners identified webinars, *Weather Stories*, and emails as some of the most valuable tools for high-impact events, but the delivery of these services at times lacked consistency in content and structure. In some instances, the services did not reach partners looking for detailed information. For example, WFO Boulder communicated nearly continuously during the height of the flash flooding with the Boulder and Larimer County EMAs, and later into the event, with downstream counties along the South Platte River in anticipation of the flood wave. The Boulder County EMA was extremely appreciative of the NWS effort, which included phone calls as often as one every 15–20 minutes during parts of the event. The Boulder County EMA Director described the level of services provided by WFO Boulder as "*accurate, appropriate, and outstanding.*" Maintaining this high level of engagement with Boulder County impeded the ability of WFO

Boulder staff to provide a consistent level of service to its other partners. Some partners stated they were unable to get through to the WFO because all phone lines were busy. Partners in extreme northeast Colorado were unaware of the impending floods until NWS Boulder issued warnings, leaving them with less time to prepare. No national NWS policy exists explicitly defining DSS, expectations for its content and delivery, and recommended operational configurations to deliver services for high impact and long duration events.

Finding 8: The NWS does not have a formal policy defining and describing DSS, resulting in inconsistent content and delivery between offices.

Recommendation 8: The NWS should implement a formal policy for DSS, as outlined in its Annual Operating Plan, that capitalizes on the Weather-Ready Nation Roadmap and defines DSS and its information formats, content, methods for dissemination and communication, as well as recommended operational configurations for effective service delivery.

3.2.3 Services and Products for Local Partners and Users: *During the Event*

Overall, partners stated they were satisfied with NWS forecasts and warnings during the event. Most partners could not identify a specific NWS product that influenced their decisions during the event, despite multiple products and headlines in effect detailing expected or forecasted impacts. When asked which NWS products they used, some partners said they relied on a select subset and did not know about or understand additional products and services available (e.g., site-specific river forecasts, *Weather Story* graphics, HWOs). Most DSS users relied not only on the NWS, but also on private contractors and, in some cases, in-house expertise, for weather and hydrology information leading up to and during the event.

The hydrologic product suite is complex and cumbersome for both NWS forecasters and partners. During this event, these products often lacked the level of detail and specificity requested by partners impacted by the September floods. The complexity of the hydrologic product suite created challenges for forecasters due, in part, to the nature of the event's transition from flash flooding to areal or river flooding, and by the volume of products required to address the widespread event. WFO Boulder issued 284 short-fused, hydrologic-related products between September 11 and September 15. Interviews with NWS forecasters revealed they spent considerable time determining which type of product was most relevant to a particular hydrologic event (e.g., flood versus flash flood, river flood statement or warning) rather than providing value-added DSS or analyzing real-time diagnostic information from radar, satellite, gages, etc.

Partners found it challenging to keep track of all the products the WFOs were disseminating and to quickly extract the specific information needed to assess a situation and make decisions. EMs reported that once major impacts began in their area, they no longer had time to view NWS products. The information was not typically detailed enough to assist during their response mode. Other partners farther downstream from the initial flash flooding expressed that lead time was minimal for the river flooding that developed and affected their communities. Several DSS users were looking for localized impact and forecast details they did not feel the NWS provided. These users required details such as how much additional rain NWS was forecasting for specific areas and when the rain would end. Some EMAs in northeast Colorado hired private weather contractors for these details during the height of the storm.

Finding 9: The hydrologic product suite continues to be complex and cumbersome and often lacks the level of detail and specificity sought by partners.

Recommendation 9a: The NWS should move from a product-driven framework to a hazards information-driven framework, which sequentially raises the level of situation awareness.

Recommendation 9b: The NWS should enhance the tools and techniques that provide objective characterization of flooding at ungaged locations so that hazard information leverages Common Alerting Protocol to articulate clearly the severity, urgency, and certainty for a given hazardous situation.

WFOs Boulder and Pueblo used a variety of other tools to communicate the threat directly as the event unfolded. These additional tools included conference calls, one-on-one phone calls, NWSchat, and WebEOC. The tools varied between the WFOs and from county to county within each CWA. For example, while some counties noted frequent phone calls and close coordination, other counties indicated little interaction with the NWS at the height of the flooding.

Finding 10: The wide variety of tools available and used to communicate between NWS offices and partners can be challenging to manage and use efficiently.

Recommendation 10: Each WFO should work with its partners to develop a unified, consistent communication and outreach program to keep partners informed about the full suite of forecast products, services, and delivery mechanisms.

3.2.3.1 EMWIN and iNWS

Many partners relied heavily on the Emergency Managers Weather Information Network (EMWIN) and Interactive NWS (iNWS) as key alert functions for NWS watches and warnings. Many partners cited EMWIN and/or iNWS alerts as their first notification of an event affecting their area. These systems provided timely text messages and/or emails, extracting the information relevant for the partners' geographic areas. Outreach and education about these tools proved to be a key component for notifications of short-term convective watches and warnings. WFO Pueblo partners praised the internally developed and managed iNWS application as their "*go to*" application for weather information and alerts. *"We could not do our jobs without iNWS"* was a common comment made at the town hall meeting in Colorado Springs. Partners in the WFO Boulder CWA made similar comments about EMWIN.

3.2.3.2 River Forecast Services

Because the NWS issues stage and flow forecasts at predetermined forecast points on rivers and streams, it often can be a challenge to estimate river conditions between the forecast points. During this event, significant flooding impacted Sterling, CO, along the lower South Platte River, causing major damage to the town's infrastructure. Unfortunately, there is no forecast point along the South Platte at Sterling. The town is about 25 miles downstream from the forecast point at Balzac and about 60 miles upstream from the forecast point at Julesburg. Interviews with regional constituents stated this lack of real-time data and forecast information significantly limited their ability to adequately prepare and respond to the flooding. Several partners did not know they could request support from the SSH or which hydrologic services NWS provided in their region. WFO Boulder conveyed to Logan County emergency management and dispatch officials as early as Saturday, September 14, the potential for record flooding because of the flood wave moving down the South Platte River. In addition, MBRFC river forecast guidance provided 2 to 3 days lead time for the flood crest at Balzac and Julesburg, respectively.

Finding 11: Some partners along the South Platte expressed a need for additional forecast points along the river, but they did not know whom to contact to request the new forecast points.

Recommendation 11: WFOs and RFCs must strengthen partner relationships and understanding through focused hydrologic outreach to build understanding of current services, the process to initiate new forecast services, and the integral role partners have in our service improvement process.

3.2.3.3 Social Media

As part of the NWS evolution of services and Weather-Ready Nation initiatives, social media has become an evolving critical means of communications with core users and stakeholders. The NWS uses social media as an official means of DSS and partner communications, but there are no formal guidelines to address the additional workload.

Management and staff at WFOs Boulder and Pueblo indicated they were aware of the impact social media has in conveying the "weather message." Both offices routinely push *Weather Story* graphic and other non-routine posts to social media as an additional means of reaching its users. During this event, both offices used social media extensively. For example, WFO Boulder issued high-impact, strongly worded Facebook and Twitter posts to highlight the catastrophic and life-threatening flash flooding on the night of September 11, 2013. As the workload continued to increase, however, the frequency and specificity of the social media posts varied based on staffing levels and familiarity with social media.

Finding 12: WFOs Boulder and Pueblo used social media during this event to increase the dissemination of critical flood-related information. Use of social media varied in frequency, consistency, and specificity due, in part, to varying staffing and operational structure.

Recommendation 12: The NWS should develop policy to address the use of social media, specifically addressing expectations during high-impact events.

3.2.3.4 Flash Flood Emergency

During life-threatening flash flood events, offices are encouraged to use the phrase "Flash Flood Emergency" in statements to highlight the urgency of the situation. WFO Boulder successfully incorporated the flash flood emergency language in their mission-critical product suite during the height of the flash flooding.

The following is an excerpt of Boulder's Flash Flood Statement product citing a Flash Flood Emergency for Jefferson and Boulder counties during the height of flash flooding on the evening of September 11:

…THE FLASH FLOOD WARNING REMAINS IN EFFECT UNTIL 415 AM MDT FOR NORTHERN JEFFERSON AND BOULDER COUNTIES...

...THIS IS A FLASH FLOOD EMERGENCY FOR NORTHERN JEFFERSON AND BOULDER COUNTIES...

AT 1153 PM MDT...LOCAL LAW ENFORCEMENT AND EMERGENCY MANAGEMENT REPORTED FLASH FLOODING IN SEVERAL LOCATIONS. 4 TO 6 INCHES OF RAIN HAS FALLEN IN SOME PLACES THIS EVENING. FLASH FLOODING IS ALREADY OCCURRING IN MANY LOCATIONS AND THIS IS AN EXTREMELY DANGEROUS AND LIFE THREATENING SITUATION.

Best Practice: WFO Boulder successfully incorporated the flash flood emergency language to raise the level of urgency for action.

3.2.3.5 Use of the Civil Emergency Message

Because WFO Boulder had a close working relationship with Boulder County regarding the potential severity of flash flooding below burn scar areas, the Boulder County EMA had ready pre-written civil emergency messages. The EMA emailed these messages to the WFO forecasters, who, in turn, retyped them for NOAA Weather Radio (NWR) broadcast purposes.

The following is an example of such a message the WFO issued during the early morning on Thursday, September 12:

THE FOLLOWING MESSAGE IS TRANSMITTED AT THE REQUEST OF THE BOULDER COLORADO EMERGENCY MANAGEMENT AGENCY.

...THIS IS A FLASH FLOOD EMERGENCY FOR BOULDER COUNTY...

LOCAL LAW ENFORCEMENT AND EMERGENCY MANAGEMENT REPORTED FLASH FLOODING IN SEVERAL LOCATIONS. 4 TO 6 INCHES OF RAIN HAS FALLEN IN SOME PLACES THIS EVENING.

EXTENSIVE AND SEVERE FLASH FLOODING WILL CONTINUE OVER PORTIONS OF BOULDER COUNTY.

THIS IS A LIFE THREATENING SITUATION FOR PEOPLE ALONG BOULDER CREEK IN THE CITY OF BOULDER...IN THE FOURMILE BURN AREA...BOULDER CANYON...LEFT HAND CANYON AND SAINT VRAIN CREEK AREA INCLUDING LYONS. PERSONS LIVING IN AND NEAR THESE AREAS SHOULD MOVE TO HIGH GROUND IMMEDIATELY AND AVOID DRIVING.

Best Practice: WFO Boulder effectively used the civil emergency message developed through its collaboration with Boulder County EMA to communicate the critical nature of the flood emergency.

3.3 Science of QPF Forecasting and Hydrologic Modeling

3.3.1 Numerical Quantitative Precipitation Forecasts

Predicting the precise timing and location of extreme precipitation can be difficult. It is easier to predict for larger areas or accumulations over longer durations than for smaller areas or shorter durations (Islam et al. 1993). The 2013 Colorado Floods, however, presented large-scale synoptic forcing, the presence of a large region of ample moisture over several days, and complex steep terrain upstream of the deep moisture. Under such conditions, forecast models should provide at least somewhat realistic guidance.

Medium-range precipitation forecast guidance from the NCEP Global Ensemble Forecast System (GEFS) and other global systems indicated Colorado was likely to encounter much higher than normal precipitation during the week of the flood. Several global ensemble prediction systems forecasted especially heavy precipitation in the northern Front Range; however, the location of maximum amounts varied considerably from run-to-run and no prediction system accurately forecasted the magnitude of rainfall that occurred.

Figure 17 provides a representative sample of the medium-range forecast guidance several days prior to the storm. The three-panel plot shows the forecast of accumulated precipitation around Boulder County and then in progressively larger regions around Boulder and to its east. The models failed to predict the rapid accumulation of precipitation over Boulder County (analyzed precipitation represented by the heavy black line), though they did forecast an anomalously wet period for this time of year. The model became more accurate over progressively larger regions, where there was increasing consistency between the forecast and analyzed precipitation amounts. The Service Assessment Team expected at least a few ensemble members would have predicted anomalously heavy precipitation in the smaller region over Boulder. This inaccuracy suggests there is room for improvement in precipitation forecasts from NCEP and other global weather prediction centers.

Figure 18 provides the analyzed and forecast precipitation patterns from the GEFS and other ensemble prediction systems at three different times before the onset of heavy rainfall. All of the models, to varying extents, predicted a local accentuation of precipitation in the northern Front Range of Colorado, but the location and magnitude varied from run to run and from modeling system to modeling system. The global ensemble prediction systems forecasted less precipitation just prior to the event, perhaps because of the spin-up problem with numerical models. Hamill, 2014, presents a more thorough examination of the performance of the forecast models (See Appendix F).

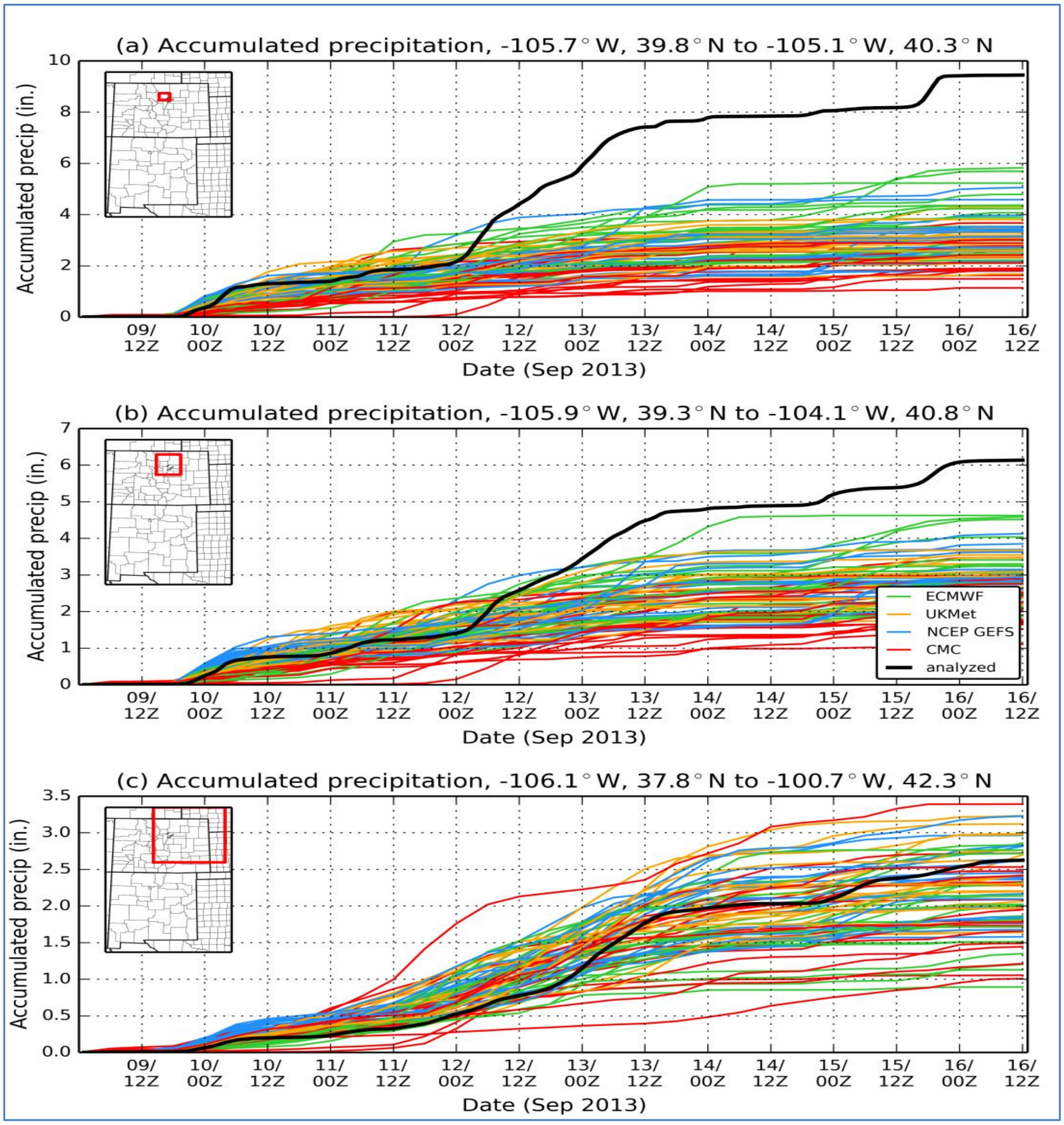

Figure 17: Shown are plume diagrams of accumulated analyzed precipitation from Stage IV data, scaled to the AHPS daily analysis totals (black) and ensemble forecasts (colors) from various ensemble prediction systems. Depicted are 20 members' accumulated precipitation forecasts for the European Centre for Medium-Range Weather Forecasts (ECMWF; green curves), the U.K. Met Office (UKMet; yellow curves); the NCEP GEFS (blue curves), and the Canadian Meteorological Centre (CMC; red curves). Panels show the accumulated precipitation averaged over three progressively larger areas, denoted by the red boxes. Forecasts were initialized at 00 Coordinated Universal Time (UTC) 09 September 2013 (6 p.m. MDT, Sunday, September 8, 2013).

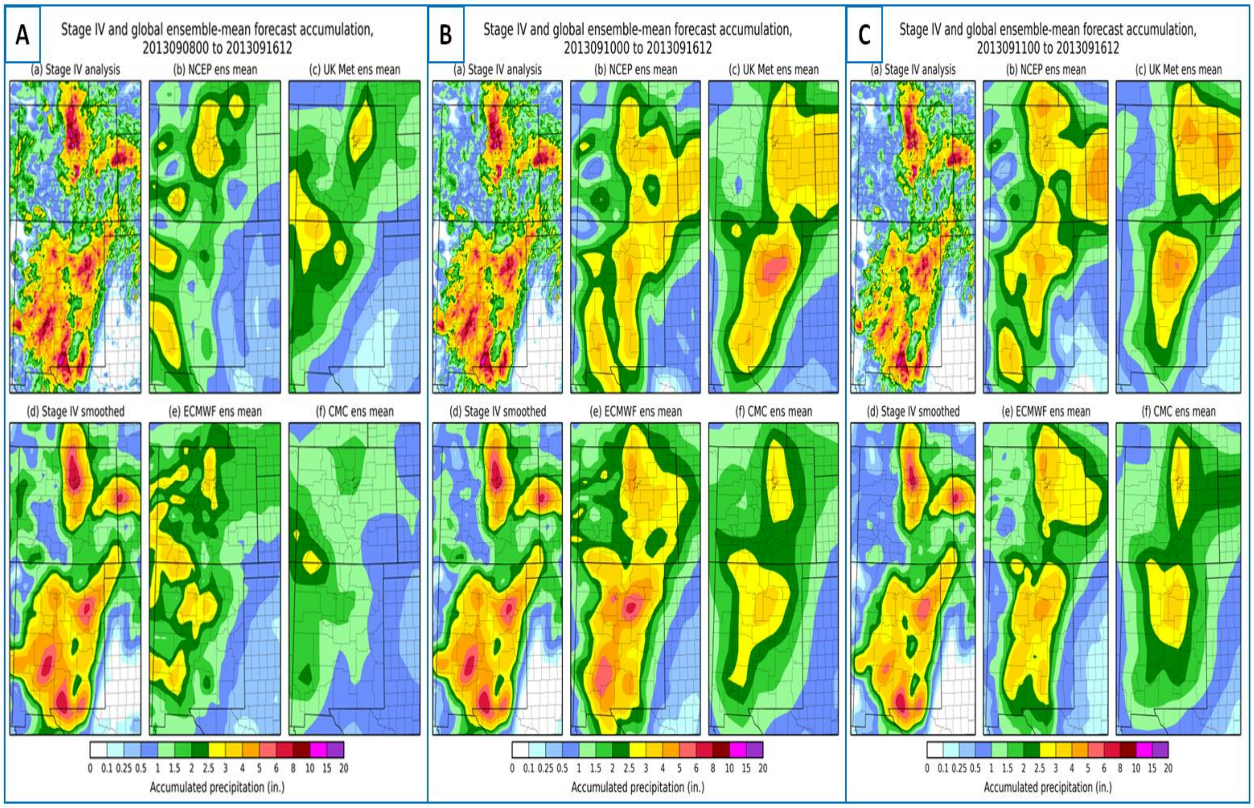

Figure 18: Shown are Stage IV and Global Ensemble-Mean forecast accumulated precipitation at three different times preceding the flood event: (A) Model runs initialized at 00 UTC September 8, 2013, (B) Model runs initialized at 00 UTC September 10, 2013, and (C) Model runs initialized at 00 UTC September 11, 2013. For each initialization time, the graphs show (a) accumulated precipitation analysis from the NCEP Stage IV data for 00 UTC September 9–12 UTC, September 16, 2013 (6 p.m. MDT September 8–6 a.m. September 16); (b) NCEP GEFS ensemble-mean forecast for the same period; (c) UK Met ensemble-mean forecast; (d) Stage-IV precipitation forecast smoothed to approximately 1-degree resolution for comparison with the coarser resolution forecasts; (e) ECMWF ensemble-mean forecast; (f) CMC ensemble-mean forecast.

As the event approached, most shorter-range forecast models, including forecasts from Global Forecast System (GFS) and North American Mesoscale Forecast System (NAM), were predicting the likelihood of heavier than normal precipitation but provided little indication of a record-setting event in the northern Front Range. The SREF system's members that used the Advanced Research Weather Research and Forecasting (WRF/ARW) model did indicate the potential for record-setting precipitation in the northern Front Range.

Figure 19 provides a representative sample of the shorter-range forecast guidance. The graphics present both the NAM and GFS deterministic forecasts (heavy lines) and ensemble predictions (thin lines) from the SREF and GEFS systems. The SREF system has several members that were forecasting very heavy precipitation at about the right time, even in the smaller region over Boulder County in the first panel. "Stamp maps" of the precipitation forecasts from individual members (**Figure 20**) indicate that SREF members using the WRF/ARW model consistently produced the heaviest precipitation. The SREF system also has members that use the Nonhydrostatic Mesoscale Model core of the Weather Research and Forecasting (WRF/NMM) and Nonhydrostatic Mesoscale Model on the B grid of the Weather Research and Forecasting (WRF/NMMB) models. While these models produced heavy precipitation in Colorado and New Mexico, they provided little indication that the heavy precipitation would be focused on the northern Front Range. Other models, such as the deterministic GFS, did forecast some heavy precipitation, but early in the morning instead of the evening of Wednesday, September 11.

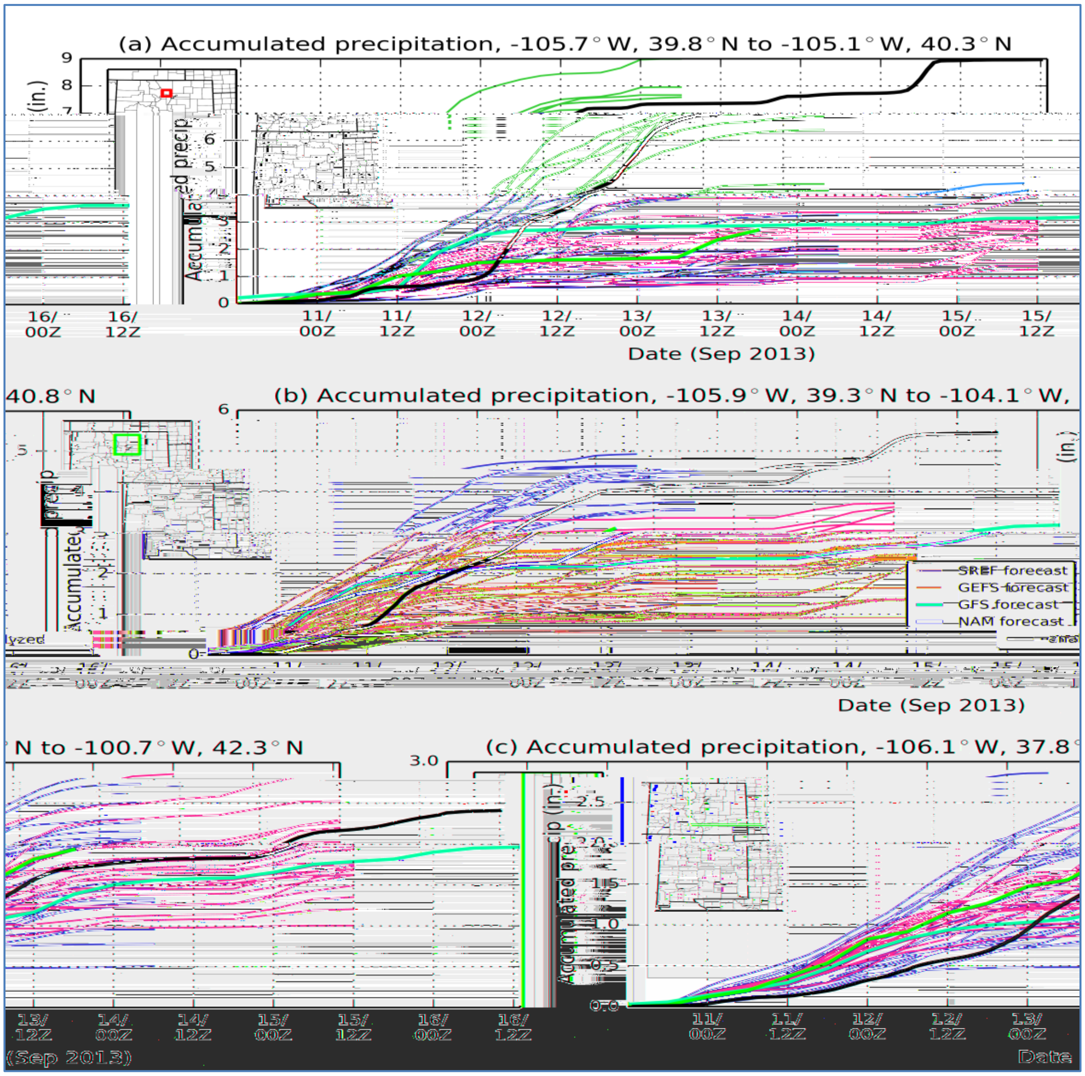

Figure 19: Shown are plume diagrams of accumulated precipitation (black) for 12 UTC (6 a.m.) September 10 to 12 UTC September 16. The heavy red curve shows deterministic NAM forecast accumulations; the heavy orange curve shows deterministic GFS accumulations. The blue curves show GEFS ensemble (data are limited to the first 5 days of the forecast), and the green curves show SREF ensemble data, initialized 3 hours later. The red box on each panel shows accumulation areas.

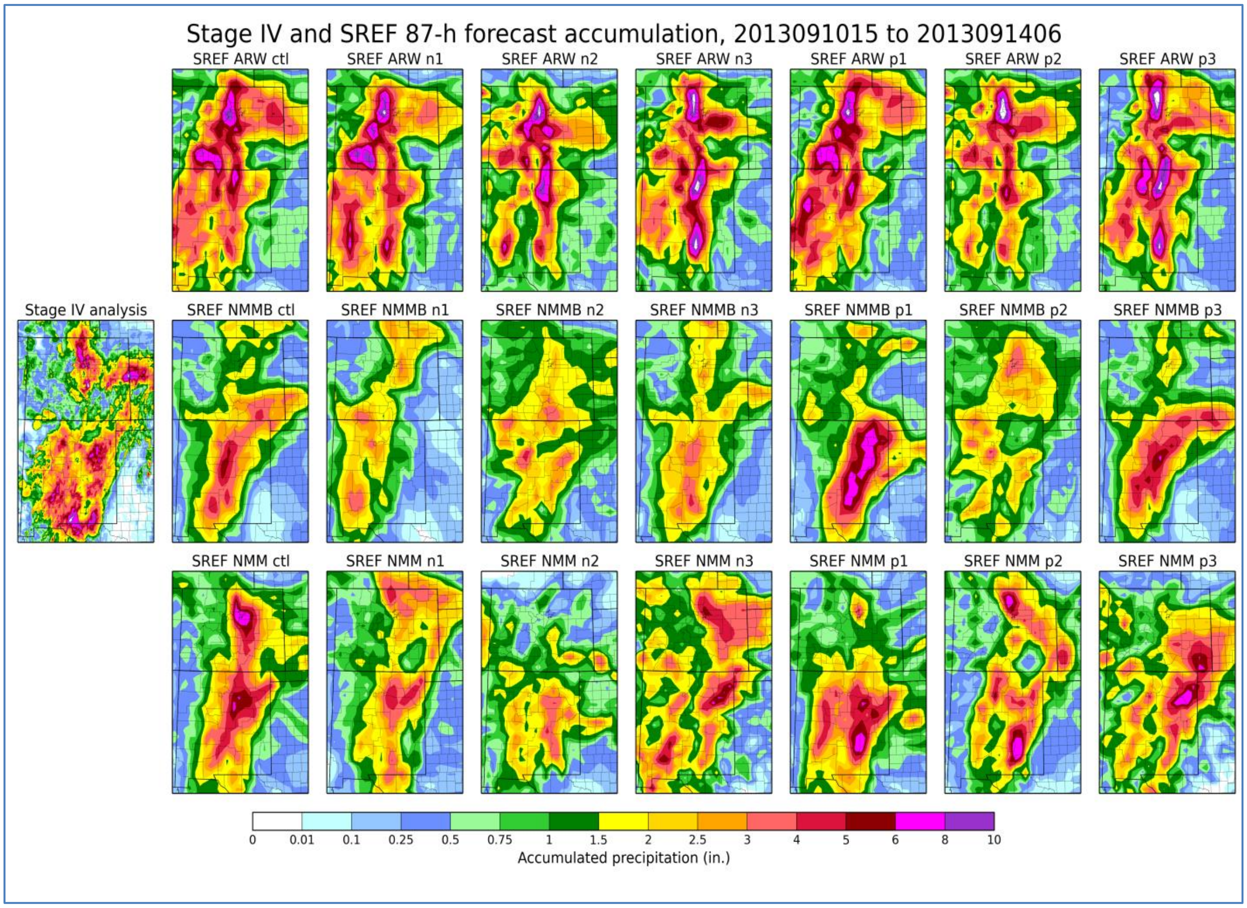

Figure 20: Shown are stamp maps from SREF forecasts initialized at 15 UTC (9 a.m. MDT) September 10, with accumulations over the 87-h period to 06 UTC (midnight) September 14. The left-hand panel presents the Stage-IV accumulated precipitation. The top row shows ensemble forecasts from the WRF/ARW initial conditions; the middle row shows forecasts from NMMB; the bottom row shows NMM.

The heavy forecast precipitation coincident with the time of the observed heavy precipitation is a notable achievement for the SREF system. Examination of forecasts initialized a day or two earlier, however, also showed plumes of SREF forecasts accumulating very large amounts of precipitation, in this case forecasting the heavy precipitation on Tuesday, when much less rainfall occurred.

Fact: A subset of members from the SREF using the WRF/ARW model indicated the potential for record-setting rainfall in the northern portions of the Front Range.

Finding 13: NOAA does not have a coordinated, visible, well-funded program to improve model QPF similar to the program for hurricane forecast improvement. The U.S. Weather Research Program has previously formulated plans to improve QPF (Fritsch & Carbone, 2004), for example; full references to cited articles are provided in Appendix F. NOAA has not fully funded and executed such a plan.

Recommendation 13: NOAA should execute a sustained, collaborative research and development program that engages academic and federal partners to improve QPF and substantially increase the skill in detecting extreme precipitation events.

NWS does not disseminate individual member output from the SREF to NWS forecasters due to bandwidth limitation. The AWIPS/AWIPS II system cannot generate diagrams such as those shown in **Figure 19** and **Figure 20**. To access diagrams such as these, forecasters must access either the Storm Prediction Center SREF site or a variety of academic websites. Other Service Assessments have raised the issue of bandwidth limitations, such as the Spring 2011 Middle & Lower Mississippi River Valley Floods and Tropical Storm Irene reports. The recently established Integration Dissemination Portfolio is expected to address bandwidth limitations.

3.3.2 Hydrologic Prediction and Dissemination

There were multiple challenges for the successful hydrologic prediction of this flood event: widespread and unexpected intensity of the rainfall, enhanced runoff issues due to burn scarred areas, and complex hydrologic processes, such as braided channel hydrology along the lower South Platte River. A braided channel is a stream consisting of multiple small, shallow channels that divide and recombine numerous times, forming a pattern resembling the strands of a braid.

WFOs use the Flash Flood Monitoring and Prediction System (FFMP) to compare observed and radar-estimated rainfall to gridded flash flood guidance. Forecasters use output from FFMP as part of the flash flood warning decision-making process. As configured, FFMP lacks the capability to use high-resolution NWP QPF or ensemble-based QPF, such as QPFs from the SREF, as a future forcing to assess flash flood potential.

Finding 14: FFMP lacks the capability to use high-resolution NWP to provide forecasters with a predictive assessment of flash flood potential in either a deterministic or a probabilistic framework.

Recommendation 14: The NWS should develop methods to provide predictive capability to current or future flash flood monitoring and prediction tools that incorporate high-resolution deterministic and ensemble NWP guidance for QPF.

WFOs Boulder and Pueblo, along with MBRFC and ABRFC, worked collaboratively to delineate burn scars in AWIPS (**Figure 21**). The two RFCs modified the gridded flash flood guidance system to isolate these areas within the flash flood grid and fixed the value at 1/2 inch in each area.

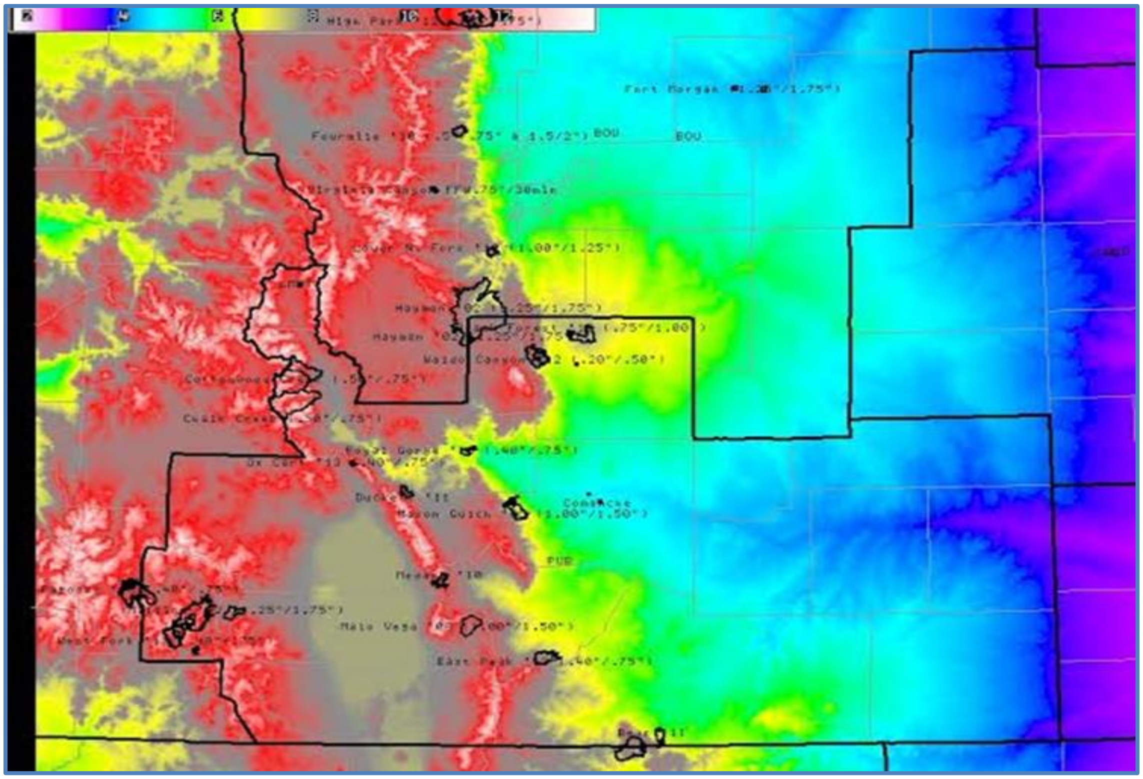

Figure 21: Shown are burn scar delineations with two values (i.e., local rainfall guidance values used for issuing flash flood advisories and warnings) in the Front Range overlaid on displays of the gridded topography. The black polygons delineate burn scars at high risk of flash flooding. The RFCs revised flash flood guidance values for the grids in these basins to account for the increased sensitivity to rainfall. WFOs monitored the radar and precipitation gages closely over these areas and issued warnings accordingly.

Best Practice: Both MBRFC and ABRFC leveraged the gridded flash flood guidance system capability to define burn scar regions and dramatically lower the guidance values over these grid cells, thereby improving the guidance provided to the WFOs.

WFOs rely on the SSHP tool to capture fast responses in small-scale, gaged headwater streams that respond too quickly for RFC lumped models to capture accurately. SSHP runs on an hourly time step, requiring observed and forecast hourly rainfall data. The system is designed to ingest manually entered hourly rainfall or gridded hourly rainfall, such as from the Multisensor Precipitation Estimator software.

WFO Boulder has several headwater and small-scale forecast point locations defined and operating in SSHP. WFO Boulder did not have automated processes in place to deliver SSHP Quantitative Precipitation Estimates (QPE) or QPF. As a result, WFO Boulder forecasters had to devote considerable time to produce just one forecast for one location. During the intense widespread flash flooding on September 11–12, WFO Boulder requested MBRFC to run SSHP for several small-scale points in Boulder's HSA.

SSHP is a stand-alone hydrologic forecast tool not directly connected to the Community Hydrologic Prediction System (CHPS). As a result, the RFC CHPS based forecasts does not route SSHP forecast flows to downstream locations. MBRFC was unable to capture the intense rapid rise and movement of the flood wave as it made its way from the flashy Front Range streams and into the South Platte River. Similarly, ABRFC also was unable to capture the very rapid rise on Fountain Creek that developed from intense convective rainfall in mountainous terrain.

Finding 15: MBRFC and ABRFC were unable to capture the intense rapid rises on the flashy streams along the Front Range and the movement of the flood wave into the larger rivers, such as the South Platte and Arkansas Rivers.

Recommendation 15: RFCs should leverage the capabilities of CHPS to demonstrate and evaluate different modeling approaches at appropriate temporal and special scales for basins that experience rapid runoff due to steep terrain.

MBRFC forecasters also found the complex hydrology of the South Platte River challenging. Portions of the South Platte River contain braided channel hydrology. Current hydrologic and hydraulic modeling techniques available to RFCs cannot account for this unique and complex hydrology.

Finding 16: A portion of the South Platte River consists of a braided channel, which added a significant level of complexity to the modeling of water through this reach of river.

Recommendation 16: The NWS should work with federal and academic water partners to demonstrate and evaluate hydraulic and hydrodynamic modeling solutions necessary to predict accurately the movement of water through complex hydrologic reaches such as braided channels.

One of the primary methods the NWS uses to display flood hydrograph information (as both a river stage and a river discharge) is the Advanced Hydrologic Prediction Service (AHPS) web pages. The displays on the AHPS web pages are a function of the preloaded stage-discharge relationships. During the flood event, inaccurate stage readings at many gaging locations provided erroneous discharges. These false reading resulted from rivers overflowing their banks, making new braided river channels that rendered the historic stage discharge-relationships invalid. The table of flows was a feature in the AHPS framework that was very troublesome for WFO Boulder. To remove access to these flows, which were incorrect because of the flooding magnitude, WFO Boulder spent considerable time and effort finding a solution in conjunction with MBRFC, CRH, and OCWWS HSD support group. The only available option was to delete the existing ratings for the points in question from the WFO hydrologic database—a highly undesirable solution. It was determined after this event that a bug in the AHPS software prohibited the tabular data from being turned off properly. The most recent March 2014 release of AHPS Build 9.0 fixes this issue.

3.4 Systems

While overall NWS systems functioned well during the event and provided necessary services, several significant deficiencies affected office operations such as forecasting, communications, data ingest, display, and dissemination. Specifically, local offices had issues using AWIPS II, with data ingest, Internet communications speed, critical communications outages, and AHPS web page display.

3.4.1 AWIPS II

WFO Boulder is an AWIPS II demonstration site and has been responsible for testing, evaluating, and documenting issues with each software deployment. The WFO documents issues using trouble tickets. Staff submits a Discrepancy Report (DR) when an AWIPS II problem adversely affects an operation or mission and is capable of jeopardizing safety, security, or other critical operational requirements. DRs are identified by a unique number and assigned a 1–5 priority. Once staff defines a DR, the fix is scheduled in a future system build based on priority and available resources.

During the record flooding, WFO Boulder opened eight AWIPS II trouble tickets to report software and system issues. **Table 6** provides a summary of those trouble tickets. AWIPS II personnel have closed two of the trouble tickets, assigned five DRs, and are investigating the final issue.

Table 6: Summary of AWIPS II trouble tickets and discrepancy reports

Ticket	Description	Discrepancy Report	Resolution
538349	Radar from Terminal Doppler	DR 16466 radar Txxx products not available	DR is classified 2, Critical, targeted for release 14.3.1 (7/14), Status: DR_16466 open
596102	Process and display ALERT data	DR 16685 ALERT Hydro Stage Data not decoding properly	DR was delivered in 13.5.2-11, Status: DR_16685 open
594856	Delivery of RFC contingency forecasts	n/a	Configuration issue was fixed at MBRFC, Status: ticket closed
591051	Adjust the Limits	DR 16643 Unable to change the QC Alert/Alarm Limits table	DR is assigned to release 14.2.1 (5/14), Status: DR_16643 open
594175 (Duplicate of 594170)	CAVE errors at BOU	DR 15844 Hydro Time Series	DR is Classified 3,High, targeted for release 15.1.1 (2/15), Status: DR_15844 closed as non-reproducible
593216	DENFFWBOU product could not be transmitted	DR 16633 TextWS: Error encountered during send of text product	Raytheon still reviewing this DR; has not been actioned for classification, Status: DR_16633 open
593139	Loop exception Hydrograph Time Series	DR 15884 Hydro Time Series – exception when trying to move TS point	DR is classified 3,High, targeted for release 15.1.1 (2/15), Status: DR_15844 open
592716	Failure to decode site specific river FCSR data	n/a	One time occurrence, Status: ticket closed as non-reproducible

One of the significant challenges NWS has experienced moving to AWIPS II is managing the list of discrepancies and ensuring resolved issues are disseminated to other AWIPS II offices efficiently. During the early summer of 2013, following a recent upgrade to AWIPS II, WFO Boulder identified a critical issue that prohibited ingest of network rain gages. Staff opened a trouble ticket and assigned a DR. Around the same time, MBRFC transitioned from AWIPS I to AWIPS II. MBRFC was unaware of the network rain gage issue until after the heavy rains and flooding had started. MBRFC had not received the fix and could not ingest needed data during the flood event.

Finding 17: The software solution addressing an issue identified by WFO Boulder prohibiting ingest of network rain gages was never shared with other AWIPS II offices, such as MBRFC, which was without these data during the flood event.

Recommendation 17: The AWIPS Program Office, in conjunction with the NWS regions should develop a mechanism to notify field offices about recently disseminated patches or fixes to mission critical AWIPS functions, such as data ingest.

The NWS transmits data to AWIPS via the Operational Systems Network (OPSnet) and the Satellite Broadcast Network (SBN). Unfortunately, these two systems do not send field offices many of the datasets available to NCEP using OPSnet or the SBN. Field offices need data developed at NCEP Environmental Modeling Center for their forecast operations.

Fact: The AWIPS II communications infrastructure does not have the ability to ingest and display ensemble forecast information from the SREF system, the only short-range system that had members correctly producing record-setting flooding.

Finding 18: The AWIPS II system and communications infrastructure is not yet capable of handling the voluminous ensemble information forecasters need to assess the uncertainty and likelihood of high-impact weather.

Recommendation 18: AWIPS II needs to display and store forecast ensemble guidance produced by the NCEP Environmental Modeling Center. Until AWIPS II adds this function, regional offices should work with NCEP and local field offices to use Local Data Manager.

3.4.2 Communications Bandwidth

NWS uses the Internet for data ingest and dissemination. During the flood event, data users in Colorado reported extensive slowdowns and delays in receiving critical weather data and radar updates from the NWS web sites. One of the NWS's primary means of dissemination is its web pages. At town hall meetings held in the Colorado Springs and Manitou Springs area, several attendees commented that the NWS web pages became slow or unusable at the height of the event. NWS forecasters at WFO Pueblo also identified the Internet sluggishness and the impacts it had on service delivery and communications with partners during the event. WFO Pueblo documented effective download speeds over OPSNet connections at below 1 megabit per second during the event. This bandwidth limitation made it difficult to maintain situational awareness and provide timely service delivery. Even though the office optimizes its network traffic to avoid system overload, bandwidth during the event was so slow the WCM briefed partners using the phone and email.

Fact: Bandwidth at WFO Pueblo was limited during the September flooding, especially during periods of peak traffic, which included the periods of high-impact weather.

Finding 19: The slow Internet connection at WFO Pueblo had a negative impact on DSS briefings, on the ability to use data display tools such as the recently introduced Experimental Data Display, and on training.

Recommendation 19: NWS should use the recently established NWS Dissemination Portfolio to ensure it can provide the necessary Internet bandwidth and infrastructure requirements, including communications redundancy to support operations during high-impact events and service backup.

3.4.3 Communications Outage

On Friday morning, September 13 (2 a.m. MDT), the fiber optic cables in Longmont and Harmony, CO, were cut, impacting communications and service delivery at WFOs Grand Junction, CO; Cheyenne, WY; and Albuquerque, NM. This cut severed connection to the AWIPS Wide Area Network, NWR circuits, and the administrative Local Area Network. The cut also affected radar data availability at the Boise, ID; Pocatello, ID; and Salt Lake City, UT, radar sites. Providers restored communications at these locations Saturday, September 14, at 6:47 p.m. MDT. During the outage, WFO Cheyenne remained operational and used AWIPS to distribute products using the onsite Very Small Aperture Terminal (VSAT). WFO Grand Junction does not have an onsite VSAT and had to request service backup from WFO Salt Lake City. NWS only has four CONUS VSAT Fly Away Kits (portable VSAT) available for emergency deployment.

WFO Cheyenne notified the CR ROC and the NWS Operations Center of the outage at 4:25 a.m. MDT, on September 13. The NWS Operations Center worked with WFO Cheyenne to transfer communications successfully to the WFO's onsite VSAT. The CR ROC made numerous requests to send VSAT AWIPS Fly Away Kits to WFO Grand Junction. It took over 12 hours for NWSH to release the kit. On September 13, NWSH told the CR ROC the VSAT would be shipped by FedEx later that evening, but would not be delivered until Monday, September 16, because the FedEx office in Grand Junction was closed for the weekend. As a result, WFO Grand Junction activated its Continuity of Operations plan and deployed a forecaster to WFO Salt Lake City, anticipating a communications outage lasting through the weekend. WFO Grand Junction immediately received several 4G MiFi devices, which provided administrative Internet communications.

The Weather Surveillance Radar 88 Doppler (WSR-88D) in Denver, CO, (KFTG) experienced a communication outage from 11:11 a.m. to 6:47 p.m. MDT on September 13. During this outage, the radar remained operational, but could not disseminate products.

Finding 20: NWSH did not send a VSAT Fly-Away Kit to WFO Grand Junction quickly or efficiently and did not deploy the unit in a timely fashion.

Recommendation 20: NWS should assign decision-making authority for release of the AWIPS VSAT Fly Away Kit to the regional director or designee.

Finding 21: Although 4G coverage is not available everywhere, when available, during a communications outage, staff can configure 4G routers to port AWIPS, WSR-88D, and Internet.

Recommendation 21: The NWS should establish a more robust and flexible approach to provide backup communication capability. Examples could include establishing VSAT capability at every office and the capability to use available 4G coverage.

3.5 Training

For the September 2013 record rainfall and flooding, NWP models generally indicated the potential for heavy rainfall ahead of this event, but varied significantly in the details. NWP models grossly under-forecast the magnitude and the axis of the heaviest rainfall from run to run. NWP models and ensembles indicated the presence of ingredients necessary for extreme precipitation in the northern Colorado Front Range during the flood event, including very high column moisture content and low-level upslope flow. In fact, models showed some of these ingredients at historically anomalous magnitudes. Although forecasters clearly recognized the potential for at least localized heavy rainfall, they did not anticipate the evolution of such a widespread and historic event

NWP and hydrologic forecast models and applications play a critical role guiding the issuance of many NWS forecast products. As the number of available models and datasets increases, it is increasingly challenging to ensure forecasters are equipped to use all available forecast data and tools. WFO forecasters expressed concern over the dramatic reduction of in-residence training and the drastically reduced access to national and regional workshops and conferences due to tightening budgets and group travel restrictions over the past several years. To compensate for reduced in-residence training, NWS has increased availability of self-paced and distance learning training; however, because of the rapid pace of change, some modules become outdated quickly, such as the WPC module discussing the PQPF product suite and its uses and limitations.

An example of a hydrologically-focused, distance learning course is the NWS Warning Decision Training Branch's course, *Recognizing High Impact Hydro Events*, in direct response to Recommendation 12 of the Service Assessment, *Record Floods of Greater Nashville: Including Flooding in Middle Tennessee and Western Kentucky of May 1–4, 2010*. This course addresses applying ensemble data in the forecast process; unfortunately, it is one of the only courses of this type currently available to forecasters. To date, only one-third of NWS forecasters have completed this course. In August 2013, the NWS released the new Hydrology Professional Development Series (PDS) containing a detailed set of Professional Competency Units (PCUs); however, significant gaps exist in available materials supporting each PCU.

Due in part to budget constraints, NWS has cancelled many hydrometeorological in-residence training courses in the past few years. The last instructor-led training focused on QPF was an online format—the COMET® Program's *COMAP Symposium on QPF/Rapid Onset Floods*, delivered in November 2010. In April 2013, COMET® offered its residence course, *Flash Flood Hydrology and QPE*, online. Although the course covered important hydrologic and QPE issues, it did not include the science of QPF. A COMET® course instructor noted during an interview with the team that the instructor-led, online approach allows training to reach more forecasters without the travel costs. This format also enables more updating of material than does the self-paced online format; however, it is difficult for the online approach to replicate the benefits of face-to-face interaction, especially during field studies, labs, and event simulations with the local SOO or DOH. Further, forecasters sometimes are pulled away from online training to work operations and lose the continuity offered by in-residence classes. In addition to the loss of in-residence training, NWS has not funded an agency-wide *Hydrologic Program Manager's Workshop* since 2007. Such workshops allow Hydrologic Program Managers to share challenges and best practices with their colleagues.

WFO Science and Operations Officers (SOOs) and RFC Development and Operations Hydrologists (DOHs) facilitate local training activities and help infuse new science and forecast techniques into operations. SOOs and DOHs develop local training plans and facilitate office training to prepare for significant events. NWS funds several programs, including the Hydrometeorological Testbed and Collaborative Science, Technology, and Applied Research Program (CSTAR), to perform applied research and transition the applicable research results into NWS operations. The successful infusion of new science and techniques at the local level relies on effective transition of such research findings into the local WFOs and RFCs.

Finding 22: Due to continued budgetary stresses and travel restrictions, NWS has reduced hydrometeorological in-residence training and conference attendance and increased its portfolio of self-paced and distance learning courses.

Recommendation 22a: The NWS should formulate a balanced approach to training, leveraging a combination of in-residence, distance learning, and self-paced training opportunities in concert with the established PDS to satisfy field training requirements. The training approach should include a renewed focus on ingredients-based methodology and use of anomaly data in the forecast process to better predict rare or record events.

Recommendation 22b: The NWS should provide a consolidated catalog of available training courses, identify and update modules that are outdated, and fill existing gaps in Instructional Components in each PDS.

WFOs Boulder and Pueblo forecasters expressed having limited knowledge, proficiency, and training on the various aspects of hydrologic service delivery, including the tools provided in WHFS, most notably Hydroview, Riverpro, and the SSHP. Although WFOs have successfully leveraged the Weather Event Simulator (WES) system to conduct event simulations for severe weather operations, no such capability exists for the core WFO hydrologic applications other than FFMP. Although forecasters were familiar with WPC Excessive Rainfall Outlooks and Mesoscale Discussions, forecasters were less familiar with the content and use of PQPF guidance. The local office training plan is an important tool that should organize existing courses and materials and facilitate a robust local training program to increase forecaster understanding and proficiency. Training plans in general at the WFOs were limited in the detail and activities geared toward hydrologic science and operations.

Finding 23: Local office training plans were limited in activities geared toward hydrologic science and operations.

Recommendation 23: Regional Headquarters should work with local field offices to ensure the development of robust training plans which leverage existing training courses. These plans should incorporate science, event simulations, and drills to ensure forecaster proficiency on all aspects of forecast and warning operations and services. Management must ensure forecasters are provided the necessary dedicated time to complete all training requirements. Where possible, NWS should accelerate results from Testbeds and CSTAR programs into training and operation activities.

AWIPS II had been operational at eight field offices, including Boulder, since early to middle 2012, with additional sites scheduled to install the software in 2014. AWIPS II does not currently provide archiving and data playback capability, which affects a local office's ability to develop case reviews and event simulations. The current AWIPS II schedule expects delivery of the archive capability with build 13.5.3.

The WES system provides playback of archive data, allowing staff to develop and facilitate event simulations for severe weather. A WES II Bridge package is under development that will allow offices to use AWIPS II archive data for playback. NWS expects delivery of this system in summer of 2014.

Finding 24: WFOs cannot play back archived hydrologic data to support event simulations for high impact hydrologic events using the core WFO WHFS applications.

Recommendation 24: The NWS should develop event simulation capability for the core WFO hydrologic program applications. Once developed, NWS must integrate hydrologic training requirements into NWS Instruction 20-101, *Use of the Weather Event Simulator*, which mandates at least four training simulations for each forecaster annually.

Appendix A Acronyms

ABRFC	Arkansas-Red Basin River Forecast Center
AHPS	Advanced Hydrologic Prediction Service
AWIPS	Advanced Weather Interactive Processing System
CDWR	Colorado Department of Water Resources
CHPS	Community Hydrologic Prediction System
CR	Central Region
CSTAR	Collaborative Science, Technology, and Applied Research Program
CWA	County Warning Area
DOH	Development and Operations Hydrologist
DR	Discrepancy Report
DSS	Decision Support Services
EM	Emergency Manager or Management
EMA	Emergency Management Agency
EMWIN	Emergency Managers Weather Information Network
FEMA	Federal Emergency Management Agency
FFMP	Flash Flood Monitoring and Prediction
GEFS	Global Ensemble Forecast System
GFS	Global Forecast System
HSA	Hydrologic Service Area
HWO	Hazardous Weather Outlook
iNWS	Interactive NWS, mobile weather service delivery
LST	Local Standard Time
MBRFC	Missouri Basin River Forecast Center
MDT	Mountain Daylight Time
MIC	Meteorologist in Charge
MPE	Multisensor Precipitation Estimates
NAM	North American Mesoscale Forecast System
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
NWR	NOAA Weather Radio All Hazards
NWS	National Weather Service
NWSH	National Weather Service Headquarters
OCWWS	Office of Climate, Water, and Weather Services
OPSnet	Operational Systems Network
PCU	Professional Competency Unit
PDS	Professional Development Series
PQPF	Probabilistic Quantitative Precipitation Forecasts
PW	Precipitable water
QPE	Quantitative Precipitation Estimates
QPF	Quantitative Precipitation Forecast
RFC	River Forecast Center
ROC	Regional Operations Center
SBN	Satellite Broadcast Network

SOO	Science and Operations Officer
SREF	Short Range Ensemble Forecast System
SSH	Senior Service Hydrologist
SSHP	Site Specific Hydrologic Predictor
USGS	United States Geological Survey
UTC	Coordinated Universal Time
VSAT	Very Small Aperture Satellite Communications Terminal
WCM	Warning Coordination Meteorologist
WES	Weather Event Simulator
WFO	Weather Forecast Office
WHFS	WFO Hydrologic Forecast System
WPC	Weather Prediction Center
WRF/ARW	Advanced Research Weather Research and Forecasting model
WRF/NMM	Nonhydrostatic Mesoscale Model core of the Weather Research and Forecasting system
WRF/NMMB	Nonhydrostatic Mesoscale Model on the B grid of the Weather Research and Forecasting system
WSR-88D	Weather Surveillance Radar 88 Doppler

Appendix B Findings, Recommendations, and Best Practices

Definitions:

Best Practice—An activity or procedure that has produced outstanding results during a particular situation that could be used to improve effectiveness and/or efficiency throughout the organization in similar situations. No action is required.

Fact—A statement that describes something important learned from the assessment for which no action is necessary. Facts are not numbered, but often lead to recommendations.

Finding—A statement that describes something important learned from the assessment for which an action may be necessary. Findings are numbered in ascending order and are associated with a specific recommendation or action.

Recommendation—A specific course of action, which should improve NWS operations and services, based on an associated finding. Not all recommendations may be achievable but they are important to document. Recommendations should be clear, specific, and measurable. The team leader and OCWWS will compose an action item for each recommendation.

Findings and Recommendations

Finding 1: There was limited direct coordination regarding rainfall potential and flash flooding potential between WPC and the impacted WFOs and RFCs prior to this event.

Recommendation 1: WPC and the WFOs and RFCs should replicate the successful winter weather coordination model for significant hydrologic events by conducting coordination calls when the potential exists for widespread heavy rainfall and flash flooding

Finding 2: WFO Boulder did not have a defined hydrology team, which limited the office's ability to respond to such a widespread and multi-faceted flood event.

Recommendation 2: WFOs should establish hydrology teams and ensure that WFO forecasters have sufficient knowledge, skill, and ability to deliver hydrologic forecast and warning services.

Finding 3: The potential activation of tertiary backup office for WFO Boulder was cumbersome and would have been inadequate for the delivery of vital hydrologic services.

Recommendation 3: The NWS should develop a dynamic service backup model that allows specified operations and services to be directed to less-impacted offices, and ensures all necessary hydrologic software applications are available for the office providing backup services.

Finding 4: State agencies that operate river gages, such as those in Nebraska, do not have an automated system in place for disseminating rating curve updates as they occur.

Recommendation 4: RFCs should work jointly with state partners to develop an automated means for agencies to share changes in existing ratings.

Finding 5: Flooding damaged or destroyed a considerable number of river gages, significantly limiting the amount of real-time streamflow data available to the WFOs and RFCs.

Recommendation 5: RFCs and WFOs should work with their partners to document the upper operating limits of river gages and to establish alternate means for obtaining field observations and measurements near damaged gaging locations during significant flood events. This coordination could be accomplished through annual meetings that would identify key gages and reporting expectations for information during hydrologic events.

Finding 6: Partners commented *Weather Story* is a beneficial graphic, but it lacks consistency in method of creation, format, content, and timeliness.

Recommendation 6: The NWS should continue enhancing *Weather Story*, increase its visibility, and standardize its implementation across the agency to meet the requirements of partners.

Finding 7: The HWO conveys hazardous weather information in the outlook period of the forecast, but its effectiveness often is reduced by its length and format.

Recommendation 7: NWS should simplify the HWO into a bulleted format similar to other NWS products. The redesign should allow more flexibility in content at the WFO level.

Finding 8: The NWS does not have a formal policy defining and describing DSS resulting in inconsistent content and delivery between offices.

Recommendation 8: The NWS should implement a formal policy for DSS, as outlined in its Annual Operating Plan that capitalizes on the Weather-Ready Nation Roadmap and defines DSS and its information formats, content, methods for dissemination and communication, as well as recommended operational configurations for effective service delivery.

Finding 9: The hydrologic product suite continues to be complex and cumbersome and often lacks the level of detail and specificity sought by partners.

Recommendation 9a: The NWS should move from a product-driven framework to a hazards information-driven framework, which sequentially raises the level of situation awareness.

Recommendation 9b: The NWS should enhance the tools and techniques that provide objective characterization of flooding at ungaged locations so that hazard information leverages Common Alerting Protocol (CAP) to articulate clearly the severity, urgency, and certainty for a given hazardous situation.

Finding 10: The wide variety of tools available and used to communicate between NWS offices and partners can be challenging to manage and use efficiently.

Recommendation 10: Each WFO should work with its partners to develop a unified, consistent communication and outreach program to keep partners informed about the full suite of forecast products, services, and delivery mechanisms.

Finding 11: Some partners along the South Platte expressed a need for additional forecast points along the river, but they did not know whom to contact to request the new forecast points.

Recommendation 11: WFOs and RFCs must strengthen partner relationships and understanding through focused hydrologic outreach to build their understanding of current services, the process to initiate new forecast services, and the integral role they have in our service improvement process.

Finding 12: WFOs Boulder and Pueblo utilized social media during this event to increase the dissemination of critical flood-related information. Its use varied in frequency, consistency, and specificity due in part to varying staffing and operational structure.

Recommendation 12: The NWS should develop policy to address the use of social media, specifically addressing expectations during high-impact events.

Finding 13: NOAA does not have a coordinated, visible, well-funded program to improve model QPF similar to the program for hurricane forecast improvement. The U.S. Weather Research Program has previously formulated plans to improve QPF (Fritsch & Carbone, 2004), for example; full references to cited articles are provided in Appendix F. NOAA has not fully funded and executed such a plan.

Recommendation 13: NOAA should execute a sustained, collaborative research and development program that engages academic and federal partners to improve QPF and substantially increase the skill in detecting extreme precipitation events.

Finding 14: FFMP lacks the capability to use high-resolution NWP to provide forecasters with a predictive assessment of flash flood potential in either a deterministic or a probabilistic framework.

Recommendation 14: The NWS should develop methods to provide predictive capability to current or future flash flood monitoring and prediction tools that incorporate high-resolution deterministic and ensemble NWP guidance for QPF.

Finding 15: MBRFC and ABRFC were unable to capture the intense rapid rises on the flashy streams along the Front Range and the movement of the flood wave into the larger rivers such as the South Platte and Arkansas Rivers.

Recommendation 15: RFCs should leverage the capabilities of CHPS to demonstrate and evaluate different modeling approaches at appropriate temporal and special scales for basins that experience rapid runoff due to steep terrain.

Finding 16: A portion of the South Platte River consists of a braided channel, which added a significant level of complexity to the modeling of water through this reach of river.

Recommendation 16: The NWS should work with federal and academic water partners to demonstrate and evaluate hydraulic and hydrodynamic modeling solutions necessary to predict accurately the movement of water through complex hydrologic reaches such as braided channels.

Finding 17: The software solution addressing an issue identified by WFO Boulder prohibiting ingest of network rain gages was never shared with other AWIPS II offices, such as MBRFC, which was without these data during the flood event.

Recommendation 17: The AWIPS Program Office, in conjunction with the NWS regions should develop a mechanism to notify field offices about recently disseminated patches or fixes to mission critical AWIPS functions, such as data ingest.

Finding 18: The AWIPS II system and communications infrastructure is not yet capable of handling the voluminous ensemble information forecasters need to assess the uncertainty and likelihood of high-impact weather.

Recommendation 18: AWIPS II needs to display and store forecast ensemble guidance produced by the NCEP Environmental Modeling Center. Until this function is added, regional offices should work with NCEP and local field offices to use Local Data Manager for this function.

Finding 19: The slow Internet connection at WFO Pueblo had a negative impact on DSS briefings, on the ability to use data display tools such as the recently introduced Experimental Data Display, and on training.

Recommendation 19: NWS should use the recently established NWS Dissemination Portfolio to ensure the necessary Internet bandwidth and infrastructure requirements are provided, including communications redundancy to support operations during high-impact events and service backup.

Finding 20: The process to secure and deliver the VSAT Fly-Away Kit to WFO Grand Junction was ineffective and did not deploy the unit in a timely fashion.

Recommendation 20: NWS should assign decision-making authority for release of the AWIPS VSAT Fly Away Kit to the regional director or designee.

Finding 21: Although 4G coverage is not available everywhere, when available, during a communications outage, staff can configure 4G routers to port AWIPS, WSR-88D, and Internet.

Recommendation 21: The NWS should establish a more robust and flexible approach to provide backup communication capability. Examples could include the establishment of VSAT capability at every office and the capability to utilize available 4G coverage where available, etc.

Finding 22: Due to continued budgetary stresses and travel restrictions, NWS has reduced hydrometeorological in-residence training and conference attendance and increased its portfolio of self-paced and distance learning courses.

Recommendation 22a: The NWS should formulate a balanced approach to training, leveraging a combination of in-residence, distance learning, and self-paced training opportunities in concert with the established PDS to satisfy field training requirements. The training approach should include a renewed focus on ingredients-based methodology and use of anomaly data in the forecast process to better predict rare or record events.

Recommendation 22b: The NWS should provide a consolidated catalogue of available training courses, identify and update modules that are outdated, and fill existing gaps in Instructional Components in each PDS.

Finding 23: Local office training plans were limited in activities geared toward hydrologic science and operations.

Recommendation 23: Regional Headquarters should work with local field offices to ensure the development of robust training plans which leverage existing training courses. These plans should incorporate science, event simulations, and drills to ensure forecaster proficiency on all aspects of forecast and warning operations and services. Management must ensure forecasters are provided the necessary dedicated time to complete all training requirements. Where possible, NWS should accelerate results from Testbeds and CSTAR programs into training and operation activities.

Finding 24: WFOs cannot play back archived hydrologic data to support event simulations for high impact hydrologic events using the core WFO WHFS applications.

Recommendation 24: The NWS should develop event simulation capability for the core WFO hydrologic program applications. Once developed, hydrologic training requirements must be integrated into NWS Instruction 20-101, *Use of the Weather Event Simulator*, which mandates at least 4 training simulations for each forecaster annually.

Best Practices

Best Practice: MBRFC established site-specific capability for headwater streams in the WFO Boulder area, mirroring the capabilities at WFO Boulder. MBRFC leveraged this functionality to provide critical forecast support for headwater streams in the WFO Boulder hydrologic service area (HSA).

Best Practice: Extensive interagency outreach and preparedness activities regarding the flash flood potential on burn scars greatly enhanced the level of threat awareness and resulted in communities having an emergency plan they could implement quickly.

Best Practice: Group email blasts, notifications, and webinars are an effective way to reach many stakeholders and partners during an event without overly taxing the resources at WFOs.

Best Practice: WFO Boulder successfully incorporated the flash flood emergency language to raise the level of urgency for action.

Best Practice: WFO Boulder effectively used the civil emergency message developed through its collaboration with Boulder County EMA to communicate the critical nature of the flood emergency.

Best Practice: Both MBRFC and ABRFC leveraged the gridded flash flood guidance system capability to define burn scar regions and dramatically lower the guidance values over these grid cells, thereby improving the guidance provided to the WFOs.

Appendix C Methodology

The Record Eastern Colorado Floods of September 11–17, 2013, Service Assessment Team completed the following actions:

- Conducted in-person interviews with multiple staff members at WFOs Boulder and Pueblo and received an in-brief from the WFO management teams, followed by a question and answer session
- Met with NWS CR Headquarters staff members in Kansas City, MO, about operations and services during the event
- Conducted in-person interviews with staff at the Missouri Basin RFC, which had responsibility for river forecasts in most of the affected areas, including the South Platte River
- Conducted in-person interview with the Staff Meteorologist at the University Corporation for Atmospheric Research in Boulder, CO
- Conducted in-person interviews with the following partners:
    - Boulder County EMA, including senior officials and the head of the Urban Flood Drainage group
    - Loveland, CO, and Aurora County Offices of Emergency Management (OEM)
    - Larimer and Weld County EMAs, and Jefferson and Logan County OEMs
    - Colorado Climate Center in Fort Collins, CO
    - On-air meteorologists at FOX9 and ABC7 in Denver, CO
    - Denver, Clear Creek County, and Adams County Offices of Emergency Management
    - Northeast Colorado Office of Emergency Management, as well as the Colorado State Office of Emergency Management
    - Science and Environmental reporter at the *Boulder Daily Camera* newspaper in Boulder, CO
- Met with community partners in Colorado Springs and Boulder, CO, including the U.S. Forest Service, KKTV and KRDO Colorado Springs on-air meteorologists, Colorado Springs Fire Department, Colorado State EMA, El Paso County EMA and Fire officials, Manitou Springs Chiefs of Police and Fire, and representatives from the Coalition for the Upper South Platte (CUSP)
- Conducted a phone interview with the leadership team at ABRFC to discuss forecast services and performance for the Arkansas Basin
- Conducted a phone interview with the Bureau of Reclamation–Eastern Colorado Area Office
- Took part in the Southern Region Rapid Evaluation of Service Activities and Performance (RESAP) debriefing for flooding that impacted New Mexico
- Evaluated WPC products and services and national guidance

Appendix D Summary of Flash Flood and Areal Flood Warnings

WFO Boulder Flash Flood Watches

Areas Included	ETN (Significance)	Issuance Time (MDT)	Expiration Time (MDT)
Central Colorado, North Central Colorado, and Northeast Colorado	05 (NEW)	5:05 a.m. (9/12/13)	12:00 a.m. (9/13/13)
Central Colorado, North Central Colorado, and Northeast Colorado	05 (EXT)	6:24 a.m. (9/12/13)	12:00 a.m. (9/13/13)
Central Colorado, North Central Colorado, and Northeast Colorado	05 (EXB)	9:58 a.m. (9/12/13)	6:00 a.m. (9/13/13)
Central Colorado, North Central Colorado, and Northeast Colorado	05 (EXT)	3:04 a.m. (9/13/13)	12:00 p.m. (9/13/13)
Central Colorado, North Central Colorado, and Northeast Colorado	05 (EXT)	10:07 a.m. (9/1313)	9:00 p.m. (9/13/13)
Central Colorado, North Central Colorado, and Northeast Colorado	06 (NEW)	4:30 a.m. (9/14/13)	6:00 p.m. (9/15/13)
Central Colorado, North Central Colorado, and Northeast Colorado	06 (EXB)	12:28 p.m. (9/14/13)	6:00 p.m. (9/15/13)
Central Colorado, North Central Colorado, and Northeast Colorado	06 (EXT)	3:28 p.m. (9/15/13)	12:00 a.m. (9/16/13)
Central Colorado, North Central Colorado, and Northeast Colorado	07 (NEW)	3:55 a.m. (9/16/13)	7:00 p.m. (9/16/13)

WFO Boulder Flash Flood Warnings

County(ies)	ETN (Significance)	Date	Issuance Time (MDT)	Expiration Time (MDT)	Verified (Y/N)
Central Washington	26 (NEW)	9/11/13	3:23 p.m.	6:15 p.m.	N
Southwest Weld, Northeast Broomfield, Eastern Boulder	27 (NEW)	9/11/13	6:36 p.m.	9:30 p.m.	Y
Central Boulder	28 (NEW)	9/11/13	7:02 p.m.	10:00 p.m.	Y
Extreme Southwest Weld, Extreme Northwest Adams, Northern Broomfield, Boulder	29 (NEW)	9/11/13	7:58 p.m.	10:45 p.m.	Y
Larimer	30 (NEW)	9/11/13	8:25 p.m.	11:15 p.m.	Y
Northwest Jefferson, Boulder	31 (NEW)	9/11/13 – 9/12/13	9:46 p.m.	12:45 a.m.	Y
Northwest Arapahoe, Southwest Adams, Central Denver	32 (NEW)	9/11/13 – 9/12/13	10:01 p.m.	1:00 a.m.	N
Larimer	33 (NEW)	9/11/13 – 9/12/13	10:49 p.m.	3:45 a.m.	Y
Northern Jefferson and Boulder	34 (NEW)	9/11/13 – 9/12/13	11:16 p.m.	4:15 a.m.	Y
Southwest Broomfield	35 (NEW)	9/11/13 – 9/12/13	11:42 p.m.	2:45 a.m.	Y
Northwest Weld and Larimer	36 (NEW)	9/12/13	12:31 a.m.	4:30 a.m.	Y
Southwest Weld	37 (NEW)	9/12/13	2:04 a.m.	5:00 a.m.	Y
South Central Larimer	38 (NEW)	9/12/13	2:34 a.m.	5:30 a.m.	Y

WFO Boulder Flash Flood Warnings continued…

County(ies)	ETN (Significance)	Date	Issuance Time (MDT)	Expiration Time (MDT)	Verified (Y/N)
Southwest Weld	39 (NEW)	9/12/13	3:07 a.m.	7:00 a.m.	Y
Central Boulder	40 (NEW)	9/12/13	4:10 a.m.	7:15 a.m.	Y
Southern Larimer	41 (NEW)	9/12/13	4:18 a.m.	7:15 a.m.	Y
Northwest Adams	42 (NEW)	9/12/13	4:20 a.m.	7:15 a.m.	Y
Southwest Adams and Central Denver	43 (NEW)	9/12/13	6:01 a.m.	9:00 a.m.	Y
Weld	44 (NEW)	9/12/13	6:52 a.m.	9:45 a.m.	Y
Northwest Adams	45 (NEW)	9/12/13	6:55 a.m.	10:00 a.m.	Y
Larimer	46 (NEW)	9/12/13	7:05 a.m.	10:00 a.m.	Y
Northern Boulder	47 (NEW)	9/12/13	7:12 a.m.	10:15 a.m.	Y
Northwest Arapahoe	48 (NEW)	9/12/13	7:24 a.m.	10:15 a.m.	Y
Central Boulder	49 (NEW)	9/12/13	8:36 a.m.	11:30 a.m.	Y
Extreme Northwest Arapahoe, Southwest Adams, Central Denver	50 (NEW)	9/12/13	9:02 a.m.	12:00 p.m.	Y
Northwest Arapahoe, South Central Denver	51 (NEW)	9/12/13	9:12 a.m.	12:15 p.m.	Y
Larimer	52 (NEW)	9/12/13	9:51 a.m.	12:45 p.m.	Y
Boulder	53 (NEW)	9/12/13	10:02 a.m.	1:00 p.m.	Y
Northern Larimer	54 (NEW)	9/12/13	10:44 a.m.	1:45 p.m.	Y
Western Arapahoe, Southwest Adams, South Central Denver	55 (NEW)	9/12/13	12:14 p.m.	3:15 p.m.	Y
Southeast Larimer	56 (NEW)	9/12/13	12:35 p.m.	3:30 p.m.	Y
Southeast Larimer	56 (EXT)	9/12/13	3:29 p.m.	9:30 p.m.	N
North Central Larimer	57 (NEW)	9/12/13	1:42 p.m.	4:45 p.m.	Y
Northwest Jefferson and Boulder	58 (NEW)	9/12/13	3:29 p.m.	7:30 p.m.	Y
Northwest Jefferson and Boulder	58 (EXT)	9/12/13	7:00 p.m.	11:30 p.m.	Y
Western Arapahoe, Eastern Douglas, Southeast Denver	59 (NEW)	9/12/13	5:04 p.m.	9:00 p.m.	Y
Larimer	60 (NEW)	9/12/13	6:07 p.m.	9:00 p.m.	Y
Southern Lincoln	61 (NEW)	9/12/13	6:28 p.m.	10:30 p.m.	N
Northeast Park, Northwest Jefferson, Clear Creek, Gilpin	62 (NEW)	9/12/13	7:23 p.m.	10:15 p.m.	Y
Northeast Park, Northwest Jefferson, Clear Creek, Gilpin	62 (EXT)	9/12/13	9:53 p.m.	1:15 a.m.	Y
Southeast Larimer	63 (NEW)	9/12/13	9:03 p.m.	2:00 a.m.	Y
Southeast Larimer	63 (EXT)	9/12/13	12:45 a.m.	8:00 a.m.	Y
Western Adams and North Central Denver	64 (NEW)	9/12/13	9:53 p.m.	3:30 a.m.	Y
Larimer	65 (NEW)	9/12/13	9:55 p.m.	2:00 a.m.	Y
Northern Jefferson and Boulder	66 (NEW)	9/12/13	10:52 p.m.	3:45 a.m.	Y
Northern Jefferson and Boulder	67 (NEW)	9/12/13 – 9/13/13	11:58 p.m.	6:00 a.m.	Y
Northeast Park, Jefferson, Clear Creek, Gilpin	68 (NEW)	9/13/13	12:09 a.m.	6:00 a.m.	Y
Lincoln	69 (NEW)	9/13/13	12:50 a.m.	3:45 a.m.	N
West Central Jefferson, Southeast Clear Creek	70 (NEW)	9/14/13	12:50 p.m.	3:45 p.m.	Y

WFO Boulder Flash Flood Warnings continued…

County(ies)	ETN (Significance)	Date	Issuance Time (MDT)	Expiration Time (MDT)	Verified (Y/N)
Central Larimer	71 (NEW)	9/14/13	2:09 p.m.	5:00 p.m.	Y
Southeast Douglas	72 (NEW)	9/14/13	2:29 p.m.	5:30 p.m.	Y
Extreme Northwest Elbert, Eastern Douglas	73 (NEW)	9/14/13	2:57 p.m.	6:00 p.m.	Y
Western Araphahoe	74 (NEW)	9/14/13	3:23 p.m.	6:15 p.m.	Y
Southwest Weld, Western Adams, Northern Denver	75 (NEW)	9/14/13	3:53 p.m.	6:45 p.m.	Y
Western Arapahoe, Southwest Denver	76 (NEW)	9/14/13	4:23 p.m.	7:15 p.m.	Y
Southeast Jefferson, Southwest Douglas	77 (NEW)	9/14/13	4:39 p.m.	7:30 p.m.	Y
Central Weld	78 (NEW)	9/14/13	4:51 p.m.	7:45 p.m.	N
Extreme Southern Jefferson, Douglas	79 (NEW)	9/14/13	5:57 p.m.	8:45 p.m.	Y
Southwest Adams, Northeast Denver	80 (NEW)	9/14/13	7:00 p.m.	9:45 p.m.	Y
Morgan, Northeast Weld, Southwest Logan	81 (NEW)	9/14/13	7:47 p.m.	10:45 p.m.	Y
Central Larimer (High Park Burn)	82 (NEW)	9/15/13	9:52 a.m.	12:45 p.m.	N
Central Boulder (Fourmile Burn and Jamestown Area)	85 (NEW)	9/15/13	10:41 a.m.	1:30 p.m.	N
Extreme Southwest Weld, Northwest Adams, Broomfield, Southeast Boulder	86 (NEW)	9/15/13	11:50 a.m.	3:45 p.m.	N
Western Arapahoe, Western Adams, Eastern Denver	87 (NEW)	9/15/13	12:32 p.m.	4:30 p.m.	N

WFO Boulder Areal Flood Warnings

County(ies)	ETN (Significance)	Date	Issuance Time (MDT)	Expiration Time (MDT)
Southern Weld, Central Adams	02 (NEW)	9/11/13	9:53 p.m.	12:45 p.m.
Northwest Arapahoe, Southwest Adams, Central Denver	03 (NEW)	9/12/13	12:59 a.m.	4:00 a.m.
Southeast Larimer (Big Thompson)	04 (NEW)	9/12/13	5:59 a.m.	2:45 p.m.
Northwest Arapahoe, Western Weld, Northern Jefferson, Larimer, Western Adams, Broomfield, Denver, Boulder	05 (NEW)	9/12/13	8:28 a.m.	8:30 p.m.
Western Arapahoe, Western Weld, Northeast Park, Jefferson, Larimer, Clear Creek, Adams, Northeast Douglas, Broomfield, Gilpin, Denver, Boulder	06 (NEW)	9/12/13 – 9/13/13	7:35 p.m.	7:30 a.m.
Western Arapahoe, Western Weld, Northeast Park, Jefferson, Larimer, Clear Creek, Western Adams, Northeast Douglas, Broomfield, Gilpin, Denver, Boulder	07 (NEW)	9/13/13	7:34 a.m.	7:30 p.m.
Western Arapahoe, Western Weld, Northeast Park, Jefferson, Larimer, Clear Creek, Western Adams, Northeast Douglas, Broomfield, Gilpin, Denver, Boulder	07 (EXT)	9/13/13 – 9/14/14	2:09 p.m.	7:30 a.m.
Western Weld, Northeast Park, Jefferson, Larimer, Eastern Clear Creek, Broomfield, Gilpin, Denver, Boulder	08 (NEW)	9/14/13	7:50 a.m.	7:45 p.m.
Western Arapahoe, Weld, Northwest Washington, Northern Sedgwick, Jefferson, Eastern Larimer, Extreme SE Clear Creek, Adams, Eastern Gilpin, Denver, Logan, Boulder, Morgan	09 (NEW)	9/15/13	9:10 a.m.	9:00 p.m.
Northwest Elbert, Southern Jefferson, Douglas	10 (NEW)	9/15/13	12:08 p.m.	9:00 p.m.

WFO Pueblo Flash Flood Watches

Areas Included	ETN (Significance)	Issuance Time (MDT)	Expiration Time (MDT)
Higher Terrain and Burn Scar Areas	16 (NEW)	9:50 a.m. (9/10/13)	12:00 a.m. (9/10/13)
El Paso County, Teller County, and the Rampart Range	17 (NEW)	9:05 a.m. (9/11/13)	9:00 p.m. (9/11/13)
El Paso County, Teller County, and the Rampart Range	18 (NEW)	3:58 p.m. (9/11/13)	9:00 p.m. (9/12/13)
East Central Colorado, Southeast Colorado, and South Central Colorado	18 (EXB)	9:19 a.m. (9/12/13)	6:00 a.m. (9/13/13)
El Paso and Teller Counties	19 (NEW)	5:12 a.m. (9/13/13)	12:00 p.m. (9/13/13)
El Paso and Teller Counties	20 (NEW)	12:51 p.m. (9/14/13)	9:00 p.m. (9/15/13)
El Paso and Teller Counties	20 (EXT)	8:05 p.m. (9/15/13)	12:00 a.m. (9/16/13)

WFO Pueblo Flash Flood Warnings

County(ies)	ETN (Significance)	Date	Issuance Time (MDT)	Expiration Time (MDT)	Verified (Y/N)
West Central El Paso	35 (NEW)	9/11/13	9:43 a.m.	1:20 p.m.	N
West Central Pueblo	36 (NEW)	9/11/13	8:45 p.m.	11:30 p.m.	Y
West Central El Paso	37 (NEW)	9/11/13	9:32 p.m.	12:30 a.m.	Y
West Central El Paso	38 (NEW)	9/12/13	12:32 a.m.	3:30 a.m.	Y
West Central El Paso	39 (NEW)	9/12/13	3:24 a.m.	6:30 a.m.	Y
East Central Fremont, Northwest Pueblo, Southwest El Paso	40 (NEW)	9/12/13	8:33 a.m.	11:30 a.m.	Y
West Central El Paso	41 (NEW)	9/12/13	10:18 a.m.	1:00 p.m.	Y
West Central El Paso	42 (NEW)	9/12/13	5:26 p.m.	8:30 p.m.	Y
Southwest El Paso	43 (NEW)	9/12/13	6:39 p.m.	9:30 p.m.	Y
West Central El Paso	44 (NEW)	9/12/13	8:23 p.m.	11:30 p.m.	Y
Southwest El Paso	45 (NEW)	9/12/13 – 9/13/13	9:26 p.m.	12:30 a.m.	Y
Central El Paso	46 (NEW)	9/15/13	12:58 p.m.	4:00 p.m.	Y
East Central Fremont	47 (NEW)	9/15/13	2:48 p.m.	6:00 p.m.	Y
West Central El Paso	48 (NEW)	9/15/13	4:08 p.m.	7:00 p.m.	Y

WFO Pueblo Areal Flood Warnings

County(ies)	ETN (Significance)	Date	Issuance Time (MDT)	Expiration Time (MDT)
West Central El Paso	03 (NEW)	9/12/13	8:08 p.m.	11:00 p.m.
West Central El Paso	04 (NEW)	9/12/13 – 9/13/13	10:55 p.m.	2:00 a.m.
West Central El Paso	05 (NEW)	9/12/13 – 9/13/13	11:24 p.m.	02:30 a.m.
Southwest El Paso	06 (NEW)	9/13/13	12:29 a.m.	03:30 a.m.
El Paso (Cheyenne Creek)	07 (NEW)	9/14/14	4:01 p.m.	10:00 p.m.

Appendix E Summary of River Flood Guidance Verification for MBRFC and ABRFC

Alphabetical listing of forecast locations by response times

NWS Handbook 5 ID	Gage Location	Response Time
MBRFC		
BELC2	South Boulder Creek near Eldorado Springs	Fast
BIMC2	Big Thompson River at Canyon Mouth	Fast
BOCC2	Boulder Creek at Boulder	Fast
DKKC2	North Fork Big Thompson River at Drake	Fast
DNVC2	South Platte River at Denver	Fast
FTDC2	Cache La Poudre River at Canyon Mouth above Fort Collins	Fast
GLDC2	Clear Creek at Golden	Fast
HNDC2	South Platte River at Henderson	Fast
LNSC2	Saint Vrain Creek at Lyons	Fast
LOVC2	Plum Creek near Sedalia	Fast
LSLC2	Big Thompson River at Mouth near La Salle	Fast
MRRC2	Bear Creek at Morrison	Fast
POUC2	Cache La Poudre River at Fort Collins	Fast
SHRC2	Bear Creek at Sheridan	Fast
GRPC2	Cache La Poudre River near Greeley	Medium
KERC2	South Platte River at Kersey	Medium
WNAC2	South Platte River near Weldona	Medium
BZNC2	South Platte River near Balzac	Slow
JULC2	South Platte River near Julesburg	Slow
RSON1	South Platte River at Roscoe	Slow
NPSN1	South Platte River at North Platte	Slow
NPTN1	North Platte River at North Platte	Slow
BDYN1	Platte River at Brady	Slow
COZN1	Platte River near Cozad	Slow
KEAN1	Platte River near Kearney	Slow
GRIN1	Platte River near Grand Island	Slow
DNCN1	Platte River near Duncan	Slow
ABRFC		
FN3C2	Fountain Creek at Colorado Springs	Fast
FHAC2	Fountain Creek near Fountain	Fast
PNNC2	Fountain Creek at Pinon	Fast
ADLC2	Arkansas River at Avondale	Medium
CDMC2	Arkansas River below Catlin Dam	Slow
LXHC2	Arkansas River at La Junta	Slow

MBRFC forecast lead times for fast response rivers

location	flood stage (FS) in feet	1st RVF fcst issued with value >= FS	1st time observed value >= FS	lead time
BELC2	4.5	9/13/13 2:38	9/12/13 5:15	0 mins
BIMC2	6.0	9/12/13 11:59	9/12/13 13:30	1 hr 31 mins
BOCC2	5.5	9/12/13 8:01	9/12/13 6:45	0 mins
DKKC2	6.0	9/12/13 12:57	9/12/13 13:30	33 mins
FTDC2	7.5	9/12/13 22:09	9/13/13 3:45	5 hrs 36 mins
HNDC2	10.0	9/12/13 11:07	9/12/13 17:15	6 hrs 8 mins
LNSC2	8.5	9/12/13 7:37	9/12/13 13:15	5 hrs 38 mins
LOVC2	8.0	9/13/13 4:20	9/15/13 0:00	19 hrs 40 mins
LSLC2	8.0	9/13/13 8:53	9/13/13 7:15	0 mins
MRRC2	9.0	9/13/13 5:39	9/13/13 15:00	9 hrs 21 mins
POUC2	10.5	9/12/13 22:09	9/13/13 5:30	7 hrs 21 mins

MBRFC forecast lead times for medium response rivers

location	flood stage (FS) in feet	1st RVF fcst issued with value >= FS	1st time observed value >= FS	lead time
GRPC2	8.0	9/12/13 16:28	9/14/13 16:15	1 day 23 hrs 47 mins
KERC2	10.0	9/12/13 11:07	9/13/13 15:30	1 day 4 hrs 23 mins
WNAC2	10.0	9/12/13 11:07	9/17/13 16:45	5 days 5 hrs 38 mins

MBRFC forecast lead times for slow response rivers

location	flood stage (FS) in feet	1st RVF fcst issued with value >= FS	1st time observed value >= FS	lead time
BDYN1	7.5	9/16/13 14:36	9/21/13 22:00	5 days 7 hrs 24 mins
BZNC2	10.0	9/12/13 11:07	9/15/13 10:15	2 days 23 hrs 8 mins
COZN1	6.5	9/16/13 14:36	9/24/13 2:00	7 days 11 hrs 24 mins
GRIN1	6.5	9/21/13 14:17	9/27/13 21:15	6 days 6 hrs 58 mins
JULC2	10.0	9/14/13 19:40	9/18/13 12:30	3 days 16 hrs 50 mins
KEAN1	6.0	9/19/13 14:40	9/26/13 10:15	6 days 19 hrs 35 mins
NPSN1	13.0	9/16/13 2:25	9/21/13 10:30	5 days 8 hrs 5 mins
RSON1	9.0	9/14/13 16:43	9/19/13 16:45	5 days 0 hrs 2 mins

ABRFC forecast lead times for fast response rivers

location	flood stage (FS) in feet	1st RVF fcst issued with value >=FS	1st time observed value >=FS	lead time
FN3C2	8.0	9/13/13 00:36	9/12/13 08:45	0 mins
FHAC2	8.0	9/13/13 5:12	9/13/13 06:15	1 hr 3 mins
PNNC2	7.0	9/13/13 14:32	9/13/13 13:00	0 mins

ABRFC forecast lead times for medium and slow response rivers

location	flood stage (FS) in feet	1st RVF fcst issued with value >=FS	1st time observed value >=FS	lead time
ADLC2	7.0	9/13 06:58	9/14/13 00:15	17 hrs 17 mins
CDMC2	8.0	9/16 19:19	9/16/13 19:45	26 mins
LXHC2	11.0	9/16/13:45	9/17/13 4:45	15 hrs 0 mins

Appendix F References

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