Information Services and Flood Warning Program Notes

Kevin Stewart, PE, Program Manager

September 2013 flood damage along Fourmile Canyon Creek in Boulder County near UDFCD border

Many Coloradans lives were changed forever by the rains that fell during the last week of the "official" 2013 flood season, traditionally defined as being coincident with UDFCD's long-running Flash Flood Prediction Program from April 15 through September 15. Over 18,000 homes and businesses in the state were damaged or destroyed by the ensuing floods with a high percentage of those properties uninsured. News reports stated that more than 17 percent of the affected properties in Boulder, Larimer, Logan and Weld counties are not within defined floodplains. The effect on public transportation was immense with the destruction of many public and private roadways, railroads, bridges and culverts. Steep mountain slopes slid to their canyon floors, streambanks failed, and the floodwaters carried huge rocks and debris as they carved new channels and creating new floodplains. Statewide flood losses are anticipated to exceed $2billion. Other accounts have referred to this record-setting rainstorm as a 1000-year event and some have even described it as being "biblical." While the last comparison may be a bit of a stretch—the rains did not last 40 days—it certainly was the event of a lifetime for many.

Sadly, nine Colorado fatalities were caused by this week's storm according to the National Weather Service. Two in El Paso County, one in Clear Creek County, two in Larimer County from flooding on the Big Thompson River and four in Boulder County. Knowing that the 1976 Big Thompson Canyon flash flood claimed over 140 lives, news stories quickly surfaced crediting early flood warning systems with saving hundreds. UDFCD is proud to have played its part in delivering warning messages and real-time data through its close partnership with the NWS and local offices of emergency management, but the real heroes that deserve the credit are many including: behavioral scientists that taught us how people respond to warnings and what could be done to improve the local warning process; community leaders that took this advice seriously, which resulted in developing better early flood detection capabilities, specialized flood prediction services, siren deployments and other enhanced public warning methods; public safety, public works and other local officials that delivered the message to those at highest risk; mountain community alliances that helped citizens know how to survive a wildland fire or flood disaster and established emergency communications for times when normal methods fail; the countless number of skilled emergency service personnel that risked their lives to save others; neighbors helping neighbors; and finally, to the people that believed the flood risk message and took appropriate actions when warned.

A specific report later in this article is devoted to shedding more light on the nature of the rainstorms and floods of September 9-15, 2013 to better understand just how rare this event really was and how UDFCD local governments were impacted. The report will attempt to answer questions like was this or was this not a 100-year or greater flood. Readers may be surprised by some of the findings.

Information services require a strong IT foundation. UDFCD's Derrick Schauer continues to make that a priority for all District programs by updating computer equipment and software, administering system security features, and assisting staff when asked and at times of desperation. Efforts in 2013 included development of a disaster recovery plan and procedure that will be tested periodically, annually reviewed and updated when necessary. The UDFCD website will undergo a major facelift and modernization in 2014. A website committee of UDFCD staff volunteers lead by Derrick is tasked with guiding this process. Keep an eye on www.udfcd.org as these changes begin to roll out and then, be sure to view this page using your favorite handheld device or smartphone. We believe you will be pleased with the results.

UDFCD's Julia Bailey has been the gatekeeper of our electronic information and GIS data since 2010. Julia's talents include making UDFCD publications and other documents easily accessible via the Internet. Be sure to read Julia's article in this issue of *Flood Hazard News* to learn about the most recent enhancements. Julia also continues to work closely with Amelia, our Administrative Services Manager, and Krystle, our Electronic Document Administrator, to improve UDFCD's records management procedures. All UDFCD programs and partner agencies will benefit from new work flow and record retrieval processes that evolve from the efforts of this dedicated threesome.

Jeremy Deischer has made excellent contributions over the past few years as one of UDFCD's most gifted student interns. The IS/FWP has benefited from his talents since 2012, but as with all good students, the bittersweet time finally arrived to say farewell and extend our best wishes as Jeremy begins his fulltime pursuit of a promising engineering career with Icon Engineering. Congratulations Jeremy! With Jeremy's departure comes a new opportunity for IS/FWP staff to work with another very capable and enthusiastic student from the University of Colorado at Denver, Devin Keener. We are confident that great things lie ahead for Devin. Welcome Devin!

2013 Flood Season Recap

Prior to epic floods of September, UDFCD's Flash Flood Prediction Program was experiencing an unusually wet and long monsoon season with the stormy weather continuing past Labor Day. By the end of first week in September, local governments served by the program had safely weathered 47 days of heavy rain potential with 43 of those days producing at least some localized flooding. By the end of September the program logged a record number of threat days since its inaugural season in 1979.

The ALERT System generated rainfall rate alarms for 31 threat days in 2013 compared to only 13 days the prior year. Specific alarm dates are noted in the table below:

Record 58 days with flood potential in 2013

May	8, **15**, 29	3
June	15, 18, 23, **28**, 30	5
July	**10**, 11, **12, 13**, **14**, **15**, **18**, 19, 20, **24**, **25**, **27**, 28, **29**, 30	15
August	**1**, **3**, 4, **5**, 6, 7, **8**, **9**, 10, 11, **12**, **13**, 18, **21**, **22**, 23, **24**, 25, **26**, 27, 30	21
Sept	3, **4**, 5, **9**, **10**, **11, 12, 13, 14, 15**, 16 18, 22, 23	14

Red dates are when rainfall measured by automated gages exceeded alarm thresholds. Yellow highlighted dates indicate heavy rainfall only affected areas outside UDFCD's main area of concern such as the Hayman Burn Area in SW Douglas County and watersheds in northern Boulder County. Blue boxes are when a NWS flash flood watch was the highest threat level reached and red designates a flash flood warning.

Twenty-four hour measured rainfall totals from the ALERT/CoCoRaHS combined dataset exceeded 3 inches on six days in 2013 (July 13, August 3, September 9, 11, 12&14). Eight other days (May 8, July 14, August 8&22, September 4, 10, 15&22) had 24-hour rain totals between from 2 to 3 inches. A storm summary table and corresponding maps are available for every day that heavy rainfall was predicted.

By late April reports of near normal mountain snowpack conditions was welcomed news for NE Colorado communities. The subsequent runoff in May and June was well-behaved. No flood warnings for the snowmelt season were needed this year for the Denver area—a good start!

May rains were uneventful with the first threat day of the year (May 8) producing quarter-inch per hour amounts in Boulder County's Fourmile Burn Area with no consequence. Precisely one-week later, Aurora experienced some minor street flooding from a short-duration rainstorm. Looking back now, the most ominous event of the month may have been the rare early morning thunder on the 29th that produced little rain but lasted an unusually long time…possibly a harbinger of what lay ahead.

By mid-June the region had dried-out and El Paso County was dealing with the worst wildfire in Colorado history, the Black Forest Fire, destroying over 500 homes and surpassing the prior-year's record held by the Waldo Canyon Fire, also in El Paso County. In 2010, Boulder County's Fourmile Canyon Fire owned this unwanted record. Subsequent of each of these fires tragic floods followed. By the end of June the District had experienced a few bouts of severe weather with a small tornado reported near DIA on the 18th, but very little rain fell over the metro area during June with Friday, June 28 producing the most.

This dry trend continued into July until the summer monsoon arrived on July 7 when heavy rainfall occurred over the Hayman burn area and other parts of southern Douglas County. By July 10 the metro area started receiving the welcome rains and the 2013 fire season appeared to be nearing its end. For six consecutive days (July 10-15) flood threats prevailed causing the NWS to issue flash flood warnings for the 12th and 13th followed by a flash flood watch on Sunday, July 14. The ALERT system logged 63 rainfall rate alarms over a 4-day period beginning Friday, July 12.

The Fourmile Burn Area (FMBA) in Boulder County was the primary target for many of the NWS flash flood warnings and advisories, much like the prior two years. While experts agreed that the watershed had experienced excellent vegetative recovery since the 2010 fire and is less prone to flooding from half-inch rainstorms, the concern remained that larger hillside debris still posed a threat and that the lack of a healthy forest and deep duff layer would warrant careful watch during rainstorms capable of approaching an inch or more in less than one-hour. Flash flood warnings were issued for the FMBA on **July 12** and **July 18** with little consequence. At this point it certainly seemed that conditions in the FMBA had improved substantially.

On Saturday, **July 13**, multiple thunderstorms moved through the District during afternoon hours. This was the first storm of the season with rainfall totals exceeding 3-inches. Flash flood warnings were issued for central Jefferson County that included Arvada, Wheat Ridge and Lakewood. The storm caused Lakewood Gulch in Denver to rise over 6 feet in a short period setting a new record for the USGS gage that has operated continuously since 1981. July 13 was also the second anniversary of the FMBA flash flood that destroyed nearly a dozen homes and threatened many lives.

In hindsight, one might see this day as the second harbinger of 2013.

For the 21-day period between July 24 and August 13, only 3 days were forecast as having no flood potential. On Saturday, **August 3**, slow moving severe thunderstorms during the afternoon and evening flooded portions of Boulder, Adams and Arapahoe counties. Every UDFCD county experienced moderate to heavy rainfall with the worst storms concentrating over the SE and NW portions of the District. The town of Erie in eastern Boulder County had considerable damage from high winds and flooding, and measured the largest rainfall amount of 3.4 inches. On the following Thursday, **August 8,** flash flood warnings were issued when a line of strong storms became stationary across the District between 5 and 7pm, dropping 2 to 3 inches on Aurora. The final flash flood warning for August occurred precisely two weeks later on **August 22** when the Ken Caryl Ranch area of Jefferson County (photo) and portions of northern Douglas County received 2 to 3 inches of rain accompanied by copious amounts of hail. That same day, our friends to the south in El Paso County experienced a 3-4 inch intense downpour that flooded Woodland Park, narrowly missing the Waldo Canyon burn area. Had that storm occurred over Waldo instead, the impact to the Manitou Springs—an area familiar with deadly post-fire flash floods—would likely have been horrific.

SPECIAL REPORT: The Rains & Floods of September 2013

Voice of the Rocky Mountain Empire

THE DENVER POST

SATURDAY, SEPTEMBER 14, 2013

DP ONLINE TODAY: Breaking news updates on Colorado's historic flooding.

The Flood's Toll

Four dead, thousands stranded or homeless

South Platte River: 50 times more water than it normally has this time of year.

Jamestown: Military helicopters rescue nearly 300 people from isolated town.

With flood warnings credited for saving hundreds of lives during the floods of September, early media attention focused on this part of story. A news release by the National Hydrologic Warning Council observed that Colorado Front Range communities were committed to a "different outcome" than what happened on July 31, 1976 in the Big Thompson Canyon. Thirty seven years of preparing for flood disasters using various techniques, not just early warning, undoubtedly saved lives and surely will help Coloradan's recover and be ready for the next big one. This special report, however, will attempt to address another perplexing question…*how big was this flood really?*

Historical Perspective

Before trying to describe how rare this event was or was not, it may be helpful to recall a few other large floods from the past and draw some comparisons. Colorado's Front Range has experienced many flood disasters since the gold rush in the late 1850's. Denver's Cherry Creek flood of 1864 was one of the more notorious events. Subsequent floods in the late 1800's and early 1900's lead to the construction of the familiar concrete-walled flood channel along Speer Blvd. in downtown Denver. The late 1800's also brought two major floods that originated in the mountains of Jefferson and Boulder counties, the Boulder Creek Flood of 1894 and the Bear Creek "Black Friday" Flood of 1896. Both of these events remain record-holders with the late May 1894 flood considered equal to the 100-year flood on Boulder Creek. The estimated peak flow on Boulder Creek from September (5,000 cfs) was less than half the estimated magnitude of the 1894 flood and roughly twice the magnitude of a more recent Boulder Creek flood that occurred in early May of 1969. The 1896 flash flood on Bear Creek claimed 27 lives and occurred in late July, the same time of year as the deadly Big Thompson flood. This mid-summer period is now commonly referred to as Colorado's summer monsoon when flash floods are most likely.

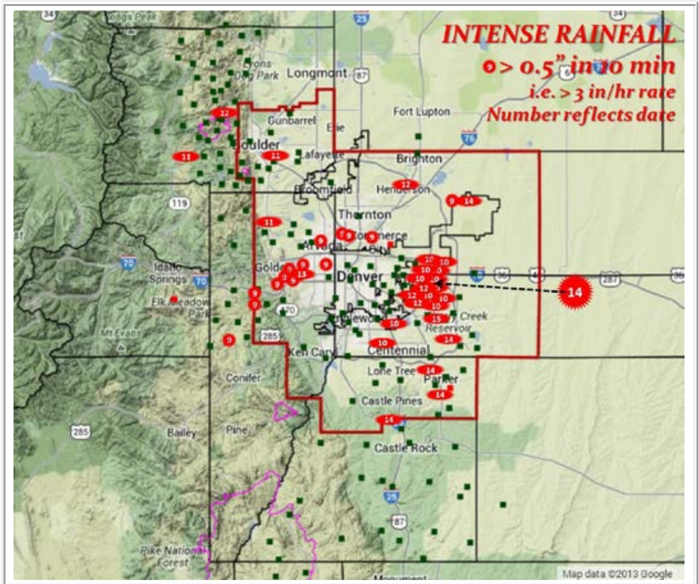
The 1965 South Platte River flood that lead to the construction of Chatfield Dam upstream of Denver remains Colorado's most costly flood in terms of property damage after considering inflationary adjustments. This historic flood occurred in mid-June prior to the monsoon season and was also caused by a 10-inch plus rainstorm. However, most of this rain fell in just over 3-hours. The character of the 2013 storm was quite different.

Generally the upper level flow of tropical moisture from Arizona ends for Colorado by mid to late August. But on rare occasions this condition has been known to persist. During the Dust Bowl period of the 1930's, one major September rainstorm in 1938 produced totals that exceeded 10-inches, causing severe flood damage to the small towns of Morrison in Jefferson County and Eldorado Springs in Boulder County in particular. Considering all the historic flood accounts of the past 150 years, the 1938 flood stands out as the single September event that most closely resembles what just took place in 2013.

The Timeline

The following map and corresponding table shows when the heaviest rainfall occurred during the 7-day period that began on Monday, September 9. The ALERT system logged 242 rainfall rate alarms during the storm but relatively few of those alarms reflect the 10-minute peak intensities shown below. It is interesting to note that Boulder County, where four fatalities and much of the worst flooding occurred, sustained the lower intensity rainfall compared to the other locations in the District.

Periods of Heavy Rainfall (September 9-15, 2013)

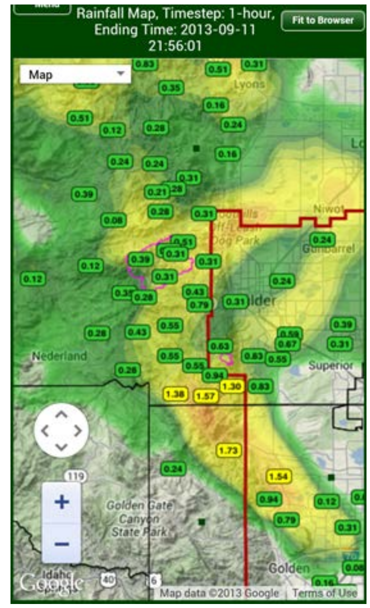


9	2 – 5pm	Lakewood, Wheat Ridge, Arvada, DIA and parts of Adams and Boulder Counties
	7 – 9pm	Bear Creek and Little Dry Creek in Jefferson and Adams Counties
10	4 – 6 pm	Denver & Aurora
11-12	9pm – 2am	Boulder County
12	4 – 9am	Boulder County
	5am – 1pm	Westerly Creek, Toll Gates and Sand Creek in Denver , Aurora and Commerce City
	4 – 10pm	Boulder County
13	5 – 6pm	Lena Gulch area of Lakewood & Wheat Ridge
14	3 – 6pm	Aurora & Douglas County
15	10am – 2pm	Denver & Aurora

On **Day 1 (9/9)** the storms were accompanied by hail and lightning with minor flooding reported in Lakewood, Wheat Ridge and Arvada where 2 to 3 inches of rain fell in a short time. Prior to the storm's arrival a flash flood watch had been issued for the Fourmile Burn Area of Boulder County. Maple Grove Reservoir on Lena Gulch in Lakewood rose about 3-feet, an early sign of what lay ahead for the region. The Boulder Office of Emergency Management later reported that the NWS had called this day to tell officials to expect lots of rain this week. By Wednesday night (9/11) this proved to be an understatement.

Day 2 (9/10) was relatively uneventful with the exception of some intense rains the struck Denver and Aurora during the late afternoon rush hour. No serious problems were reported as light rain continued throughout most of the day over much of Boulder and Jefferson counties with 24-hour accumulations between 0.5" and 1.0" at many locations.

By noon of **Day 3 (9/11)** rainfall totals since Monday approached and exceeded 3 inches at many mountain locations and over the adjacent plains. Watersheds were becoming saturated while the rains continued. The upper Left Hand Creek basin in the central Boulder County high country measured some of the largest totals with five gages in that area reporting over 3 inches. Morning forecasts alerted officials that storms this day could produce upwards of 3 inches in 2 to 3 hours if the worst happens. Local emergency managers diligently monitored the situation throughout the day. During the afternoon another half-inch fell over large areas with some isolated locations receiving more than an inch. Between 6 and 7pm, an intense storm developed in eastern Boulder County prompting the NWS to issue its first flash flood warning of the day by 6:50pm. This warning area did not include either the City of Boulder or the mountains. The remainder of the day would test everyone involved. Emergency Operation Centers (EOC's) were soon fully staffed. Between 7 and 10pm an additional 2 to 3 inches of rain fell over SE Boulder County. The map shows a one-hour snapshot of rain amounts and radar at 9:56pm. Between 10pm and 5am the flooding reached its climax in the City of Boulder and throughout much of Boulder County. Forecasters, emergency managers, first responders, public works agencies and many other local officials were dealing with reports of fatalities, missing persons, 30-foot walls of water in canyons and dam failures. Many lives would soon be changed forever by the events of this day.

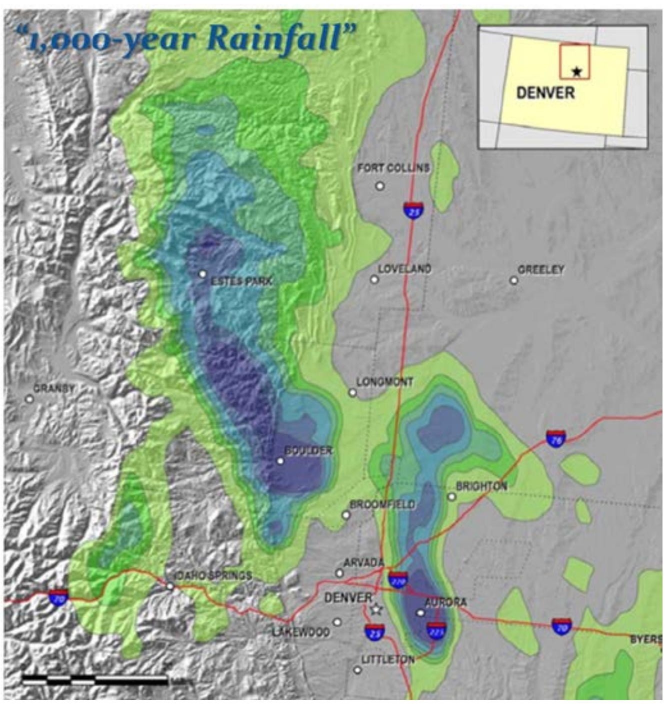


As the dawn of **Day 4 (9/12)** approached, the rain in Boulder County refused to end, but became less intense while the destructive flooding continued unabated. At this time the storm redirected its energy at the Sand Creek watershed in Denver, Aurora and Commerce City. Between 5am and noon more than 5 inches fell over the Westerly Creek basin, a left bank tributary to Sand Creek. A dam failure at the Rocky Mountain Arsenal National Wildlife Refuge forced a partial evacuation of Commerce City. Fortunately an old railroad embankment downstream of the dam held the surge of water and prevented serious damage to the city. In the Westerly Creek basin, four flood control impoundments prevented more serious damages from occurring. Floodwaters on Sand Creek caused considerable bank erosion that threatened the Metro Wastewater Treatment Plant near its confluence with the South Platte River. At the end of the day, thanks to a number of flood control and major drainageway improvements completed by local governments and UDFCD over the years, the flood losses that occurred here were not too bad and no lives were lost.

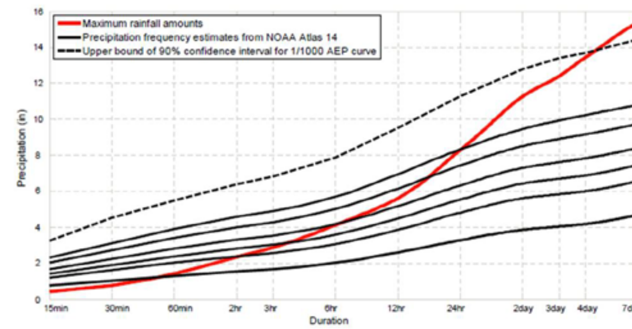
The rains continued over the next three weekend days but the worst of the flooding was over for UDFCD jurisdictions. The heaviest amounts occurred in Douglas County, Aurora and Broomfield with Saturday and Sunday measurements nearing 3-inches at some isolated locations. No serious problems were reported during this episode of rain from the September Storm of 2013.

Rainfall Amounts & Frequency

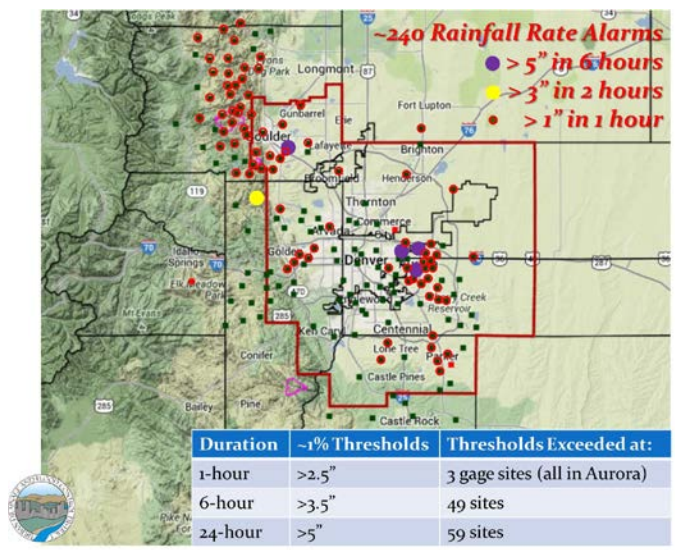
An early technical analysis prepared by NOAA officials categorized the September 2013 rainstorm as a 1000-year event (see map below). Statements were also made to news reporters suggesting that the storm was of “biblical” proportions. Having struggled to answer many difficult questions during the storm from forecasters, emergency managers and others, this writer can certainly understand the biblical reference, but knowing that the rain did not last for 40 days, it is probably safe to conclude that its magnitude was less than biblical. The next logical questions to emerge related to the flood itself. Specifically, was this a 100-year flood…a 1000-year flood…or something worse? The remainder of this special report section will try to address these questions but as details continue to surface about this flood, the opinions expressed herein may change.



The map represents a comparison of the 24-hour maximum rainfall measurements with NOAA’s recently updated precipitation frequency atlas for this region (NOAA Atlas 14). The darkest blue areas are where those measurements exceeded 0.1-percent annual exceedance probability (AEP) values. It is clear from this analysis that the September event was extremely rare with respect to the rainfall that occurred over a 24-hour period. To better understand how this rainfall affected the flooding, the storm’s temporal distribution needs to be considered. The following AEP curve helps explain this by showing the maximum rainfall amounts (red line) measured by an automated rain gage located near the mouth of Boulder Canyon at the Boulder County Justice Center.



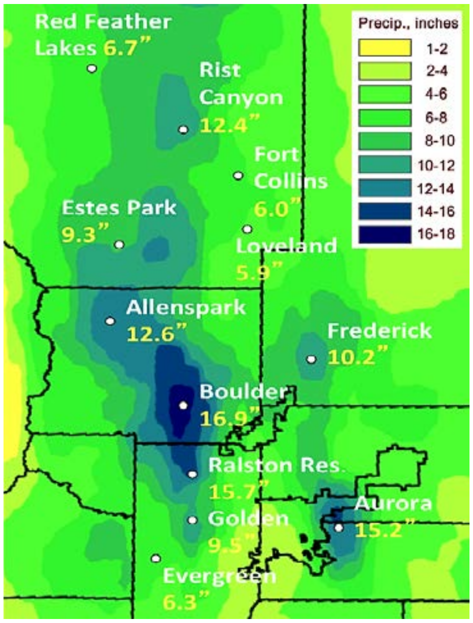
Note that the measured rainfall does not exceed the 1-percent (100-year) threshold until the storm’s duration is greater than 6-hours. This may also be a good time to point out that a 1% AEP rainfall at a point does not imply that a flood of equal probability will occur downstream. Also, flood magnitudes are strongly influenced by high rainfall intensities over relatively short time periods and not by rainfall totals exclusively. Rainfall averages over upstream watershed areas are also important. No simple answer here!

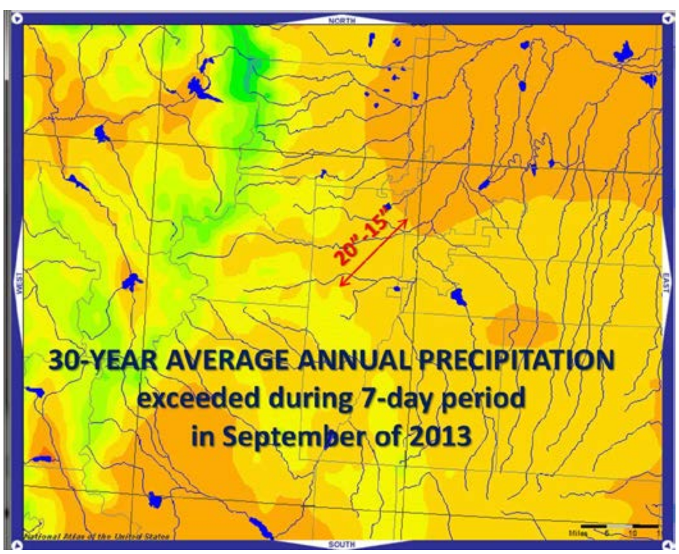


Another way to consider rainfall frequency is to take closer look at the rainfall rate alarms generated by the ALERT system and the maximum accumulations per unit time. The above map shows gage locations where various alarm thresholds were exceeded during the week of September 9. The thresholds in the legend do not include the 0.5”/10-minute (3 in/hr) rate that was discussed earlier in this report.

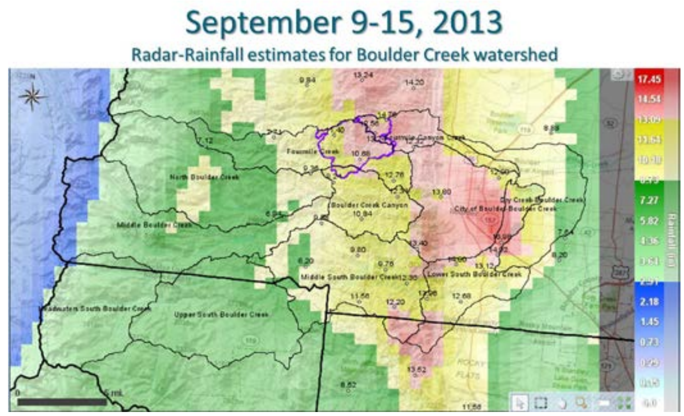
The table lists approximate 1% annual chance rainfall amounts for each corresponding duration. The right column indicates the number of gage sites that exceeded the corresponding 100-year thresholds during the 7-day period. This finding is consistent with the NOAA AEP graph for the Justice Center gage.

Comparing the 7-day rainfall totals to the annual average rainfall for the region illustrates how unusual this event was relative to climatic norms. Note that the larger amounts shown on the map to the right exceed the 30-year annual averages for the same location.





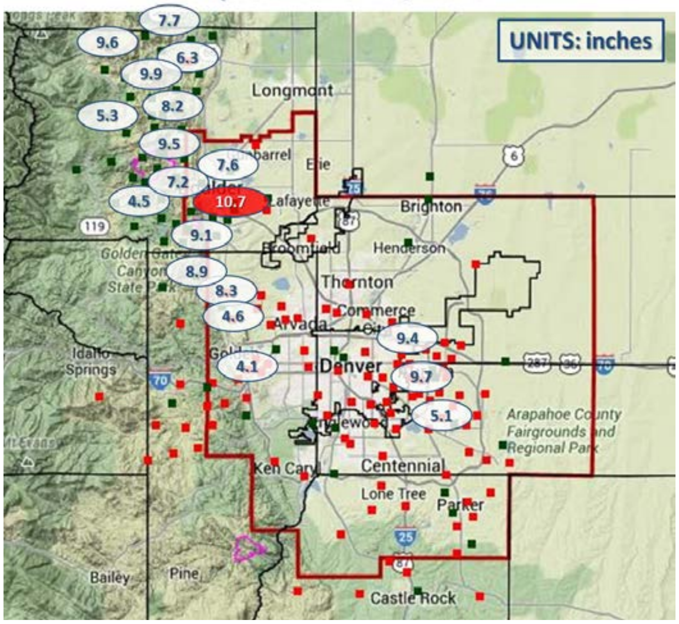
The following gridded rainfall map for the Boulder Creek watershed reveals where some of the larger storm totals occurred during the week. These 1km grids represent a summation of incremental 5-minute radar-rainfall estimates that were bias corrected in real-time using rain gage observations from the ALERT system. The top scale value of 17.45 inches reflects the maximum grid estimate for the 7-day period.



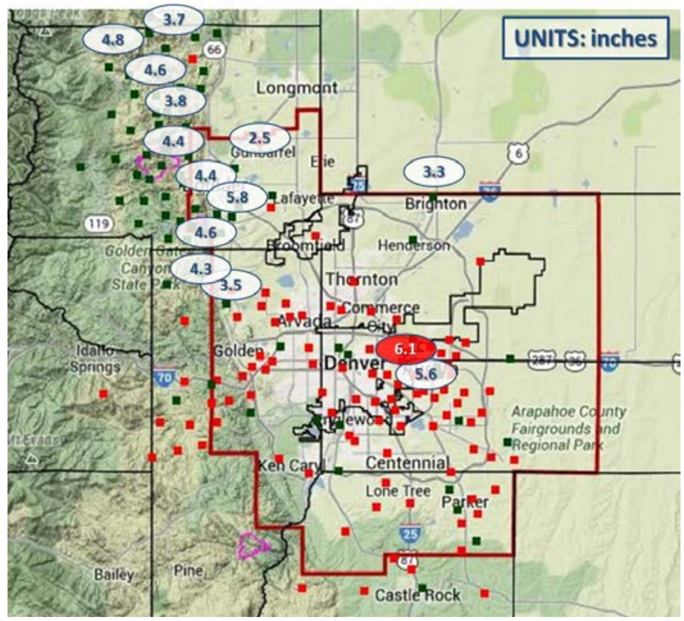
A closer look at the rainstorm temporally and spatially helps explain some of the observed flood conditions. The subsequent series of 4 maps shows where 24-hour, 6-hour, 1-hour and 10-minute maximums were measured. Notice that both the 24-hour maximum and the 10-minute peak intensity occurred at the same gage location in Boulder—the South Boulder Road crossing of South Boulder Creek. This is consistent with the above map and helps explain the observed flooding along South Boulder Creek including the area adjacent to Foothills Parkway known as the "West Valley Overflow." The 24-hour and 6-hour peaks also correlate well with other areas that experienced some of the worst flooding. The short duration peaks (1-hour and 10-minute) prove that the mountains of Boulder County did not experience the most intense rainfall, however, that area did tally many of the largest storm totals. Intense rainfall with very large accumulations also fell on the Westerly Creek basin in Denver and Aurora, putting four flood control impoundments to the test—Utah Park, Expo Park, Westerly Creek Dam and Kelly Road Dam.

Utah Park in Aurora, Colorado is a detention basin that worked as designed to minimize damage from floodwater to neighboring property during the September, 2013 flooding.

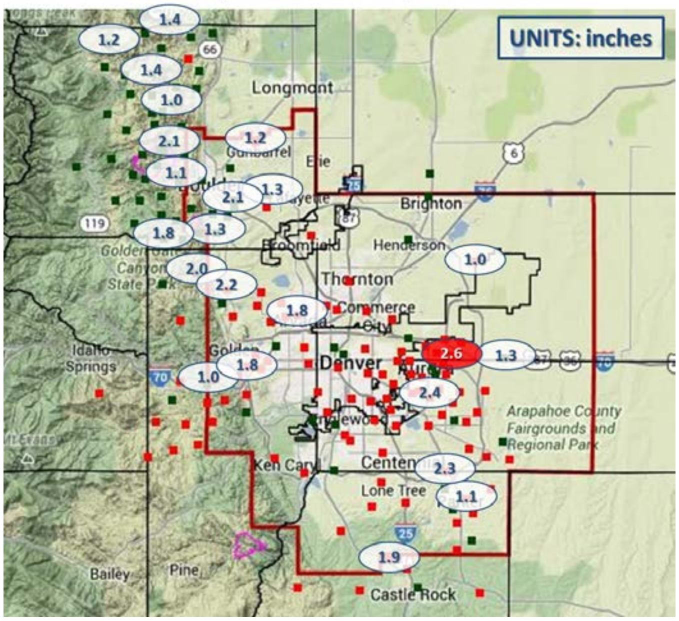
Peak 24-hour Rain Totals
September 9-15, 2013



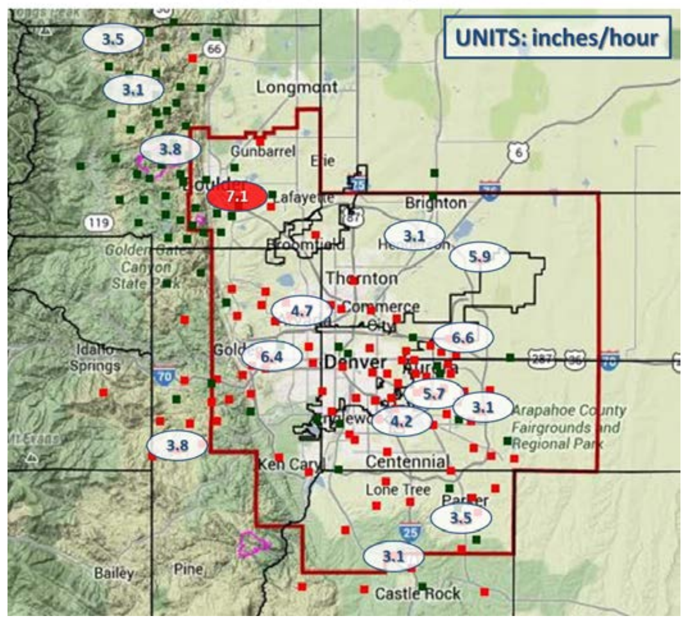
Peak 6-hour Rain Totals
September 9-15, 2013



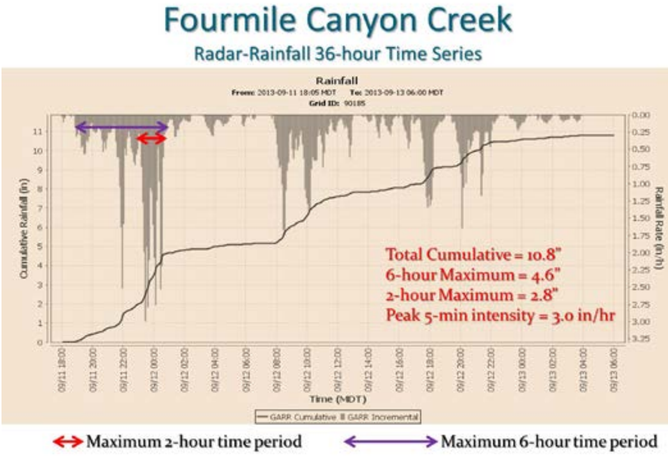
Peak 1-hour Rain Totals
September 9-15, 2013



Peak 10-minute Rain Intensities
September 9-15, 2013



The preceding maps and related discussion presents a somewhat static perspective on the storm. The following graph illustrates how rainfall progressed over a 36-hour time period. This plot of gage-adjusted radar-rainfall (GARR) runs from 6pm on Wednesday (9/11) to midnight Thursday (9/12) and is typical of observations made at many other locations. The intense periods of the storm occur in waves that are not sustained. This storm pattern does not resemble what engineers use to design flood control projects or delineate floodplain limits. Although the 2- and 6-hour maximums in this example nearly equal 100-year thresholds, the peak 5-minute intensities do not. Standard rainfall distributions used in major drainage design contain peak rates approaching 8 in/hr, which is 2.5 times more intense than the example below.



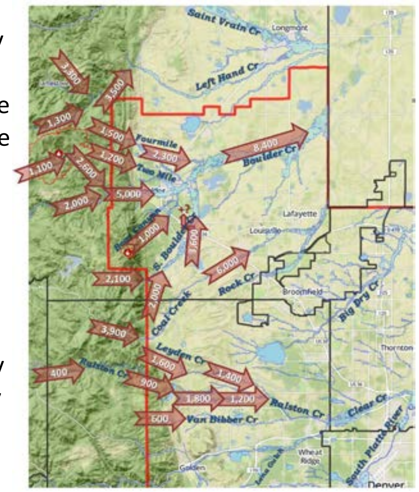
In summary, the rainfall that caused Colorado's September 2013 flood disaster came in waves, accumulated amounts over a 24 to 48-hour period that greatly exceeded 100-year (1% AEP) thresholds, and covered large areas. Each wave of rainfall activity produced amounts that were far more common to the region with the exception of a few isolated areas. Boulder County's 1-hour rainfall maximums illustrate this well with the largest measurements ranging from 1.0 to 2.1 inches, corresponding respectively to 5-year (20% AEP) and 50-year (2% AEP) frequencies. Consequently, peak flood flow estimates at many locations were surprisingly lower than expected. Other factors affected the flood magnitudes and impacts.

Flood Peaks & Frequency

New channel cut by Fourmile Canyon Creek in Boulder County near UDFCD border. Actual creek channel is left of photo. Damaged parking area served the Anne U. White Trailhead prior to the flood.

Normally peak flood flows are relative easy to estimate from maximum recorded gage heights at streamgages. This was not the case for this particular flood for a number of reasons. Many streamgages were destroyed or damaged by the floodwaters. At some locations stream channel banks and beds were reshaped by the flood and at other locations old channels were completely obliterated and their paths rerouted. Some gages measured water depths that exceeded their published discharge ratings. Consequently, indirect flow measurements became the best option for estimating flood peaks.

To accomplish this monumental task, the District sought help from a world-renown research scientist with over 40 years of experience making peak flow estimates of this type. Thanks to Robert D. (Bob) Jarrett, Ph.D., estimates were obtained for many locations of interest. Bob is a paleoflood hydrologist recently retired from the USGS who spent his federal service career evaluating evidence left by floods that in some cases date back 100's of years. Given the massive amounts of rock and debris that were displaced by the floodwaters, Bob contributions have certainly proved vital in trying to better comprehend the actual magnitude of this flood. By achieving this task, engineers will have the critical information they need to help the region recover effectively and limit damages that future floods will cause.



The map shows some of the preliminary peak flow estimates of particular interest to the District. Assuming these estimates are reasonable, the next difficult task is trying to understand the corresponding flood extents and damages that resulted. For many locations this flood may best be described as both a geologic and hydrologic disaster. As steep mountain slopes gave way, thousands of tons of sediment, large rocks and fallen trees reached valley floors and flooded streams. Stream banks, roadways and buildings collapsed adding to the debris being carried by floodwaters. At points where the movement of debris was either obstructed or slowed, temporary dams formed and the water backed-up until the failure point was reached. Then a large surge of water would impact a relatively short distance downstream where walls of water were reported by witnesses. Eventually the debris load would be deposited. This condition was commonly observed throughout the high country and adjacent plains during the flood.


Landslide in Two Mile Canyon in Boulder County


Fourmile Canyon Creek in Boulder County


Fourmile Canyon Creek near canyon mouth in Boulder County


Fourmile Canyon Creek in City of Boulder

While news reports and articles were quick to state that Colorado had just experienced a 100-year or 1000-year flood, such generalizations are often misleading. The actual flood magnitudes and corresponding frequencies vary quite widely and are stream/location specific. Many peak discharge estimates fall well-below 100-year (1%) thresholds. For example, the 5,000 cfs estimate for Boulder Creek at the canyon mouth is considered a 25-year flood, which has a 4% annual chance of occurring. The 2,100 cfs on South Boulder Creek at Eldorado Springs is also classified as a 4% chance event. A 30 to 40-year (2-3%) peak was estimated for Fourmile Canyon Creek that runs through north Boulder, while the next canyon to the south—Two Mile Canyon Creek—may have exceeded the 500-year (0.2% chance) threshold. All of the above examples are either within or near the City of Boulder.

Streams reaches and locations within UDFCD where flood peaks either approached or exceeded the 100-year (1%) threshold include:

County	Streams/Locations
Boulder	Two Mile Canyon Creek, Coal Creek
Jefferson	Coal Creek, Leyden Creek
Denver	Westerly Creek (Kelly Road Dam to Colfax Ave.)
Arapahoe	Upper Westerly Creek basin in Aurora

Considering the extreme amounts of rainfall, this short list of streams may seem too short. Many other smaller drainageways as well as developed areas outside of mapped floodplains bore heavy damage from the floodwaters, but the peak flows that caused these losses are still unknown. The above table only lists major drainageways where floods peaks are known to have topped 100-year levels inside District boundaries.

The Saint Vrain Creek watershed lies north of the District in Boulder County. Many locations there experienced severe flood conditions, most notably the communities of Jamestown, Lyons and Longmont. Preliminary flood peak estimates for Left Hand Creek and James Creek (see map), North and South Saint Vrain Creeks, and the main stem of the Saint Vrain through Lyons and Longmont approached 500-year (0.2%) levels. Areas further north in Larimer County along the Big Thompson River and its tributaries also sustained massive flood damage.

Ongoing efforts will further refine the peak discharge estimates for the September floods. As difficult as this task is, it may be far more difficult to explain why some numbers are so large and considered extremely rare, while "more frequent" flood peaks caused some of the worst damages and inundation extents. The debris impacts will certainly be part of this conversation. Bob Jarrett believes that some of the larger landslides carried huge water volumes that surged upon reaching streams causing flow rates to spike. This effect would be compounded when debris dams formed as previously described. After debris-related surges occur, flood peaks can quickly attenuate because the surge lacks the volume of water necessary to sustain high flow rates for long distances downstream. As rain keeps falling, more runoff is added to the streamflow. When the rainfall becomes intense, the peak runoff rates increase causing stream levels to rise more rapidly. As floodwaters begin to slow down, the huge debris loads find their final resting spots in and adjacent to creek channels. When channels become obstructed, the floodwaters seek new paths creating new channels. All of these factors contributed to the floods of September 2013.

Dams & Reservoirs


Arvada/Blunn Reservoir spillway

Leyden Dam spillway in Arvada


Kelly Road Dam


RMA Havana Pond dam failure

When a foot of rain falls, large reservoirs and impoundments are bound to fill and spill, and that's precisely what they did during the floods of September. Dam spillways are intended to handle large flood flows safely. Occasionally dams fail. Only one dam failure (Havana Pond at the Rocky Mountain Arsenal National Wildlife Refuge) on Thursday, September 12 caused public safety concerns in the District, resulting in an evacuation of Commerce City's Irondale neighborhood. Thanks to an old railroad embankment 1.5 miles downstream that held back the floodwaters, the threatened homes were not impacted by this breach. One other small dam failed on Leyden Creek upstream of Colorado Highway 93 but this incident went unnoticed due to all the other flood problems that were occurring at the time.

At other locations, dam spillways that rarely overtop operated safely. When this happened it attracted considerable media attention. News reporters frequently used the term "breach" to describe an operating spillway. This was alarming news for many who associate the word "breach" with a dam failure, knowing that the potential consequences can be catastrophic particularly where large dams are involved.

Some large dams that concerned District local governments during the September floods include: Evergreen Lake on Bear Creek at Evergreen; Ralston Reservoir on Ralston Creek west of State Highway 93; Arvada/Blunn Reservoir on Ralston Creek east of SH-93; Leyden Dam on Leyden Creek in Arvada west of SH-72 (Indiana Street); Maple Grove Reservoir on Lena Gulch in Lakewood; and Kelly Road Dam on Westerly Creek south of East 11th Avenue. All of these structures stored tremendous amounts of floodwater, had damages downstream and performed precisely as intended. Had these dams not existed, flood damages would have been far worse.

Some Closing Thoughts

There is little doubt that Colorado experienced an extremely rare flood event at a time of year when it was least expected. The magnitude of the multi-day rainstorm was "off-the-charts," being described as a 1000-year event and even biblical. The 24- and 48-hour totals were very rare indeed, resulting in huge runoff volumes, thus explaining why high spillway flows occurred at so many dams and reservoirs. The storm's 1-hour maximums, however, were far more common to the region with the exception of a few isolated areas of more intense rain (James Creek in Boulder County; South Boulder Creek in SE Boulder; Coal Creek Canyon and Leyden Creek in Jefferson County; and Westerly Creek in Aurora & Denver). Other heavily-damaged areas in and near the mountains experienced flash flood conditions aggravated by landslides and debris that temporarily dammed streams, then after weakening, freed enormous destructive surges of floodwater. Channel banks gave way destroying roadways, bridges and culvert crossings. New channels and floodways were formed, disregarding the many homes and buildings that lie in the flood's path.

While the September 2013 flood was unquestionably disastrous, past floods have been worse. The fatalities (*9 total statewide including 4 in Boulder County, 2 of which within the District*) were tragic but the number was low by comparison to past floods. Many factors contributed to this outcome including: 30+ years of preparing for the "next Big Thompson Canyon flash flood"; advances in communication technologies; early advisories given to local authorities concerning developing threats; early flood warnings; real-time rainfall and stream level information; radar and other storm tracking technologies; wildland fires that lead to increased flood awareness and community preparedness; deployment of sirens and other means of public warning; training of first-responders and decision-makers; coordination of information during the event; cooperation amount the agencies involved; and an appropriate response to warnings by those at highest risk.

Although flood-related losses within UDFCD boundaries were significant, many completed drainage and flood control improvements performed quite well and prevented damages. Over the past 40 years UDFCD has worked with its local governments to define flood hazards, to educate people about flood risks, to deploy technologies for detecting floods, to improve early warning capabilities; and to increase the capability of rivers, creeks, gulches and urban drainageways to safely transport floodwaters. After the September floodwaters had receded, one citizen familiar with UDFCD's work may have said it best when he tweeted that this was the District's "finest hour."

Meteorological Support

The 2013 flood prediction and notification services were provided by Genesis Weather Solutions in partnership with Skyview Weather for the 7th consecutive year. This program has served UDFCD local governments for the past 35 years with early predictions of potential and imminent flood threats along with a variety of related forecast products like daily heavy precipitation outlooks, quantitative precipitation forecasts (QPF), and storm track maps. GWS President Bryan Rappolt has participated actively as an F2P2 forecaster for the past 20 years through various business enterprises. Bryan's Skyview partners included lead forecaster and 7-year veteran Brad Simmons supported by Jeffrey Auger, Chris Brinson, Alan Smith, David Bruggeman and Skyview's President Tim Tonge. The F2P2 was established after the devastating July 31, 1976 Big Thompson Canyon flash flood that claimed 143 lives.

The Flash Flood Prediction Program (F2P2) operates from April 15 through September 15 in close partnership with the National Weather Service and focuses primarily on threats from heavy rainfall. The U.S. Army Corps of Engineers provides notifications of high releases from Chatfield, Cherry Creek and Bear Creek dams that are subsequently disseminated by F2P2 meteorologists to affected UDFCD jurisdictions. Flood advisories and warnings concerning mountain snowmelt runoff during late spring and early summer are provided by NWS.

With the September flood disaster occurring on the final week of the program, the District extended F2P2 services to the end of the month. During that 2-week period messages concerning low level threats were issued for four days, September 16, 18, 22 and 23. Of these four days, 9/22 produced the greatest rainfall totals with 1.5 to 2-inches occurring over much of Aurora. What a year this has been!

With the 2013 flood season forecast operations presumed to be nearing completion in late August, UDFCD once again asked Judy Peratt to evaluate the services provided. After the shock of the September floods, additional work was requested to capture any new observations. As a former director of emergency management for Jefferson County, Judy's interviews continue to help UDFCD discover what works well and possible changes to consider. UDFCD greatly values the feedback from all the participating local officials that represent emergency management, communications, public works and emergency services.

The floods proved helpful in revealing where attention should be focused to fine-tune the program slightly, but the general consensus was that UDFCD local governments were well-served in 2013 and that no major operational changes are needed. Training needs will remain a high priority for 2014 and criteria for low flood threshold notifications will be revisited. Notifications are now delivered by so many methods that the number of phone contacts being made to busy 911 communication centers could effectively be reduced without compromising critical information flow. For a complete archive of F2P2 messages and related products visit f2p2.udfcd.org.

CoCoRaHS Update

UDFCD has been a CoCoRaHS sponsor since 2001 and routinely makes use of this valuable resource. The storm summary maps available from the F2P2 webpage are an excellent example. UDFCD worked with CoCoRaHS staff in the aftermath of the September floods to document rainfall amounts collected throughout the storm period. Their efforts were instrumental in preparing a number of very helpful and interesting publications and maps. Be sure to visit www.cocorahs.org to check out all that they have concerning the 2013 flood and past events. And if you are not already a highly-valued CoCoRaHS observer, please consider becoming one today.

EMWIN-Denver Regional Update

The EMWIN-DR steering committee continued to meet quarterly in 2013 under the leadership of Rick Newman, Deputy Director of Emergency Management for Jefferson County. UDFCD's Julia Bailey and Kevin Stewart are active members of Rick's committee. A recent move by the Adams County Office of Emergency Management provided an opportunity to upgrade and relocate the satellite downlink equipment. Because the dissemination software is being supported by UDFCD at its Diamond Hill office, it made sense to eliminate the Internet link between Adams County and UDFCD by developing downlink capabilities at Diamond Hill. New smaller dish antennas helped make this feasible with the rooftop placement nearly impossible to see from the ground. The new installation was completed in December with assistance from Amateur Radio Emergency Services (ARES) volunteers. The Emergency Managers Weather Information Network provides 22 northeast Colorado communities with timely NWS weather warnings and advisories. During the week of September 9-15, EMWIN-DR distributed over 440 alerts to subscribers engaged with the flood emergency.

ALERT System News

East Toll Gate at Hampden Rain/Stage Gage

The ALERT system currently collects real-time data from a network of six repeaters that receive transmissions from 219 gaging stations accommodating 195 rain gages, 103 stream gages and 26 full weather stations. Two new stations were installed by the City of Aurora in 2013—a combination rain/stage gage on East Toll Gate Creek at Hampton Avenue and a rain gage at the Blackstone Golf Course. Both sites employ a new more robust data protocol known as ALERT2™.

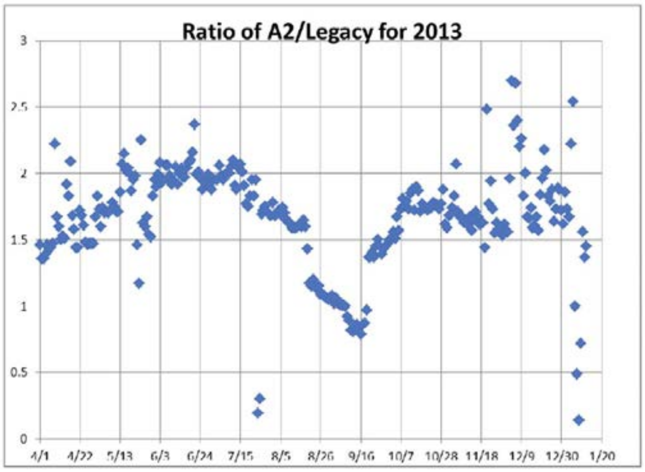
OneRain and Water & Earth Technologies (WET) provided preventative maintenance and repair services for 2013, enabling base stations to successfully process well over 9 million ALERT data reports. Annual reports and other documents are available concerning 2013 maintenance activities (for links see Resources box at end of article).

Record high water measurements were set in 2013 at 40 of the 103 stage gages, 39 of which occurred during the floods of September. Annual peaks occurred at 69 sites between September 9 and 15. The following table further illustrates the unusual nature of the September rains. The 229.74 tip count represents a 9-inch average rainfall total over the entire rain gauge network of 195 sites. Comparing this to the prior 7 years shows that the September 2013 rainfall was 8 times greater than the 7-year September average and 2.5 times more than the maximum average for any single month with May 2011 in second place.

Monthly Average Tip/Count Summary

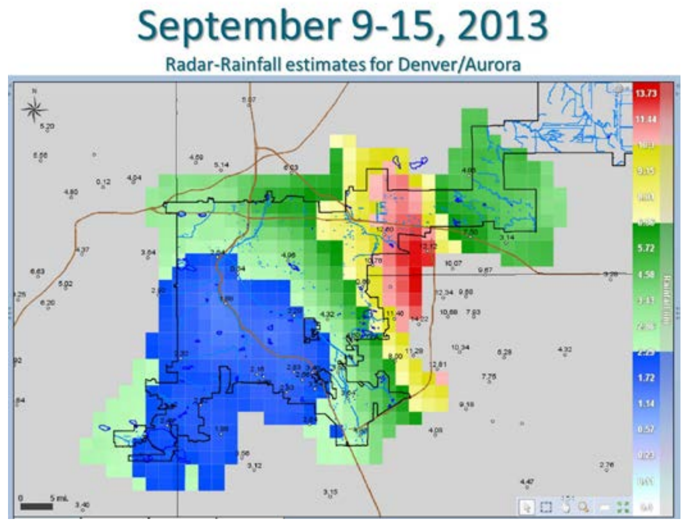
Year	Jan*	Feb*	Mar*	Apr	May	Jun	Jul	Aug	Sep	Oct*
2006	4.62	5.92	18.39	20.47	19.44	13.75	74.03	46.89	24.17	41.13
2007	11.56	5.40	29.75	65.03	68.30	15.87	36.20	46.38	22.13	29.50
2008	4.05	7.38	12.26	20.57	54.82	26.06	16.43	90.20	37.54	19.59
2009	6.33	3.11	11.37	59.26	63.45	68.00	65.00	20.00	27.29	30.24
2010	5.97	11.90	32.54	70.57	39.63	56.04	50.23	31.01	4.18	18.31
2011	6.78	7.45	7.54	33.94	92.68	39.42	90.87	18.25	37.67	25.73
2012	4.89	13.57	2.35	30.17	38.97	19.35	73.03	11.31	48.81	22.32
2013	2.96	14.31	21.86	35.96	45.87	16.39	52.33	50.63	229.74	

Two primary websites were supported during 2013. The public website uses a software package developed and maintained by OneRain called Contrail Web. UDFCD's homepage links directly to this service. The second website is designed for use by UDFCD Flood Warning Program partner agencies. It displays ALERT data collected by a NovaStar-5 base station located at UDFCD and developed by HydroLynx Systems. The website and NS-5 platform are maintained by WET. Both base stations also ingest data from satellite-monitored stream gages operated by the USGS. In 2013 a new procedure was developed for NS-5 to collect data from Colorado Division of Water Resources (DWR) streamgages.



As a reminder that we don't live in a perfect world, one system glitch did occur that went undetected until after the September floods. It started in mid-July when a new ALERT2 radio receiver at Diamond Hill began to gradually deteriorate. On August 19 it took a nose dive (see above plot), but the significant decrease in performance was yet unnoticed because the legacy data continued to flow in reliably. Fortunately this backup data communications system carried us through one of the worst floods many of us will witness in a lifetime. Given how important the real-time ALERT data was during the flood, this "failure" serves as a reminder that diligent monitoring and redundancy are vital components for critical systems.

Some other failures also occurred in 2013 that are not easy to guard against. The September floods damaged or destroyed 15 ALERT streamgages, 10 of which were located in Boulder County. The photo shows what happened at the James Creek streamgage near Jamestown. Streams affected include Boulder Creek, Fourmile Creek, South Boulder Creek, North Saint Vrain, South Saint Vrain, Left Hand Creek and James Creek—all in Boulder County; Sand Creek through Aurora, Denver and Commerce City; Cherry Creek in Denver; Westerly Creek in Aurora; and Bear Creek in Jefferson County.



As technology continues to advance, many ideas long dreamed of are now possible. By integrating ALERT rainfall data with NWS Radar, innovators can provide more useful ways to recognize threats and alert decision-makers when critical thresholds are exceeded anywhere within a pre-defined area. The above map shows gage-adjusted radar rainfall (GARR) estimates over Denver available to local officials during the September floods. The red grids are over the Westerly Creek basin in Aurora and the maximum grid estimate for this area was 13.73 inches for the 7-day storm period. Five-minute rainfall intensity thresholds were pre-selected for automated notification via email or text message. The 2-month Denver test was scheduled to stop at the end of August, but the firm that developed this application—Vieux, Inc. of Norman, Oklahoma—extended the service through September.

UDFCD will continue to provide quality information services to all of our partners and the public. Your ideas on how we can better serve you are always welcome.

Resources

A complete archive of daily forecasts, flood threat notifications, storm track predictions, storm summary maps, and other products can be found at f2p2.udfcd.org. See www.udfcd.org/FWP/ALERT/wl/annual_peaks.xlsx for a table of annual and record water level/streamflow peaks measured by the ALERT system. For detailed operation and maintenance reports visit:
www.udfcd.org/FWP/ALERT_Reports/
& www.udfcd.org/FWP/F2P2_Reports/
Read the NOAA report on exceedance probability for the 9/2013 Storm.
Learn more about the weather system that delivered the 9/2013 Storm.

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