SEVERE FLOODING
ON THE COLORADO FRONT RANGE
September 2013

Muddy flood waters of Boulder Creek in Boulder, Colorado, during the rain and flooding event of September 2013. Photo: Getty Images.

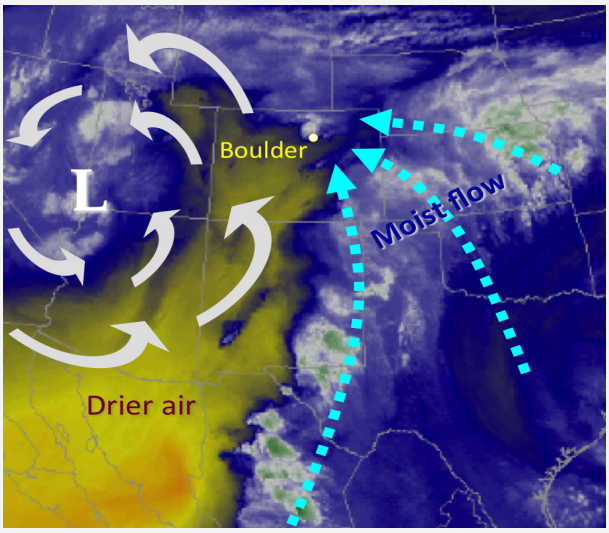
A PRELIMINARY ASSESSMENT

from the CIRES Western Water Assessment at the University of Colorado, NOAA ESRL Physical Science Division, and the CSU Colorado Climate Center

THE WEATHER

An unusually persistent and moist weather pattern led to rainfall totals from September 9th - 15th that have been observed in only a handful of events on the Front Range in the past century.

- The very heavy rainfall was due to a combination of an unusually deep, moist flow and a stationary weather pattern that consistently focused that moisture towards the Front Range.
- A near-stationary low-pressure system over the Great Basin pulled a strong plume of monsoonal tropical moisture from the Pacific Ocean off western Mexico (right); as the event progressed, the circulation brought yet more moisture from the Gulf of Mexico on easterly and southeasterly flow.
- The upslope flow drove the moisture against the foothills, and a stalled front helped generate lift and rainfall over an even larger area.
- Most of the rain fell in 36 hours, from the afternoon of September 11th until the early morning of September 13th.
- By contrast, the July 1976 Big Thompson and July 1997 Fort Collins flood events were more thunderstorm-driven events with much smaller footprints, shorter durations, and higher peak rates of rainfall.
- All-time record or near-record precipitation was recorded during the week across the Front Range.



Deep plumes of moisture (blue, white, and green) are drawn towards the Front Range from the Pacific and the Gulf of Mexico by the circulation around an upper-level low (L) over the Great Basin, at 11:15 pm MDT on September 11, 2013, during the peak rainfall intensity in Boulder. Drier air is shown in yellow. (Satellite image: CIMSS, University of Wisconsin)

Western Water Assessment
CIRES
COLORADO CLIMATE CENTER

Released September 25, 2013 http://wwa.colorado.edu email: wwa@colorado.edu

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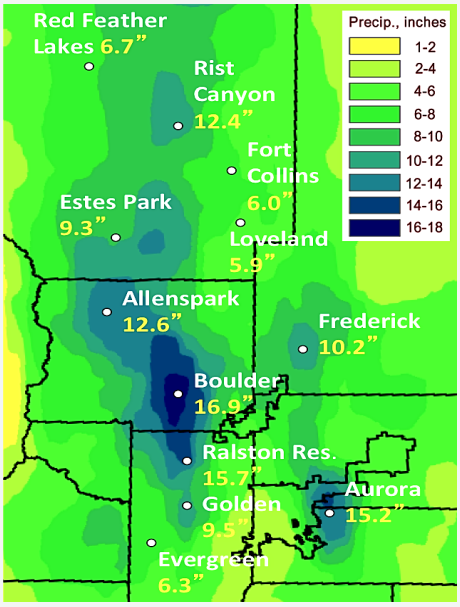
- Seven-day rainfall totals (9/9 to 9/15) exceeded 10″ from Golden through Boulder into Larimer County, and in Aurora (map, *right*).
- Boulder's COOP weather station (since 1893) set new records for 1-day (9.08″), 2-day (11.52″) and 7-day (16.9″) totals; the previous 1-day record was 4.80″ and previous 1-month record was 9.59″.
- New 1-day, 2-day, and 7-day benchmarks were set at many other COOP stations with shorter records and also at high-elevation SNOTEL sites; heavy precipitation fell as rain all the way to the Continental Divide.
- The same event also generated one-week rainfall totals of over 10″ in El Paso County, and over 5″ in east-central and southwestern CO, and much of NM.
- **In the context of the entire Front Range this was a rare precipitation event, especially for September, and in some respects unprecedented.**
- Multi-day rainfall events in Sept. 1938 (10″ max), June 1965 (16″ max), and May 1969 (14″ max) had similar spatial extents; the footprint of the 1938 event was most similar to 2013.
- It has been reported that this was a "1000-year rainfall" for the Boulder area based on the NOAA *Atlas 14* precipitation frequency analysis; however, this analysis extrapolates from the historical record using statistical assumptions that have large uncertainties for very rare events.



Total precipitation from 9/9 - 9/15/2013, showing large areas with >10″ of rain and the maximum of ~17″ in Boulder. Representative totals of >6″ for selected locations are shown. (Map: Colorado Climate Center, CSU)

THE HYDROLOGIC IMPACT

The very heavy rains caused severe to extreme flooding across the northern Front Range and downstream areas in northeastern Colorado; the peak flows at many gages and the overall extent of flooding were probably unmatched in at least 35 years.

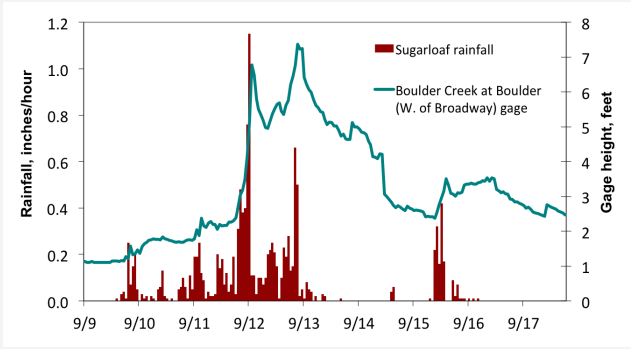
GAGE	2013 PEAK (preliminary)	NEW RECORD	PREVIOUS/CURRENT RECORD	COMMENT
Bear Creek at Morrison	9.1′	No?	9.2′ on 9/1/1938	
Clear Creek at Golden	6.8′; 1550 cfs	No	2370 cfs on 7/10/1983	
Boulder Creek at Boulder	8.2′; 5,000 cfs	No	~11,000 cfs on 5/30/1894	1894 estimated
St. Vrain Creek at Lyons	>8.8′	Yes?	8.1′; 10,500 cfs on 6/22/1941	Gage destroyed 2013
N. Fork Big Thompson R., Drake	10.2′	Yes	9.3′ on 7/31/1976	
Big Thompson, Canyon Mouth	>8.2′	Maybe	~19.9′, ~31,000 cfs on 7/31/76	Gage destroyed 2013 and 1976
Poudre R. at Ft. Collins	10.8′; 8420 cfs	Yes?	10.5′, 7,710 cfs on 4/30/1999	Gaged since 1975
S. Platte R. near Fort Morgan	24.7′; 50,600 cfs	No	83,700 cfs on 5/31/1935	

Preliminary flood peaks from selected gages on Front Range drainages affected by flooding, September 2013, compared with previous flood peaks. (Data: USGS, Colorado DWR, UDFCD)

- In some drainages the peak flow appears to have been higher than the previous record peak height or discharge from the past 35 to 80 years (see table above).
- This was likely a 100-year flood (or more accurately: a 1% probability per year flood) in some drainages but not in others, including Boulder Creek.
- *Note that the 2013 data is preliminary, and comparisons with past flood events is complicated by physical changes in the upstream basin and its management (e.g., dam releases), and changes in the stream channel around the gage.*
- Flooding events in the Front Range in May 1935 and June 1965 were as widespread and by some measures

had greater magnitudes, but were focused to the south of the 2013 event.

- The September 1938 flood event had a similar north-south footprint, with similar peak flows in several drainages, and occurred at the same time of year.
- Because the peak rainfall intensities (inches per hour) were generally lower than in previous Front Range floods (see graph at right), the peak flows in the 2013 event may have been lower than one would expect from the very high precipitation amounts.
- Recent moderate- to high-severity burns clearly enhanced local flooding (and debris flows) in some drainages, e.g., Fourmile Creek west of Boulder, but likely had only a minor impact on the flooding overall.



Hourly rainfall intensity at the Sugarloaf RAWS station 6 mi. west of Boulder compared with gage height on Boulder Creek at Boulder (west of Broadway). The first flood peak closely followed the heavy rainfall before midnight on 9/11-12, when 3.5" fell in 6 hours. (Data: rainfall: RAWS via WRCC; and streamflow: Colorado DWR; plotted by Jeff Lukas, WWA)

THE CHANGING CLIMATE

Research is underway at CIRES and NOAA to determine how human-caused climate change may have influenced this event and whether the risk of similar events occurring in the future will increase. The most plausible influence of climate change: Slightly more water vapor being made available for precipitation.

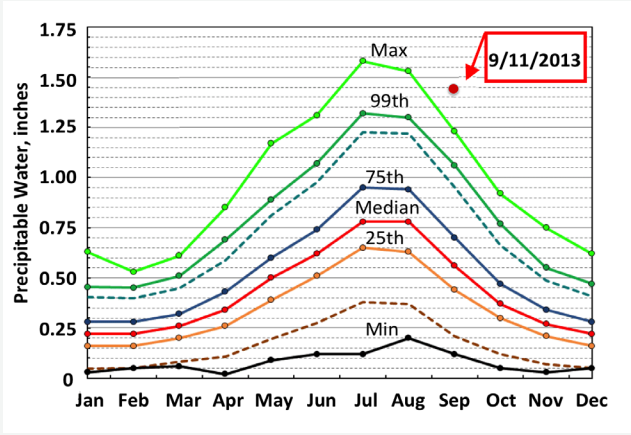
- Because human changes to the atmosphere have made the weather-climate system warmer and more moist, one can reasonably say that *all* weather systems are now under the influence of climate change.

Water Vapor

- Warmer air can contain more moisture; it is believed that human-caused warming has caused about a 3-5% increase in atmospheric water vapor on a global basis.
- By extension, this effect may have been responsible for a small increase in the water vapor in the moisture plumes that fed the Front Range event.
- Total moisture content of the atmosphere above Denver on September 11th was observed to be at record levels for September (figure, *right*).

Heavy Rainfall Events

- No increasing trend has been observed in the past century in very heavy rainfall (extreme 1-day and 5-day events) in the southwestern US (including Colorado), unlike other regions of the US and the world; a different metric of heavy precipitation shows a small upward trend for this region.
- Heavy rainfall events are projected to increase in frequency in the future over many parts of the globe; the projected trends for Colorado are less certain.



The range of total atmospheric precipitable water (PW) over Denver from 1948-2012, as measured by balloon soundings at Denver. The measurement on September 11, 2013 (red dot) was higher than any previous September reading. The prominent seasonal curve reflects that warmer air is able to contain more water vapor. (Plot adapted from NOAA NWS.)

The Unusual Weather Pattern

- Again, the extraordinary rainfall in this event was due mainly to the unusual and persistent weather pattern that funneled abundant moisture towards the Front Range and enhanced the lift.
- This atmospheric circulation in the 2013 event was very similar to that in the September 1938 event.

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- It has been hypothesized that slow-moving weather systems like this one may become more common under climate change due to changes in the jet stream, but the evidence for this is very uncertain.
- Climate researchers at CIRES, NOAA, CSU, and elsewhere will systematically address the climate change "attribution" of this event, through analysis of observations, historical trends, and climate model experiments.

FRONT RANGE FLOODING RISK IN LIGHT OF 2013

- Flood risk is the product of a *natural hazard* (likelihood of climatic and hydrologic extremes) and the *societal exposure* and *sensitivity* (homes, infrastructure, and other assets in the path of flooding).
- The natural hazard of flooding for the Front Range includes not just smaller-scale convective events with very high rainfall intensity (e.g., Big Thompson, July 1976), but also rain-on-deep-snowpack events (May 1894), and broader-scale, long-duration rain events with mainly lower intensities (September 2013).
- We need to be cautious when interpreting estimates of the likelihood of rare events; it is difficult to make reliable assessments given the relatively short observed record.
- The likelihood or return interval of a flood is not necessarily identical to the likelihood or return interval of the precipitation event associated with the flooding; additional factors besides total precipitation affect flood magnitude.
- Given the record of similar past events (photo, *right*), an event like September 2013 could occur again even in the absence of climate change.

Railroad tracks hanging over the washed-out bed along South Boulder Creek near present-day Highway 93 near Marshall, after the September 1-3, 1938 flood. The gaged peak discharge in the 1938 flood (7390 cfs) was much higher than that of September 2013, though the latter was influenced by floodwater retention in Gross Reservoir. (Photo courtesy of the Urban Drainage and Flood Control District, UDFCD).

- Total societal exposure to flooding on the Front Range has increased in the past several decades due to population growth and development; recurrence of a previously experienced natural hazard will tend to cause comparatively more damage.

RESOURCES

The September 2013 Front Range Floods
http://cires.colorado.edu/blogs/flood

Boulder Area Flood of September 2013: Climate and Weather Info
http://www.esrl.noaa.gov/psd/boulder/flood2013

Historic Rainfall and Floods in Colorado – climate.gov, NOAA
http://www.climate.gov/news-features/event-tracker/historic-rainfall-and-floods-colorado

Colorado Flood 2013 - Colorado Climate Center, CSU
http://COFlood2013.colostate.edu

Inside the Colorado Deluge – UCAR/NCAR AtmosNews
http://www2.ucar.edu/atmosnews/opinion/10250/inside-colorado-deluge

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Released September 25, 2013