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.
• 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.

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.

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

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.

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 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.
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.

- 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.

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

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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