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Inside this issue

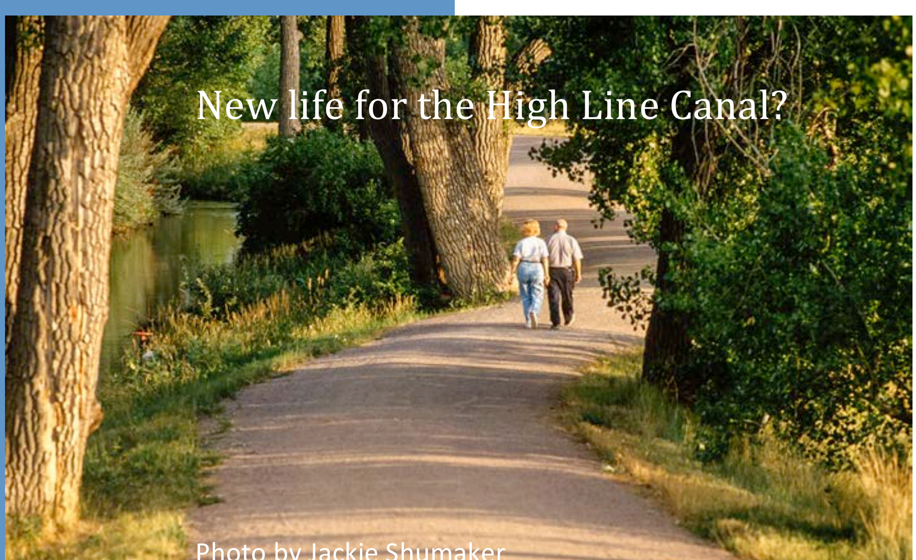

Photo by Jackie Shumaker

Rainfall – Runoff Analysis for the September 2013 Floods in Boulder, CO

By
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Introduction

Many people in the City of Boulder (City) and across the Front Range recall the "biblical" rainfall and "1,000-year" storm characterizations of the September 8 – 16, 2013 flood. Flooding was devastating in many watersheds as steep mountain canyons emptied runoff, rocks and debris into drainageways crossing the City for days. While many stream gages were washed out during the flood, observed high water marks and hydraulic analyses conducted following the flood were used to estimate peak flows and to approximate the floodplain extents. Working with the City of Boulder and the Urban Drainage and Flood Control District (UDFCD), Wright Water Engineers, Inc. (WWE) analyzed the rainfall and runoff response from the 2013 flood within the City.

This analysis indicates that for many creeks in Boulder, the runoff response from the event was below adopted regulatory 100-year peak flow rates. Watersheds analyzed include South Boulder Creek, Bear Canyon Creek, Skunk Creek (including Kings Gulch and Bluebell Canyon Creek), Gregory Canyon Creek, Boulder Creek, Goose and Twomile Canyon Creeks, and Wonderland and Fourmile Canyon Creeks. A summary of the findings for South Boulder Creek, Boulder Creek, and Fourmile Canyon Creek are presented below. A copy of the full report with information for all of the above-mentioned watersheds can be obtained from the UDFCD Electronic Data Mapping site (http://udfcd.gisworkshop.com) by searching under any of the affected streams.

The analyses conducted by WWE included determining the 5-, 10-, 15-, and 30-minute, and 1-, 2-, 6-, 12-, and 24-hour "worst case" rainfall return periods for the 2013 flood for watersheds within and draining through Boulder. Based on analysis of "worst case" rainfall (e.g. the maximum depth of precipitation falling during a given "window of time" during the storm), the short-duration (5-, 10-, and 15-minute) rainfall depths resulted in return periods typically less than the 10-year design storm. However, for longer durations, return periods increased dramatically. For 12- and 24-hour durations, rainfall depths often exceeded the NOAA Atlas 14 1,000-year precipitation depths. Coupled with rainfall-runoff modeling by others, this information helps to explain why a "1,000-year storm" did not produce a "1,000-year flood."

In addition to the work done to characterize rainfall return periods, the team also performed comparisons with design storms (UDFCD 2-hour rainfall distributions used in the Colorado Urban Hydrograph Procedure [CUHP] for many watersheds) to compare the design storm rainfall intensities with the observed intensities. This information, along with flow estimates/measurements collected by Dr. Bob Jarrett, flow estimates from City consultants, and 2013 flood inundation mapping prepared by the City, allowed WWE to evaluate the relationship between return periods for rainfall (defined by comparison with NOAA Atlas 14) and return periods for runoff (defined by comparison with peak flow return period data from existing master plans).

South Boulder Creek

The upper portions of the South Boulder Creek watershed experienced total rainfall depths somewhat lower than those used in the 100-year 72-hour general storm used in recent master planning efforts. However, short-duration intensities were higher than those used in the general storm. The heavy rainfall in the upper watershed did not begin until the evening of September 12, by which time considerable downstream flooding had occurred from runoff from the portion of the watershed below Gross Reservoir, a Denver Water storage facility located on South Boulder Creek at the lower end of the upper watershed.

The middle and lower portions of the watershed experienced several strong surges of rainfall, the heaviest of which was on September 11, when flooding in many urban areas in Boulder was at its worst. An additional surge on the 12th and into the 13th added another 3 to 5 inches of precipitation on saturated soils, producing further flooding. Total rainfall depths for the lower watersheds were considerably larger than for the 100-year general storm; and rainfall intensity was also greater, which helps to explain the severe flooding experienced on South Boulder Creek and it's West Valley Overflow in the city, despite relatively minor runoff contributions from the upper watershed above Gross Reservoir.

South Boulder Creek bike path washed out near U.S. Highway 36. Source: CH2M HILL

Bull Gulch post-flood railed railroad embankment (looking north). Source: Michael Baker International

Runoff measurements by Dr. Jarrett and from UDFCD ALERT stream gages were used to develop runoff estimates within the South Boulder Creek watershed. Runoff estimates indicate that the watershed above Gross Reservoir was not a major contributor to the flooding experienced in the City. This is due to a variety of factors, including the fact that the heaviest rain in the upper watershed occurred late on the 12th and into the 13th of September, while the lower watershed had the most intense rain (and flooding) on September 11. In addition, storage was available in Gross Reservoir that aided in attenuating runoff, and Denver Water diverted some of the runoff from the upper watershed to Ralston Reservoir in the Ralston Creek watershed.

It is somewhat surprising that the rainfall in the upper watershed late on the 12th and early on the 13th did not produce greater peak flows, with 3- to 6-hour rainfall depths with return periods of greater than 100-year falling on the upper basin. However, the largely forested upper watershed would have substantial hydrologic losses from depression storage (alpine lakes), interception, infiltration and storage in forest litter, as well as transient storage (i.e., temporary storage in floodplain overbank areas as the flood moves down the canyon), which would delay and lessen peak flow rates and helps to explain the runoff response observed.

Debris in Boulder Creek near Folsom Street. Source: UDFCD

To evaluate the runoff return periods, WWE compared flow estimates from the 2013 flood to hydraulic model results for the general storm (72 hours) and the thunderstorm (6 hours, higher intensity). The estimated flow rate at Eldorado Springs of between 2,000 and 2,100 cfs corresponds to a 50- to 100-year return period for the general storm and a 10- to 25-year return period for the thunderstorm, which tends to produce higher peak flows than the general storm for larger return periods. The flow estimate of roughly 5,600 cfs along South Boulder Creek near Highway 93 exceeds the 500-year frequency modeling results for the general storm and falls between a 50- and 100-year event for the thunderstorm modeling results.

It should be noted that the flow at this location was heavily influenced by a large (2,000 cfs) contribution from a tributary called Doudy Draw, which experienced very intense rainfall, well in excess of design storm parameters, in addition to a large surge of water and debris from a railroad embankment failure in a tributary called Bull Gulch. The area above the embankment failure was approximately 0.80 square miles (only a small portion of the overall watershed); however, the sudden release from the embankment failure, combined with the very intense rainfall drove the high runoff rates observed for the Doudy Draw watershed.

Boulder Creek

During the 2013 flood precipitation depths and intensities within the Boulder Creek watershed generally increased from west to east with total rainfall from September 11 – 13 of approximately 2.6 inches in the west sub-watershed increasing to approximately 9.7 inches in the east sub-watershed. Rainfall return periods for the worst-case 6-hour durations ranged from a 25-year to greater than a 300-year event.

To understand the flooding that occurred along Boulder Creek in 2013, it is important to recognize that the creek characteristics change dramatically over a short distance as it passes through the City. The creek goes from a steep mountain stream, to an urban waterway/greenway within the City, to a plains stream with a broad floodplain and meandering channel downstream of the City. Runoff estimates for peak flows in the upper Boulder Creek watersheds ranged from less than a 10-year to a 15-year event. Through the City, the peak flow estimates increase to approximately a 25-year event. East of the City, near the City of Boulder Wastewater Treatment Plant, where Boulder Creek spreads out across a broad floodplain, the runoff estimates were approximately equivalent to a 25-year event. In many areas along the corridor, gravel pit embankments were overtopped or breached, connecting a broad floodplain. This study did not evaluate runoff further east than the wastewater treatment plant.

Fourmile Canyon Creek

Within the Fourmile Canyon Creek upper and middle sub-watersheds, maximum 1-hour rainfall depths were between NOAA 10- and 50-year design rainfall depths, which are consistent with the peak discharge estimates developed by Dr. Jarrett at these locations. For durations of 3 to 12 hours, the maximum rainfall depths from the 2013 flood were in the range of 100- to 200-year NOAA design rainfall depths. The maximum 24-hour rainfall depths were approximately 8.5 inches, which are greater than the NOAA 1,000-year, 24-hour design rainfall depths.

The lower Fourmile Canyon Creek sub-watersheds east of the foothills experienced more intense rainfall in the early part of the storm (evening of September 11th) than the upper sub-watersheds, but had less total rainfall over the 36-hour period. Maximum 1-hour rainfall depths for these sub-watersheds were between NOAA 10-year and 50-year design rainfall depths.

Runoff measurements from Dr. Jarrett for the upper reaches of Fourmile Canyon Creek indicate a 25-year to 50-year flood. Further downstream on Fourmile Canyon Creek in the City, the estimated peak discharge of 2,300 cfs is in the range of a 50-year to 100-year flood. Significant flooding also occurred on portions of Wonderland Creek east of Broadway

Fourmile Canyon Creek west of Broadway. Source: Muller Engineering Company

Fourmile Canyon Creek overflow path along Topaz Drive. Source: UDFCD

where flows from Fourmile Canyon Creek spilled to the south to Wonderland Creek.

Fourmile Canyon Creek is a classic alluvial fan situation in an urban area. In large floods, there will be significant debris that will clog culverts, damage or destroy bridges, reroute flows, etc., and thus spread out from the apex of the fan at the base of the foothills. In the 2013 flood, there was significant channel avulsion (formation of a new channel)/migration upstream of Broadway on Fourmile Canyon Creek.

Conclusions

Based on the detailed analysis of the rainfall and runoff response for the September 2013 flood within the City of Boulder, the following general conclusions can be drawn:

- For longer rainfall durations, watersheds in the City experienced very infrequent return periods (e.g. 100-year, 500-year, 1,000-year). Shorter durations had more frequent return periods and sub-hour durations in many cases had return periods of less than a 10-year event. Peak intensities never rose to the levels used in 100-year design storms, and the runoff response in many cases was less than a 100-year return period. When evaluating rainfall for short-duration return periods, and the resulting runoff, it is important to keep in mind that in many watersheds, there were several "waves" of intense rainfall over the duration of the storm, and the rainfall that occurred later in the storm was on saturated ground, and the runoff response would be magnified beyond what the rainfall return period would indicate.
- The comparisons with design storms demonstrate that the assumptions relative to the temporal distribution of rainfall are conservative (e.g. high intensities over short durations). In most cases, peak rainfall intensities from the actual 2013 event were no more than ⅓ to ½ of design storm values and did not produce the peak flow rates that the design storm produces for the same amount of rainfall due to the temporal and spatial distribution of rainfall.
- The runoff response was typically between a 25- and 50-year event for many watersheds; however, some watersheds including lower portions of South Boulder Creek and the lower portion of Fourmile Canyon Creek experienced flows on the order of a 100-year event or greater.