

# SYMPOSIUM ON PRECIPITATION EXTREMES: PREDICTION, IMPACTS, AND RESPONSES

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Cover Caption: GOES-8 water vapor image of Hurricane Mitch from 26 October 1998. Satellite winds derived from NOAA/NESDIS/CIMSS are plotted over tropospheric layers, in the color scheme indicated.

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## 1. INTRODUCTION

Increased emphasis on extreme rainstorm and flood documentation will maximize benefits from emerging technologies, will help improve hydrologic modeling, and improve flash-flood forecasting. Convective rainfall is characteristically localized and can have large gradients in both rain rates and rainfall amounts over very short distances, often a few kilometers or less. In remote areas, systematic precipitation networks may be sparse or nonexistent. Limited resources often preclude extensive, instrumented data collection efforts, and there also is a likelihood rainstorms and floods will not occur in instrumented basins.

Two paleohydrologic (geomorphic and hydrologic) techniques to estimate rainfall amounts of convective rainstorms are being developed and evaluated for mountainous areas. Paleohydrology includes the study of flood-transported sediments and botanic information from past floods preserved in river basins (Jarrett, 1991; Jarrett and Tomlinson, 2000). Paleohydrology, which can be viewed as forensic hydrology, uses this physical evidence to make inferences of hydrometeorologic information. Elements of this presentation include discussions of the: (1) approach, results, and benefits for recent, historic, and prehistoric rainstorm reconstructions in the Rocky Mountain region; (2) limitations and uncertainties of rainfall estimates, and; (3) transfer to other hydroclimatic regions.

In this paper, the approach is discussed for the community of Buffalo Creek, located about 50 km southwest of Denver, Colorado (fig. 1a). On May 18, 1996, an intense wildfire (Buffalo Creek fire) burned about 50 km<sup>2</sup> of forest, produced hydrophobic (water-repellent) soils, and making the area more susceptible to flooding. Subsequently, two people were killed and several million dollars in public and private property damage were caused by a flood on the evening of July 12, 1996 (Colorado Water Conservation Board, 1997). Maximum water depths as much as 4 m occurred within about 30 to 45 minutes of the storm's onset in Buffalo Creek, Spring Creek, and the North Fork South Platte and South Platte Rivers. The paleohydrologic rainfall estimate for the July 12th storm was at least 110 mm in about an about an hour, and the storm footprint (within the 25 mm isohyet) was about 120 km<sup>2</sup>.

For comparison, Henz (1998) estimated a maximum rainfall of about 130 mm, and Fulton (1999) estimated a

maximum of 72 mm; however, their storm footprints were located slightly different and were much larger. The paleohydrologic results were obtained by July 16, 1996 (two days of field and office work) and subsequently were used for emergency flood response. The paleohydrologic methodology is a flexible, "storm-chasing" approach that provides independent, cost-effective rainfall estimates, and can be used to complement conventional instrumented monitoring.

## 2. STUDY AREA

The community of Buffalo Creek is located in the foothills of the Colorado Rocky Mountains (fig. 1a). The community, at an elevation of about 2,012 m, consists of several hundred homes within a montane forest (predominantly ponderosa pine, lodgepole pine, Douglas fir, and aspen). Accumulation of organic litter (duff) in forested areas primary pine needles has an average depth of about 75 mm. Topography is rugged (slopes range from 5 to 60 percent) and soils are shallow (~ 1 m to bedrock with numerous outcrops), moderately well drained, and composed of coarse sandy gravel (Sphinx-Legault-Rock granite complex). The climate is semiarid and mean annual precipitation is about 400 mm. The 100-yr, 1-hr rainfall is about 55 mm for the Buffalo Creek area (Miller et al., 1973). Most streams in the study area are ephemeral. These streams flow into Buffalo Creek and the North Fork South Platte and South Platte Rivers, which primarily are fed by melting snowpack and trans-basin flow diversions. Stream gradients typical range from about 0.005 to 0.06 m/m. Flood flows in the Colorado foothills can result from generalized rainstorms, spring snowmelt, but primarily result from intense, localized thunderstorms (Jarrett, 1990).

## 3. METHODS

In the first or geomorphic method, rainfall amounts can be inferred from the amount of hillslope erosion, maximum size of sediments transported, and deposition characteristics, preferably on sparsely vegetated hillslopes. The hillslopes used should have as similar characteristics as possible. The dimensions of fresh rills, gullies, and headcuts as well as maximum size of sediments transported and their deposition characteristics are obtained and located on topographic maps. Local residents can often provide valuable information about the rainstorm including rainfall "bucket data," storm duration, and hail (which also can be

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inferred from damage to vegetation). Bucket data and nearby systematic gaged data are used to correlate rainfall data with geomorphic evidence accounting for variability such as soil type and cohesiveness, vegetation cover, and hillslope gradient and length. Then, variations in the geomorphic evidence in the storm area are used to estimate a rainfall amount where geomorphic data are available. Finally, an isohyetal map is drawn considering available data. Sometimes, storm path can be inferred for recent storms.

In the second or hydrologic method, indirect estimates of peak discharge can be obtained for many small basins in the area affected by the storm. The emphasis is obtaining peak-discharge data for small basins (<1-3 km<sup>2</sup>) where spatial and temporal rainfall variability is assumed to be small, thus, providing more reliable paleohydrologic rainfall estimates. High-water marks (HWMs) of recent floods or paleostage indicators (essentially old HWMs) for paleofloods, channel geometry, and hydraulic data for a stream are used to estimate peak discharge such as with the critical-depth method (Jarrett, 1991; Jarrett and Tomlinson, 2000).

Rainfall-runoff (RF-RO) modeling with physical basin attributes also can be used to derive independent estimates of rainfall for each small basin. RF-RO modeling is used to back-calculate rainfall intensity and amounts from the peak discharge and a description of basins. Limited space precludes including RF-RO model results. Hydrologic rainfall estimates are used to: (1) help draw the isohyetal map with available geomorphic rainfall estimates; (2) develop isohyetal maps for historic and prehistoric rainstorms; (3) compare results with other independent sources of rainfall data or; (4) provide rainfall estimates if no other source exists.

#### 4. RESULTS

No systematic precipitation or streamflow monitoring existed in the Buffalo Creek burned area in 1996. On July 15-16, 1996 (before additional rainstorms), data collection consisted of obtaining rainfall bucket data, peak flow, and paleohydrologic data for the area.

Eleven rainfall bucket observations were available from residents who had various types of plastic rain gages. Maximum rainfall for the July 12, 1996 storm was about 80 mm in the community of Buffalo Creek and headwaters of Spring Creek (fig. 1a); residents stated most of the rain fell about 2000 to 2100 MDT.

The amount and location of fresh rill and gully erosion on hillslopes generally less than 5-10 m in length was compared to nearby rainfall amounts for the July 12<sup>th</sup> storm. Hillslopes (burned or unburned with sparse vegetation) with less than about 25 mm rain (bucket data) had some sediment movement and minimal rill development. Hillslopes that received about 50 mm of rain typically had rills about 75 mm deep and 50 mm wide. Hillslopes that received about 75 mm of rain typically had extensive rilling and numerous gullies up to 0.5 m deep and a meter wide. Hillslope erosion in areas

without any bucket data then was used to estimate rainfall in areas from these general relations. Numerous gullies up to a meter deep and 3 m wide, very extensive rilling, and large headcuts were documented in an area about 2.5 km southeast of Buffalo Creek near the headwaters of Sand Draw, Spring Creek, Shinglemill Creek, and Spring Gulch. This area of maximum erosion was used to infer the location and area of maximum storm rainfall amount of at least 110 mm (fig. 1a).

Large quantities of sediments were mobilized on hillslopes and in channels in the burned area during the July 12<sup>th</sup> storm. A distinct black, burn boundary (line) on rocks defined pre-flood ground surfaces and was used as a reference to estimate the general surface erosion from sheetwash (overland flow). Care was taken to estimate general erosion rather than the local erosion around a rock. In addition, pillars of soil were preserved under some surface rocks and metal objects on the burned areas. The area of maximum sheetwash also was limited to the headwaters of Shinglemill Creek, Spring Gulch, Sand Draw, and Spring Creek.

Sediments moved on hillslopes ranged from silt to cobble-sized material, and 2.5-m diameter boulders were transported in some channels. A large amount of the flood-transported sediment was deposited as alluvial fans. Many new fans had dimensions of about 100 m x 30 m x 1.5-2 m such as in Sand Draw, Spring Creek, Shinglemill Creek, and Spring Gulch. Well preserved, fresh tributary fans on the Buffalo Creek floodplain were used to infer relative flood timing, and that the storm moved easterly (downstream), which likely exacerbated flooding.

In unburned vegetated areas, rainfall also was inferred by the amount of duff that floated and was repositioned by sheetwash. Rainfall less than about 50 mm (depending on duff thickness and composition) partially floated and reoriented needles, twigs, and other elongated debris perpendicular to the flow direction and spaced about 2 to 4 cm distance apart. These micro-scale features appear to have functioned as small dams ponding rainfall and hindering rainfall runoff. Rainfall greater than about 50 to 75 mm produced a cascading failure of these small debris dams. Small channels were preserved within the duff (similar to channel incision), which enabled peak discharge estimation. These features are similar to log jams in rivers such as the 1982 Lawn Lake dam failure in Rocky Mountain National Park, located about 100 km northwest of Denver, Colorado (Jarrett and Costa, 1986).

Peak-flow estimates for twenty streams, ranging in size from about 0.1 km<sup>2</sup> to the total burned area of about 50 km<sup>2</sup>, also were used to help identify areas of maximum rainfall. These basins have varied characteristics such as vegetation cover, burn intensity (including no burn), watershed aspect and slope, and sediment sizes. A number of severely-burned small basins in areas of maximum rainfall had unit discharges (peak discharge divided by drainage area) from about 45 to 60 m<sup>3</sup>/s/km<sup>2</sup>. [For comparison, the maximum unit

discharge was about  $40 \text{ m}^3/\text{s}/\text{km}^2$  for the largest known floods for unburned basins in Colorado (Jarrett, 1990; Jarrett and Tomlinson, 2000.) The peak discharge estimate was  $450 \text{ m}^3/\text{s}$  (+/-20%) for Buffalo Creek about 0.8 km upstream from its confluence with the North Fork South Platte River (fig. 1a). The total drainage area at this site is  $133 \text{ km}^2$  (lat.  $39^\circ 23' 27''$ , long.  $105^\circ 16' 15''$ ). The contributing area at this site for flood runoff (essentially all from the burned area) was about  $19 \text{ km}^2$  (unit discharge  $\sim 24 \text{ m}^3/\text{s}/\text{km}^2$ ). Unburned basins with 50 to 75 mm of rainfall had unit discharges less than  $0.1 \text{ m}^3/\text{s}/\text{km}^2$ . This is consistent with long-time residents' observation that no significant flooding had occurred in the Buffalo Creek area in about 70 years.

The paleohydrologic evidence then were used to help define the spatial characteristics of the rainstorm and to draw an isohyetal map (fig. 1a). Rainfall amounts decreased rapidly outside the burned area and the storm footprint within the 25 mm isohyet was about  $110 \text{ km}^2$  (fig. 1a). In conjunction with the National Weather Service and Colorado Water Conservation Board, study results were used on July 18, 1996, to help determine threshold-rainfall amounts that could produce hazardous flooding.

## 5. DISCUSSION

The South Platte River at South Platte (streamflow-gaging station 06707500) is located just downstream from the confluence of the North and South Forks of the South Platte River (fig. 1a). The flood of record was  $179 \text{ m}^3/\text{s}$  since the gage was installed in 1904. The peak discharge was about  $325 \text{ m}^3/\text{s}$  (+/-25%) on July 12, 1996, was produced by runoff from the total burned area of about  $50 \text{ km}^2$ . This gage has total drainage area of  $6,680 \text{ km}^2$ , thus, although less than one percent of the basin burned, the effects of the fire had a major impact on flood hydrology.

Henz (1998, this proceedings) analyzed Doppler radar signatures and upper-air observations for the July 12<sup>th</sup> storm, but without prior knowledge of bucket data or these paleohydrologic estimates (fig. 1a). Henz estimated maximum rainfall of about 130 mm in about an hour from the cell located near the head of Spring Creek with similar core isohyetal patterns, a storm footprint (for less than about 50 mm) nearly twice as large, and oriented slightly different (fig. 1b). Fulton (1999) evaluated the performance of the Weather Surveillance Radar-1988 Doppler rainfall estimate for the July 12, 1996 storm. He estimated a maximum of 72 mm of rain for 2000-2100 MDT and located about 2 km south of Buffalo Creek (not shown) and similar size as Henz's.

These comparison suggests that paleohydrologic techniques provide reasonable estimates of rainfall amount and spatial coverage. There is some potential for misinterpretation with the paleohydrologic approach due to variations in rainfall intensity during a storm and how they produce variations in the character of geomorphic evidence and flooding. Paleohydrologic

estimates were found to be difficult to obtain when the time between storms is small. This is due in part to time for hillslope recovery and difficulty discerning HWMs for different storms when a large flood precedes smaller floods. Uncertainties in rainfall amounts also can affect paleohydrologic results. Geomorphic rainfall estimates had greater uncertainties for rainfall less than about 25-50 mm in an hour. Combining geomorphic and hydrologic methods and obtaining field data soon after a storm, for various hydroclimatic settings (including stages of post-fire watershed recovery), and validating results for numerous storms should help improve the paleohydrologic estimates. Using all sources of information (systematic and bucket data, paleohydrologic, radar, and satellite) should provide the most reliable estimates of rainfall characteristics.

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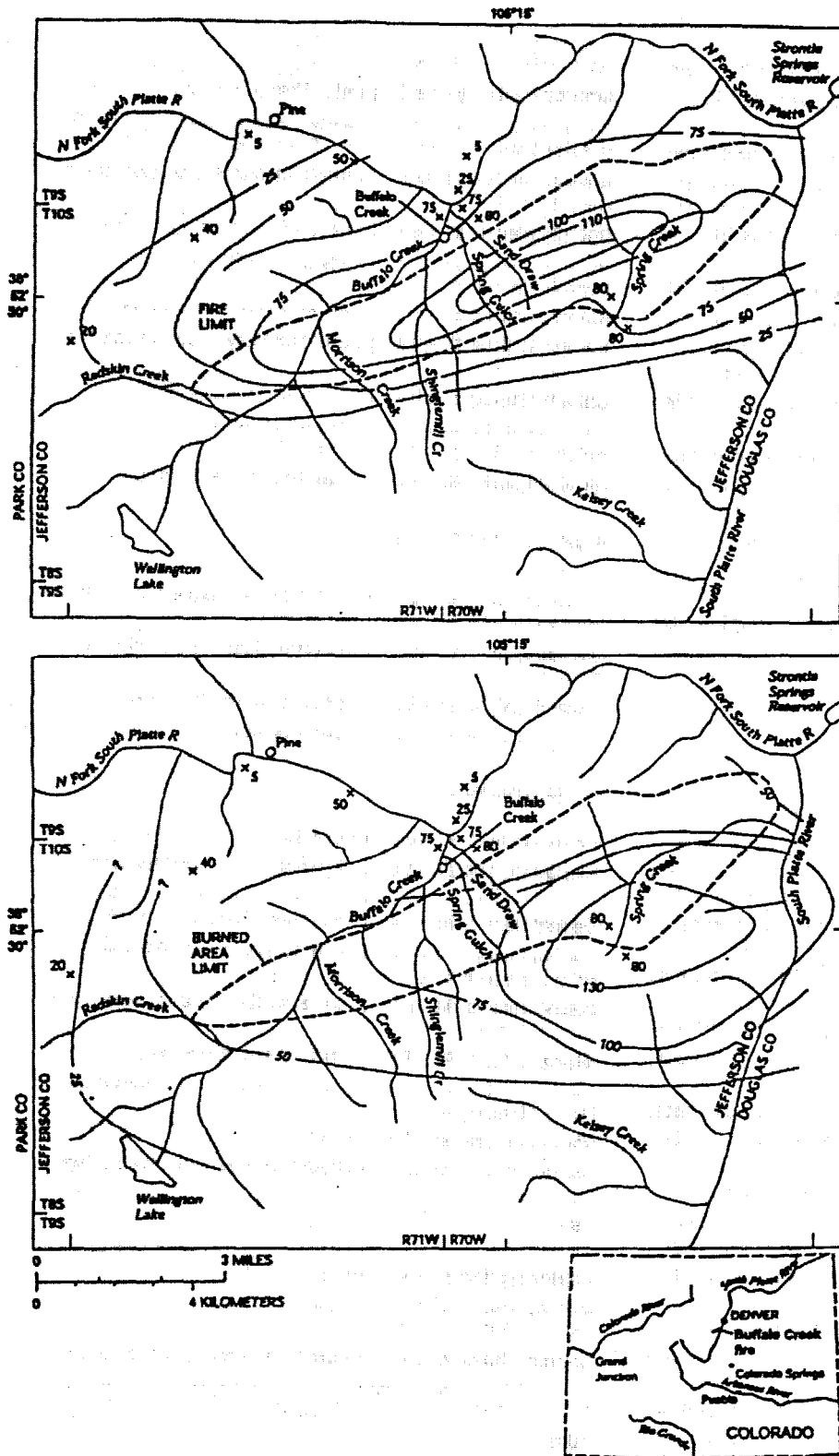


Figure 1. Map of the Buffalo Creek study area showing the extent of May 18, 1996 wildfire (heavy-dashed line). Inset map at lower right shows the general location of the study area near Denver and Colorado Springs, Colorado. Twenty-four hour rainfall amounts in millimeters from the bucket survey shown as "x." Isohyets, in millimeters, for the July 12, 1996 rainstorm: a.) from peleo hydrologic rainfall estimates; and b.) from Henz's NEXRAD radar rainfall reconstruction.