2.1 COMET® FLASH FLOOD CASES: SUMMARY OF CHARACTERISTICS

Matthew Kelsch
Cooperative Program for Operational Meteorology, Education and Training (COMET)
University Corporation of Atmospheric Research (UCAR), Boulder, Colorado

1. INTRODUCTION

Flash floods are phenomenon in which the important hydrologic processes are occurring on the same spatial and temporal scales as the intense precipitation (Kelsch et al., 2000). Flash floods are among the most deadly weather events in their impact but remain somewhat elusive in definition. Unlike other forms of dangerous weather, such as severe thunderstorms, there is very little objectivity to the definition of a flash flood. A flash flood cannot be defined by either the amount of rain or the response of the stream because both vary significantly from one event to another. Rather, the National Weather Service (NWS) uses a definition based on the time lag from the causative rainfall to the flood, with that time lag being six hours or less (NWS, 2001).

Data and analyses for more than two dozen flash flood events are part of the hydrometeorological material at the Cooperative Program for Operational Meteorology, Education and Training (COMET®). Some of these appear in the NWS/COMET case study library. Many were used as detailed laboratory exercises during residence courses such as *Hydrometeorology* (http://www.comet.ucar.edu/class/hydromet/index.htm#00-3) and the *COMAP Symposium on Heavy Precipitation and Flash Flooding* (http://www.comet.ucar.edu/class/comap_symposium/index.htm). A number of cases were presented as part of flash flood training in various multi-media training materials including the *Flash Flood Operations and Awareness Teletraining* (http://www.comet.ucar.edu/class/FLOAT_2001/index.htm) that was delivered in July 2001. A virtual field trip Webcast titled *Urban Flooding: It Can Happen in a Flash* (http://meted.ucar.edu/qpf/urbanf/indexm.htm) is based on the Fort Collins, Colorado, laboratory exercise and field trip from the hydrometeorology course. The Webcast titled *A Social Science Perspective of Flood Events* (http://meted.ucar.edu/qpf/socperfe/index.htm) looks at the societal response to flash flood events.

With the large variety of events and a number of subject matter experts working with the COMET Program, we have explored some of the common characteristics of flash floods throughout the United States. This paper will review and summarize these findings. Flash floods that are associated with ice jams and structural failures (such as dam or levee breaks) are not included.

2. CASES

The asterisks in Figure 1 shows the locations of flash flood events that were investigated for this study (Kelsch, 2001; Baeck and Smith, 1998; Davis, 2000). More detailed information is given in Table 1. These events were all significant flash flood events that fit the NWS definition where the flood occurred within six hours of the causative rainfall. In some cases, however, the flash flood occurred in far less than six hours. In other cases the severe flash flood occurred within six hours of the most intense rainfall, but that period of intense rainfall occurred during a long-duration rainy period. They all fit the qualitative definition that distinguishes a flash flood as a flood in which the runoff is occurring on the same time and space scales as the causative precipitation. Many of the cases, especially those in non-mountainous regions, occurred in areas where there had been a large amount of alteration to the landscape, such as urbanization. All cases shown involve intense convective precipitation. The dashed areas in Figure 1 were categorized more as general flood events rather than flash floods.

**Corresponding author address*: Matthew Kelsch, UCAR/COMET, P.O. Box 3000, Boulder, CO 80307-3000; email: kelsch@ucar.edu

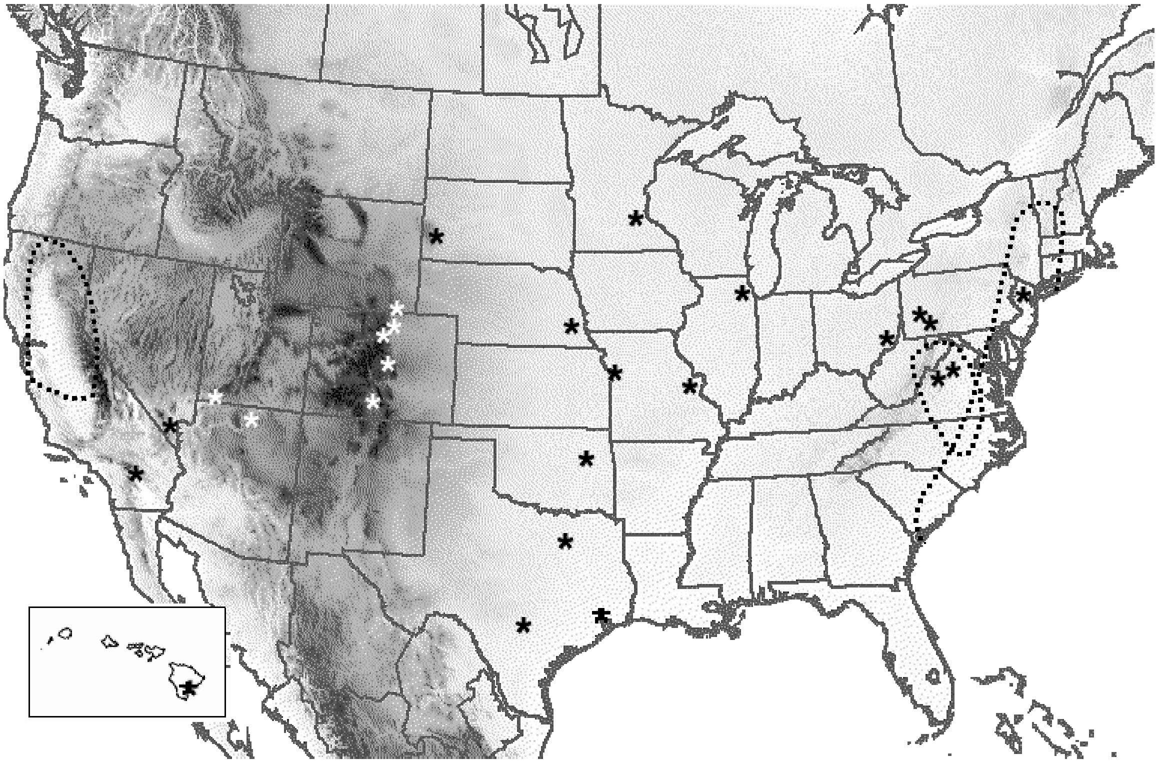

Figure 1. Asterisks indicate the locations of flash flood events. All asterisks are the same, different colors are used to optimize the contrast with the underlain topographic image. The black dashed areas indicate events with more widespread general flooding.

Table 1. Locations and dates of the flash flood events along with basin sizes, peak rainfall rates and storm total accumulations associated with the events. Some events from outside the United States are included. A couple very recent events depicted on Fig. 1 are currently being reviewed and are not yet listed in the table.

Location	**Date**	**Basin Size (km^2)**	**peak rate (mm/h)**	**accumulation (mm)**
Sparta, New Jersey	12 Aug. 2000		120	250
Omaha, Nebraska	7 Aug. 1999	10-75	150	350
Saguache, Colorado	31 July 1999	80	125	190
Forest Falls, California	11 July 1999	35	>100	
Las Vegas, Nevada	8 July 1999		100	75
San Antonio, Texas	17 Oct. 1998	10-65	200	530
Kansas City, Missouri	4 Oct. 1998	25	>125	100
Zion Nat'l Park, Utah	27 July 1998	75	75	45
Fort Collins, Colorado	28 July 1997	30	125	250
Appalachians, Virginia	6 Sept. 1996	50-100	200	400
Biescas, Spain	7 Aug. 1996	30	150	165
Aurora, Illinois	18 July 1996	30-55	>125	430
Buffalo Creek,Colorado	12 July 1996	25	100	75
Apuanian Alps, Italy	19 June 1996	60	270	
Kinsey Run, Virginia	27 June 1995	50	300	500
Dallas, Texas	5 May 1995	10-30	225	100
Shadyside, Ohio	14 June 1990	32	>100	
Etna, Pennsylvania	30 May 1986	16	125	200
Cheyenne, Wyoming	1 August 1985	33	100	170
Johnstown, Pennsylvania	20 July 1977	39	>100	300
Big Thompson, Colorado	31 July 1976	75	~100	300
Rapid City, South Dakota	9 June 1972	125	200	350
mean		**47**	**>146**	**246**

3. PRECIPITATION

Precipitation characteristics were reviewed for the cases shown in the previous section to identify common features. All of these flash flood events resulted from intense convective precipitation, but the magnitude of the intensity and the duration of the intense precipitation showed a great deal of variability.

Storm total accumulations that resulted in major flash flood episodes varied from as little as roughly 50-75 mm (2-3 in), as in the Las Vegas, Nevada, storm of 8 July 1999 to roughly 500 mm (20 inches) as was the case in part of Madison County, Virginia, on 27 June 1995. The spatial and temporal distribution of the heavy precipitation is very important for the flash flood problem. In some cases the short-duration high-intensity precipitation may be more important to the flash flood danger than extended duration or excessive accumulation.

The peak intensity of the events given in Table 1 shows the peak rates that were sustained for roughly a 15-30 minute period. These are not hourly accumulations since the greatest precipitation rates typically occur over periods of less than an hour. In some of the bigger events, the peak precipitation rates may recur a number of times over several hours in one localized area. Precipitation intensity information may be critically important in areas characterized by very fast-response drainage basins. For example, the devastating flash flood that struck Dallas, Texas, on 5 May 1995 was the result of a significant but not a very unusual storm total accumulation of about 100 mm (4 in). However, that 100 mm fell very quickly with a peak precipitation rate of 225 mm/h (9 in/h). The most intense precipitation occurred over heavily urbanized basins that were roughly 30 km^2 (12 mi^2) and resulted in very rapid and severe runoff. Peak intensities for the events in Fig. 1 varied from about 75 mm/h (3 in/h) in some of the southwestern U.S. cases to 300 mm/h (12 in/h) in more humid locations of the central and eastern United States. If we look at all of the events that occurred from the Rockies region westward, the average peak intensity is about 125 mm/h (5 in/h) and the average storm total accumulation is about 180 mm (7.2 in). In the central and eastern U.S. and Hawaii, the average peak intensity is about 200 mm/h (8 in/h) and the average storm total accumulation is about 315 mm (12.6 in). The general differences between regions along with the variability within a climate region demonstrate why quantitative rainfall thresholds may be insufficient for defining a flash flood threat.

Although the precipitation in these storms was convective in nature, the characteristics of the convection varied. In most cases there was some degree of tropical maritime characteristics associated with deep tropical moisture and relatively weak to moderate instability and wind shear. Some cases exhibited remarkable low-centroid characteristics with tremendous low-level precipitation production, warm cloud tops, and minimal lightning activity. Further enhancement of precipitation production in low-centroid storms can occur where an axis of low-level wind intersects a boundary (either terrain or meteorological). The events in Sparta, New Jersey, on 12 August 2000 and Fort Collins, Colorado, on 28 July 1997 were classic examples (Kelsch, 1998). However, a small percentage of flash flood events occurred in severe weather environments where an intense burst of rain and hail over a small, fast-response basin can lead to rapid flooding. These types of storms, like those that struck Dallas, Texas, on 5 May 1995 or Kansas City, Missouri, on 4 October 1998 can be especially challenging forecast problems because they don’t fit the classic composites of flash flood scenarios (Maddox et al., 1980, Maddox et al., 1979) and concurrent severe weather can require large amounts of forecasters’ time and resources.

4. BASINS

Historically, the NWS has approached the flash flood problem primarily as a precipitation problem. Although the precipitation characteristics are a vital piece of information, the hydrologic response to that precipitation is easily as important, and in some cases, more important. A look at the flash flood events in section 2 show that flash floods are not limited to where it rains the longest and the hardest. Figure 1 shows that many events take place in steep terrain areas of the western U.S. and the Appalachians. In the central U.S. most events involve urbanized basins. A number of events occur in the arid southwestern U.S. where annual precipitation amounts are relatively low and the drainages and stream channels have evolved such that they are generally low-volume compared to the generally larger volume stream channels found in more humid, deep-soil areas. Thus, short-duration intense rainfall can overwhelm some of the small stream channels in arid areas very quickly. In one case, 12 July 1996 in Buffalo Creek, Colorado, a forest fire had significantly altered the land and resulted in enhancement of both the amount and speed of runoff during a short-duration heavy rainfall (Warner et al. 1999). In the central and eastern U. S. stream channels are typically higher volume and soil layers are generally deeper. In these areas the role of antecedent moisture is important for increasing the flash flood threat by increasing stream levels soil saturation. This decreases both the ability of the soil to absorb additional water and the ability of the stream channel to accommodate the runoff without going into flood.

One of the most common basin characteristics is the small size. The average size of the basins or sub-basins for the flash flood events in Table 2 is only 46 km^2 (18 mi^2). Given the small area covered by intense convective precipitation, the smaller drainage basins are more likely to have rapid response to the precipitation. There are several ways that the magnitude of a flood crest can be further enhanced in these small basins. First, a convective storm located completely within a small basin that is either quasi-stationary or moving slowly down the slope of the basin will present a greater danger than a convective storm that is only partially in the basin and/or moving slowly up the slope of the basin. Second, steep slopes can enhance the speed of the runoff toward the bottom of the basin. Third, impermeable surfaces decrease the infiltration rates and increase runoff. Impermeability can be either naturally occurring (rocks, clay soils) or human-altered surfaces (urban developments, deforestation). Fourth, saturation of soils is important for decreasing infiltration rates and increasing runoff. This may be less important in areas with thin impermeable soil layers. Fifth, artificial drainage structures and blockages such as culverts, channelized streams, retention ponds, levees, and low bridges can significantly alter the behavior of floods during anomalously intense precipitation events by preventing the natural processes from occurring. Flood control structures work best if no debris blockages occur, and if the amount of water moving through the drainages is within the planned "worst case scenario."

5. SUMMARY

Improvements to flash flood warnings have been most apparent in those cases that not only involve high-intensity rainfall, but also excessive accumulations. These cases are most likely to follow the classic scenarios outlined in flash flood studies since the 1970s. The more difficult situations are those that involve intense precipitation, but not extended durations or atypically large total accumulations. Often there are specific hydrologic factors that contribute to enhanced speed and amount of runoff. This can include urbanization, fire-altered landscape, steep and naturally impermeable surfaces, and low-volume or altered stream channels. Sometimes severe weather occurring with or immediately preceding a flash flood can be a distraction due to the large amount of resources it takes in the forecasting environment.

Whether it is the classic or non-classic set up for flash flooding, hydrologic tools to date have offered little assistance with allowing warnings to specify the greatest threat areas. Forecasters typically do not know the locations or hydrologic conditions of their small, fast response drainages. The behavior of the water as it moves along or within the surface layers is easily as important as the rainfall. Although the Area Mean Basin Estimated Rainfall (AMBER) program was not a hydrologic tool in terms of hydrologic modeling, it offered forecasters the ability to infer some hydrology by providing basin information on the same scales as multi-sensor rainfall data (Davis, 2000). This is very important since flash floods are distinguished from main-stem river floods in that the runoff is occurring with the same spatial and temporal scales and the rainfall. Implementation of AMBER-like functionality in the NWS Flash Flood Monitoring and Potential (FFMP) tool is a necessary first step before eventually implementing models that can provide guidance for more effective and detailed flash flood warnings.

Finally, the improvement of mesoscale precipitation guidance is very important for improved flash flood warnings as well. QPF is one of the more difficult variables to forecast in Numerical Weather Prediction (NWP). NWP QPF for intense convective rainfall in the 1-6 hour range and improved modeling of precipitation efficiency factors are necessary for accurate flash flood warnings. Until then NWP and forecaster expertise can determine the general magnitude and location of the greatest threat, but forecasting for specific localized areas often falls into the nowcasting regime.

6. ACKNOWLEDGEMENTS

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7. WORLD WIDE WEB LINKS

From the COMET Classroom Education and Training pages, http://www.comet.ucar.edu/class/index.html, you can access *Hydrometeorology* classes, http://www.comet.ucar.edu/class/hydromet/index.htm#00-3, and the *COMAP Symposia on Heavy Precipitation and Flash Flooding*, http://www.comet.ucar.edu/class/comap_symposium/index.htm.

From the COMET Computer-based Training Modules pages, http://www.comet.ucar.edu/modules/index.htm you can access the *Flash Flood Operations and Awareness Teletraining* material, http://www.comet.ucar.edu/class/FLOAT_2001/index.htm, the Webcast titled *Urban Flooding: It Can Happen in a Flash*, http://meted.ucar.edu/qpf/urbanf/indexm.htm, and the Webcast titled *A Social Science Perspective of Flood Events*, http://meted.ucar.edu/qpf/socperfe/index.htm.

The NWS Glossary of Hydrologic Related Terms can be found at, http://www.crh.noaa.gov/hsd/hydefa-c.html.

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