3.5 FLOOD SAFETY: WHAT HAVE HISTORIC FLASH FLOODS TAUGHT US?

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1. INTRODUCTION

Flash floods are among the deadliest of weather phenomena. News coverage frequently brings us images of people and objects being swept away in raging floodwater. All too often survivor accounts suggest that the deluge occurred so quickly that there was no time to respond. Many flash flood victims are swept away while inside their vehicles. Sometimes devastating flash floods occur in areas experiencing drought. Expanding urban environments result in a greater risk of flash floods because urbanization generally increasing flood risk when compared to rural environments.

This manuscript reviews lessons learned from flash flood episodes in both rural and urban settings. It will examine the role of intense rainfall and the ground conditions that lead to flash floods. Runoff, that is, the behavior of water once it is on the ground, is often very important for determining the location and severity of flash flooding. Several cases will be described to emphasize the rapid evolution and localized nature of flash floods and the safety issues and societal impacts associated with these rapid-onset events.

2. WHERE AND WHY

Flash floods occur when rainfall is too intense for the ground to absorb the volume of water. Therefore, we pay attention to two critical factors: 1) intense rainfall rate, and 2) ground characteristics that enhance runoff.

Intense rainfall rates are typical during warm-season showers and thunderstorms. The ability of the ground to quickly absorb water, called the infiltration capacity, has a direct impact on how much water will head for the nearest stream or underpass as runoff. With lower the infiltration capacity, less rain water enters the soil, and more runs across the surface contributing to flooding.

Infiltration capacity is related to soil moisture, soil type, and soil surface conditions. In general, wet soil will have less infiltration than dry soil, and more flood risk. But in some areas the soil type and the soil surface conditions may be much more important to flood risk than soil moisture. Soil composed of clay will not allow rapid infiltration of water and thus result in greater flood risk than sandy soil, even if the clay soil is dry. Soils covered by impervious material, like parking lots, will have almost no infiltration capacity and result in much higher flood risks than soils that are naturally vegetated.

Steeply sloped watersheds are more prone to flash flooding because the water drains to the stream channel much more quickly than in flatter watersheds. That does not mean that flash floods cannot occur in gently sloped watersheds, but a greater slope increases the flood risk by increasing the speed of the runoff.

Many flash floods occur on very small watersheds. Often the surface area contributing the runoff that causes the flood is less than 40 km^2 (less than 15 mi^2).

2.1 The Kansas Turnpike, 30 August 2003

An example of how intense rainfall in a small drainage area can contribute to deadly flooding is dramatically illustrated in the Kansas Turnpike flash flood of 30 August 2003. This flood took place along a rural interstate highway in a part of the United States that is not known for steep terrain.

During the early evening of 30 August 2003, persistent torrential rain produced 150-200 mm (6-8 in) of precipitation along and immediately east of the Kansas Turnpike in east-central Kansas (Fig. 1). The heaviest rains fell at the headwaters of Jacob Creek which drains only 5-8 km^2 (2-3 mi^2) upstream of the turnpike. This is the bright yellow area on Fig. 1 to the right of the highway. With the

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ground already wet from earlier rainfall, large amounts of runoff surged downhill toward the turnpike. A culvert designed to carry the waters of Jacob Creek under the highway could not accommodate the large amount of runoff. Water backed up in Jacob Creek at the turnpike and onto the highway itself. Water then rose to a depth of almost a meter (3 ft) on the highway as it pooled up against a series of concrete barriers that separated the northbound from the southbound lanes of the turnpike. Vehicles became stalled in the deep waters.

At roughly 9:30 PM local time, 12 of the concrete barriers down the median of the turnpike broke loose from the weight of the floodwater and surged downstream along with 7 vehicles. Sadly, six people lost their lives. Fig. 2 shows the section of the turnpike that experienced the severe flooding. Erosion downstream (left) of the interstate can be seen in the photo.

This incident reminds us of three important lessons about flash floods. 1) Flash floods develop quickly in very localized areas. In this case intense rainfall for several hours in a small drainage area was the culprit. 2) Human development and alterations to natural watersheds can become the focus of flash floods even in rural areas. 3) Vehicles are unsafe refuge in floods.

2.2 Cheshire County, New Hampshire, 9 October 2005

Major flooding occurred across Cheshire County in the southwestern corner of New Hampshire on 9 October 2005. Unlike the Kansas Turnpike flood described in the previous section, the New Hampshire incident involved widespread flooding. But like the Kansas Turnpike, it was human-engineered structures that turned a somewhat notable flood situation into a deadly flash flood event.

Heavy rains had fallen over Cheshire County on 8 October, and an area of particularly intense rain moved across the county again during the night of 8-9 October. Fig. 3 depicts the rainfall amounts in southern New England with the circled area identifying Cheshire County, New Hampshire. Flooding was reported in numerous locations as runoff from the steep hillsides inundated small streams.

The worst flooding episode occurred in the predawn hours and was associated with water that became impounded by road embankments. Structural failure at some of these embankments resulted in sudden releases of floodwater. The most dramatic example of this occurred on Warren Brook just upstream of the small town of Alstead. Water had backed up behind a road embankment and formed a lake about 7.6 m (25 ft) deep and covering an area of about 5 hectares (12 acres). The road embankment failed just before sunrise and tore a path of devastation for 10 km (6 mi) along Warren Brook and the Cold River. There were several fatalities. Fig. 4 shows an example of the destruction left behind after the flood surge passed.

Among the most important lesson taken from this flash flood was the need for interagency collaboration. Although the National Weather Service had flood warnings for the area, their weather forecast models and advanced radar data do not inform forecasters where culverts get clogged with debris. Emergency officials in Cheshire County used the National Weather Service information and were especially alert to problems developing during the night. Fortunately, many people were evacuated along Warren Brook and the Cold River before the flash flood surged through.

2.3 Big Thompson, Colorado, 31 July 1976

On Saturday evening, 31 July 1976, the picturesque Big Thompson River canyon in Colorado was teeming with activity. It was the eve of Colorado’s centennial statehood celebration. It was also the month of the nation’s bicentennial and the very popular Rocky Mountain National Park rests at the upper end of the Big Thompson watershed.

During a four hour period that evening a thunderstorm deluged the upper parts of the canyon and its tributaries with up to 305 mm (12 in) of rain. The intense rain ran off the rocky surfaces and quickly down the steep terrain into the Big Thompson River. This rapidly swelled the river to a magnitude that was many times more volume than had ever been recorded. Many sections of U.S. Highway 34 through the canyon were obliterated along with many vehicles (Fig. 5). The flood claimed 145 lives, more than 70% of the victims were in vehicles when they lost their lives. Evidence of the flood's power can still be seen today.

The Big Thompson flood reminded us how quickly an intense thunderstorm can lead to disaster. But it was also a wake-up call for the vulnerability of people in vehicles. Today in canyons around Colorado, posted signs remind people to abandon their vehicle and climb to safety in flash floods, a decision that saved many lives that night. Another important survival action learned from this event was to avoid driving into floodwater at all by staying on parts of the road that were sufficiently elevated.

2.4 Lawn Lake, Colorado, 15 July 1982

Sometimes it does not take the wrath of Mother Nature's rainstorms to trigger flash floods. In many communities the failure of a dam or levee is a worst-case scenario. And these failures can occur at any time, even on sunny days.

Lawn Lake was a high elevation mountain lake perched above treeline in Colorado's Rocky Mountain National Park. It was formed behind an earthen dam.

Just about sunrise on 15 July 1982, the Lawn Lake dam failed and the water tumbled violently down the steep mountainside. The town of Estes Park was safely evacuated before the flood surge reached its downtown, but closer to the dambreak site, 2 campers died in the debris-laden deluge.

The alluvial fan, which is the massive debris deposit laid down by the flood, is one of the park's most beautiful and educational locations today (Fig. 6). Broken trees and multi-ton boulders that were hurled down the mountain are still a vivid reminder today about the incredible force of floodwater. It's an especially important reminder given that hundreds of earthen dams in less-than-ideal shape still exist across the United States and around the world.

3. THE URBANIZATION PROBLEM

The impact of urbanization on the natural watershed processes is resulting in a large increase in flash flood occurrences. Two factors come into play in urban areas: 1) there is more surface runoff during rain because of the impermeable surfaces, and 2) the runoff reaches the streams must faster when compared to natural settings.

What does this mean? It does not take as much rain to produce a severe flood in an urbanized watershed as it would have in the pre-urban conditions. In addition, the time that elapses from when the rain begins and the flood is raging can be under 30 minutes!

Modifications to stream channels such as straightening out of meanders, removing vegetation, and possibly lining the stream channel with concrete, all help increase the speed that water can flow and reduce the amount of water than goes into the ground. Storm sewer networks and the road grid can act as tributaries and quickly transport water from around the city and into the low spots or the stream channels.

3.1 Las Vegas, Nevada, 19 August 2003

During the late afternoon of 19 August 2003, heavy thunderstorm activity deluged the city of Las Vegas, particularly the northwestern parts of the city and its northwestern suburbs. Up to 76 mm (3 in) of rain fell in an hour, with a total of over 127 mm (5 in) in some areas (Fig. 7). Many of the natural basins in this region are quite small and heavily urbanized. As a result the time from the peak rainfall to the onset of severe flooding can be very short, under an hour.

As these basins transport water into the northwest side of Las Vegas, many of the natural channels, washes, and flood plains are forced into culverts. When the culverts cannot handle the volume, water surges downstream along the road. Rapid and turbulent floodwaters inundated many roadways in the northwestern parts of the city. Numerous rapid water rescues were performed, almost all for people in vehicles including some of the rescuers themselves (Fig. 8).

The Las Vegas flood reminds us how rapidly flooding can occur in cities and how vulnerable people in vehicles are to floodwater surging down roadways.

3.2 Fort Collins, Colorado, 28 July 1997

During the period of 5:30-10:30 PM local time on 28 July 1997, Fort Collins, Colorado received over 250 mm (10 inches) of rain, mainly on the western side of town (Fig. 9). Severe flooding along roadways, ditches and several small streams caused tremendous damage to university buildings and residences just downstream of the heaviest rainfall.

As the floodwater moving through the network of roads, ditches, and storm sewers surged into the small streams, these streams then swelled to historic proportions. Spring Creek, shown in dark blue on Fig. 9) was severely affected. Its flow increased from its normally placid rate of under 0.25 cubic meters per second (under 10 cubic feet per second), to a phenomenal 234 cubic meters per second (8250 cubic feet per second). The massive flow of water entered one of the cities planned “detention ponds” which is designed to mitigate flooding. This detention area is just upstream (to the left) of the red X’s in Fig. 9. But the detention pond filled up and the excess water surged downstream derailing a train, destroying trailer homes, undermining bridges, and causing explosions and fires when flammable material and electric lines were swept into the deluge (Fig. 10).

The Fort Collins flash flood provided some important lessons about flash floods in urban settings. Travel and communication become extremely difficult, so make sure you have a plan *before* the flood. Hazardous and flammable materials often become part of the flood hazards. And, of course, people in vehicles often need to be rescued from very dangerous situations.

4. SUMMARY

Flash floods typically result from a combination of intense rainfall and rapid runoff. Past flash floods provide important lessons about how to prepare for future events. Flooding will continue to happen. Human engineered structures often become the focus of the most severe episode within a flood event. This occurs mainly because water gets temporarily impounded by artificial barriers, and then the water is released suddenly when those barriers fail.

Vehicles are an unsafe place to be during floods. It only takes 45-75 cm (18-30 in) of water to float a vehicle. Once floating, the vehicle will quickly move to the faster-flowing water, which is typically the deeper part of the channel.

Flash floods occur very quickly after the start of intense rainfall. Often the time elapsed between the start of the rain and the flash floods is 3 hours or less, and in some urban watersheds, it can be under 30 minutes. It also takes less rainfall in an urban watershed to produce a severe flash flood.

Flash floods, especially in urban areas, may contain hazardous materials, broken electric lines, sewage, etc. Explosions and fires during flash floods are not uncommon.

The best defense against a flash flood is to avoid it. Turn around if you see floodwater in front of you. Never drive through flood water. If necessary, abandon your vehicle.

5. ACKNOWLEDGEMENTS

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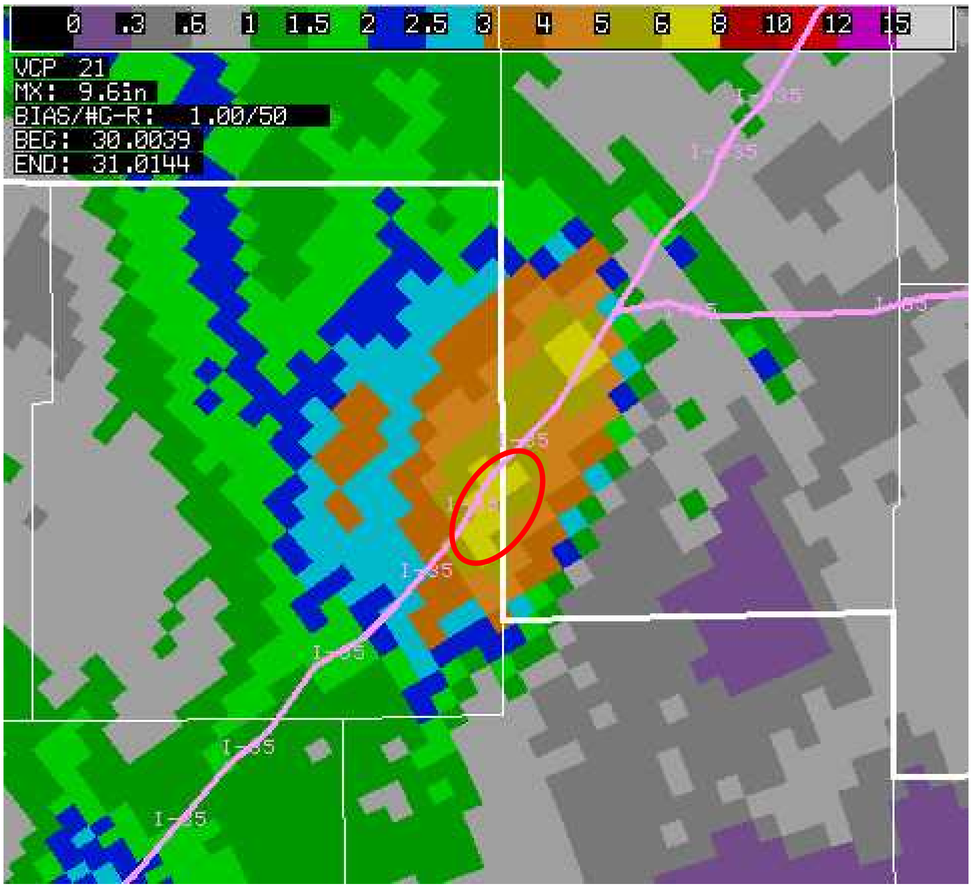

Figure 1: Radar-derived precipitation accumulation (inches) as of 0130 UTC 30 August 2003. The pink line is U.S. Interstate Highway 35, the Kansas Turnpike. White lines are county boundaries in east-central Kansas. The storm of interest is circled in red.

Figure 2: Aerial view of the flash flood area along the Kansas Turnpike taken just after the 30 August 2003 flash flood. To the left of the roadway is “downstream” where erosion scars are evident.

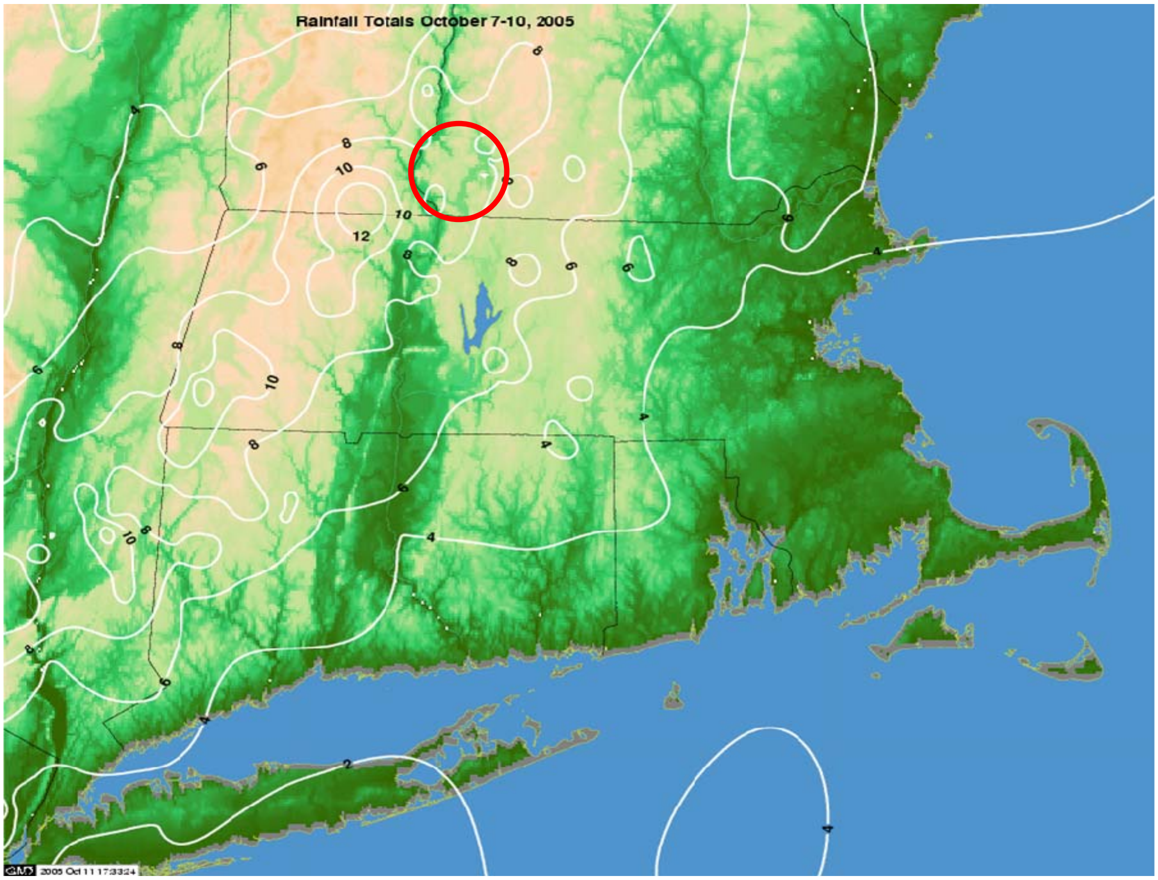

Figure 3: Rainfall analysis (in inches) on a topographic map of southern New England. Cheshire County is in the southwestern corner of New Hampshire as indicated by the red circle. Most of the rainfall at that location occurred on the night of 8-9 October.

Figure 4: Damage to a roadway from the 9 October 2005 Cheshire County, NH flash flood.

Figure 5: Damage to U.S. Highway 34 in the Big Thompson Canyon, Colorado from the 31 July 1976 flash flood.

Figure 6: Alluvial fan, or flood deposits, remaining in Rocky Mountain National Park, Colorado, due to the 15 July 1982 Lawn Lake dam failure.

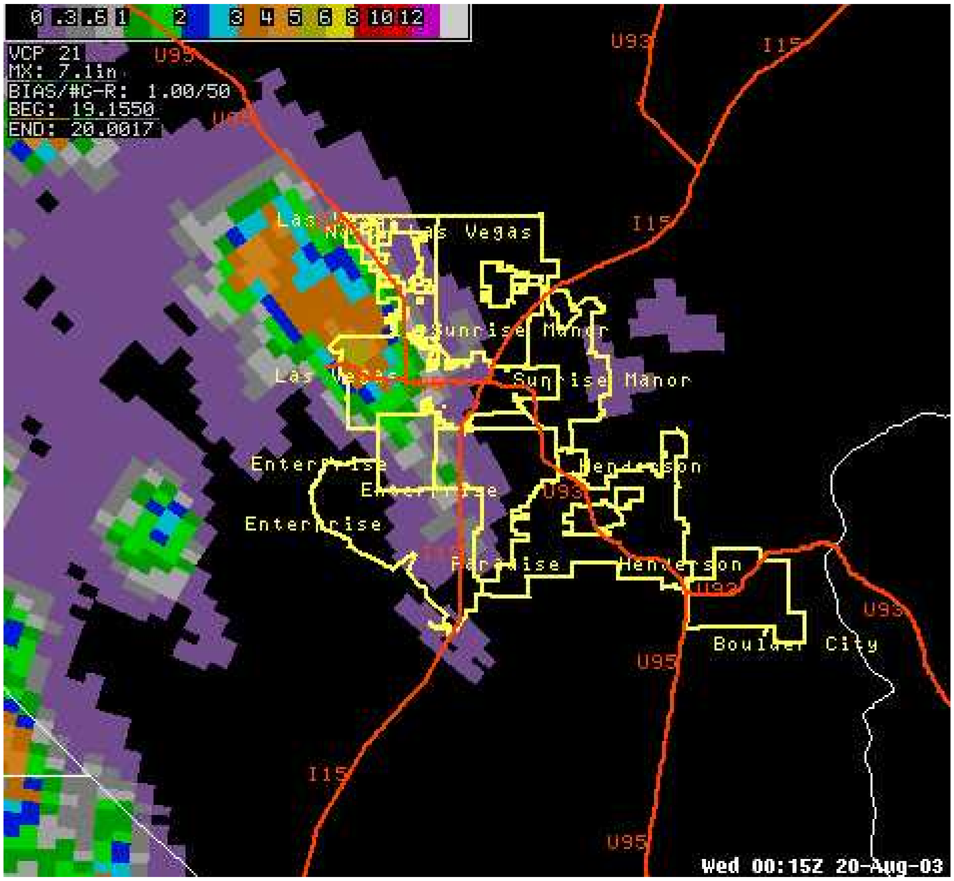

Figure 7: Radar-derived rainfall accumulation (in inches) as of 0015 UTC 20 August 2003. Much of this fell in about an hour. Yellow lines show the boundaries or Las Vegas, Nevada and its suburbs. Red lines are the main roadways.

Figure 8: Rescues during the Las Vegas, Nevada flash flood of 19 August 2003.

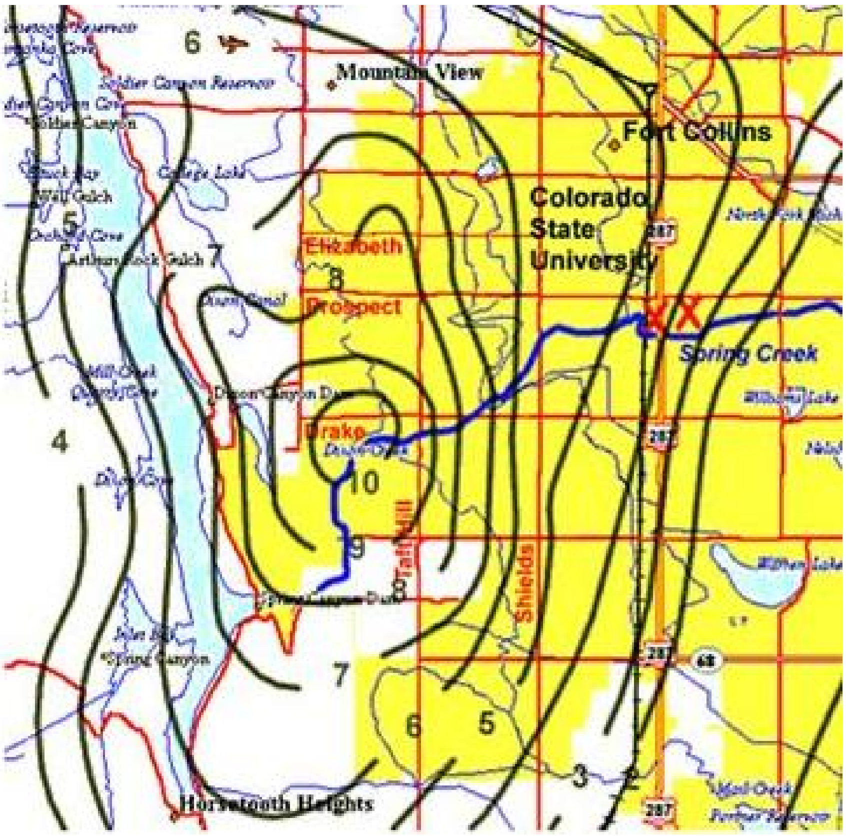

Figure 9: Rainfall analysis (in inches) for the Fort Collins, Colorado area for 2330 UTC 28 July 1997 through 0500 UTC 29 July 1997. Yellow shading shows the urbanized areas. Spring Creek is highlighted in blue, major roads in red, and the railroad in black. The two red "X's" show where fatalities occurred, four in a mobile home park (left x) and one in a nearby residential area. Spring Creek drains 13 square miles between its headwater and the red X's.

Rescue worker paddling a boogie board into the Johnson Mobile Home Park during the flood, 11:20 PM.

Figure 10: Rescue actions during the Fort Collins, Colorado flash flood of 28 July 1997.