Two Floods in Fort Collins, Colorado: Learning from a Natural Disaster

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ABSTRACT

A flash flood in Fort Collins, Colorado, on 28 July 1997 resulted in 5 deaths, 62 injuries, and more than $250 million in property damage. Following the 1997 flood, a great many changes were made in the city's preparedness infrastructure. On 30 April 1999, a combination of heavy rain and melting snow caused a second, less serious flood event. This article reports on the changes implemented following the first flood and their effectiveness during the second.

1. Introduction

A devastating flash flood in Fort Collins, Colorado, on 28 July 1997 resulted in 5 deaths, 62 injuries requiring hospitalization, and more than $250 million in property damage (Weaver et al. 1998; Petersen et al. 1999; Weaver 1999). Rainfall totals were so large that in some places across the region they approached 500-yr return frequencies. Significant flooding occurred in about half the city, with the most serious events taking place in and around a normally tranquil stream known as Spring Creek and in many neighborhoods in central and southern Fort Collins.

Following the 1997 flood, a great many changes were made in the city's preparedness infrastructure. On 30 April 1999, the culmination of two days of heavy stratiform rain falling onto thousands of hectares of melting snow caused volume flooding along the Poudre River in northern Fort Collins. Though this river was not a problem during the 1997 flash flood, the Poudre incident gave the response community the opportunity to test its new system. Only about half the planned changes were in place at the time, but results from this first experience exceeded the expectations of the emergency management staffs of both the City of Fort Collins and Larimer County. This article reports on the changes implemented and their effectiveness during the 1999 flood.

2. Preparedness and mitigation efforts

Following the 28 July 1997 flash flood, emergency planners from the City of Fort Collins and Larimer County worked in partnership with citizen-volunteers and staff from the Federal Emergency Management Administration (FEMA), the National Oceanic and Atmospheric Administration (NOAA), Colorado State University (CSU), and the Cooperative Institute for Research in the Atmosphere (CIRA) to develop an exhaustive listing of places where the city's emergency response system either fully or partially failed. Once these weak points were identified, the next task was to design innovative, realistic solutions to eliminate, or at least mitigate, their impact. The problems identified fell naturally into one of two categories: 1) lack of awareness and/or recognition of the unfolding disaster, and 2) problems in communication. Some of the proposed solutions are listed below. Parenthetical notations identify those items that were in place at the time of the second incident.

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Awareness and/or recognition

- *Better interaction with National Weather Service forecasters.* The City of Fort Collins Office of Emergency Management has improved its working relationship with the National Weather Service (NWS), including making a conscientious effort to interact regularly with the NWS Warning Coordination Meteorologist (WCM) for the region. (This improved interaction was in place by 30 April 1999.)
- *Less human-dependent severe weather notification.* The city has installed an NWS Emergency Manager's Weather Information Network (EMWIN) that receives weather products (including watches, warnings, and advisories) automatically. Software plug-ins allow the system to send messages via e-mail, or to a printer, and can trigger a number of electronic pagers based on "keyword" cues. (In place by 30 April 1999.)
- *Improved monitoring of rainfall and runoff.* The need for several new automated precipitation and stream flow gauges was identified, especially within flood-prone areas. Information from this network is transmitted electronically to the Fort Collins Stormwater Utility Office and the city Emergency Manager (EM), giving a real-time view of rainfall and stream levels. (Most new gauges were in place by 30 April 1999.)
- *Better feedback from the city to the NWS.* Fort Collins has installed a prototype system called the Local Area Data Acquisition and Dissemination system that allows Fort Collins to automatically transmit stream flow and precipitation data back to the NWS. (Though this system had not been installed by 30 April, the most critical observations were transmitted by telephone to NWS forecasters.)
- *Locally generated Stormwater notifications during flood events.* Fort Collins Stormwater Utility is implementing a new program called "WatchDog." The software monitors precipitation and stream flow measurements electronically. Thresholds are set, upon which automatic actions are then taken. For example, an excessive stream flow along a local river or creek might trigger automatic notification at the police department and/or the Office of Emergency Management, alerting them that a recreational area or a bike path needs to be closed and that discharge levels within the city are reaching dangerous levels. (This system is not in place as of this writing.)
- *Assessing the ramifications of heavy rain in near–real time.* The Stormwater Utility office, together with the city's Geographic Information Systems (IGS) staff, are developing a real-time flood inundation mapping and notification system that integrates a newly acquired, high-resolution digital terrain model (0.6-m vertical resolution) with a variety of other inputs including weather forecasts, stream flow data, rain rates, and hydrological expertise. The information will be used to initialize a computer-based runoff model[1] that will provide near–real time flood forecast information to the city EM as an event unfolds. (This database was not in place on 30 April 1999 but is nearly complete as of this writing.)
- *Improved access to environmental information during severe weather events.* As proposed, this concept requires a special staff to be on hand in the Emergency Operations Center (EOC) during emergencies, and ideally includes 1) a "tactical meteorologist" (now manned by a volunteer from the CSU Department of Atmospheric Science or CIRA), 2) a GIS technician (city staff), and 3) a Stormwater representative (city staff). Each of these positions is at the same physical location in the EOC and is equipped with at least one computer, a dedicated phone line, and a large-screen projector. The goal is to provide city officials with the most current environmental information possible during natural disasters. During flooding events, for example, weather data from satellite and radar are displayed in real time, water-depth information is updated in real time with stream and precipitation gauge data, and digital photographs from trouble spots around the city are projected for analysis and discussion. (This entire system was in place by 30 April 1999; see section 3 below.)

Communications

- *Direct communications with citizens who may be "in harm's way."* A "reverse-911" dialing system that allows the EOC to send a prerecorded message to about 200 homes per minute over the telephone is now in place. A specific threat area is selected electronically from a map at the dispatch console, allowing the dispatcher to 1) quickly warn residents in imminent danger, 2) direct the residents

[1]Several components are being integrated for this application. For a brief listing see the appendix.

to public sources of information, and 3) help control call volume by specifying when and *when not* to call 911. (This system was not in place on 30 April 1999 but would not have been needed given the outcome of the event.)

- *Informing the general population at risk.* A new, low-power AM radio station (broadcasting at 530 kHz) was set up in November of 1999. It is designed to help keep the public informed during disasters. The station is advertised locally at regular intervals and mentioned as an information source on the reverse-911 message. The station is equipped with an emergency power system, so that it can continue transmitting in the event of power loss. (Not in place on 30 April, but see media discussion below.)
- *Educating/supporting E-911 dispatchers.* Natural disaster information cards were designed that cover a variety of natural disasters. The cards are similar to those used by 911 dispatchers for emergency medical directions. Designed locally, they have been reviewed and edited nationally and include input from NOAA, FEMA, and the American Red Cross. These cards are designed to allow dispatchers to quickly sort out the serious incidents from the trivial and obtain information vital to rescue units. The cards can be found online at www.ci.fort-collins.co.us/C_SAFETY/oem/overview_ndic.htm.

3. The 30 April 1999 event

Prior to 29 April 1999, discharge rates for the Poudre River were running close to normal for that time of the year, with values of between 100 and 200 cubic feet per second (cfs)[2]. However, a series of unusual weather events changed the situation in a very short period of time. Beginning 21 April, there was a 2-week period of moderate rainfall along the Front Range of the Rocky Mountains, and of heavy, wet snows in the nearby foothills to the west (Colorado Climate Center 1999). Mountain/foothills snowfall became heavy on 22 April, and by 26 April new snow, more than a meter deep, had accumulated across most of the contributing area within the Poudre River watershed.

On Thursday, 29 April, a second system—one that was warmer than the first—began to bring moderately heavy rainfall along the entire Front Range including the foothills where the wet snows from the days before had already begun to melt. Stratiform rain falling at a rate of 0.4–0.7 cm h^{-1} seems modest compared to summer storms that can produce 10 times those rates, but thousands of hectares of sloping terrain were being affected by the steady rain and it was falling onto a very deep, very wet snow. The result was "volume flooding," an unusual occurrence in Colorado (Colorado Climate Center 1999). Discharge rates along the Poudre River started to increase rapidly early in the day on 29 April (Fig. 1). Part of the Stormwater Utility's action plan when high discharge rates are first noted is to begin inspecting the local rivers, creeks, and ditches to verify those higher values locally, and to search for blockages in culverts and drains. These inspections gave first indications of a serious potential for flooding. In fact, flow rates were increasing so fast that the Stormwater Utility flood plain manager contacted the city's EM on the evening of 29 April to discuss the situation and formulate a tentative action plan. The proactive procedures put in place following the 1997 flood had given response officials the opportunity to identify a developing problem at its very inception. It should be noted that the EMWIN successfully provided a planned redundancy at this point. At 1758 mountain standard time (MST), the NWS issued a flood watch for Thursday night and all day Friday. The full text of this watch arrived at the Office of Emergency Management, triggering the EM's pager at 1810 MST. This message would have alerted officials even if the stream gauges had malfunctioned, or failed entirely. Furthermore, the EMWIN system forwarded continuing updates throughout the night, and

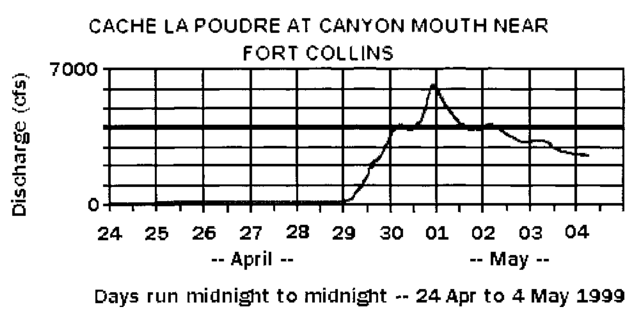

FIG.1. Chart showing discharge rates at the mouth of the Poudre canyon, approximately 8 miles northwest of Fort Collins. The chart gives discharge rates in cubic feet per second (cfs) for the period 24 Apr–4 May 1999. Increments are at 12-h intervals beginning at midnight (MST) on 24 Apr.

[2]Discharge rates in the United States are typically given in cfs. For conversion purposes 1 cubic foot = 28 liters ~0.028 cubic meters per second.

this information was reviewed at 0600 MST the following morning.

By the morning of 30 April, discharge rates along the Poudre River just upstream from Fort Collins had increased to nearly 4000 cfs—20 times greater than just 24 hours earlier. In fact, this flow rate is just 2000 cfs short of what is considered flood stage in certain parts of the city. Furthermore, an early morning flood watch and watch statement called for rain, possibly heavy at times, to continue throughout the day. Finally, at about 0830 MST, the city EM learned that the Larimer County emergency office had become flooded and had lost its telephone system. Because there was the possibility of a large population area being affected by dangerous river flooding, with critical systems already starting to be affected, the decision was made to initiate joint city–county emergency operations.

The new police services building (within which will be housed a brand new EOC) had not been constructed yet, so a conference room at the Fort Collins Stormwater Utility building was utilized as the operations center. The room was chosen because it was large and equipped with multiple telephone outlets and computer stations. The center was fully functioning by 1100 MST, with a total of 19 people from several agencies present. In addition to city, county, and university emergency management staff, there were representatives from the police, the Stormwater Utility, and the Poudre Fire Authority (the local fire department). A media representative was also designated. By noon, the meteorologist was projecting animated loops of western U.S. satellite imagery, and local radar output, onto a large projection screen at the front of the room. The GIS technician also had detailed city/county maps displayed, onto which flooding reports and discharge rates were plotted as they were received.

As discharge rates along the river began to increase, city staffers were sent to photograph troublesome areas along local rivers and creeks. In most cases, these locations were selected by Stormwater engineers and the EM; then police officers in the vicinity provided preliminary assessment. Within the hour, digital photos of what was actually occurring around the city were available (Fig. 2), and problem areas were plotted on the GIS maps of the city. Furthermore, through this real-time assessment process, the media representative could provide a constant flow of new information, which was what reporters needed to keep the public informed. For this event, local radio stations were briefed at regular intervals. In the future, with the AM radio station up and operating, information for commercial stations and the general public will be made available at 30-min intervals by the emergency manager from the EOC.

Staff briefings were held at noon, 1600, 2000, and 2200 MST. The environmental team presentations formed the focal point for these discussions. In addition to the projected computer output, a whiteboard was set up at the center of the room summarizing pertinent environmental data. There were several columns of frequently updated numbers. For example, one column listed 3-hourly river discharge-rate *forecasts* for the upcoming 24-h period, a second had *actual* discharge numbers (entered as they were received), a third column had 3-hourly rapid update cycle model precipitation *forecasts,* a fourth *actual* precipitation amounts from local gauges, and so forth.

As in all weather-related emergencies, there were several unexpected occurrences. One of these was that the rainfall turned out to be persistent enough to cause local flooding in some of the drainages around the city that were *not* associated with the Poudre River. During the previous week, the Fort Collins area had received nearly 9 cm of liquid equivalent precipitation. It had been so cold that the rain changed to snow and back several times over a 4-day period. With the cool temperatures and cloudy skies, not much evaporation had occurred. Plus, the frost line was still several centimeters deep, rendering the soil generally impervious to percolation. To add to the saturation problems, Fort Collins received an additional 4.4 cm of rain on

FIG. 2. In addition to the serious flooding that occurred along the Poudre River, many other areas around the city experienced significant flooding. This photograph (taken by digital camera) shows a flooded Spring Creek bike trail beneath the Riverside Avenue bridge on the late afternoon of 30 Apr 1999. For other photos from this event refer to http://www.ci.fort-collins.co.us/C_SAFETY/oem/flood99.htm.

29 April. Thus, the heavier rains on 30 April (a 24-h total of 6.1 cm at the CSU weather station) almost immediately turned to general runoff.

Midafternoon found flooding beginning at various low points all across the city. Once again, the proactive response by EOC staff helped identify these areas early and allowed for important mitigation responses. For example, several homes were protected by sandbags, because the city knew *where* to look. These homes suffered less damage on 30 April than they had in several previous incidents in which the flooding had been much less significant. Several flooded roads were closed before automobile drivers could take questionable risks. In the 1997 flood, hundreds of people drove their vehicles into moderate to very deep water. Many of those vehicles were either totally lost or suffered hundreds of dollars in damage to engines, upholstery, or electrical systems. A total of $4.7 million in automobile insurance claims were processed. The city was criticized for not blocking roads earlier. This time no such damage occurred.

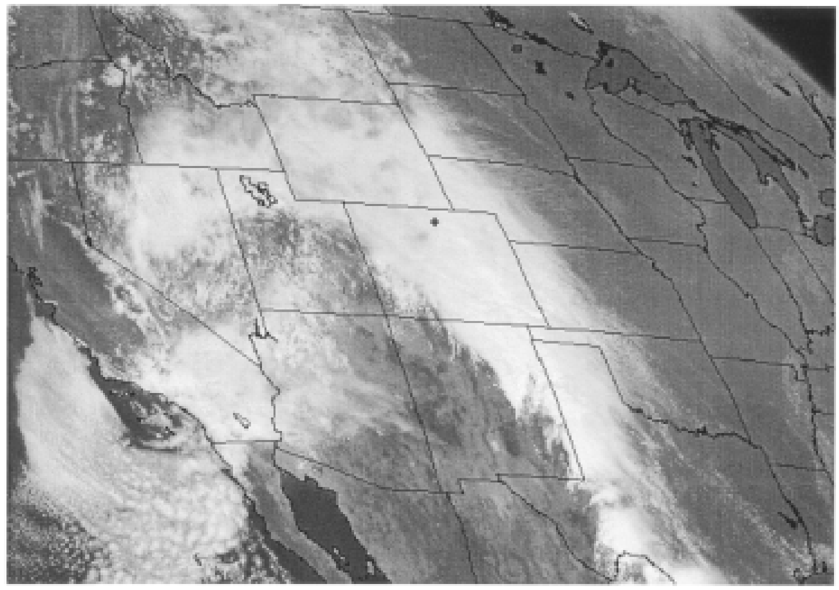

FIG. 3. *GOES-West* visible wavelength image from 12:00 noon (MST) on 30 Apr 1999 showing large comma-shaped system over the western United States. The plus sign in north central Colorado marks the location of Fort Collins.

As the afternoon progressed, the weather and flooding situation seemed to be getting a little worse than expected. Slightly more rain fell in the city than was forecast for the periods 0800–1100 MST and 1100–1400 MST, though Poudre River discharge rates seemed to be increasing approximately as forecast. By 1500 MST discharge rates were nearing 5500 cfs. The concern by officials in the EOC was that the additional rainfall, plus the rapid snowmelt, would soon increase those discharges to values even higher than originally predicted. The rain had been expected to begin decreasing around 1700 MST, but the satellite loops at that time showed that the large weather system (Fig. 3) had stalled—it was not moving eastward as the earlier models had indicated it would. Plus, right around that time (1717 MST) came the worst possible news. An agricultural dam on the north fork of the Poudre (upstream from Fort Collins) had failed, and an additional 1000–1200 cfs of water was headed toward the city.

This is the point where the improved communications with the Denver, Colorado, NWS Forecast Office paid off. The local meteorologist called the lead forecaster in Denver several times between 1700 and 1900 MST trying to develop a realistic expectation as to what effect the additional rainfall plus runoff would have both before and during the confluence of the dam-breach water with the Poudre River. The forecasters and hydrologist in Denver, working with EOC staff, arrived at the conclusion that—while the synoptic system did seem to be stalled—temperatures in the foothills would soon be below freezing, a factor that would help mitigate the snowmelt problem. With this in mind, the EOC team decided that another couple of hours of "wait and see" might be appropriate before ordering any evacuations. This proved to be an excellent decision for a couple of reasons. First of all, at 1910 MST it was learned (through the NWS) that the dam that had failed was not situated on the north fork of the Poudre River as had been earlier reported. Second, even though computer models indicated that the rains would continue throughout the night, the large low pressure system began to move eastward and weaken just before 2100 MST (Fig. 4). Rain rates decreased slowly and by 2300 MST had ended completely. A light drizzle started up just after 0200 MST as the core of the system passed overhead, but the heavier rains, along with the river flooding, were over. By carefully continuously reviewing the NWS forecast information, monitoring river levels, and analyzing the satellite imagery and radar data, the determination

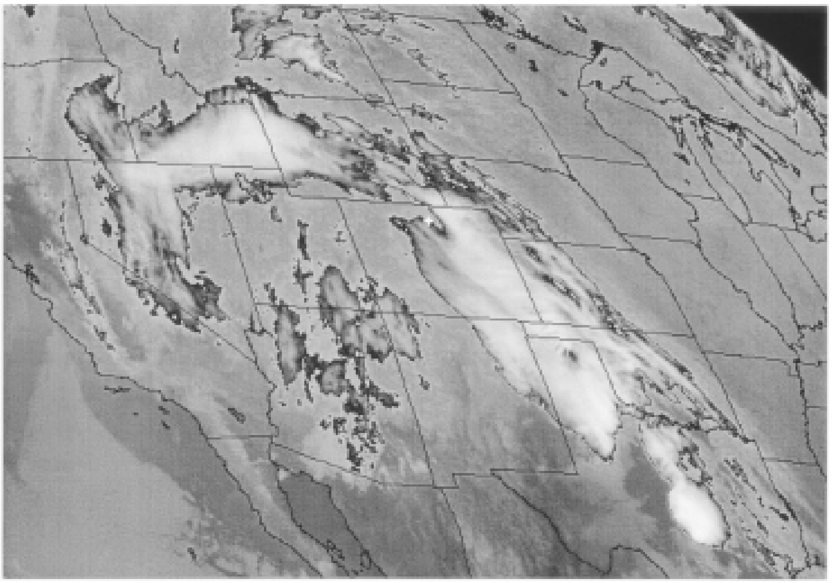

FIG. 4. *GOES-West,* 10.7-μm wavelength image from 9:00 P.M. MST on 30 Apr 1999. The plus sign in north-central Colorado marks the location of Fort Collins. Image shows the previously stalled upper system as it begins to move eastward (compare Fig. 3), and weaken somewhat (e.g., clouds breaking up over and north of Fort Collins).

was made that the majority of the EOC staff could be released by 2230 MST, reducing the need for additional overtime costs for the city and the county. Note that this decision to scale back was made while the Poudre River discharge rate was still increasing (Fig. 1). The city estimates that the bill for keeping the EOC fully staffed throughout the night would have run about \$3,000–\$5,000 per hour in overtime costs alone. It is estimated that by closing the EOC early, Fort Collins saved as much as \$20,000–\$25,000 of the city's emergency budget. Much more significant is the dollar cost and inconvenience to the community saved by *not* evacuating hundreds of homes along the Poudre River flood plain unnecessarily.

4. Final remarks

The rains that occurred over the last 10 days of April 1999 resulted in the second greatest monthly precipitation total for April in Fort Collins since record keeping began in 1889. Other parts of Colorado were more severely affected, and combined flooding along Fountain Creek (near Colorado Springs, Colorado), the Arkansas River, and the Poudre River were sufficient to warrant a federal disaster declaration for the entire state. Although the damage along the Arkansas River was by far greater than in any of the other places listed, including Fort Collins, this period appears to constitute the greatest rainfall and flooding event ever to occur in April in Colorado.

Compared to the 28 July 1997 flood, the 1999 event was much less severe in the City of Fort Collins. In July of 1997, 27 cm of rain fell in a little over 5 h in western parts of the city. This occurred over ground where nearly 10 cm of rain had fallen the night before. Urban runoff depths in Fort Collins reached 1–4 m in many locations, and nearly half the heavily populated area was affected. The 1999 flood produced almost none of the dangerous runoff of its predecessor and affected a much smaller percentage of the city. In fact, for a large number of residents, the second case could easily have become an irritating false alarm. However, by closely working with the media, the consequences of overwarning thousands, and unnecessarily evacuating hundreds, of people were mitigated.

Comments from city and county officials on the performance of the specific emergency management tools were almost entirely positive. The stream flow gauges successfully identified the risk; the EMWIN system communicated from the NWS the increasing danger in a timely fashion; and subsequent conversations with the NWS forecasters in real time set parameters for dealing with it. The feedback to the NWS staff in Denver helped them by providing real-time ground truth information from Fort Collins. Most useful of all (according to the Fort Collins Office of Emergency Management) was the ability to have a meteorologist, a hydrologist, and a GIS technician available in the EOC as the situation evolved. This on-scene expertise allowed the EM to quickly and accurately access the complex scientific information that was coming into the EOC in a nearly continuous stream. While not all emergency management offices around the country have access to similar resources, those that do should certainly utilize them whenever possible. Other offices should consider having staff members receive a little training in using meteorological Web sites and in interacting with NWS forecasters. Weather Service WCMs across the country are anxious to develop better interaction with emergency managers in their county warning areas and are adept at setting up interactions that *work* during natural disasters.

The last comments concern the so-called problem of false alarms. While there is little research on how false alarms affect the willingness of the community at large to take action during subsequent warnings, it might be time to reconsider the conventional wisdom on how the emergency response community views, or should view, such events. The level of professionalism in the emergency management community continues to increase (e.g., Drabek 1989). As Mileti (1999, 328–329) points out, "Today there is wide acceptance of the idea that managing disasters requires specialized knowledge, skills, and training . . . The National Coordinating Council on Emergency Management (now the International Association of Emergency Managers) has awarded certificates in emergency management to over 600 people since 1993." In many places, the shift has already begun toward the appreciation that false alarms offer the professional emergency responder several benefits, including 1) realistic training opportunities, 2) a chance to allow diverse agencies to test their interaction points in advance of actual disasters, and 3) a realistic environment in which to test recent innovations in technology.

Currently the NWS is engaged in a program to substantially lower the false alarm rate. While such an effort may seem laudable in most applications, events like those described herein show that not all overwarnings are bad. In fact, this example highlights the positive aspects of a "near miss" forecast for the response community, and it shows that through the proper gathering and dissemination of information, the negative effects with respect to the general population can be significantly mitigated. A more in-depth understanding of how the local population at risk perceives natural hazards could provide insights as to how one should treat false alarms, particularly near misses. Our experience indicates that by viewing the near miss false alarm as a potential opportunity, rather than an irritation, emergency managers worry less about this aspect of the warning process than that of successful detection. With such a shift in paradigm might come more realistic guidelines concerning the way the NWS handles warnings and advisories. To summarize, false alarms directed at the general public may produce negative outcomes (though to what extent is unknown) and should, whenever possible, be reduced, or at least mitigated locally; near miss false alarms transmitted to the emergency response community may produce training opportunities and insight into improving community safeguards. Indeed, a two-tiered warning process might be the best solution, wherein an early and detailed outlook to the response community would precede less lengthy public statements.

Perhaps the most innovative part of the Fort Collins plan has been the systematic effort to focus on automated warning techniques and redundancy in all such systems. Furthermore, the majority of the components have been designed to handle a wide range of disasters, not just floods. Years from now, when the community memory of the devastating 1997 flood has faded, and those who were directly involved are no longer part of the Office of Emergency Management staff, the lessons learned from the 28 July event should still be the key to a more effective handling of natural disasters.

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Appendix: Flood inundation mapping

The real-time flood inundation mapping system being implemented by the City of Fort Collins Stormwater Utility is actually an integration of several components. The main parts include the following.

1) STORMWatch—a database used for the precipitation and stream flow gauges.
2) Stormwater Management Model—a hydrologic model currently in use by the city.
3) Catchment Forecasting System—software designed to forecast stream discharge based on real-time hydrometeorological observations, quantitative precipitation forecasts, and the physical layout of drainage basins.
4) HEC-2, HEC-RAS, or EXTRAN—all three are hydraulics models that are currently used by the city. These models will be used to compute water-surface elevations.

To learn more about this relatively complex integration of systems, the interested reader can contact the City of Fort Collins, Colorado, Stormwater Utility Office. The flood plain manager at the time of this writing is Marsha Hilmes-Robinson. She can be reached at mhilmesrobinson@ci.fort-collins.co.us.

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