Fort Collins Flood 1997: Comprehensive View of an Extreme Event

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Abstract: The July 1997 flood in Fort Collins was caused by the heaviest rains ever documented over an urbanized area in Colorado, and offers a data base and multifaceted set of lessons about flood planning, mitigation, response, and recovery for engineers, flood managers, and urban officials. The storm dropped 10 to 14 inches in 31 hours and some peak discharges greatly exceeded projected 100-year and 500-year flows. Five people died, 54 were injured, about 200 homes were lost, and 1,500 homes and businesses were damaged. Damages at Colorado State University were about $100,000,000, including catastrophic losses to the library. The paper summarizes the flood experience and provides lessons in five categories: urban drainage and flood control, risk management, mitigation, flood response, and public involvement.

INTRODUCTION

On July 28, 1997, an extreme flood disaster hit Fort Collins, Colorado with the heaviest rains ever documented in an urbanized area of the state. It was one of the major urban floods of recent years in the United States and was labeled a ''500-year event'' by the media, causing major impacts on the city and its people. This postflood analysis describes the causes, consequences, and lessons of the event.

A flood should be viewed from several different perspectives. The examination in this paper includes views from meteorology, hydrology and hydraulics, planning and mitigation, response and recovery, and public reaction. In addition, the paper contains a unique description of a university's response to a major campus flood. The writers draw from their own studies and from the Flood '97 Conference at Colorado State University, which compiled first-hand accounts from persons who dealt with the flood.

The city manager's report (Fischbach 1997) showed five people dead, 54 people injured, 200 homes destroyed, and 1,500 homes and businesses damaged throughout the City. Four of the five deaths were residents in a trailer park, and one was a resident downstream, near the trailer park. Other parts of town also had frightening experiences and intense damage. The City spent about $5,000,000 on flood recovery, most of which it will recover from the federal government and insurance.

CONTEXT OF THE FLOOD

Complacency about floods in semiarid areas exists because of their infrequency. But although the 1997 flood caught the community by surprise, Fort Collins had experienced a great deal of flooding in the past and had reason to be vigilant. In fact, notable past floods in Fort Collins' history include the events of 1864, 1891, 1902, 1904, 1938, 1951, 1977, and 1992 (Charlie 1997). The original town, a military post called Camp Collins, moved to its present site after the flood of 1864.

The September 1902 flood was caused by about 6.2 inches of rain in 48 hours. The City had significant damage, but the campus had few buildings and suffered little. Two people died during the 1904 flood. By 1938 the campus was vulnerable, and on September 2–3, 1938, 4.6 inches of rain in about 48 hours flooded five buildings on the Oval, similar to the 1997 flood. In 1951, on August 3, 6.06 inches of rain fell in 27 hours, with 3 inches in 3 hours. Again, buildings on the Oval flooded. A number of improvements were completed, mainly storm sewers, but these helped little during the flood of 1997, for they were simply overwhelmed. Spring Creek, the site of the main disasters in 1997, also experienced serious flooding in 1951.

Meanwhile, near Fort Collins, the August 1976 flash flood on the Big Thompson River killed 139 people within a few hours (McCain 1979). Six to ten inches of rain fell over a wide area of the basin and the estimated peak discharge was more than four times the previous maximum during 88 years of record. Prior floods on several other streams in the foothills had approximately equaled the Big Thompson experience.

Another recent Colorado flood occurred in 1965, along the foothills. Peak discharges were caused by heavy, intense rain that fell over a three-day period when the ground was already wet, similar to the Fort Collins experience but longer-lasting. Rain cells with maximum depths of 14 inches were widespread, and peak discharge of the South Platte River through Denver was 40,300 cfs, some 1.8 times the previously recorded peak of 22,000 cfs (record starting in 1889). Eight deaths were attributed to the floods, and about $508,000,000 in property damage occurred, mostly in the Denver area (Matthai 1969).

These previous flood experiences illustrate the susceptibility of Fort Collins and the Front Range to infrequent severe flooding, and set the context for the flood of 1997.

STORM

The storm that caused the flood of 1997 received much attention from the meteorological community because it produced ''atypical rainfall and urban runoff complexities'' (Kelsch 1998). Although interesting for its size, the storm also highlights several lessons for urban stormwater managers.

After a day of heavy rain, a deluge of about six inches fell suddenly in an hour and a half, producing peak flows all around town and causing much damage in the City and at Colorado State University. As Fig. 1 shows, the maximum

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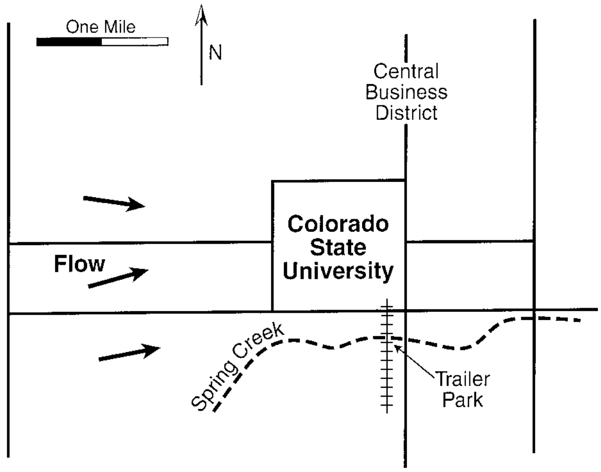

FIG. 1. Maximum Rainfall in Western Part of City

rainfall occurred in the western part of the City, and the two major centers of damage were along Spring Creek and at Colorado State University.

Weather patterns leading to the flood illustrate how flash floods occur suddenly. In the weeks leading up to the flood, Fort Collins and vicinity experienced six weeks of predominantly hot and very dry weather. But in the last week of July the humidity increased as moist tropical air drifted northward. On Sunday the 27th, a fairly strong cold front moved southward into the region and served as the trigger to help initiate numerous storms over northern Colorado late that afternoon. As this weather pattern developed, many meteorologists noted the strong similarity to weather conditions associated with previous flash floods—the Rapid City storm of June 9, 1972, and the Big Thompson flood of July 31, 1976, for example.

The first round of storms, late on Sunday afternoon, was not unusual. Small, localized storms, complete with crashing thunder and gusty winds, brought torrents of rain to areas in the lower foothills just west and northwest of Fort Collins between 5 and 6 p.m. MDT. After dropping as much as 2.4 inches of rain near the south end of Horsetooth Reservoir, the storms quickly diminished and brought only a light shower to most of the city. But instead of clearing off after dark—the normal summer weather pattern—moist southeasterly winds strengthened. Low, dark clouds hugged the foothills. Late at night, rains developed again, but this time with a different character. Steady rains without the accompaniment of lightning or thunder expanded along the base of the foothills. Areas two or more miles east of the foothills again received relatively light rains, but at the immediate base of the foothills, heavy rainfall was noted. A gloomy July 28 dawn brought a temporary break in the rainfall, but then downpours began again, this time even more localized. While most of Fort Collins had a cloudy, cool morning, rain poured along the base of the foothills from 8 a.m. to noon.

A detailed time history of the storm is given by Doesken and McKee (1998) from their analysis of rainfall reports gathered from citizen observers at more than 300 locations in and near Fort Collins. Unknown to most residents of Fort Collins, 6–10 inches of rain had already fallen by midday July 28 from the north end of Horsetooth Reservoir to northwest of the small town of Laporte. Areas west and southwest of Fort Collins received 2–4 inches of rain. Flooding was severe during the day in and near Laporte.

Rainfall abated across the region Monday afternoon (July 28). However, high-humidity air continued in place and, around 6 p.m. MDT, bands of heavy showers began again. Once more, the heaviest showers were concentrated near the foothills. As the evening progressed, rains increased. Around 8:30 p.m., after more than two hours of heavy rain, the rains diminished east and southeast of the city. At this same time, the storm's intensity increased in western portions of Fort Collins. From 8:30 to 10 p.m., the heaviest sustained rainfall of record, with rainfall rates occasionally reaching 6 inches per hour over southwest Fort Collins, inundated the city and sent huge volumes of runoff flowing downhill across the city from west to east. After this awesome crescendo of rainfall, the rains ended mercifully and abruptly between 10 and 10:30 p.m. in southwest Fort Collins with lighter rains continuing north of town until after 11 p.m.

When the evening storm was over, more than 10 inches of rain had fallen in the Spring Creek basin, in southwest Fort Collins, with 5 to 8 inch totals widespread over the western half of the city. Remarkable rainfall gradients were noted southeast of the storm center with less than 2 inches of rainfall over most of southeast Fort Collins. In fact, many citizens were unaware of the raging flood waters heading eastward.

Since hourly data were first published for Fort Collins in 1940, several storms have had one-hour rainfall totals exceeding 2 inches. However, most intense storms in this area have relatively short lives, and no 6-hour period has ever come close to dropping as much rainfall on campus as the 5.3 inches that fell from 6–10:30 p.m. July 28, 1997 (McKee and Doesken 1997).

Overall, 10–14.5 inches of rain fell over an approximately 30-hour period in a band extending along the base of the foothills from southwest Fort Collins northward to northwest of Laporte (Fig. 2). Rainfall of this intensity is rare, but storms of similar magnitude, such as the Big Thompson flood of July 1976, have been observed roughly once every 10–20 years somewhere in Colorado, with a distinct preference for being in or near the eastern foothills of the Rocky Mountains (McKee and Doesken 1997).

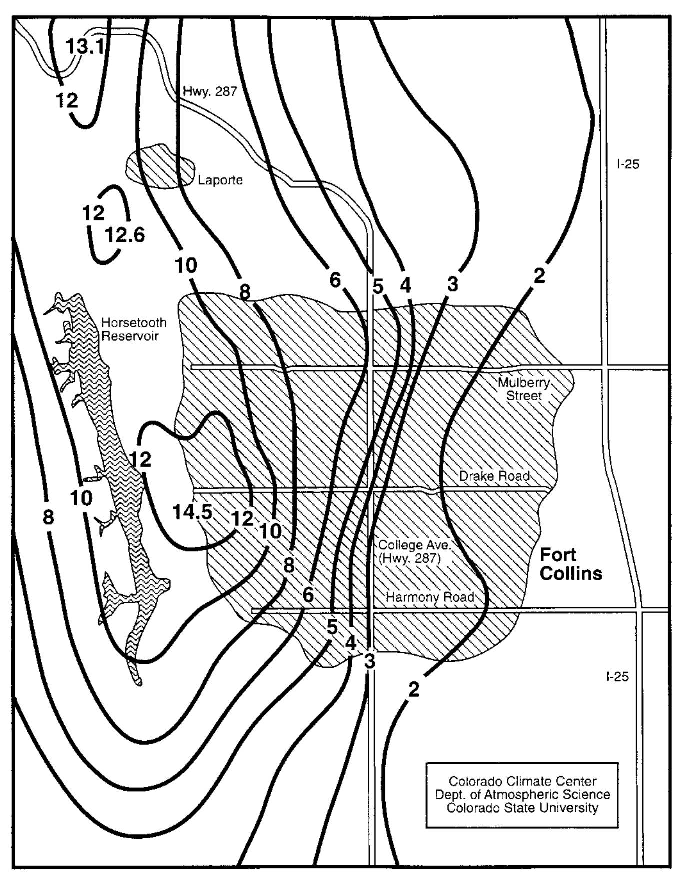

FIG. 2. Rainfall (Inches) for Fort Collins, Colo., 4 p.m. MDT July 27 through 11 p.m. MDT July 28, 1997

Meteorological information from the Fort Collins flood, as summarized above and described in McKee and Doesken (1997), Kelsch (1998), and Petersen et al. (1999), offers insights that aid engineers in understanding flash flooding and in explaining hazards to local officials and the public, thereby fighting complacency. In this case, the time-wise development of the storm's intensity created unusually severe runoff effects, which are described in the next section. The unique program operated by the Colorado Climate Center—which relies on local, citizen-operated weather stations—also offers lessons for improving hydrologic data without added expense.

RUNOFF

While the storm was remarkable, the runoff was at least as dramatic, with magnitudes greatly exceeding estimated 100-year and 500-year flows in some places (Table 1). This illustrates that these estimated flows should be used cautiously, especially when vulnerable facilities are exposed, as they were in Fort Collins.

A brief explanation of the runoff event will set the context for the flood's damage. Hydraulically, the two main flow paths that caused greatest damage during the flood were along Spring Creek and through the Colorado State University campus (Fig. 1).

As shown in Table 1, the City of Fort Collins made an analysis of peak flows in different parts of the City to compare them with previously estimated 100- and 500-year flows (Hilmes 1997). Note that along Spring Creek, where major damage occurred, actual flows exceeded the previously estimated levels by factors of two or more. For the ''combined flow below canals'' on Spring Creek, the discharge was 8,250 cfs while the FEMA 500-year discharge was 3,325 cfs, an exceedance factor of 2.48 (Note: The authors recognize that flood magnitudes are not known to three significant figures, but the city's basic data were used in this calculation). This is the point where water ponded behind a railroad embankment, swept four rail cars off the tracks, and overtopped the tracks, resulting in flooding of the trailer park to the east and the loss of lives. Downstream of College Avenue, the discharge decreased to about 5,000 cfs due to storage behind the railroad embankment, illustrating the storage effect of an embankment.

The storm greatly exceeded the capacity of storm-water facilities in the City, which are designed for 2–100 years frequency. By 8:30 p.m., when more than 3 inches of rain had fallen, detention ponds began overtopping and there was no storage available for the additional 6 inches of rain that fell in the next hour and a half. The College Avenue bridge was blocked by trailers, and many arterial streets were overtopped and damaged.

Irrigation canals in the West are important drainage features, not because they can convey much water, but because they appear to have capacity but in reality are so flat that they only can capture and convey small quantities of runoff. In Fort Collins, floods with recurrence intervals greater than 25 years overtop these canals and head east toward town and the university.

On the campus, as shown in Fig. 3, water generally flows from west to east. During minor events, most water is captured by the storm sewer system and does not affect the campus; but in larger events, water ponds and overflows. Flows on campus were estimated by using rainfall data from the 1997 event and modeling to estimate discharges at various points on the campus. As shown by Fig. 3, they greatly exceeded the anticipated 100-year flows estimated in an engineering study (Frick 1997).

For example, at Elizabeth and Shields Streets the estimated peak discharge entering the campus was 1870 cfs (Fig. 3), compared to a projected 100-year value of 490 cfs. The estimated flow from the Lagoon area into the Engineering parking lot was 930 cfs, compared to a projected 100-year value of 50 cfs. The estimated flow through the railroad embankment—near the heating plant, and where flooding had occurred in 1938 and 1951—was 320 cfs, compared to a projected 100-year flow of 40 cfs.

At the College Avenue Gym, at the east border of campus,

TABLE 1. Preliminary Discharge Estimates

Location (1)	July 28, 1997 discharge (cfs) (2)	FEMA 100-year discharge (cfs) (3)	FEMA 500-year discharge (cfs) (4)
Spring Creek			
Taft Hill Road	3,900	1,492	2,347
Downstream of Taft Hill	3,300	1,492	2,347
Drake Road	4,200	1,635	2,575
Downstream of Drake Road	3,700	1,635	2,575
DS Shields above Canals	5,200	1,955	3,090
Combined flow below Canals	8,250	2,135	3,325
Drop Structure—Channel	6,100	—	—
Overflow to South	850	—	—
Wallenberg	1,300	—	—
Indian Meadows Condos	—	1,528	1,846
Indian Meadows Condos	5,000	1,528	1,846
Mathews	5,500	1,528	1,846
Endora Park	6,000	2,187	2,920
RR Trestle	5,860	2,187	2,920
Fairbrooke			
Willow Lane Townhomes	425	260	420
Fairbrooke/Dorset Drive Combined	1,750	326	—
Fairbrooke Channel	530	—	—
Dorset Drive	1,220	—	—
Clearview			
Clearview Channel-Taft Hill	2,400	532	670
Clearview Channel-Avery Park	2,500	532	670
Plum			
Culvert-Jefferson Commons	370	356 (developed)	—
Fossil Creek			
LeMay Avenue—Southridge	1,800	2,520	—

Note: Estimates are as of 1/16/98 (original in Hilmes 1997).

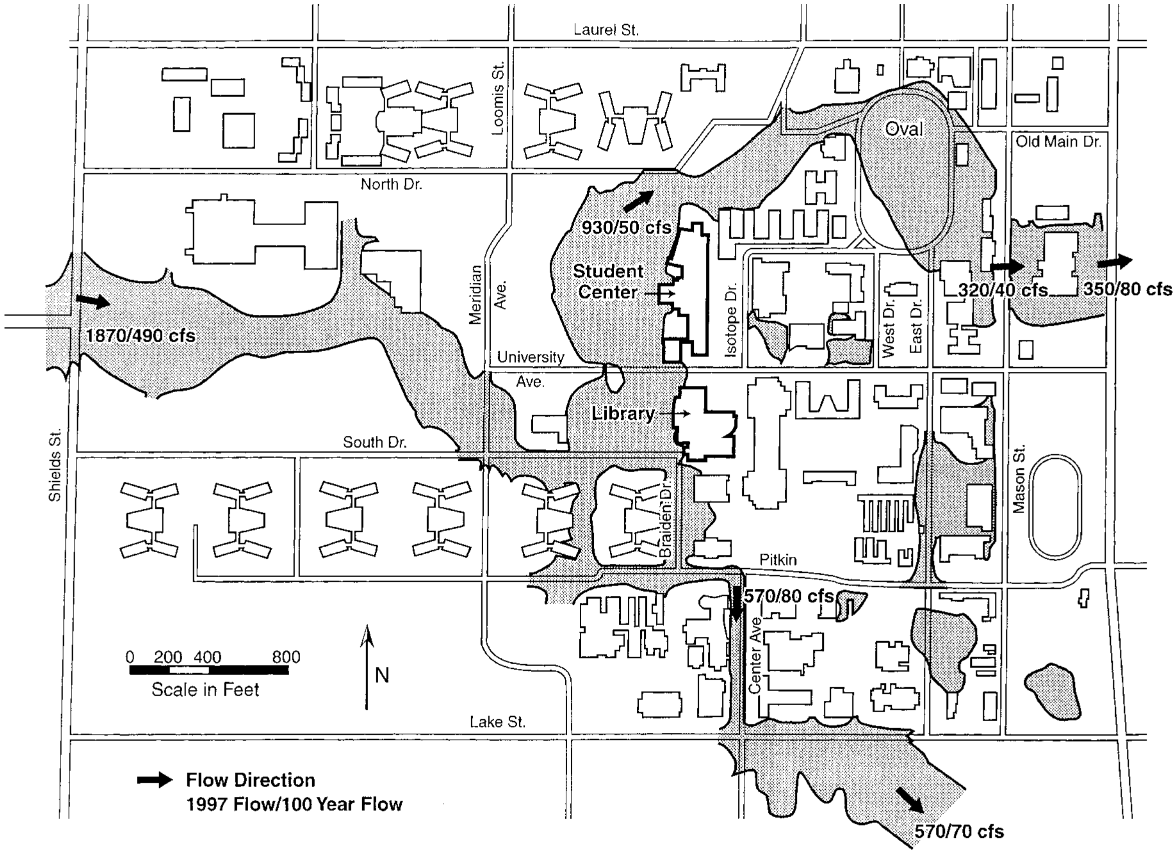

FIG. 3. Areas of Inundation—July 1997

the 1997 water levels were 1.3 feet higher than the 100-year event. At the heating plant, the water levels exceeded the 100-year elevations by 5.2 feet and up to 7.2 feet at the building entrance. At the Engineering parking lot, the flood elevation was 2 feet higher than the projected 100-year level. The water level in the Lagoon area west of the Lory Student Center and Morgan Library was 2.7 feet higher than the 100-year elevation.

For engineers designing urban drainage systems, these details illustrate that actual flows can far exceed anticipated flows in interior areas that are downstream of heavy rainfall.

ACTIONS BY THE CITY

The City's flood preparation and response offer valuable lessons for flood planners, and demonstrate that predisaster mitigation activities can reduce loss of lives and damage to property. As Fort Collins grew to over 100,000 in 1997, the number of people and structures located in the floodplain increased greatly. By 1980, the City had joined the National Flood Insurance Program (NFIP) and organized a Stormwater Utility, which implements self-funded mitigation measures that, in some cases go beyond federal requirements. These include outreach projects, regulation of floodplain development, design criteria for structures in the floodplain, preparedness and warning activities, land acquisition, informational services, drainage systems maintenance, and information on hazards. Two examples of stringent requirements are restrictions on homes in the floodplain, and using postdevelopment flows rather than current hydrology to design facilities. In December 1996, the Federal Emergency Management Agency (FEMA) recognized the City's programs and awarded a Class 6 rating in the Community Rating System (CRS) program. CRS is a FEMA program to reward communities that go beyond minimum NFIP requirements to protect citizens and reduce property losses. As a Class 6 community, citizens in Fort Collins receive a 20% discount on flood insurance. The City is ranked in the top 10 communities out of about 1,000 communities participating in the CRS.

It is not possible to quantify exact savings from mitigation activities, but they can be inferred from pre- and postflood data. As shown in Table 2, selected structures had been acquired prior to the flood in the Spring Creek floodplain and floodway. These included 30 mobile homes, 9 residential homes, one 15-person retirement home, and one business. From these data, mitigation apparently saved from $2,800,000 to $5,500,000 in damage, and could have saved as many as 98 people. In addition, approximately 45 residential and/or

TABLE 2. Estimated Number of Lives and Property Positively Affected by Predisaster Mitigation

Structure type (1)	Number of structures affected (2)	Range of value assumed per structure, not including contents (3)	Number of people assumed affected per structure (4)	Estimated direct mitigation savings (5)	Estimated lives saved (6)
Mobile home	30	$40,000–100,000	2	$1,200,000 to 3,000,000	60
Residential	9	$125,000–200,000	2	$1,125,000 to 1,800,000	18
Critical facility	1	$150,000–250,000	15	$150,000 to 250,000	15
Commercial	1	$300,000–500,000	5	$300,000 to 500,000	5
Total	41	—	—	$2,775,000 to 5,550,000	98

commercial structures had been removed from the floodplain, and, assuming total loss of these structures, this may have resulted in an additional $5,625,000–$9,000,000 in damage prevented. These estimates consider only structures mapped within the 100-year regulatory floodplain, and since the flood exceeded the 100-year event, potential savings might be greater. In addition, lives may have been saved and damage prevented by other mitigation activities such as public outreach, acquisition of floodplain land and open space preservation, enforcement of regulatory standards that exceed minimum NFIP standards, and land use planning. In any event, and regardless of the actual savings, the writers believe that predisaster mitigation was a success.

The flood taught the City that the 100-year return period is only a reference value and that it is prudent to anticipate higher flows as well. Although storm-water facilities worked, they were overwhelmed by the extraordinary event. The Stormwater Utility gained valuable experience by observing the operation of components in the system, such as culverts, pipes, and detention ponds, but also learned lessons about key features such as the railroad embankment, which was designed for the 500-year flow. Flows upstream of the embankment exceeded the 500-year level, and the culverts under the embankment, which were designed for the 100-year flow, could not handle the event and the embankment was overtopped. This is the site where the rail cars derailed and a culvert that had been plugged blew open. Maintenance of storm-water systems has been a problem in many systems, and its importance was illustrated by this flood (Grigg 1990). While maintenance in Fort Collins is generally good, blockages still occurred at College Avenue just downstream of the trailer park, and debris from homes and cars floated all over town.

Emergency response to a flood receives far more attention than do mitigation or the functioning of storm drains. Emergency response is a cross-cutting activity that must be planned and executed by flood management authorities such as city governments. The response in Fort Collins was overseen by the Poudre Fire Authority. Levy (1997) reported that the night of July 28 was very busy for the emergency response team, beginning with rescues. From 8:30 until about 10:45 p.m., 15 minutes before the flood in the trailer park, firefighters rescued over 200 people from cars, buildings, and areas that were flooded. Colorado State's Police Department had to relocate to city facilities because their emergency center was flooded. In the city's 911 dispatch center, calls averaged every 16 seconds during the peak flooding. According to City Manager John Fischbach (1997), the City's incident command system worked well, but as with other floods, the full impact of the event was not immediately apparent. When the city manager was called at about 10 p.m., the flood's severity was not apparent to him; but an hour later, the deputy city manager reported ''. . . a major flood down in the trailer park . . . a train that's overturned . . . and buildings burning.'' When the city manager arrived at the Police Department's Command Center, everything was in turmoil. This illustrates the rapid build-up of a flood emergency requiring timely response.

Plans to document floods should be built into contingency plans. One day after the flood, volunteers from local engineering firms and state and federal agencies were organized to locate high water marks, many of which are now marked with permanent monuments meant to educate the public. Discharge estimates were provided by consulting engineers and local, state, and federal agencies.

EXPERIENCES AT COLORADO STATE UNIVERSITY

Colorado State University's experiences offer unique lessons about flooding at a university, and may be useful to other schools and libraries (Morris 1997). The university, located as an enclave inside the city, is responsible for its own public works management, including flood control. The university grounds appear flat and not vulnerable to flooding, but the appearance is deceiving. In fact, most members of the university community had little concept of campus flood potential. Now awareness is very high.

Damage was surprisingly high and, as shown by their responses, the flood galvanized the university community to a high degree. The most visible damages were the inundation of about 425,000 library volumes and loss of an entire semester's textbooks in the bookstore (Fig. 3). In addition, over 200 faculty, staff, and students lost personal and professional materials, in some cases a lifetime of research documents. Over 40 buildings had some damage, especially to vulnerable utilities and building control systems located in basements. Over 60 graduate students, some with families, lost possessions and were displaced from their residences. Total damage to the campus was well over $100 million (about a third for the library collection, another third for facilities, and a third in areas such as loss of business, relocation costs, contents of buildings, and personal loss of individuals). Through February 6, 1998, some $2,250,000 in time and effort had been spent on flood recovery for cleanup, relocations, replacements, security, and similar items (Lenihan, personal communication, 1998).

Immediately after the flood, the university's Facilities Department organized an emergency management team, and five immediate priorities were established: health and safety; personal and professional losses; resume summer classes as soon as possible (the university only missed about two days of summer semester); clean up; and prepare for (and minimize the disruption to) the fall semester. As the result of the university's response, there was no delay in opening school a month later.

Some of the engineering and physical tasks that confronted the university's facility managers included the major effort of draining water and restoring the functionality of buildings, verifying the structural integrity of buildings, estimating damages, and restoring essential systems such as heating, ventilation and air conditioning, electric systems, elevators, and building alarms. A basic level of security had to be instituted and document recovery was an immediate priority. One safe with well over $1,500,000 in promissory notes had to be rescued. Campus communication was a critical factor because employees expressed concern about health and safety.

In an emergency like this, organizational tasks consume major amounts of time. Tasks included documenting losses for FEMA and insurance agents, providing information systems for financial aid and registration, implementing cash management systems, managing contracts, and supervising consultants and part time personnel (there were 1,000 people cleaning up the campus). Staff were under stress and a stress management program was required for them.

The university selected a freeze-dry book recovery process. Packing library books immediately was critical because wet books deteriorate biologically until frozen. The university initially anticipated recovery of about 80% of the damaged books, but the process will take two to four years, and it is unknown what the success rate will be. A new book costs $70–90, and a book can be restored for about $30. While the freeze-dry plan was the major initial recovery effort for the library, the university was simply overwhelmed by the outpouring of voluntary donations, including from civil engineers, and staff had to be diverted to manage the donation program.

PUBLIC REACTIONS TO THE FLOOD

As shown by the flood, recovery requires a community to look beyond physical issues and understand that multifaceted losses trigger significant grief reactions (Cook and Oltjenbruns 1998). That the flood galvanized the attention of the campus community is shown by numerous events and stories, such as the city's and university's one-year anniversary events and the announcement by Colorado State historian James Hansen that his next volume of the university's history will begin and end with the flood account.

According to Oltjenbruns (1997), community members experienced many losses in the flood, including loss of life, physical spaces, belongings, resources, and dreams. Children in the city were frightened in the days after the flood when rain fell. Adults had uneasy reactions to ongoing heavy rainfall. There is a strong physical component to grief responses. Many experience an absolute sense of exhaustion, partly due to the cleanup and partly due to grief. Individuals might experience eating disorders, sleep disorders, headaches, and increased susceptibility to illnesses. Sadness is at the core of the grief response. Other emotional components are anger, frustration, and feelings of survivor guilt. Psychological responses to grief include an inability to concentrate, mental exhaustion, feeling distracted, and focusing over and over on the loss event and its aftermath.

Grief reactions are often magnified by factors that define the flood, such as intensity and duration of reactions, and special challenges of a particular type of loss. These variables would be relevant to the study of loss following an unexpected natural disaster such as this flood. They include the suddenness of the event (no time to prepare), preventability (related to questions of ''why'' this had to happen and increased anger, a normal part of grief), likelihood of multiple losses (bereavement overload), ambiguity of the loss (inability to predict actual magnitude of loss), and disenfranchisement of the bereaved (society's not validating individuals' ''right'' to grieve). Losses can be so overwhelming that posttraumatic stress disorders and grief responses begin to interact. When traumatic events occur simultaneously, such as water rising, currents rushing, and flames encircling, human beings become overwhelmed with the horrible situation, and this occurred in the mobile home park and for the emergency personnel.

The media is a key link with the public during and after a flood, and planners and emergency response managers work closely with them. Greiling (1997), executive editor of Fort Collins' daily newspaper, described how the flood received extensive coverage in the United States and abroad. Television network staffers from the major networks were on the scene, and the story made national news for a day or two, after which most stories were in the local media. Within 90 days after the flood, *The Coloradoan* had published 282 stories that dealt in some way or another with the flood.

While not widely understood, grieving is a common and healthy reaction; it is crucial that the community give support and not risk disenfranchising individuals who have suffered. Grief lasts longer than many persons accept, regardless of the type of loss. Positive outcomes of losses and grief may include a stronger sense of community and improved facilities. But emotional pain will continue and ongoing support is needed or else members of the community may feel disenfranchised from those who they feel do not understand or care about their experiences.

LESSONS FROM THE FLOOD

The Fort Collins flood can be interpreted in the context of flood policy in the United States, where flooding is the most destructive and costly natural disaster faced by the nation, accounting for 85% of disasters declared annually by the U.S. president (Schilling 1987).

Although the timing of floods varies, most regions of the country face significant flood hazards, ranging from slowly developing big-river floods to devastating flash floods that strike without warning. The Fort Collins flood occurred in a policy climate which began with emphasis on structural measures prior to the 1960s and which shifted to nonstructural mitigation from the 1970s onward (Grigg 1996; *Floodplain management* 1992). Today, four basic strategies for flood measures are generally accepted (*Floodplain management* 1992): modify susceptibility to flood damage and disruption (e.g., zone or regulate land use in the floodplain); modify flooding (e.g., use flood control reservoirs); modify impact of flooding on individuals and the community (e.g., use mitigation techniques such as insurance and floodproofing); and restore and preserve natural and cultural resources of floodplains (e.g., recognize the values of floodplains and use them for recreation and other appropriate activities).

The wisdom of these policy directions has been verified by large-river floods, such as the Great Mississippi River flood of the summer of 1993, and by flash floods such as the Fort Collins event. However, after the 1993 Mississippi River event, an Interagency Floodplain Management Review Committee (*Sharing* 1994) found that people and property throughout the nation remain at risk from flooding, many don't understand the risk, and the division of responsibilities between federal, state, tribal, and local governments needs better definition. The Fort Collins flood provided further perspective on the committee's recommendations on government organization, objectives for environmental quality and economic development, cost sharing for predisaster, recovery, response, and mitigation activities, federal programs to enhance the floodplain environment and provide for natural storage in bottomlands and uplands, the National Flood Insurance Program, vulnerability to damages of those in the floodplains, reviews of projects, responsibility for levees, and flood data.

Taking into account the background on flood policy, and recent Colorado experiences, lessons from the Fort Collins flood can be formulated in the following categories: urban drainage and flood control; risk assessment and management; mitigation; flood response by management authorities, including emergency and postflood response, both in the city and at the university; and public involvement, including emotional impacts.

Urban Drainage and Flood Control

Stormwater systems in the city were subjected to the heaviest rains ever documented over an urbanized area in Colorado, and documentation was extensive—so the flood provides data and case study information for research, demonstration, and the training of officials.

Postflood analysis showed that estimated design flows should be used cautiously, especially when vulnerable facilities and lives are at risk. Peak discharges greatly exceeded projected 100-year and 50-year flows. The city's storm drainage and flood control systems functioned but were overwhelmed. This showed that planning for normal storms, such as 2- to 100-year events, does not take care of extreme flows, and that the concept of the minor and major urban drainage systems is appropriate (Whipple et al. 1983).

Good maintenance of the stormwater system was critical, and damages would have been greater if drainage systems had not been cleared prior to the flood. Fort Collins' Stormwater Utility, with its organized program and system of charges, demonstrated that stormwater maintenance pays dividends (Hilmes 1997).

The data collection program operated by the Colorado Climate Center, which uses citizen volunteers, showed how a great deal of reliable hydrologic data can be gathered without raising costs, and offers an alternative to those who say that data collection programs are too expensive to maintain.

Risk Assessment and Management

The flood focused attention on quantification of risk, vulnerability of key facilities, communication of risk, and citizen complacency. In the flood, the engineering tool of the return period seemed somewhat ineffective to communication risk and taught the City that the 100-year or 500-year floods are only reference values and that more extreme events are quite possible. Research is needed on characterizing flood risk more effectively. Vulnerable key facilities were exposed during this flood, but the extraordinary damage at Colorado State University could have been prevented by floodproofing measures. The damage showed that vulnerable facilities should receive special attention in storm drainage studies.

The media are the key link in communicating risk to the public. Flood managers should establish relationships with the media early in the planning process and engage the media in educating the public against flood complacency. In this way, cities can have flood mitigation programs taken seriously.

Mitigation

While prevented losses are not as spectacular as actual losses, the city's program demonstrated that loss of lives and property can be reduced through mitigation. This was affirmed on June 3, 1998, when Fort Collins was designated by FEMA as Colorado's first Project Impact Community. This is a FEMA initiative to make communities more ''disaster resistant.''

Management Lessons

The flood offers lessons for organizational and contingency plans of public sector and university managers. It showed the importance and payoff of contingency planning, which is emphasized today in an era of potential natural disasters, terrorist attacks, and computer system breakdown. Contingency planning is an interagency activity, but civil engineers should participate because they can predict the timing, severity, and location of potential flooding. Postflood activities in the city and at Colorado State University offer lessons in organization, financial management, media relations, public involvement, and organization of support teams. These are detailed in Grigg (1998), and Fort Collins can provide information to other communities. Engineers should have documentation procedures built into contingency plans. Flood data can be lost quickly, and if preserved, can aid postflood studies. Of special interest from the Fort Collins flood are lessons about campus recovery, offering classes, preserving unique facilities, and recovering from major loss of library books.

Public Involvement

Disasters bring surprisingly strong and diverse reactions and emotions from the public, and special support systems are required. The Fort Collins flood provides a laboratory to study public reactions and emotions and how well the community and campus responded. If there is but one lesson, it is that public grief should be taken seriously, perhaps as seriously as responding to physical losses; otherwise, the intangible suffering and pain may harm individuals and the community in subtle ways. Research into public reactions and emotions from the flood should provide valuable lessons.

SUMMARY AND CONCLUSIONS

The 1997 flood in Fort Collins was caused by the heaviest rains ever documented in an urbanized area of Colorado and provided valuable lessons for flood professionals, especially about heavy, flash floods in urban areas of the Mountain West. Experience with the flood affirmed the value of mitigation, a functional storm drainage program, and preparation for emergency response, and provided valuable lessons for engineers, planners, and managers working in the flood arena. Lessons from the flood in five categories seem worthy of study. In urban drainage and flood control, the flood showed that interior floodways not mapped in a flood insurance program can be highly vulnerable, and affirmed the wisdom of providing dual, or major and minor, stormwater systems, with special attention to vulnerable facilities and residents. The flood also underscored the importance of effective stormwater maintenance for both minor and major systems to ensure the functionality of stormwater systems during extreme events.

Concerning risk assessment and management, the flood experience showed that, while it was an extreme event, perhaps on the order of once in 500 years, it should not have been a total surprise, for significant flooding along Colorado's Front Range and in Fort Collins had occurred before. However, citizen complacency and postflood trauma were clearly in evidence, in spite of this record of past flooding. The flood also exhibited unusual rainfall and dramatic runoff and provided a wakeup call that current practice in assigning return periods to such extreme events needs to be reviewed. The levels of damages and trauma from the flood clearly showed the value of predisaster mitigation. They offer a data base for further study about the levels of benefits and prevented losses due to different approaches to mitigation.

Fort Collins' and Colorado State University's experiences with emergency response and flood recovery constituted monumental efforts and were effective. They can be studied by other cities for lessons in preparing contingency plans and protecting vulnerable facilities.

The flood provided an education for public officials in dealing with emotional impacts and community trauma from sudden disasters. Both the city and the university put much effort into engaging the public, including their employees, in postflood commemorative events to remember victims, celebrate recovery, and raise awareness of flood hazards. These public involvement activities thus sounded a positive note and helped to build community spirit in Fort Collins.

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