Natural Hazard Research

WARNING FOR FLASH FLOODS
IN
BOULDER, COLORADO

Thomas E. Downing
Institute of Behavioral Science
University of Colorado

Prepared for the
Urban Drainage and Flood Control District
Denver, Colorado

July, 1977

Working Paper #31

Warning for Flash Floods in Boulder, Colorado*

Who would be directly affected by a major flood in Boulder? How might their response to warning of a flash flood be influenced by characteristics of the warning? What other factors may affect their response? What benefits might emergency flood proofing yield in a flash flood situation? This study attempts to answer these and other important questions.

A major flood (1% or 100-year) on Boulder Creek would directly affect over 1500 residents in the city, and over 400 residents in the two major canyons west of Boulder, Boulder Canyon and Fourmile Creek Canyon. If all the tributaries in the city were to flood in a 1% event, the affected residents would number over 8,000. The risk to life is greatest closer to the mountains and in the canyons. In the canyons and the city, west of 28th Street, almost 5,000 people might be found on the Boulder Creek and Fourmile Creek flood plains on a typical weekday afternoon. During the evening, the exposed population would be over 5,000; about 3,000 people would be present later at night. The need for an effective warning system is obvious.

Age, education and socio-economic status have been found to influence how people respond to warnings. Of more practical importance in the design of a warning system are the variables related to the

---

*Research for this paper was funded by Denver Urban Drainage and Flood Control District. The viewpoint of this study is that of the author and does not reflect the opinion of the Urban Drainage and Flood Controll District.

characteristics of the warning: reliability of the detection network; credibility of the warning; the nature of the communication mode; the content of the message; confirmation of the warning; the number of warnings received; and public awareness of the hazard. Other important variables include the presence of environmental cues and the type and attitude of the group a person is in when the warning is received.

A section of the flood plain was studied to determine what benefits emergency flood proofing might yield. With an hour lead time, perhaps a maximum of 25% of the damages to the contents of residential, commercial, industrial and government buildings could be avoided by turning off the gas and electricity, and by elevating or removing furniture, equipment, personal papers and other valuables from the flood's path.

A number of scenarios were developed to depict several alternative warning systems and the hypothetical response by the population exposed to flooding; they include estimates of deaths and injuries, and of the outcome of emergency flood proofing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

PREFACE

This paper is one in a series on research in progress in the field of human adjustments to natural hazards. It is intended that these papers will be used as working documents by the group of scholars directly involved in hazard research as well as inform a larger circle of interested persons. The series was started with funds granted by the U.S. National Science Foundation to the University of Colorado and Clark University but now is on a self-supporting basis. Authorship of papers is not necessarily confined to those working at these institutions.

Further information about the research program is available from the following:

Gilbert F. White
Institute of Behavioral Science
University of Colorado
Boulder, Colorado 80309
U.S.A.

Robert W. Kates
Graduate School of Geography
Clark University
Worcester, Massachusetts 01610
U.S.A.

Ian Burton
Institute of Environmental Studies
University of Toronto
Toronto, Ontario, Canada
M5S 1A4

Requests for copies of these papers and correspondence relating directly thereto should be addressed to Boulder. In order to defray production costs, there is a charge of $2 per publication on a subscription basis or $3 per copy if ordered singly.

ACKNOWLEDGEMENTS

A large number of people have been involved in this project. The research was funded by a grant from the Urban Drainage and Flood Control District, under the direction of L. Scott Tucker. Bill DeGroot managed the project for the District. The faculty director, to whom I owe much, was Gilbert F. White. Others who have graciously reviewed various parts of the research or participated in this project included a number of Federal agency representatives, Boulder City and County officials, academic researchers, engineering consultants, and private citizens.

The views expressed in this report are those of the author, and do not necessarily reflect those of the Urban Drainage and Flood Control District in Denver.

FLOODS AND FLOOD STUDIES IN BOULDER

Flooding in Boulder presents a serious threat to life and property, although the hazard has not lacked study. In 1910 an architect, Frederick Law Olmstead, Jr., recommended a plan for dealing with floods, including further study of the problem. Since that time over 25 studies have been carried out, evaluating the hazard and recommending a range of adjustments that includes channelization, storage, dams, levees, land use regulation, enlarged flood ways and emergency preparedness (see Table 1). To date, few of the recommended actions have been implemented. In the meantime, the number of people and the value of property exposed to flooding has increased.

Perhaps part of Boulder's historical apathy can be attributed to a lack of serious flooding within the city (see Table 2). The flood of 1894 is the most serious flood event to have occurred since the town was settled. Yet in that flood only one life was lost due, in part, to the flood's slow onset.

In the wake of such floods as those in Rapid City (1972) and the Big Thompson Canyon (1976), the effort to prepare for a serious flood in Boulder has been renewed. The U. S. Army Corps of Engineers has re-evaluated the probable discharge and flood plain limits of a 1% (100-year) flood.* The new discharge estimate is 12,000 cubic

---

*A 1% flood is one which has a 1% chance of occurring in any given year, regardless of when the last flood occurred. This corresponds to a statistical average of once every 100 years. Severe floods can occur back-to-back; Minot, North Dakota, has had three 100-year floods within ten years.

TABLE 1

BOULDER CITY FLOOD HAZARD STUDIES: 1910-1977 (Adapted from Ericksen, 1974.)

DATE	AGENT	LOCATION BOULDER CREEK	LOCATION NORTHERN TRIBUTARIES	LOCATION SOUTHERN TRIBUTARIES	STUDY TYPE HAZARD EVALUATION	STUDY TYPE ENGINEERING CONTROL	STUDY TYPE SPECIAL REGULATIONS	RECOMMENDATIONS
1910	Olmstead	x	x			x	x	Hazard evaluation; channelization; levees; land use regulation
1912	Metcalf and Eddy	x			x	x		Channelization; levees floodways
1921	Burns and McDonnel	x	x			x		Enlarge bridge clearances; bank protections; channelization
1945	Corps of Engineers	x			x	x		Floodwalls; levees; channelization
1946	De Boer	x			?	?	?	?
1948	U. S. Geological Survey	x		x	x			-
1955	Debler	?	?	?	?	?	?	?
1957	Soil Conservation Service	x	x	x	x	x		Proposed Boulder Watershed Protection Project
1958	White	x			x			-
1959	Corps of Engineers			x	x	x		Flood control dam
1960	U. S. Geological Survey	x			x			Flood control and land use requlation
1961	U. S. Geological Survey	x			x			Hydrological Investigation Atlas HA 41
1961	U. S. Geological Survey	x			x			-
1961	Plan Boulder	x	x	x			x	Land use regulation through cooperation
1965	Civil Defense	x					x	Emergency planning
1966	White	x	x	x			x	Land use regulations; warnings and preparedness; hazard evaluation of tributaries

TABLE 1 (continued)

DATE	AGENT	LOCATION			STUDY TYPE			RECOMMENDATIONS
		BOULDER CREEK	NORTHERN TRIBUTARIES	SOUTHERN TRIBUTARIES	HAZARD EVALUATION	ENGINEERING CONTROL	SPECIAL REGULATIONS	
1969	Corps of Engineers	x			x			Avoid hazardous locations
1969	Wright-McLaughlin		x		x	x		Channelization and storage
1969	Wright-McLaughlin	x			x	x		Channelization and storage
1970	Wright-McLaughlin	x			x	x		Channelization and storage
1970	Wright-McLaughlin			x	x	x		Channelization and storage
1972	Corps of Engineers	x			x			Flood plain information map for management purposes
1973	Wright-McLaughlin			x				Channelization and storage
1973	CECEP*	x				x	x	Multipurpose physical and social measures: in progress
1973	Corps of Engineers	x			x	x		Channelization, levees, and floodwalls
1977	Corps of Engineers	x			x	x	x	Channelization, flood-ways, flood plain evacuation, flood proof-ing, insurance land use regulation, emergency evacuation plans.

*Corps of Engineers Committee on Environmental Planning, Boulder Subcommittee

TABLE 2

HISTORY OF FLOODING IN BOULDER (From Ericksen, 1974.)

DATE	ESTIMATED DISCHARGE (CFS)	ESTIMATED DAMAGES ($)	LIVES LOST	DOCUMENTARY SOURCE	COMMENTS
May-June 1844		-		USGS (1948)	Regionally extrapolated
June 1864	C. 11,000	-			Severe flood, small hazard potential
May 24 1876				USGS (1948)	Severe flood, increasing hazard
June 1 1894	C. 11,000 C. 9,000 C. 4,700	108,000	1	USGS (1948) Metcalf and Eddy (1912) Burns and McDonnel (1921)	Severe flood, high damage cost County damages $650,000
May 1904				Wright-McLaughlin	Minor
July 8 1906				Emerson (1956) Metcalf and Eddy (1912)	Sunshine Creek down Pearl Street; silt and water damage 4 feet above bank near 3rd and Pearl
August 1909				Emerson (1956)	Minor, general flooding
July 23 1909			2	Emerson (1956)	Twomile Creek
June 2 1914	5,000			USGS (1948)	Moderate; extensive damage to water facilities
August 1-2 1919		3,760		Perrigo (1946)	Severe flooding of Boulder and Gregory Creek and others
1921	3,000			USGS (1960)	Minor
June 7-10 1923				USGS (1948)	Moderate: high snow-melt factor
Sept. 8 1933				Emerson (1956)	Twomile Creek severely flooded
May 28 1935				Emerson (1956)	General flooding, especially S. Boulder

TABLE 2 (continued)

DATE		ESTIMATED DISCHARGE (CFS)	ESTIMATED DAMAGES ($)	LIVES LOST	DOCUMENTARY SOURCE	COMMENTS
Sept. 1-4	1938				USGS (1948)	Minor
	1941				White (1958)	Local damages on small tributary streams, especially Twomile and Fourmile
	1947				Emerson (1956)	
	1949				Emerson (1956)	
	1942				White (1958)	
August 3	1951				Emerson (1956)	
August 31	1951				White (1958)	Goose Creek and North Broadway
	1954				Emerson (1956)	Goose and Sunshine Creeks
June 16-20	1965				Dieffenderfer (1973)	Bouder Creek
Sept. 1-2	1966				White (1966)	
May 4-8	1969	2,500	2,800,000	3	COE (1969)	Boulder Creek and tributaries, severe losses but only moderate flooding
Spring	1973					Southern tributaries - minor

feet per second (cfs), as compared to the previous estimate of 7,400 cfs. The Corps also proposed several flood plain management alternatives. In May, 1977, the Boulder City Council approved further study for a combination of an enlarged flood way in the western part of the city and land use regulation, and for selected removal of buildings and flood proofing elsewhere. The flood warning system is also being analyzed for improvement. The Sheriff's Department and the County Hydrologist have distributed rain gages to volunteer observers. A more systematic analysis of possible flood detection networks was undertaken by Leonard Rice Consulting Water Engineers, Inc., with funding from the City and the County of Boulder and the Urban Drainage and Flood Control District.

Eve Gruntfest's study (1977) of human behavior in the Big Thompson Flood, also funded by the Urban Drainage and Flood Control District, has provided considerable insight into the problem Boulder faces in reducing the potential loss of life from flooding. The report, Recommendations for Front Range Communities with Flood Hazards (Downing, 1977) summarizes some of the important considerations for the design of an effective warning system.

This research project was undertaken with the goal of applying what we know of warning systems to the design of an effective flash flood warning system for Boulder. A workshop, held in May, 1977, addressed this problem. The City Council has subsequently directed the Boulder City Manager to make recommendations for the warning system's improvements. The following questions were addressed in this study:

1. Who is directly exposed to flooding in Boulder?
2. What variables influence how people respond to flash flood warnings?
3. What can be done to reduce the number of lives that might be lost in a flash flood?
4. Given a limited amount of lead time, what measures could be undertaken to reduce damages from a flash flood?
5. What benefits might such measures yield?

A summary of the methods used is followed by a review of the warning system and the variables that influence warning response. Several scenarios are presented to illustrate how alternative warning systems might function.

It is the hope of those concerned about the flood hazard that appropriate preventive actions will be undertaken before a major disaster tests the effectiveness of a new warning system.

ESTIMATING FUTURE HUMAN BEHAVIOR: RESEARCH METHOD

The many studies of the Boulder flood plain have yielded a variety of maps delineating the hazard area in the city, but as yet no large-scale maps of the canyon flood hazard zones. City-wide estimates of the residents exposed to flooding are based on the 100 Year Flood Plain Map, adopted August, 1969, revised March, 1976. This map (see Figure 1) is based on a 1% discharge estimate of 7,400 cfs for Boulder Creek at the mouth of Boulder Canyon, and on comparable estimates for the major tributaries joining Boulder Creek east of the foothills.

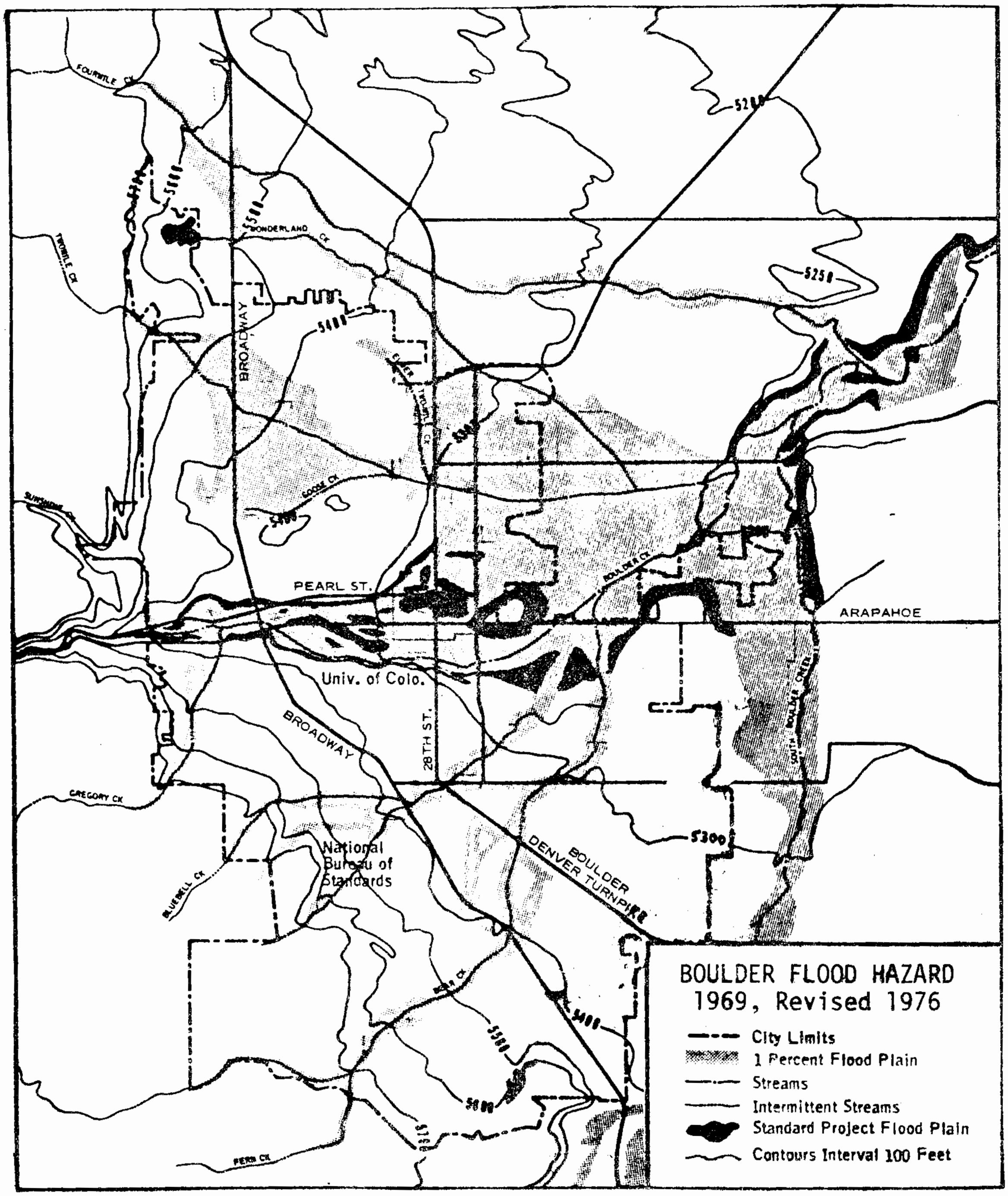

FIGURE 1 100-YEAR FLOOD PLAIN MAP
Based on 7,400 cfs discharge. Standard project flood plain corresponds to the 0.2% (500-year) flood (adapted from Ericksen, 1975).

The major hazard to life is in the canyons and along Boulder Creek, west of 28th Street. Estimates of the 1% (100-year) flood hazard area in the canyons were based on rough observations for a 12,000 cfs discharge at the mouth of Boulder Canyon.

Buildings bordering on the flood plain were generally included in the counts. In many cases, people occupying these buildings would need to evacuate, as they would be vulnerable to floods larger than the 1% flood.

More detailed estimates of the population exposed to flooding were conducted for the Boulder Creek flood plain west of 28th Street and for Boulder and Fourmile Creek Canyons. In the city, the 1976 Corps of Engineers' schematic map, adjusted to reflect dry islands, as delineated on their October, 1976 map of the 1% (100-year) flood plain, formed the study area (see Figure 2).

The first part of the present study involved estimating how many people would be exposed to flooding in Boulder, Colorado. The population-at-risk can be divided into three groups: residents of the flood plain, people who work in the flood plain, and visitors in the area when the flood occurs. The procedure for estimating the numbers in each of three groups, summarized here, is more fully described in Appendix A along with the detailed counts.

The numbers of residents were estimated by counting the number of houses, apartments and trailers in the flood plain, and then multiplying the housing stock counts by average multiples. Counting the number of workers in the flood plain (for the detailed study area only) involved listing each commercial, industrial or government establishment and estimating the number of employees.

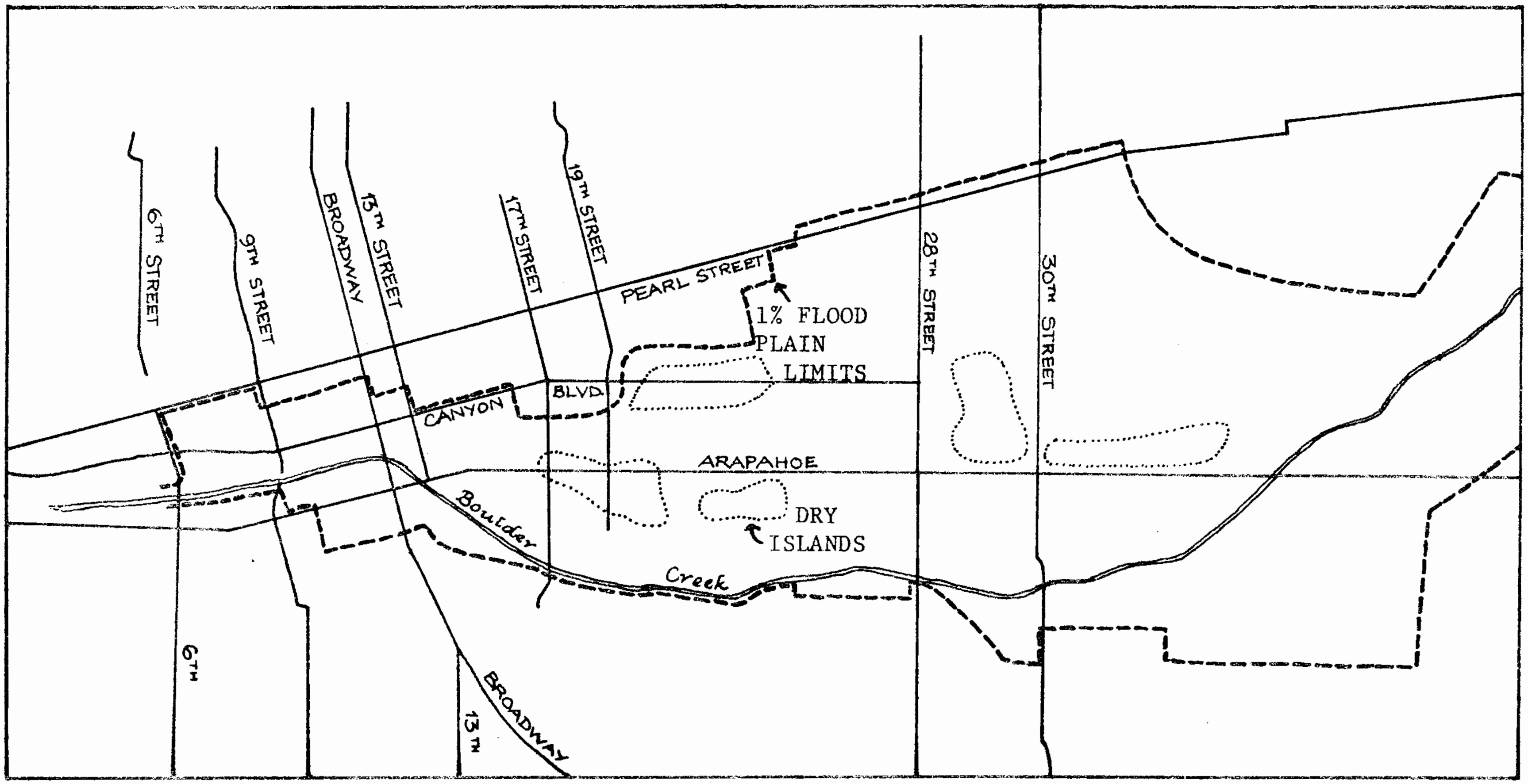

FIGURE 2 BOULDER CREEK STUDY AREA
Based on 12,000 cfs discharge as mapped on the Corps of Engineers' 1976 schematic map of 1% (100-year) flood plain, adjusted to reflect dry islands as delineated on their October, 1976 map of the Boulder flood plain. Study area includes flood plain west of 28th Street only.

Estimating the number of visitors likely to be in the flood plain was more speculative. Estimates were made for each center of attraction (businesses, stores, parks, restaurants), and for those driving through.

The numbers of residents, workers and visitors were calculated for 4:00 PM, 7:00 PM and 11:00 PM on an average weekday. The separate estimates were then combined to correct for possible overlap of counts.

Although saving lives is the primary benefit of a flash flood warning system, with an adequate warning, some property damage may be prevented through emergency flood proofing. The magnitude of these savings was estimated for the city portion of the detailed study area. In the canyons, emergency flood proofing is likely to be of little benefit due to the short lead time in a flash flood situation. Appendix B explains the estimating procedure. Briefly, it involves estimating the value of the contents of buildings exposed to flooding, the expected damages from a 1% (100-year) event, and the percentage of the damages that could reasonably be avoided given various lead times. This procedure was perhaps little more than quantified guesswork, but its purpose is to indicate the possible monetary benefits of a warning system.

Past studies of how people responded to warnings of imminent danger have linked behavior to a large number of variables.* These studies provide the basis for estimating how people might respond to a flash flood in Boulder. The relationships between the variables

---

*Several sources review the warning-response literature: Mileti (1974); Mileti, Drabek and Haas (1975); and McLuckie (1970 and 1973).

and response are discussed in the next section.

To illustrate the influence of the warning-related variable, four warning systems were conceptualized, reflecting the range of preparedness from the current state of affairs to a detailed, integrated system. Table 3 describes the levels of the warning variables for each alternative. A scenario was developed for each system, describing how the system might work and estimating how people might respond to the warnings.

The scenario methodology is, by its nature, speculative. It attempts to project into the future the consequences of current or proposed trends and actions. Future events may be influenced by variables not included in the scenario. The scenarios attempt to focus on the most typical human behavior, but they illustrate the range of behavior patterns that might be expected.

The physical event, the meteorology and hydrology, is the same for each scenario. The storm is patterned after the one Ericksen (1974 and 1975) used in his scenarios of flooding in Boulder (see Figure 3). Its intensity was changed to reflect the Corps of Engineers' 1976 estimate of the 1% (100-year) discharge, 12,000 cfs.

The progress of the flood downstream is roughly similar to the Corps of Engineers' hydrology for their design storm. Which streams flood, the magnitude and velocity of the waters and the exact timing of flooding at various locations depends on the nature and location of the storm and rainfall. Flood crests for the city are shown on the hydrograph in Figure 4. The storm used here is but one of a wide range of possible storms that could cause disastrous flooding.

TABLE 3

COMPARISON OF SCENARIOS

Indicates the levels of the variables used to build each scenario, and includes the results of the warnings.

VARIABLE	SCENARIO I BOULDER FLASH FLOOD	SCENARIO II UPGRADED PREDICTION CAPABILITIES	SCENARIO III MODERATE WARNING SYSTEM	SCENARIO IV INTEGRATED FLOOD WARNING SYSTEM
Prediction network:	Some volunteer rain observers, one flash flood alarm	Stream gages, volunteer rain observers	Rain and river gages, volunteer rain observers	Thorough coverage by automatic and volunteer networks, and a regional radar unit, possibly computer assisted
Maximum lead time:	Less than 30 minutes	30 minutes	45 minutes	45 minutes (confirmed) to several hours (general)
Preparedness:	Inadequate plan, outdated, not practiced, some planning done by individual agencies	Moderate plans written but are not up-to-date or practiced, no direct link to large establishments	Detailed plans poorly maintained, similar to II. Large establishments not linked directly	Comprehensive planning, detailed, updated, practiced, direct links to large establishments
Public education:	Sporadic news stories, low level of public awareness	Sporadic new stories, low level of public awareness	Long-range, extensive; media, brochures, public utility bills used, no signs, less coverage in canyons	long-range extensive, media, brochures, public utility bills, signs used at frequent intervals
Source of warnings:	Sheriff, Police Fire Departments	Sheriff, Police, Fire Departments	Sheriff, Police, Fire Departments	Sheriff, Police, Fire Departments
Dissemination mode:	Loudspeakers	Loudspeakers, sirens, media, some personal contact	Some personal contact, loudspeakers, sirens, media, telephones	Emphasis on personal contact, loudspeakers, sirens, media, telephone fan outs, used

TABLE 3 (continued)

VARIABLE	BOULDER FLASH FLOOD	SCENARIO I UPGRADED PREDICTION CAPABILITIES	SCENARIO II MODERATE WARNING SYSTEM	SCENARIO III INTEGRATED FLOOD WARNING SYSTEM
Content:	Vague reference to expected magnitude and lead times. Low level of urgency, lack of specific evacuation directions, no reference to: past events, confirmation, or number of warnings	General wording with respect to magnitude and lead time in early stages. Safe areas not included in content	Specific messages, includes directions to climb to high ground in canyons, location of evacuation routes in city, moderate sense of urgency	Same as III, including reference to number of warnings, confirmation of what others are doing, and relating flood to known landmarks, emergency floodproofing advice given where appropriate
Response:	Over 90 dead, less than 100 injured, little property damage avoided	About 65 dead, less than 100 injured, little property damage avoided	About 30 dead, less than 50 injured, 1/3 of the possible reductions in property damage are avoided	Less than 12 dead, few injured, 3/4 of the possible reductions in property damage are avoided.

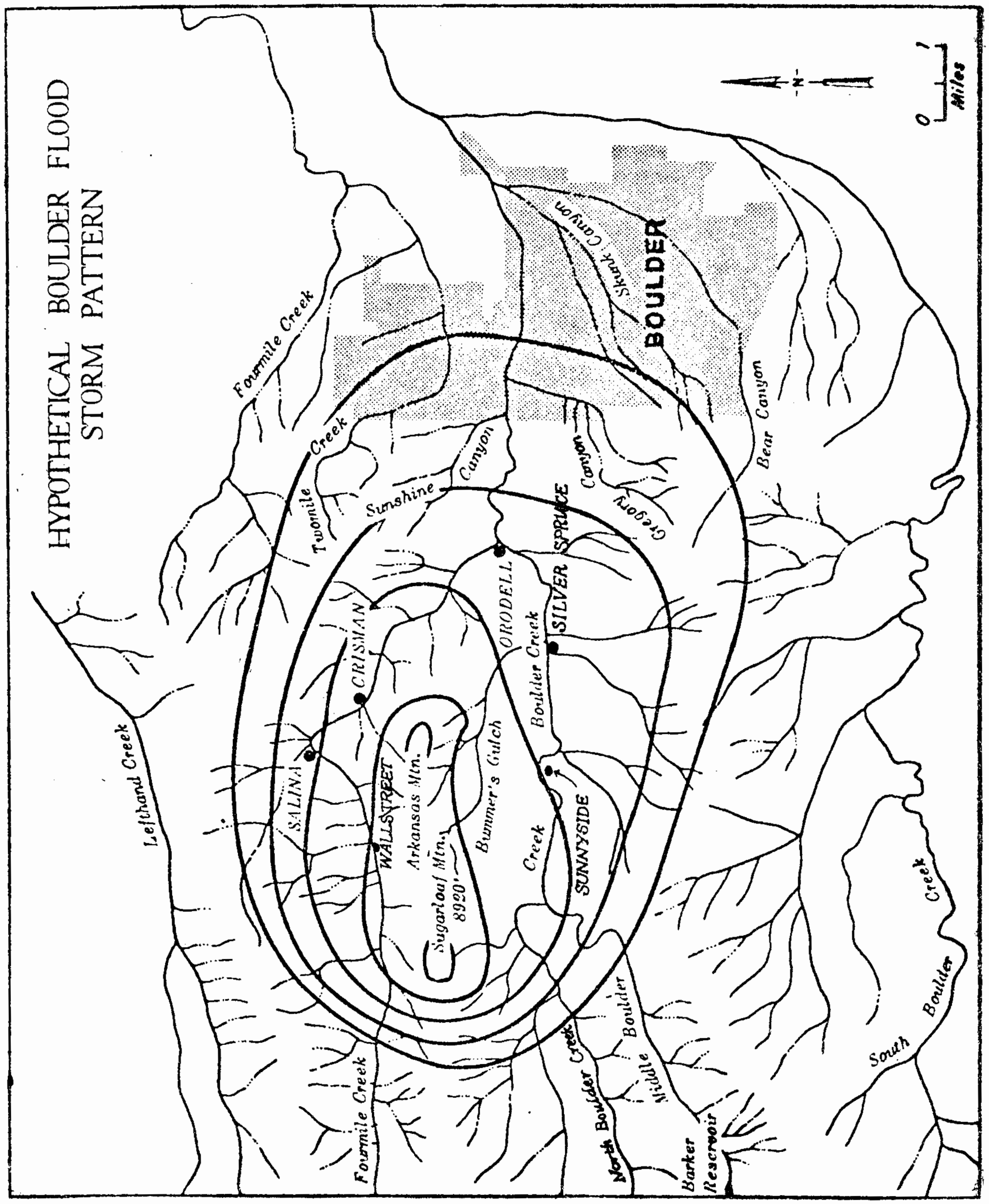

FIGURE 3 HYPOTHETICAL STORM PATTERN
Rainfall intensities are not estimated, but precipitation amounts are sufficient to cause a 12,000 cfs discharge at the mouth of Boulder Canyon (adapted from Ericksen, 1975).

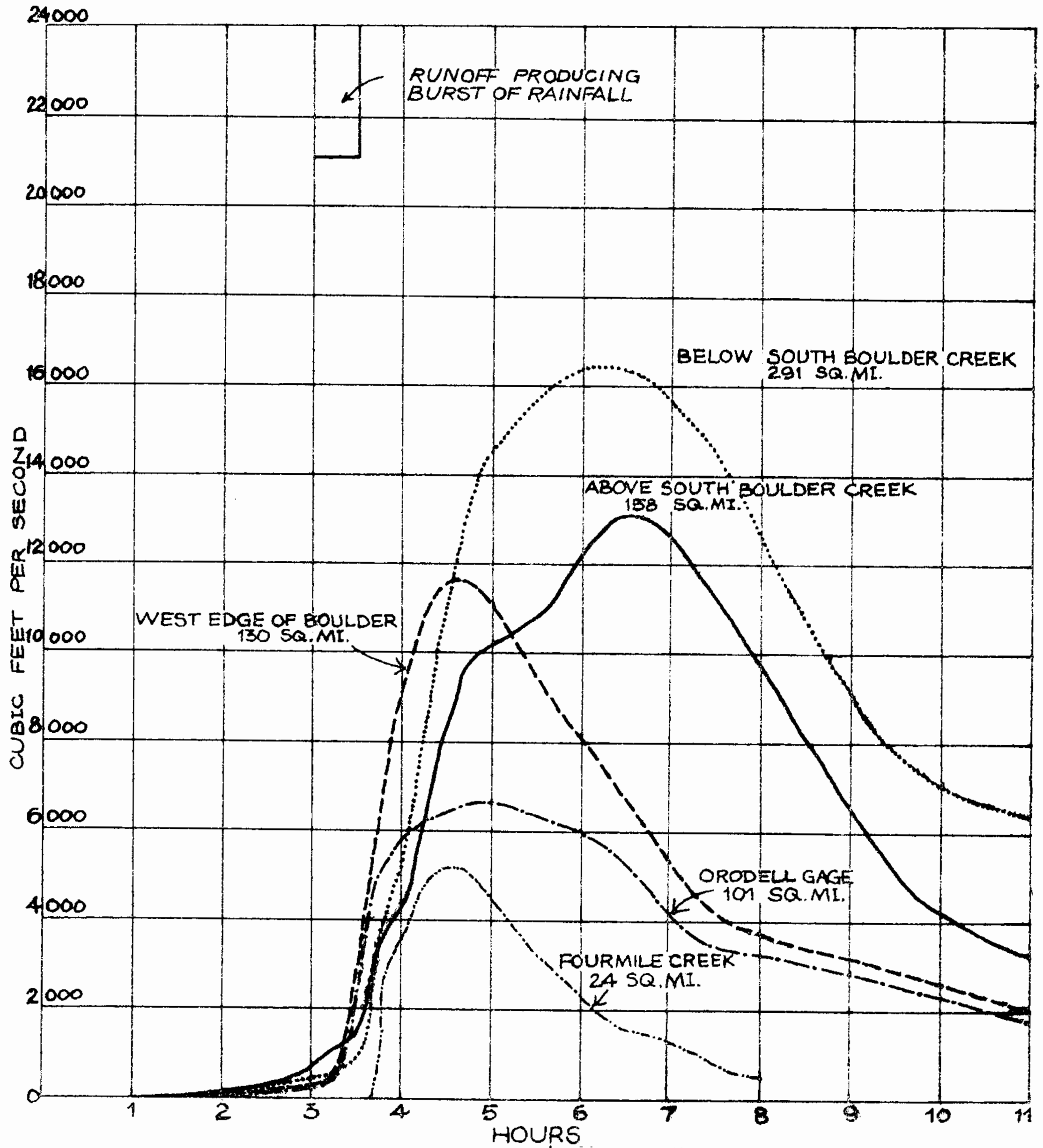

FIGURE 4 HYDROGRAPH OF HYPOTHETICAL 1% FLASH FLOOD
Lead time between middle of flood-producing rainfall and crest of flood on west edge of Boulder City is 1 1/4 hours. This table is for a different type design storm than used in this report, but illustrates lack of time available for emergency evacuation. Flood heights given in the scenario are from the same data (Corps of Engineers, 1976).

THE WARNING PROCESS: WHAT VARIABLES AFFECT HOW PEOPLE RESPOND TO WARNINGS?

The warning process may be divided into several components (see Figure 5): an alert of potential, the physical event, the detection network, warning agencies, user response, and results. This discussion deals primarily with the official warning process. In addition, many people may be warned by relatives, friends or neighbors. Unfortunately this unofficial warning process cannot be relied upon to warn everyone.

Warning agencies may be alerted by the National Weather Service or private meteorologists of the potential for flash flood-producing storms to develop over the region. The agencies can then "gear up" to monitor the storm if and when it occurs.

The nature of the storm determines the magnitude of the threat. The time of day the flood occurs affects detection and human response. The presence and observation of environmental cues (heavy rain, clouds, rising river) has been found to enhance adaptive response to flood warnings (Mack and Baker, 1961).

The detection network, typically radar, rain and stream gages, and volunteer observers, is responsible for estimating the magnitude and expected lead times of the flood. Lead time can be defined in various ways. In general, it refers to the amount of time between the first warning (or prediction) of a flood and its arrival. Three aspects of the network are particularly important. The system, of course, must be reliable. No one will get warned from official sources if the network fails to detect the flood, or fails to transmit

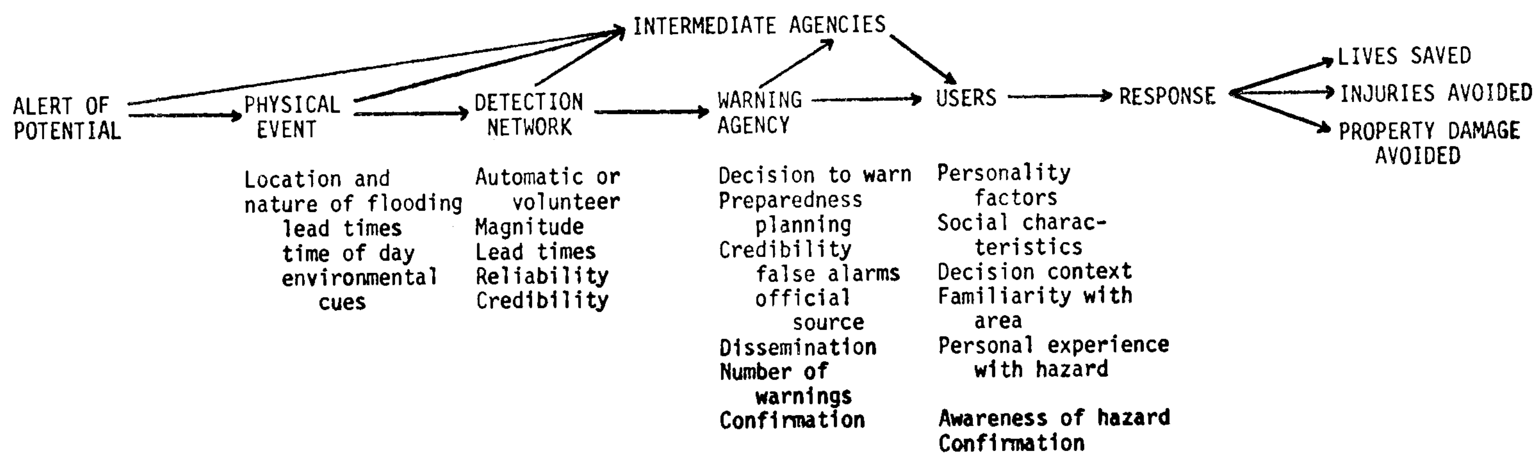

FIGURE 5. THE WARNING SYSTEM (Adapted from a model by Gilbert F. White.)

the data to the proper officials. Additionally, if the network's credibility is low--if it has a high false alarm rate--over the long run both officials and citizens will trust the system less and less, and the warnings will become less effective (Anderson, 1970). The amount of time between the first warning of the event and its impact is also important. The subsequent warning activities will have to be carried out within the time limits determined by the physical event and the detection network. Several levels of warning may be used: 1) an alert notifies the appropriate emergency personnel of the potential danger (but is not disseminated to the public); 2) a watch is disseminated to the public and indicates meteorological conditions in the area are conducive to a flood event; and 3) a warning tells everyone that flooding is imminent or occuring. If the lead time is short, the warning may not be preceded by both a watch and an alert.

Prediction of a flood is transmitted to the warning agencies. Responsibilities for detection and warning may rest with the same group, or warnings may go through several channels before reaching the public. If the messages are not clear, response will be less adaptive.

Effective decision-making in a flash flood situation is related to the extent of preparedness planning. This involves developing and practicing emergency procedures for a flash flood situation. Appendix C lists the decisions that might be called for in a flash flood. The emergency plan should consider faulty telephone lines, blocked highways (from landslides), and the absence of key officials, among other things. One of the keys to an effective warning system is the maintenance of the preparedness capabilities, including regular contact between its members (observers, officials, and key citizens), periodic practices of the whole or sections of the plan, the updating of personnel and telephone lists, and maintenance of the rain and stream monitoring equipment.

With the data provided by the prediction network, the warning agency must decide whether or not to issue a warning. To insure a more objective decision, public officials should be freed from responsibility for the consequences of a false alarm.

The first reports of an imminent flood threat must be confirmed to insure an accurate warning. Warnings from official sources have been found to encourage a more adaptive response than those from unofficial sources (Drabek and Boggs, 1968; Mileti, 1974). Warnings disseminated through personal communication modes, such as telephones, bull-horns and face-to-face, are much more effective than the impersonal modes (Drabek, 1969). Although sirens are often misinterpreted, they may be useful in mobile home parks and at night when many will be asleep. The warnings should be disseminated through as many channels as available. Large establishments (schools, offices) should be directly linked into the warning network.

If the lead time is sufficient, the content of the warnings can encourage some emergency flood proofing measures without undue risk to life; however, in the canyons, evacuation should be emphasized. Other aspects of the message include specific instructions as to evacuation routes and means; a moderate sense of urgency; the most accurate estimate of the size of the expected flood possible, relating it to known landmarks; an estimate of when the flood will arrive; examples of others taking adaptive actions; mention of who made the prediction if that person is known to be credible; confirmation from other sources, e.g., the mayor; the number of warnings issued in the particular area; and mention of environmental cues, if appropriate. Warning messages from different sources should agree in content, and increasing degrees of specificity are desirable as more is known about the flood.

The users of the warnings, the flood plain occupants, typically seek to confirm the first warning they receive. This may involve calling official sources (police, sheriff), checking the radio and TV, or finding out what friends and neighbors are doing. In Rapid City, only about 20% of the people evacuated after the first warning (Mileti, 1973). Warnings should be issued repeatedly, and indication of number of warnings should be given. An adaptive response to a warning of imminent danger requires a major alteration in one's normal activities and may be accompanied by some risk--as in climbing the wet side of the canyon.

Certain characteristics of the users themselves have been related to response in disaster studies. Personality traits may influence response, but are difficult to anticipate in a warning system. Past experience with only minor flooding may hinder adaptive response to a major event, as has happened in many flash flood disasters: "We never thought the water would get that high." A person's familiarity with the area, particularly the location of high ground, may be related to response.

The elderly and low and high socio-economic level groups tend to respond less adaptively to warnings than other age and social status groups (Mack and Baker, 1961). In a number of disasters the elderly have formed a disproportionately large number of the victims because they are less able physically to move (Hutton, 1976).

Many studies have noted that the kind of group a person is in strongly affects his reactions. Family groups tend to respond more adaptively than peer groups,* probably because of a greater sense of responsibility among the group's members. Family members, if separated when the warning is received, often try to reunite and evacuate as a unit. This contributes to problems of convergence onto the hazard area, as well as to tying up telephone lines (Drabek and Stephenson, 1971).

The attitude of peer group members is also important (Mack and Baker, 1961). In one motel in the Big Thompson the proprietor showed little concern about the rising river until evacuation had to be accomplished by knocking a hole through the ceiling because the outside staircase was under water. One of the visitors led the way. For other groups, the delaying of evacuation was fatal (Gruntfest, 1977).

Panic is not typically a widespread response to a preimpact flash flood warning. Panic may occur when an individual is trapped by the flood, with no escape route open (Quarantelli, 1964).

Public information, one of the more important aspects of a warning system, can be used to expand the exposed population's

---

*Eve Gruntfest's study (1977) of the Big Thompson flood found the opposite behavior pattern, but it appears to be due to the influence of other variables.

experience of the hazard. Particularly where the population turnover is high, as in Boulder where about 50% of the city residents change addresses each year (City of Boulder, 1976), the education efforts need to be conducted at frequent intervals. Information on other types of adjustments, such as federally subsidized flood insurance, may be included in the education program. The use of any natural resource (in this case the flood plain) entails some level of environmental risk. The public deserves to know what the risks of living in the flood plain are, and how those risks might be reduced.

SCENARIO I: THE BOULDER FLASH FLOOD

This scenario describes what might happen in a severe flash flood in Boulder, with the level of preparedness of January, 1977. The events described below represent only one set of possible actions; the outcome of an actual flood could be either more or less disastrous. This account provides the basis for the other three scenarios' description of the effect of different levels of community preparedness. To reflect the more likely situation, the flood is assumed to occur some years after the Big Thompson. The population estimates, however, are for 1976.*

The day could be any in the flood season, late spring to early fall. However, few are concerned about the hazard flooding presents in Boulder. It has been some years since the Big Thompson flood.

---

*The scenario, accompanied by eyewitness accounts of other flash floods provides the narrative for a slide presentation available from the Insitute of Behavioral Science that compares pictures of Boulder before a flood with postdisaster slides of the Big Thompson and Rapid City.

Many of the flood plain occupants were not in Boulder in 1976; others do not believe anything so disastrous will happen to them.

Over 500 people live in flood-prone areas of Boulder Canyon or Fourmile Creek Canyon. Perhaps 400 more are visiting the canyon areas this particular afternoon. In the city an estimated 1,530 residents have their homes in the Boulder Creek 1% flood plain. In the area west of 28th Street, workers and visitors number over 3,050 (see Appendix A).

For a while the city and county had been actively involved in preparing for the flood hazard. The Corps of Engineers had completed their study of Boulder Creek. The estimate of the 1% discharge had been changed, but no formal action had been taken on proposed flood mitigation measures. The initiative of city and county officials to upgrade the current warning system had diminished; concerns over a severe drought had taken precedence, although severe thunderstorms occur in drought years. Sporadic news stories, reports, and statements by citizens and officials concerned about the flood hazard attracted little attention.

The day had started out a typical weekday. Although the weather forecast called for a chance of thunderstorm activity in the afternoon, the same forecast had been given many times over the previous several weeks. About 4:30 PM large thunderstorms are noted west of Boulder, centered on Sugarloaf Mountain, between Fourmile and North Boulder Creeks. The moderate rain prompts many of the picnickers in the canyons to head for home. Light rain in the lower canyon areas and the city causes little concern. Many expect the storm to clear up later in the evening, as often happens.

At 5:15 PM the National Weather Service issues a general flash flood watch for gulches and low-lying areas in the Front Range canyons of Gilpin, Jefferson, Boulder and Larimer counties.*

The watch is announced about a half hour later by many radio stations. Some of the TV stations report the watch on their evening weather reports. In the canyons few hear the message. Radio and TV reception is poor in many areas because of the terrain and the storm. Few people in town pay much attention to the watch.

By 5:30 PM the tunderstorms have intensified; 6:00 marks the middle of the intense rain storm that will cause Boulder Creek and Fourmile Creek to flood within an hour.

The flash flood watch alerts the Boulder Regional Communications Authority to the potential for flash flooding in gulches and low-lying areas. By 5:45 several mountain residents have called in to report heavy rain. The Communications Center tries to confirm the reports but the list of rain observers has not been updated recently, and many of the observer telephones are disconnected or not working due to the rain. Dispatchers are busy handling calls reporting rock slides and other traffic hazards related to the rains. After considerable delay, the reports of heavy rain are confirmed, either by telephone or radio; heavy rain, two to three inches in one and one-half hours, is reported in certain locations. The Sheriff's

---

*In many cases the National Weather Service would not issue a watch because of the lack of information and the localized nature of flash floods. Although not prepared to do so at the time of this writing, they may, in the future, disseminate alerts to key warning agencies, but not the public. If neither an alert or watch were issued, the situation could be much worse than presented here.

deputy on duty that night sends a patrol car up Fourmile Creek Canyon to check on the river. He also contacts the volunteer fire departments in the canyons to obtain more information about the possibility of flooding.

Upon receiving confirmation of the rainfall amounts and the rising river from the Communications Center, the National Weather Service issues a flash flood warning at 6:15 PM. The warning emphasizes flooding in tributaries and low-lying areas in a number of the Front Range canyons near Boulder. The warning is carried, after some delay, on a number of radio and TV stations. Many in the city discount the warning.

As reports of the rising river reach the Communications dispatchers, they alert the fire departments, Director of Public Facilities, Sheriff's personnel, University and City Police and the City Manager. The local radio stations are also notified to help warn the public. About 6:20 PM the Sheriff, called in from home, makes the decision to start evacuating flood-prone areas of the canyons. One of the Communications Center dispatchers starts to call canyon residents on the emergency call list. The canyon fire departments alert neighbors in their areas. Extra patrol cars are sent up the canyons to alert the residents of Silver Spruce, Orodell and Canyon Park.

Throughout the canyons the lack of information about the expected magnitude of the flood hampers the warning effort. The volunteer firemen (men and women) and the deputy sheriffs are not sure how urgent their message is. Many people are told to drive out of the canyon. The residents hesitate. Few are aware of the flash flood hazard. Even fewer have planned evacuation routes and procedures. Confused by the warnings and unsure what action is appropriate, many try to confirm the warning by calling official sources or friends, or by checking to see what their neighbors are doing. A large number of people, in particular those driving through the canyons, never receive warning of the flood. Many residents do not have telephones and for others the lines are down. Some do not hear the sirens and loudspeakers on the patrol cars. Others do not associate the sirens with flood danger. A number who believe the warnings linger, gathering papers, possessions or pets.

At 6:30 PM the run-off floods Wallstreet, in some places reaching over eight feet above the stream bed. Salina and the Junction are quickly inundated by debris-filled torrents. The alert comes too late for most of the residents. Upstream occupants try to warn those downstream, but the lack of telephones and time limits their success. Although the heavy rains alert some, several groups of friends do not realize the danger until too late. Many are fortunate to escape when they hear the water coming. Half a dozen are killed. Climbing fifty feet up the side of the canyon would have saved their lives.

Early phone calls alert Crisman to the rapidly rising water. Many of the families are warned and evacuate promptly. An elderly couple unwilling to climb the canyon side tries to drive out of the flood. In the narrow canyon north of Crisman the turbulent water reaches almost ten feet above its normal stage, carrying with it bridges, cars and houses.

About the same time as Crisman floods, North Boulder Creek washes out the bridge on Colorado 119 as it joins the already raging Boulder Creek. One man abandons his car seconds before it is washed off the road. A number of motorists farther upstream are not so fortunate. The quickly rising water sweeps more than one camper downstream. Many tourists in the canyon narrowly escape disaster when fallen rocks on the road prevent their driving farther; the rising river forces them to climb the side of the canyon.

Around 6:40 PM the water triggers the Orodell flash flood alarm. Shortly afterward, news of the flooding at Crisman reaches Boulder. After consulting with the City Manager, the ranking police officer orders the evacuation of the 1% flood plain. Officers are confused as to the extent of the flood plain, the location of safe areas, and proper evacuation routes. The warning messages do not specify how to evacuate or where to go. No one knows how long it will take for the flood waters to reach Boulder, or how serious the danger is.

The lack of rain in Boulder and the uncertainty as to the expected magnitude of the flood contribute to a sense of complacency among the residents. Of the residents who do believe the warning, some collect valuables and pets. Severe traffic problems develop as many in the flood plain evacuate and others converge on the areas to help out or watch.

Word of the flooding at Crisman also reaches Orodell. The volunteer firemen and deputy sheriffs renew their warning efforts; this is especially difficult because many of the houses are across the river. Many newcomers are unaware of the flood hazard; their response, in many cases, is too late to be effective.

Around 7:00 PM, the Fourmile Creek flood waters reach Orodell, cresting over ten feet above the stream bed. Numerous side canyons also flood, damaging houses that are well above the main stream. A volunteer fireman is killed trying to reach residents on the far side of the river. Over a dozen people die, including several trapped in the Wagon Wheel Motel when it is inundated.

Peripheral thunderstorms cause Sunshine and Gregory Creeks to flood at about the same time as does Orodell. Little warning is received in these areas. A group of picnickers is drowned trying to cross Gregory Creek. Sunshine Creek crests four to six feet above normal. Several people die in these two normally placid creeks.

Boulder Creek continues to flood as raging side gulches empty into the main stream. A bridge upstream from Silver Spruce clogs with debris and temporarily dams the water. At 6:55 PM a wall of water released from behind the bridge and from a side gulch inundates parts of Silver Spruce thought to be safe. Although most of the residents have evacuated, some are killed. A car of guests from the El Vado Motel, trying to drive out of the canyon, is washed off the road near Orodell. A car full of students returning from a day in the mountains is swept off the road below Orodell; one manages to escape.

The Fourmile Creek discharge has already caused some areas of Boulder to flood. With reports of the flooding at Silver Spruce and at the hydroelectric plant, the police decide to sound the Civil

Defense alert sirens.

The quickly rising water floods the Canyon Park subdivision at about five minutes after seven. Although most of the families there have been warned and safely evacuated, one person is lost trying to climb the wet canyon wall after gathering some valuables. Somewhat later the water in that area crests well over ten feet above the stream bed.

The evacuation of the Boulder flood plain is hampered by several things. Those further away from the creek respond slowly. Few realize how fast the water is rising. A number of the elderly do not hear the sirens or, if they are warned, are reluctant to leave their homes. Groups of singles or peers tend to disregard the warnings. In many cases, store managers and proprietors instill a false sense of security in their customers.

As the water overflows the creek banks, several people belatedly trying to escape the apartments east of Eben G. Fine Memorial Park are swept to their deaths.

Although the Communications Center continues to function on emergency power, the Justice Center is isolated by the flood waters.

The Sixth Street bridge is quickly demolished as the water climbs to eight feet over its normal level. The City Public Works crews, in the early stages of flooding, try unsuccessfully to keep the bridges free of debris. Each bridge temporarily dams the water, releasing it as a wave when the bridge finally gives way.

The flood waters pile up behind the Ninth Street bridge, overtopping it by several feet, before the bridge is washed out.

The resulting wave of water engulfs the Library and Municipal Building. In the constricted channel through the Library, the creek reaches over fifteen feet above its normal height. The Municipal Building, Chamber of Commerce building, proposed Senior Citizens Center site, and First National Bank are engulfed in water running at moderate velocities about three feet deep.

As the flood rushes eastward, the Terrace View Manor apartments are undermined by the scouring of water ten feet over its normal height. Several homes near 17th Street are completely demolished. The flood plain near Athens Court is engulfed by three feet of water. The Harvest House cottages are destroyed as the water crests five feet above the bank of the creek.

The debris-laden Boulder Creek flood waters carry over 40 people to their deaths within the city. Some are caught watching the rising river; an impromptu concert at the Band Shell had attracted a small crowd. A dozen patrons of restaurants in the flood plain die trying to get to cars; in one case part of a restaurant is swept into the stream.

A number of residents of the University's married student apartments are killed. One family tries to save its car. A child is playing near the river. Several students coming back from the University are caught crossing the foot bridge; they are trying to reach their families.

East of Folsom Street several groups of people are trapped by the flood waters: shoppers in the Arapahoe shopping centers, apartment dwellers, guests in the Harvest House cottages south of the creek, residents east of 28th Street, and other visitors to the area. Some are in cars, some on foot.

Throughout the city the same stories are repeated many times. The initial warnings of a flash flood meet wide-spread skepticism. Later, as the creek starts overflowing its banks and as rumors of disaster in the canyons filter down to the city residents, many decide to evacuate. However, too many wait too long; many die as they seek escape in their cars.

Some manage to save important papers and remember to turn off the gas and electricity and to elevate their more valuable belongings. In the few minutes before disaster strikes, however, few think to take such measures to reduce their losses.

Over 90 people are known to have died in the flood. The bodies of others never will be recovered; they are listed as missing. Almost 100 people, including many elderly, are injured, a quarter of them seriously. Tales of harrowing escapes are recounted for months afterward.

The next day finds refugees camped on hill tops or stowed in schools and the University fieldhouse. The results of years of indifference to the flood hazard are symbolized by the ruins of the Municipal Building.

Direct damages within the city exceed $21 million to structures alone (Corps of Engineers, 1976a). West of 28th Street, damage to the contents of homes, offices and stores adds about $1.75 million to the flood's toll (see Appendix B). Cleanup costs and damages to utilities contribute further to the reconstruction costs.

Many things, in fact, worked well; in other disasters they have not. In Rapid City the Civil Defense sirens were not sounded because no one knew where the alarm switch was. In Boulder, key people could have been out of town, and important equipment could have malfunctioned. Telephones could have gone out much earlier. Flooding could have occurred in other canyons and tributaries such as Twomile, Goose, Fourmile Canyon, South Boulder, Bear, Bluebell and Skunk Creeks, not to mention the St. Vrain or Lefthand Creeks. It could have been either a holiday or night; people would be asleep and unable to see the flood in the dark. The death toll could have been much greater.

SCENARIO II: UPGRADED PREDICTION CAPABILITIES

This scenario represents what might happen if a more sophisticated detection network were installed, accompanied by only a low level of preparedness planning.

Several years earlier the city and county had studied possibilities for a flash flood warning system. A network of volunteer rainfall observers was established. Several stream gages were installed, assuring the city of perhaps a 30-minute lead time between the detection of a flash flood and its arrival on the west edge of town.

Concurrent with the installation of the hardware, moderately detailed preparedness plans were drawn up. These, however, had not been kept up to date over the intervening years; names and phone numbers are wrong, officials have forgotten their roles, and some newcomers have not even read the plan. The larger establishments (banks, hotels, restaurants) in the flood plain are not specifically included in the warning network, nor have they organized their own preparedness plans.

Efforts to inform the public of the flood risk and of appropriate responses to flash flood warnings have been sporadic. Occasional news articles and radio announcements have heightened the awareness of only a small number of people. Most of the flood plain occupants do not think they will ever be directly involved in a serious flood.

With thunderstorms intensifying around 5:30 PM, reports of heavy rain start to reach the Boulder Regional Communications Center. These are passed on to the National Weather Service which, at 6:15, issues a flash flood warning for several canyons in the Boulder Front Range areas. At about the same time, the appropriate emergency personnel are notified of the hazard by tone alert radio receivers. The volunteer fire departments respond and start to alert canyon residents in their areas.

Although the reported rainfall amounts indicate that a serious problem could exist, the river gage flash flood alarms have not yet been triggered. As a result, the early warning messages in the canyons are rather general. Although few take immediate action, the early warnings do serve to raise the level of concern of many people.

At 6:30 PM, Wallstreet, followed by Salina and the Junction, floods; this triggers the first flash flood alarm. However, the alarm comes too late for the upstream residents; Crisman is warned minutes before being flooded though Orodell has more time to prepare.

On Boulder Creek the confirmation of flooding comes too late for Silver Spruce and areas upstream.

Although most people in both canyons are warned, the response in only fair. The lack of lead time prevents everyone from receiving a warning. Many get only one rather general alert. Lacking confirmation of the threat, they hesitate, uncertain of what to do. Messages received over the radio and loudspeakers are less effective in promoting evacuation. Many, in particular newcomers unaware of the hazard, die trying to escape in their cars. Over 35 people lose their lives in the canyons west of Boulder.

The flash flood alarms and reports of flooding at Crisman prompt the police to start evacuating Boulder's 1% (100-year) flood plain. Warning efforts there proceed somewhat more smoothly than in the canyons. Loudspeakers and sirens on patrol cars, Civil Defense sirens, and the local radio stations are used to disseminate the warnings. Time does not allow for extensive personal contact.

Although most of the city flood plain occupants receive more than one warning, in many cases their response is not adequate. Many of the newcomers and visitors are unaware they are in any serious danger. As the flood's magnitude and lead time are confirmed, the warning messages become more specific. Officials and citizens alike are unsure of the location of safe ground or evacuation routes. The lack of time and the traffic jams keep many from evacuating safely.

Few people think to turn off the gas and electricity, or have the time to elevate furniture and protect valuables.

The flood waters reach the west edge of town shortly after 7:00 PM. The rushing water carries many people with it as it engulfs the flood plain. Almost 30 people die in the city, less than 100 are injured, and little property is saved from the flood's ravage.

SCENARIO III: A MODERATE WARNING SYSTEM

This scenario reflects how warning response might be affected by a fairly sophisticated detection network, coupled with a moderate level of preparedness planning and extensive public education efforts.

In the summer of 1977 a series of rain and river gages had been installed in the mountains west of Boulder. In addition, a fairly widespread network of rainfall observers had been established. The system is designed to provide a 45-minute lead time for the city, with later confirmations of the flood size and travel rate. In the upper reaches of the canyons, the lead times are about 15 minutes.

Plans for response to flash flooding are fairly detailed, although only sporadically maintained. Schedules and criteria for making the important decisions are specified, and responsibilities are delegated. Nevertheless, the turnover in city and county staff catches some officials unprepared. The planning has not included the early notification of large establishments; their preparedness plans are inadequate.

Along with the development of the preparedness plans, a long-range public education effort was begun. Officials work closely with the media each spring. Brochures or flyers are mailed out yearly to flood plain occupants. The public utility bills are used to notify residents of the flood risk. The education messages describe the risk, identify the flood plain, mark safe areas, and list appropriate actions to take in a flood situation, including evacuation and emergency flood proofing. Coverage in the upper parts of Fourmile Canyon has been less comprehensive than in the city.

By 6:00 PM the automatic rain gages and calls from observers report heavy rainfall west of Boulder. This information is promptly relayed to the National Weather Service and local emergency personnel. The National Weather Service issues a flash flood warning, specifically including Boulder and Fourmile Creek Canyons. As the volunteer fire departments start alerting residents in the canyons, they are fairly sure of the flood threat. Subsequent confirmations of rainfall and flooding give the warners increased confidence in the importance and urgency of their task. Had a less credible network been installed, the volunteers may not have acted so promptly, especially if previous alerts had been false alarms.

At 6:25 PM the first river alarm is triggered. The warning is relayed to Wallstreet several minutes before it floods. Salina and the Junction have more time. Many escape in time, but several are caught by flooding side gulches.

Downstream from the Junction and in Boulder Canyon the lead times are longer. The messages are specific, including directions to climb to high ground up the sides of the canyon. The warnings are distributed primarily by sirens and loudspeakers, with some door-to-door warning and telephone contact before the lines go down. Some people are able to get radio warnings.

The response to the warnings in the canyons is generally adaptive. Most of the residents receive several warnings; many climb to high ground. However, some disbelieve the warnings or linger too long before they evacuate. A number of the tourists driving through the canyons receive only general warnings. Some try to drive out of the danger.

By 6:30 the potential for disaster in Boulder is clear to the policeman on duty, and the decision to evacuate the 1% (100-year) flood plain is made. With the longer lead times, more emergency personnel and neighbors are able to go door-to-door and use telephones. Sirens, loudspeakers and radio announcements are used to confirm the warnings.

Most residents respond fairly well. The warning messages encourage the elevation of valuables and disconnection of gas and electricity. Traffic problems are less severe since non-emergency traffic is prohibited from the area.

Despite the warning efforts, some die. Many are influenced by the actions of those that leave promptly, but some, particularly those in groups of friends and the elderly, delay their evacuation until too late. Perhaps as many as 30 people die in the flood, over half of them within the canyons. Fewer than 50 suffer injury.

In the 45 minutes between the first warning and the first serious overbank flow in town, many residents take the precautions of furniture and valuables and turning off gas and electricity. For most businesses, the warning comes too late to try to carry out such measures. Perhaps a third of the damages to building contents that might have been reduced in the available time are actually avoided. West of 28th Street alone, this amounts to over $130,000 in reduced damages (see Appendix B). Many valuable papers are also saved.

SCENARIO IV: AN INTEGRATED FLOOD WARNING SYSTEM

This scenario represents what might result from detailed and careful planning of the flash flood warning system. The detection network includes a regional weather radar station east of Boulder and a combination of automatic and volunteer monitored rain and stream gages (see report by Leonard Rice Water Consulting Engineers). These are linked by radio to the Boulder Regional Communications Authority, where a computer helps the trained officials interpret the incoming data. Several hours before the rain gages report heavy rainfall, one hour before a flash flood would crest in the city, the flood threat could be roughly forecast, with more accurate confirmations as the gages continue to monitor the event.

The preparedness planning has been comprehensive. The flash flood plain has been detailed and well-maintained by City and County officials. Practice alerts are run to check for weak links.

Telephone calls to key people in each neighborhood, backed up by patrol cars, sirens, loudspeakers and radio messages, are relied upon to spread the warnings. Names and telephone numbers are updated yearly. Radio communication is maintained where telephones are unreliable. Plans were made to notify the large establishments in the flood plain early in the warning process. Most of these have developed in-house preparedness plans.

Complementing the preparedness planning is an extensive public education effort. Attractive signs advising people of the hazard and directing them to climb the canyon side in the event of a flood were placed at key points in the canyons. In the city, signs were erected marking the expected limits and heights of flooding. The newspapers and radio and TV stations are utilized at appropriate times. Brochures describing the hazard are widely distributed through business and citizen groups, Sheriff and Fire departments, general mailing, as a part of real estate transactions and rental contracts, and through the schools. Announcements on public utility bills are also used periodically.

Throughout the educational campaigns, the emphasis is on reducing deaths and property damage. The repeated message is that the hazard, although infrequent in occurrence, is of sufficient magnitude to warrant careful planning.

About 4:00 PM the radar station reports large thunderstorms building over the mountains west of Boulder. This information prompts the Boulder Regional Communications Center dispatchers to alert their list of flood emergency agencies of the possible danger. Off-duty personnel are called in; people are alerted to watch their rain gages and the stream's height. The radar reports of rainfall and intense thunderstorms are sent to the National Weather Service. They issue a flash flood watch for several canyons of the Front Range west of Boulder.

By 5:30 the automatic rain gages report heavy rainfall centered on Sugarloaf Mountain. Upon receiving these reports, the National Weather Service puts out a flash flood warning. All available emergency personnel are mobilized.

Shortly after 6:00, enough rain has fallen, with little sign of letting up, to prompt evacuation of the canyon flood-prone areas and the high risk zones in the city. Sirens and loudspeakers on patrol cars, door-to-door contact, telephone call-out fans, and radio and TV stations run frequent messages alerting people of the threat and directing them to tune in Boulder stations, which by 6:30 are only broadcasting emergency messages.

In the canyons, people respond promptly to the warnings. Many receive confirmation from second and third sources. The content of the messages is similar: "The Boulder County Sheriff has received confirmed reports of extreme amounts of rainfall. Severe flash flooding is imminent. You are advised to go to high ground. Do not try to drive out of the canyon. This is the first warning." Many have prepared for evacuation by collecting emergency supplies in one place and planning places to go.

With the initial warnings, the roads in the canyons are blocked at both ends, an early precaution against cars entering the danger zone. Many motorists are out of the canyon by the time the flood hits. As the rains continue to fall, the canyon roads become impassable due to rock falls or flooding side gulches. With confirmation of serious flooding, motorists are told to abandon their cars for higher ground.

As the creeks rise, the river gages confirm the flood threat. Rough estimates of the flood size and lead times are made and incorporated into the warning messages, along with reports of the flood's impact upstream and people's response to the warnings elsewhere. The Civil Defense sirens are sounded when the flood is fifteen minutes away. For many, this is the final cue to evacuate.

In Boulder, response to the flash flood warnings is highly adaptive. Evening crews in stores and businesses are able to elevate or move many valuables. Many residents also save substantial amounts of their personal papers and property. Many cars are moved to high ground. Almost three fourths of the possible avoidable damages are actually avoided--this amounts to over a quarter of a million dollars west of 28th Street alone (see Appendix B).

The longer lead times allow almost all to evacuate safely. A few are caught in the flood; they do not heed the maxim: "Always keep yourself between high ground and the rising water." They simply wait too long. Less than a dozen people die in the flood waters, and only a few are injured.

The early warning allows for evacuation centers to be prepared for the displaced. Emergency communications are quickly established to handle incoming and outgoing calls inquiring about the safety of friends and relatives. The city, county and state get a jump on the reconstruction process.

There are things no warning system can do. Homes and offices, stores, hotels and restaurants, streets and bridges, gas, water, sewer and telephone lines, and public and private buildings are destroyed or damaged. Flood insurance, for those who had bought it, covers some of the loss. Weeks pass before much of the debris is removed. Planning and financing the reconstruction takes months of frustrating effort. A year later the flood's ravages can still be seen.

RESPONSE TO AN EARLY AFTERNOON FLOOD

If the thunderstorms were to grow and intensify west of Boulder around 2:30 in the afternoon, the warning situation in the mountains and the city would be substantially different from that later in the evening. Initial notice of the heavy rainfall might be somewhat delayed as many would not be at home to monitor the rain gages; most would be at work or out shopping. If a radar station were established, it could provide an alert several hours in advance. This would give key people time to get in position to monitor rainfall. Perhaps 300 residents would be in the canyons, as opposed to about 450 in the evenings. Residents and visitors in the canyons might total 800 people in the middle of the afternoon. Once the seriousness of the storm is confirmed, the response by the emergency personnel in the city would be rapid, as more people would be on hand during the day. In the canyons fewer volunteer firemen would be able to respond quickly to a flood warning. Warning in the canyons would have to rely heavily on the notification of key people in each area and the efforts of city and county personnel.

In Boulder, dissemination of the warnings would be easier, but some serious problems might develop. Perhaps half of the flood plain residents would be at work or school. Massive convergence onto the flood plain of families trying to reunite, interested onlookers, and volunteers and emergency units would create severe traffic jams, seriously jeopardizing the evacuation effort. Messages by the radio stations may help to limit the convergence. Telephone lines would also be tied up, perhaps to the point of being useless for emergency warnings.

West of 28th Street the total number of people exposed to flooding in the city would be over 4,000, somewhat less than the estimated 4,500 people in the 1% (100-year) flood plain during the evening. There would be fewer residents and visitors than during the evening but, depending on the day, most of the work force would be on the job. Although this increases the risk to life, it also increases the potential for reducing damages through emergency flood proofing. The amount of preparedness planning, including employee education, within each establishment (particularly the larger ones) would determine the level of damage avoidance.

Response to a warning of a flash flood during the daytime will be influenced by the same factors as described in the previous scenarios. There may be a greater willingness to evacuate during the day and a greater visibility of environmental cues.

A FLASH FLOOD AT NIGHT

Late at night, between 10:00 PM and midnight, it is most difficult to disseminate a warning. Less than a third of the visitors and workers exposed to flooding in the afternoon or evening (in the canyons and west of 28th Street in the city this is about 1,000 people) might be in the flood plain at 11:00 PM. However, many of the residents (almost 2,000 people west of 28th Street and in the canyons) will be asleep.

Detection of the storm may be delayed if volunteer observers are not watching their rain or river gages. The relatively fewer numbers of emergency personnel able to respond promptly, especially if home phone lists are out-dated, will slow the entire warning process. Ordinary sirens may fail to wake the soundest sleepers. Those who are awakened will likely not be prepared to respond quickly; many will seek confirmation of the warning. Dressing for going outside will take more time. At night the weak links in a warning system could prove fatal to many people. Little in the way of emergency flood proofing is likely to be accomplished, except perhaps in those establishments which are occupied all night.

During the night the warning messages should emphasize safety. Radio stations may need to be alerted earlier during the day, if the situation warrants it, to insure they will still be on the air if a flood develops.

OF GREATER AND LESSER FLOODS

This study was based on a hypothetical 1% (100-year) flood. Planning for the flood hazard should also consider floods of greater magnitudes. A 0.2% (500-year) flood would inundate a larger amount of land beyond the 1% (100-year) flood plain. The velocities, depths and debris loads of the flood waters would be greater, causing a much higher risk to life. Damage to buildings in a 0.2% (500-year) flood on Boulder Creek is estimated to exceed $37.5 million (Corps of Engineers, 1976a). An effective warning system for a 1% event should also be able to pick up the more extreme event, in which case warning messages should emphasize safe evacuation.

More frequent floods of a lower magnitude are also likely to occur. A reliable and credible warning system should be able to distinguish somewhat between the more frequent events (the 4% or 25-year floods) and the more severe 1% (100-year) floods. This would enable evacuation of only the areas likely to be flooded and prevent overwarning, which would be detrimental to later warning efforts.

Flooding caused by snow melt or long duration rainfall would allow for greater flood-fighting efforts, including bridge clearing, sand bagging and emergency flood proofing. A flash flood warning network could also provide reasonably accurate forecasts of flood heights and lead times in a slow flood situation.

LEARNING FROM OTHER DISASTERS: THE NEXT STEPS IN THE DESIGN OF AN EFFECTIVE FLASH FLOOD WARNING SYSTEM

Flash floods have exacted a high toll in recent years: 237 dead in Rapid City, South Dakota (1972); 139 dead in the Big Thompson Canyon, Colorado (1976); and nine dead in El Dorado Canyon, Nevada (1974). Property damage has totaled hundreds of millions of dollars. In the meantime, the people and buildings in flood-prone areas continue to increase.

Along Fourmile and Boulder Creeks, west of 28th Street only, 3,000-5,000 people could be exposed to flooding, depending on the time of day. In the city itself, over 8,000 people live in flood-prone areas.

Given the present efficiency of the warning system, the situation in Boulder is quite serious. Many people in the canyons would get no warning. In the city the warning time would be too short to allow for everyone to be evacuated safely. Many of the flood plain occupants are elderly and will need assistance in evacuating their homes. Many residents living near tributary streams also face a significant risk to their lives.

Buildings that would be severely damaged in a 1% event include the Library, Municipal Building, Terrace View Manor, University housing buildings, Harvest House, many residences and other buildings. Important records, supplies and equipment would be lost, increasing the social disruption that would follow the flood.

The surest method to reduce human and property losses is to remove the vulnerable buildings from the flood plain. Even if this were undertaken, an effective flash flood warning system would be needed to reduce the loss of life, the subsequent social disruption, and some of the damage to the contents of residential, commercial and government buildings.

Despite the sophistication of the prediction network, if planning for the flood hazard does not include careful consideration of warning dissemination, warning content, and other variables that influence response to the warnings, the system may fail its major purpose: safe evacuation of vulnerable areas.

The necessary steps in implementing an effective warning system include determining what level of protection is appropriate, possible funding strategies, what agencies have what responsibilities, who is to oversee the entire operation, what public information measures are appropriate, and drawing up a preparedness plan with the participation of all involved officials (see NOAA, 1977 for a guide to this process. The Front Range communities report [Downing, 1977] also contains some specific recommendations).

The major historic floods in Boulder have had a fairly slow onset, which greatly reduces the threat to life. However, the potential for a major flash flood is obvious. Although no one can predict when, a flash flood will occur sometime in the future. In its wake will be destruction. Can we afford not to be prepared?

BIBLIOGRAPHY

Anderson, William A.
1970 "Tsunami Warning in Crescent City, California and Hilo, Hawaii." Pages 116-124 in National Academy of Sciences, The Great Alaska Earthquake of 1964: Human Ecology. Washington: National Academy of Sciences.

Bates, F. L., et al.
1963 The Social and Psychological Consequences of a Natural Disaster: A Longitudinal Study of Hurricane Audrey. Publication 1081. Washington: National Academy of Sciences, National Research Council.

Beard, Leo R.
1975 Generalized Evaluation of Flash-Flood Potential. Center for Research on Water Resources. Technical Report CRWR 124. Austin: University of Texas.

City of Boulder
1965 Flood Report Survey. Planning Report. Boulder, Colorado.

1969 August 1969 (Revised in March 1976) 100-Year Flood Plain Map.

1976 "Social Report, 1976." Prepared by William Conger and Melba Shepard.

(no date) Local Disaster Plan: City of Boulder and Rural Areas. Boulder, Colorado. (Written after October 1971.)

Cochrane, Harold C.
1975 Natural Hazards and Their Distributive Effects. Boulder, Colorado: University of Colorado Institute of Behavioral Science.

Corps of Engineers Committee on Environmental Planning
1973 "Boulder Creek Flood Control Plan." Boulder, Colorado.

Day, Harold J. and Kwang K. Lee
1976 Flood Damage Reduction Potential of River Forecast Services in the Connecticut River Basin. NOAA Technical Memorandum NWS HYDRO-28. Silver Springs, Maryland.

Downing, Thomas E.
1977 Warning for Flash Floods in Front Range Communities. Report prepared for the Urban Drainage and Flood Control District, Denver, Colorado. Boulder: University of Colorado Institute of Behavioral Science.

Drabek, Thomas E.
1969 "Social Processes in Disaster: Family Evacuation." Social Problems 16, #3 (Winter): 336-349.

Drabek, Thomas and Keith Boggs
1968 "Families in Disaster: Reactions and Relatives." Journal of Marriage and the Family 30 (August): 443-451.

Drabek, Thomas E. and John S. Stephenson, III
1971 "When Disaster Strikes." Journal of Applied Social Psychology 1, #2: 187-203.

Environmental Science Services Administration
1969 The Virginia Floods, August 19-22, 1969, A Report to the Administrator. Washington: U. S. Government Printing Office.

1970 A Plan for Improving the National River and Flood Forecast and Warning Service. Washington: Government Printing Office.

Ericksen, Neil J.
1974 A Scenario Approach to Assessing Natural Hazards: The Case of Flood Hazard in Boulder, Colorado. Unpublished dissertation. Department of Geography. University of Toronto.

1975 Scenario Methodology in Natural Hazards Research. Boulder, Colorado: University of Colorado Institute of Behavioral Science.

Follansbee, Robert and Leon R. Sawyer
1948 Floods in Colorado. U. S. Geological Survey Water Supply Paper #997. Washington: U. S. Government Printing Office.

Grigg, Neil S., Leslie H. Botham, Leonard Rice, W. J. Shoemaker and L. Scott Tucker
1975 Urban Drainage and Flood Control Projects, Economic, Legal and Financial Aspect. Colorado State University Environmental Resources Center, Completion Report Series, No. 65. Fort Collins, Colorado.

Gruntfest, Eve C.
1977 What People Did During the Big Thompson Flood. Natural Hazards Research Working Paper 32. Boulder: University of Colorado Institute of Behavioral Science.

Hughes, L. A. and L. L. Longsdorf
1975 Guidelines for Flash Flood and Small Tributary Flood Prediction. NOAA Technical Memorandum NWS CR-58. Washington, D.C.

Hutton, Janice R.
1976 "The Differential Distribution of Death in Disaster: A Test of Theoretical Propositions." Paper presented at the Joint Meeting of the Society for the Study of Social Problems and the American Sociological Association, New York City.

Instituut Voor Sociaal Onderzoek Van Het Nederlandse Volk Amsterdam
1955 Studies in Holland Flood Disaster 1953. Committee on Disaster Studies of the National Academy of Sciences/ National Research Council. Volume I. Washington: National Academy of Sciences.

Janis, Irving L.
1962 "Psychological Effects of Warnings." Pages 55-92 in Baker, George W. and Dwight W. Chapman, Man and Society in Disaster. New York: Basic Books.

Mack, Raymond W. and George W. Baker
1961 The Occasion Instant. National Academy of Sciences, National Research Council Disaster Study #15. Washington: National Academy of Sciences.

McLuckie, Benjamin F.
1970 The Warning System in Disaster Situations: A Selective Analysis. Research Report #9. Columbus, Ohio: The Ohio State University Disaster Research Center

1973 The Warning System: A Social Science Perspective. National Oceanic and Atmospheric Administration.

Metcalf, Leonard and Harrison P. Eddy
1912 The Improvement of Boulder Creek and the Sewarage, Drainage and Disposal of the Sewage of Boulder, Colorado. Report prepared for the Boulder City Improvement Association. Boston: Metcalf and Eddy, Consulting Engineers.

Mileti, Dennis S.
1972 Behavioral Response to Short-Term Natural Hazard Warnings. A Working Paper presented to the International Seminar, Organizational and Community Responses to Disasters, Disaster Research Center, Ohio State University. Columbus, Ohio.

1974 A Normative Causal Model Analysis of Disaster Warning Response. Unpublished dissertation. Department of Sociology, University of Colorado.

1975 Natural Hazard Warning Systems in the United States: A Research Assessment. University of Colorado Institute of Behavioral Science.

Mileti, Dennis S., Thomas Drabek and J. Eugene Haas
1975 Human Systems in Extreme Environments: A Sociological Perspective. Boulder, Colorado: University of Colorado Institute of Behavioral Science.

National Advisory Committee on Oceans and Atmosphere
1972 The Agnes Floods: A Post-Audit of the Effectiveness of the Storm and Flood Warning System of NOAA. Washington: U. S. Government Printing Office.

National Oceanic and Atmospheric Administration
1971 Arizona Floods of September 5 and 6, 1970, A Report to the Administrator. Natural Disaster Survey Report 70-2. Rockville, Maryland.

1972 Black Hills Flood of June 9, 1972, A Report to the Administrator. Natural Disaster Survey Report 72-1. Rockville, Maryland.

1973 Final Report of the Disaster Survey Team on the Events of Agnes, A Report to the Administrator. Natural Disaster Survey Report 73-1. Rockville, Maryland.

1975 A Federal Plan for Natural Disaster Warning and Preparedness, First Supplement, FV 1976-1980. Federal Coordinator for Meteorological Services and Supporting Research. Washington: U. S. Government Printing Office.

1976 Big Thompson Canyon Flash Flood of July 31-August 1, 1976, A Report to the Administrator. Natural Disaster Survey Report 76-1. Rockville, Maryland.

1977 Flash Flood Preparedness Planning Guide. By H. James Owens. (Forthcoming from the National Weather Service).

Olmstead, Frederick Law, Jr.
1910 The Improvement of Boulder, Colorado. Report prepared for the City Improvement Association. Boulder: City of Boulder.

Quarantelli, Enrico L.
1964 "The Behavior of Panic Participants." Pp. 68-81 in D. P. Schultz (Ed.) Panic Behavior. New York: Random House.

Raymond, Lyle S., Jr.
1976 "Flood Warning Systems: Can We Apply What We Know?" Synopsis of the New York State Senate Subcommittee to Investigate Flood Warning Systems and Flooding Damage Following Hurricane Eloise in September, 1975. Cooperative Extension, Cornell University, File No. 76-50. Ithaca, New York.

Scanlon, Joseph and Brian Taylor
1975 The Warning Smell of Gas. Emergency Planning Canada, Field Report 75-2. Ottawa, Canada.

Scanlon, Joseph, et al.
1976 The Port Alice Slide. Emergency Planning Canada, Field Report 76-1. Ottawa, Canada.

Susquehanna River Basin Commission
1976 Neighborhood Flash Flood Warning Program Manual. Prepared by Stewart K. Wright. Publication No. 45. Mechanicsburg, Pennsylvania.

1976a Planning Guide, Self-Help Flood Forecast and Warning System, Swatara Creek Watershed, Pennsylvania. Prepared by Stewart K. Wright. Publication No. 42. Mechanicsburg, Pennsylvania.

U. S. Army Corps of Engineers
1969 Flood Plain Information, Boulder Creek and South Boulder Creek. Volume II, Boulder Metropolitan Region, Colorado. Prepared for Denver Regional Council of Governments.

1972 Special Flood Hazard Information Report, Boulder, Creek, City of Boulder, Colorado. Omaha: Department of the Army.

1976 Boulder Creek at Boulder, 100-Year Flood Hydrographs at Designated Locations.

1976a Boulder's Flood Protection Decision--A Choice to Live With. Public Information Fact Sheet. Omaha, Nebraska.

1976b Revised Boulder Creek 100 Year Flood Plain Map (Approximate).

1976c Untitled schematic map of Middle Boulder Creek flood plain.

1977 "Boulder Creek Flood Profiles."

U. S. Geological Survey
1961 Floods at Boulder, Colorado. Hydrologic Investigations Atlas #HA-41. Washington: U. S. Department of the Interior.

University of Colorado
1972 "Flood Hazard on University of Colorado Property." Reports by students in Geography 501, Autumn 1972. Department of Geography.

Wasserman, E.
1975 Use of Radar Information in Determining Flash Flood Potential. NOAA Technical Memorandum NWS ER-60. Garden Island, New York.

White, Gilbert F.
1939 "Economic Aspects of Flood-Forecasting." Transactions of the American Geophysical Union.

1964 Choice of Adjustment to Floods. Department of Geography Research Paper #93. Chicago: University of Chicago Press.

1966 Flood Hazard Reduction and Flood Plain Regulations in Boulder City and County, Colorado. Report requested by Planning Department, City of Boulder and County Planning Commission, Boulder.

Wilkinson, K. and P. Ross
1970 Citizen's Response to Warnings of Hurricane Camille. Social Science Research Center, Report No. 35. Jackson, Mississippi: Mississippi State University.

Williams, Gerald
1976 Application of the National Weather Service Flash-Flood Program in the Western Region. NOAA Technical Memorandum NWS WR-103. Salt Lake City, Utah.

Williams, Phillip, Jr., et al.
1972 Flash Flood Forecasting and Warning in the Western Region. NOAA Technical Memorandum NWS WR-82. Salt Lake City, Utah.

APPENDICES

APPENDIX A
THE POPULATION EXPOSED TO FLOODING IN BOULDER, COLORADO

If flooding were to occur in Boulder in the next several years, who would be directly affected? This question was addressed in three parts. First, the number of residents occupying flood-prone areas of the city was estimated. Next, the approximate number of people exposed to flooding in Boulder and Fourmile Creek Canyons was counted. Finally, the numbers of residents, workers and visitors in the Boulder Creek flood plain west of 28th Street were estimated for various times during the day (these counts were also extended to the flood-prone areas of the two canyons). Each set of estimates will be discussed in turn.

The numbers of housing units in the flood plains considered in this study were obtained from air photographs, subdivision plats, block counts, visual surveys and spot checks. The numbers of residents were then estimated using the following multiples:*

Single family dwellings	3.11 (city)	3.2 (county)
Trailers	2.0	
Apartments	1.82	

Error in these counts is estimated to be less than 5%. Floods, of course, are not confined to lines drawn on a map. The character

---

*City multiples are from R. L. Polk and Company, Profiles of Change, Boulder, Colorado, 1975. For trailers, the multiples are based on estimates by the Housing Inspection Department, City of Boulder County Land Use Department. The author is grateful to Bill Conger, City Human Resources Department, for compiling most of the estimates of residences within the city limits.

and location of the storm will determine which streams flood. Flooding could be over a large area or confined to only one or two basins. Although this study is based on a 1% (100-year) flood, less frequent events of a greater magnitude need to be considered in preparing for the event.

City-wide Estimates of Residents Exposed to Flooding

The only map delineating flood-prone areas for the entire city is the 100-Year Flood Plain Map, adopted August, 1969, Revised March, 1976 (see Figure 1). This map is based on a 1% discharge estimate of 7,400 cfs for Boulder Creek at the mouth of Boulder Canyon and on comparable estimates for the major tributaries joining Boulder Creek east of the foothills.

Table A-1 summarizes the resident population exposed to flooding within the city. Over 8,000 people live in identified flood-prone areas; most are in the Twomile Creek Basin. Most of the households in this area are middle income, middle aged families, although considerable numbers of elderly, young families and singles also live in the flood plain. Except near the foothills, overbank flow in the Twomile Creek Basin is likely to be shallow and low velocity. Flooding will deposit a considerable amount of silt, disrupt traffic and affect a large number of apartments, several trailer courts, a school and Boulder Community Hospital, as well as single family dwellings and commercial buildings.

Along Boulder Creek the exposed population is diverse. The apartments, including the University complexes, and low income dwellings house many students. The population includes significant numbers of singles and families; young, middle aged and elderly; and lower to middle aged socio-economic levels.

The flood plain populations of the other tributaries--Sunshine, Gregory, Bluebell, Skunk and Bear Creeks--are predominantly middle class, middle aged families.

Boulder and Fourmile Creek Canyons

Over 500 people are estimated to reside in flood-prone areas of Boulder and Fourmile Creek Canyons (see Table A-1). As no adequate flood plain maps exist for the canyons, this estimate is based on a rough visual survey of housing stock. Borderline cases were generally included in the counts since these people would probably have to evacuate in the case of a major flood.

Except for a dozen trailers and two motels, dwellings in the canyons are mostly single family houses. In the upper reaches of Fourmile Creek Canyon many of the dwellings are small cabins. There an "alternative" life style prevails; many work at home. The population appears to be fairly stable, although bimodal: the older residents who have been there a number of years and the younger more transient population. Below Poorman's Hill the residents are generally middle class, and most commute to Boulder for work. In Boulder Canyon the population is dominated by upper middle class, middle aged families, with and without children.

Estimates for the numbers of visitors and workers in the canyons could be quite large, depending on the particular day and the weather.

Residents, Workers and Visitors, West of 28th Street

Following such disasters as occurred in Rapid City and the Big Thompson, and drawing on a wider base of Front Range flood data, the Corps of Engineers have concluded that the more likely 1% (100-year) discharge would be about 12,000 cfs at the mouth of Boulder Canyon. This discharge has been applied only to Boulder Creek--mapped on a schematic map and the less detailed October, 1976 map. The schematic map, altered to include the dry islands shown on the October map, was used to delineate the Boulder Creek flood plain west of 28th Street, the study area for estimates of the numbers of residents, workers and visitors exposed to flooding (see Figure 2). This study area represents the highest hazard zones within the city; east of 28th Street flood waters would have lower depths and velocities.

An estimated 1,530 residents live in this part of the flood plain (see Table A-3). About 150 of these live in the highest hazard zone, corresponding to the 4% (25-year) flood plain. Although the canyon data are not divided by risk, another 250 people probably live in the highest risk zones in the canyons.

Over 1,400 workers might be in the study area on an average weekday afternoon. During the evening less than half that number would be working in the flood plain, primarily in restaurants, retail and grocery stores, gas stations, and in various office buildings. Later at night less than two hundred might be working in the flood plain. Only a couple people would be working in the canyon flood-prone areas.

Restaurants, theaters, offices, parks, motels and stores all attract visitors to the flood plain. In addition, a number of people would be driving through. Over 2,500 visitors might be in the flood plain in the afternoon or evening, less than 900 later at night. The time of day and day of the week, the weather, and the scheduling of special events such as concerts, meetings and sports events will greatly influence the actual numbers of flood plain visitors.

Table A-3 summarizes the estimates for the population exposed to flooding west of 28th Street. Also given is an estimate that takes into account residents not at home, absent workers and possible overlap between the three groups. In the afternoon almost 5,000 people in the canyons and west of 28th Street would be directly affected by a major flood, in the evening over 5,000 would be vulnerable, and 3,000 would be vulnerable at night.

TABLE A-1
RESIDENTS OF FLOOD PLAINS IN BOULDER
Based on the 1969 100-Year Flood Plain Map for within
The City Limits (7,400 cfs discharge), and visual observations for the canyons.

FLOOD PLAIN	HOUSES	POP.	APTS.	POP.	TRAILERS	POP.	TOTALS UNITS	TOTALS POP.
FOURMILE CREEK								
Orodell	35	112	0	0	8	16	43	128
Crisman	23	74	0	0	0	0	23	74
Junction	5	16	0	0	0	0	5	16
Wall Street	16	51	0	0	1	2	17	53
Salina-Summervl	15	48	0	0	0	0	15	48
Sunset	10	32	0	0	3	6	13	38
Subtotal	104	333	0	0	12	24	116	357
BOULDER CANYON								
Canyon Park	11	35	0	0	0	0	11	35
Orodell	6	19	0	0	0	0	6	19
Silver Spruce	17	54	0	0	0	0	17	54
Above tunnel	20	64	0	0	0	0	20	64
Subtotal	54	162	0	0	0	0	54	172
CANYON SUBTOTALS	158	505	0	0	12	24	170	529
SUNSHINE CREEK WITHIN CITY LIMITS	12	38	0	0	0	0	12	38
GREGORY CREEK	28	90	0	0	0	0	28	90
BLUEBELL, SKUNK CR.	240	747	60	109	0	0	300	856
BEAR CREEK	220	685	0	0	0	0	220	685

TABLE A-1 (continued)

FLOOD PLAIN	HOUSES	POP.	APTS.	POP.	TRAILERS	POP.	TOTALS UNITS	TOTALS POP.
TWO MILE CREEK								
Mtns.--Broadway	230	715	31	147	0	0	311	862
Brdwy--Folsom	725	2255	37	67	0	0	762	2322
Flsm--City Lmt.[1]	175[2]	544[2]	262	477	367	734	804	1755
Subtotals	1130	3514	380	691	367	734	1877	4939
BOULDER CREEK--city								
West of Folsom	209	650	391[3]	712[3]	0	0	600	1362
East of Folsom	33	103	29	53	0	0	62	156
Subtotals	242	753	420	765	0	0	662	1518
TOTALS	2030	6332	860	1565	379	758	3439	8655

NOTES:
1. Includes 155 low income houses (population = 482), 3.11 used as the multiple.
2. Does not include ten ground floor apartments east of Eben G. Fine Memorial Park, probably within the flood plain but not on the 100-Year Flood Plain Map.
3. Includes the portion of Fourmile Canyon Creek flood plain with the city limits. The two flood plains merge near Valmont Road.

MULTIPLES: Single Family Dwellings: 3.11 (city), 3.2 (county); Trailers: 2.0; Apartments: 1.82.

TABLE A-2
VISITOR AND WORKER ESTIMATES
Based on Corps of Engineers' schematic map of the Boulder Creek 1% flood plain (12,000 cfs), west of 28th Street only, altered to reflect dry islands as delineated on their October, 1976 map.

LOCATION	VISITORS 4:00 PM	VISITORS 7:00 PM	VISITORS 11:00 PM	WORKERS 4:00 PM	WORKERS 7:00 PM	WORKERS 11:00 PM
OFFICE BUILDINGS						
Library, Mun. Bldg.	100	50	0	80	20	0
Other large bldgs.	85	0	0	195	30	10
Medium bldgs.	25	0	0	140	0	0
Small bldgs.	10	0	0	40	0	0
Subtotal	220	50	0	455	50	10
AUTOMOTIVE						
Large	30	20	0	120	40	0
Other	15	10	10	70	10	10
Subtotal	45	30	10	190	50	10
MANUFACTURING	0	0	0	90	5	0
FOOD SERVICE						
Stores	90	60	10	60	45	20
Restaurants	750	1355	180	225	220	90
Subtotal	840	1415	190	285	265	110

TABLE A-2 (continued)

LOCATION	VISITORS 4:00 PM	VISITORS 7:00 PM	VISITORS 11:00 PM	WORKERS 4:00 PM	WORKERS 7:00 PM	WORKERS 11:00 PM
RETAIL						
Large	105	95	0	120	95	15
Other	65	20	0	130	25	0
Subtotal	170	115	0	250	120	15
SERVICE ORIENTED	60	5	0	55	5	0
MOTELS, HOTELS	175	205	190	80	55	35
NURSING HOMES[1]	100	100	60	10	10	5
THEATERS	50	275	175	10	10	10
SCHOOLS[2]	25	0	0	5	0	0
PARKS IN CITY	45	40	10	0	0	0
DRIVING THROUGH[3]	500	450	150	0	0	0
TOTALS	2230	2685	785	1430	570	195
BOULDER CANYON						
Picnic turnouts[4]	125	100	10	0	0	0
Red Lion[5]	10	10	10	0	0	0
El Vado Motel	10	10	10	5	5	5
Driving Through[6]	300	250	130	0	0	0
Subtotal	445	370	130	5	5	5

TABLE A-2 (continued)

LOCATION	VISITORS 4:00 PM	VISITORS 7:00 PM	VISITORS 11:00 PM	WORKERS 4:00 PM	WORKERS 7:00 PM	WORKERS 11:00 PM
FOURMILE CREEK						
Wagon Wheel	30	30	30	5	5	5
5 space campground	10	10	10	0	0	0
Driving through[6]	40	30	10	0	0	0
Other parking	15	10	0	0	0	0
Subtotal	95	80	50	5	5	5
CANYON TOTALS	540	450	180	10	10	10
GRAND TOTALS	2770	3135	965	1440	580	205

NOTES: 1. Residents of the nursing home are counted as visitors.

2. This assumes the school, Boulder High, is in summer session, with no classes. During the school year classes are out at 3:10, although a number of activities may be scheduled for later hours. There are 110 faculty and staff and 1,900 students.

3. 530 cars were counted driving through the flood plain from air photographs flown in February, 1976. The weekend–weekday difference is probably large. This estimate attempts to exclude visitors or workers counted elsewhere.

4. There are 13 along Boulder Creek. Count from air photographs, probably flown in the afternoon, Summer, 1971, was 299 cars.

5. Restaurant itself is probably not in the flood plain. This number reflects visitors near the restaurant.

6. This estimate attempts to exclude flood plain residents. 378 cars were counted on Boulder Canyon Road from the 1971 air photos.

TABLE A-3
TOTAL POPULATION-AT-RISK ESTIMATES

For 4:00, 7:00 and 11:00 PM on a typical day during the week. For within the study area only. Combined estimates take into account people at work and random vacancies.

FLOOD PLAIN	4:00		7:00		11:00	
	PREVIOUS COUNTS	COMBINED ESTIMATES	PREVIOUS COUNTS	COMBINED ESTIMATES	PREVIOUS COUNTS	COMBINED ESTIMATES
CANYONS						
Residents[1]	529	300	529	450	529	475
Visitors	540	500	450	400	180	150
Workers	10	5	10	5	10	5
Subtotal	1079	805	989	855	889	630
CITY[2]						
Residents	1527	800	1527	1400	1527	1450
Visitors	2230	2000	2685	2500	785	750
Workers	1430	1375	570	550	195	175
Subtotal	5187	4175	4782	4450	2507	2375
TOTAL	6266	4980	5771	5305	3396	3005

NOTES: 1. Based on visual survey of estimated property-at-risk.
2. For the flood plain (Boulder Creek only) west of 28th Street, based on the U. S. Army Corps of Engineers 1976 schematic map of the 1% (100-year) flood plain, but not counting dry islands as represented on their smaller scale October, 1976 map.

APPENDIX B
DAMAGE REDUCTION IN A FLASH FLOOD SITUATION

With an adequate warning, some of the damages to the contents of residential, commercial, industrial, and government buildings could be avoided in a flash flood situation. The adoption of emergency flood proofing measures and their success is influenced by the amount of time between a warning and the onset of a flood, the value of the contents-at-risk, whether the building has more than one floor, the manpower available to move valuables, the extent of preparedness on the part of the building occupants, the expected height of flooding, and the human response to the warning of a rare event.

The same study area as in the population survey was used to determine potential damage reduction: the Boulder Creek flood plain west of 28th Street as delineated on the U. S. Army Corps of Engineers' 1976 schematic map, adjusted to reflect dry islands in the flood plain as delineated on the smaller scale Corps of Engineers' October, 1976 map. This portion of the Boulder Creek flood plain has the highest number of residential structures. East of 28th Street the flood plain is primarily developed by commercial and industrial uses. There several large establishments would account for much of the flood damages. Figure 2 shows the study area.

Inventory of Buildings in the Study Area

Table B-1 summarizes the locations and types of the residential buildings in the study area. Most of the houses are fairly old, built around 1900. The apartment complexes are much newer. The average value of the contents on the ground floor of a house was estimated to be $6,000. This includes furniture, carpets, electrical appliances, kitchen wares, books and records, and other personal belongings. Two cars, for an average value of $2,500, were assumed to belong to each house. (Cars, which are easily moved, were included for residential buildings only.) The contents of apartments were estimated to be $3,500 per unit. One car, with an average value of $1,500, was assumed to belong to each apartment.

Commercial and industrial buildings are categorized by type and size in Table B-2. Estimates of the average value of the ground floor contents are based on figures obtained from the county assessor's office and interviews for a sample number of establishments. The error is probably significant, but the estimates provide at least an order of magnitude basis for calculating the benefits of emergency flood proofing. Although there are few larger buildings, they contribute disproportionately to the total estimates. The level of preparedness and the response by building managers in the larger establishments will greatly influence the total benefits of emergency preparedness.

Government buildings in the study area are the Municipal Building, Public Library, Park Central Building, Data Processing and Fire Department offices, Youth Action Center, and the Band Shell. Estimates of their contents are included in the commercial estimates (all are offices except the Band Shell which is included in the service section).

Emergency Flood Proofing

Given an adequate amount of time between the warning of a flash flood and its impact, a certain amount of the flood damage can be avoided. The surest method of reducing flood damages is to remove the property from the flood's path. On an emergency basis this can be done with cars and perhaps with valuables such as stereos, televisions and personal papers. Some furniture and other valuables can be carried to the second floor or elevated above the expected height of the flood waters. Turning off the gas and electricity can help prevent fires and keep electrical motors from shorting out.

With more extensive preparedness planning, openings to the buildings can be sealed and display cases elevated by pulleys. The following estimates have not considered this type of contingency flood proofing, as it requires permanent structural alterations. However, its role in reducing flood damages should be considered.

A prerequisite for effective emergency flood proofing is an accurate forecast of the height of flooding and its expected time of arrival. Many people have died in flash floods because they delayed their evacuation while getting valuables, moving cars or retrieving pets or animals. With an accurate forecast, timely warning and adequate public education and preparedness, much can be done to reduce the flood's impact. Even though little of monetary value is saved, if important papers are retrieved, the postdisaster disruption can be lessened. In the more hazardous flood-prone areas, particularly the canyons, the emphasis should be on saving lives rather than property; emergency flood proofing is of no benefit it the entire building is destroyed.

Costs associated with emergency flood proofing include a partially increased risk to life, warning system costs, employee training, public education, income lost while moving, and actual moving costs.

Damage Reduction by Emergency Flood Proofing

To determine the benefit of emergency flood proofing the following steps were taken:

1. The value of the contents-at-risk was determined.

2. The expected flood heights for a 1% event were estimated. An average value was used for each segment of the flood plain. Estimated flood height for the 25-year flood plain is four feet, for the 50-year flood plain, two feet, and one foot for the 100-year flood plain.

3. The extent of damage to contents was estimated. The Federal Insurance Administration stage damage curves were used for residential property (taken from Grigg, et al., 1975).

4. Estimates were made of the percentage of the damage to contents that could be avoided, given adequate preparedness and warning, for lead times of 60, 45 and 30 minutes.

These estimates are presented in Tables B-3 and B-4. Table B-5 gives the percentages upon which the damage reduction estimates in Table B-4 are based. The percentages take into account whether or not the building has more than one story, the lead time, and the number of people available when the warning is received.

The estimates in Tables B-3 and B-4 represent the maximum amount of emergency flood proofing benefits possible given the various lead times. The actual benefits achieved will depend upon how many (and which) people carry out such efforts. This will be influenced by the characteristics of the warning system: public education, prediction capabilities, warning source, message content (whether or not emergency flood proofing is encouraged), confirmation of warning, and means of warning dissemination. The influence of these variables was included in the estimation of the actual amount of emergency flood proofing benefits realized for each of the scenarios.

Conclusion

Though this study lacks the precision necessary to be definitive, its purpose is to illuminate the potential benefits, as well as problems, of emergency flood proofing. Downstream from the study area the total benefits might be comparable with the estimates. Flooding there would be shallower in most places, and lead times longer.

TABLE B-1
PROPERTY EXPOSED TO FLOODING ALONG BOULDER CREEK,
WEST OF 28TH STREET
Based on 1976 Corps of Engineers' schematic map of the Boulder Creek flood plain, with correction for dry islands as delineated on their October, 1976 map (see Figure 2).

FLOOD PLAIN	Houses 1 story	Houses 2 story	Ground Floor Apts.	Residential Population	Number of non-Residential Establishments
W CITY LIMITS TO BROADWAY					
25 year	0	2	10	24	23
50 year	1	6	8	36	11
100 year	7	3	44	111	34
Total	8	11	62	171	68
BDWY TO FOLSOM					
25 year	9	2	38	103	30
50 year	28	12	81	272	11
100 year	113	56	189	870	25
Total	150	70	308	1245	66
FOLSOM TO 28TH					
25 year	0	0	0	0	0
50 year	0	1	59	110	30
100 year	0	0	0	0	36
Total	0	1	59	110	62
TOTAL OF FLOOD PLAIN					
25 year	9	4	48	127	53
50 year	29	19	148	418	52
100 year	120	59	199	919	95
GRAND TOTAL	158	82	395	1526	200

TABLE B-2
NONRESIDENTIAL BUILDINGS IN THE BOULDER CREEK 1% FLOOD PLAIN, WEST OF 28th STREET
Based on 1976 Corps of Engineers schematic map of the Boulder Creek flood plain with adjustments for dry islands as delineated on their October, 1976 map (see Figure 2).

BUILDING TYPE	NOS.	ESTIMATED VALUE OF CONTENTS	ESTIMATED 1% FLOOD DAMAGE
OFFICES			
Large	12	1,020,000	423,150
Medium	21	275,250	73,600
Small	17	32,750	7,150
	50	1,328,000	503,900
AUTOMOBILE			
Large	5	672,000	259,100
Other	22	168,600	16,400
	27	840,600	275,500
FOOD SERVICE			
Grocery (large)	2	350,000	42,500
Grocery (other)	4	23,000	4,150
Restaurants	22	431,700	84,350
	28	804,700	131,000
RETAIL			
Large	9	786,300	159,400
Medium	17	278,900	62,200
Small	23	54,000	10,850
	49	1,119,200	232,450
SERVICE			
Motels, theaters, etc.[1]	13	326,200	73,800
Other[2]	22	170,000	17,650
	35	496,200	91,450
MANUFACTURING	10	230,000[3]	43,000
TOTAL	199	4,818,700	1,227,400
% of contents value			25.5%

NOTES: 1. Includes Boulder Art Center, Boulder Athletic Club, Good Samaritan Nursing Home, Pioneer Museum.
2. Includes barber shops, dental offices, cleaners and other miscellaneous-service oriented businesses.
3. Watts-Hardy accounts for almost half of this.

TABLE B-3
ESTIMATES OF EMERGENCY FLOOD PROOFING BENEFITS FOR RESIDENTIAL PROPERTY,
FOR FLOOD PLAIN WEST OF 28TH STREET (SEE FIGURE 2)

Percentages are for the maximum probable percent of flood damage avoidable given various lead times. Time of day when the flood strikes will affect how many Residents undertake such measures.

FLOOD PLAIN		CONTENTS VALUE	1% FLOOD DAMAGES EXPECTED	REDUCTIONS GIVEN LEAD TIMES OF: 60 min	45 min	30 min
25 YEAR						
Bldgs	%			29%	19%	7%
	$	246,000	86,100	25,300	16,700	5,900
Cars	%			100%	75%	50%
	$	137,000	68,500	68,500	51,700	34,250
50 YEAR						
Bldgs	%			38%	28%	18%
	$	806,000	185,400	69,800	51,600	33,000
Cars	%			100%	75%	50%
	$	462,000	46,200	41,200	30,900	20,600
100 YEAR						
Bldgs	%			43%	33%	23%
	$	2,917,500	265,600	114,300	87,700	61,200
Cars	%			100%	75%	50%
	$	1,193,500	59,700	37,300	28,000	18,650
TOTAL						
Bldgs	%			39%	29%	19%
	$	3,969,500	537,100	209,400	145,000	100,100
Cars	%			100%	75%	50%
	$	1,792,500	174,400	147,000	110,600	73,500

TABLE B-4

POSSIBLE REDUCTIONS IN DAMAGES TO CONTENTS OF NONRESIDENTIAL BUILDINGS

For lead times of 60, 45 and 30 minutes, and for 4:00 and 7:00 on a typical workday. estimates are for Boulder Creek study area (Figure 2).

BUILDING TYPE	1% damages	4:00 60 min	4:00 45 min	4:00 30 min	7:00 60 min	7:00 45 min	7:00 30 min
OFFICES							
Large	423,150	103,600	82,400	61,300	50,200	29,700	8,550
Medium	73,600	15,600	11,800	8,200	6,500	3,700	0
Small	7,150	1,150	750	400	500	350	0
AUTOMOBILE							
Large	259,100	129,550	27,700	38,850	86,700	56,300	28,150
Other	16,400	3,300	2,500	1,600	2,100	1,400	500
FOOD SERVICE							
Grocery (large)	350,000	5,000	3,000	1,300	5,100	3,000	1,300
Grocery (other)	23,000	500	300	100	500	300	100
Restaurant	431,700	9,300	6,700	5,050	9,300	6,700	5,050
RETAIL							
Large	786,300	28,000	20,000	12,100	22,300	15,050	7,100
Medium	278,900	9,300	6,200	3,100	4,400	3,100	0
Small	54,000	1,900	1,200	700	800	550	0

TABLE B-4 (continued)

BUILDING TYPE	1% damages	60 min	4:00 45 min	30 min	60 min	7:00 45 min	30 min
SERVICE							
Motels, theaters	326,200	14,400	16,850	10,100	13,900	10,400	6,700
Other	170,000	2,700	1,850	950	2,500	1,750	0
MANUFACTURING	230,000	6,500	4,300	2,150	5,200	3,000	1,300
TOTALS	1,227,400	330,800	236,550	145,900	210,000	135,300	58,750
% of damages		27%	19%	12%	17%	11%	5%

TABLE B-5

PERCENTAGES USED TO ESTIMATE POSSIBLE DAMAGE REDUCTION FOR NONRESIDENTIAL BUILDING CONTENTS

For various lead times and dependent on nature of business, number of stories and available staff

BUILDING TYPE	One Story						More Than One Story					
	Full Staff			Minimum Staff			Full Staff			Minimum Staff		
	60 min	45 min	30 min	60 min	45 min	30 min	60 min	45 min	30 min	60 min	45 min	30 min
Office	15	10	5	7	5	0	25	20	15	10	5	0
Automobile (large)	50	30	15	30	20	10	Does not apply					
Automobile (other)	20	15	10	15	10	5	Does not apply					
				No Staff								
				7	5	0						
Grocery	12	7	3	Does not apply			15	10	5	Does not apply		
Restaurant	10	7	5	Does not apply			15	12	10	Does not apply		
Retail	15	10	5	7	5	0	20	15	10	10	5	0
Service	15	10	5	7	5	0	20	15	10	10	5	0
Manufacturing	15	10	5	12	7	3	Does not apply					

APPENDIX C
ELEMENTS OF THE WARNING PROCESS

This is a partial list of the activities that might be included in a warning system. A complete list could include identification of responsible officials for each decision.

PRE-FLOOD ACTIVITIES
- Public Information
  - post signs indicating
    - height of historic floods
    - evacuation routes and procedures
  - prepare and distribute local brochures
  - prepare regional brochures and distribute
  - enact hazards disclosure law or agreements
  - require warning on state travel maps
  - solicit news media coverage of hazard
  - incorporate hazards in schools curriculum
- Emergency Preparedness
  - prepare detailed flood plans and distribute
    to each involved official
  - conduct periodic practices
  - update plans periodically
  - stockpile appropriate emergency supplies

PREDICTION OF FLOODING
- Monitor Weather With Radar
- Obtain Precipitation Amounts
  - automatic rain gages
  - volunteer observer reports
- Obtain River Stage Data
  - automatic river gages
  - volunteer observer reports
- Assess Expected Magnitude of Flooding
- Assess Expected Lead Times
- Confirmation of Rainfall, Flooding

NOTIFICATION OF OFFICIALS OF POSSIBLE FLOODING
- Fire Departments
- Sheriff and Deputies
- Police
- Local Hydrologists
- Radio Personnel
- TV Stations
- Ambulances

NOTIFICATION OF OFFICIALS OF POSSIBLE FLOODING (continued)

- Search and Rescue Groups
- Parks and Recreation Personnel
- Highway Departments
- Public Works Personnel
- City Manager, Mayor
- Hospitals
- Military
- Relief Groups
- Emergency Communications Groups

FORMULATION OF WARNING MESSAGE*

- *Mention Who is Giving Warning
- *Degree of Urgency (Alert, Watch, Warning)
- *Expected Magnitude, Related to Known Landmarks
- *Expected Lead Time
- *Proper Actions
- *Location of Safe Areas
- *Evacuation Routes
- Number of Warnings Issued in Area
- Confirmation of Flooding From Other Sources
- Reports of What Others Are Doing
- Reference to Past Floods, Here or in Other Areas
- Mention of Environmental Cues, if Present
- Emergency Floodproofing
- Precaution Against Convergence

EVACUATION DECISION

- *Exact Areas to be Evacuated
  - canyons
  - city
  - county

WARNING DISSEMINATION TO PUBLIC

- Methods
  - radio
  - phone calls
  - loudspeakers
  - Civil Defense sirens
  - television
  - door-to-door
  - sirens on patrol cars, emergency vehicles
  - tone alert radios
- Special Warning To
  - commercial establishments
  - theaters, restaurants
  - hotels, nursing homes
- Close Highways
- Bridge Clearing Patrols

---

*Starred items could be included in the first, brief messages; subsequent warnings could provide more detail.

POST-FLOOD ACTIVITIES

Notification of State and Federal Agencies

- relief groups
- Federal Disaster Assistance Administration
- Governor
- President
- Urban Drainage and Flood Control District
- Department of Housing and Urban Development
- Corps of Engineers
- United States Geological Survey
- State Geological Survey
- Federal Insurance Administration