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The Austin, Texas, Flood of May 24-25, 1981

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for the

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FOREWORD

The Committee on Natural Disasters was formed to study the impact of natural disasters such as earthquakes, floods, tornadoes, and hurricanes on engineered structures and systems. The objectives of the Committee's work are to improve protection against disasters by providing factual reports of the consequences of these extreme events of nature and to stimulate research needed to understand the hazards posed by natural disasters.

The members of the Study Committee for the Austin flood were chosen by consultation with the members of the Committee on Natural Disasters, the Executive Secretary of the Committee, and the Chairman of the Study Committee. The Study Committee met two times in Austin. At the first meeting it was apparent that the flood event had been monitored very completely by engineers from the City of Austin, the U.S. Geological Survey Area Office, and the staff of the U.S. Weather Service in Austin. Thus there was no need for the Study Committee to obtain field measurements of the flood event. Rather, this report summarizes factual information about the flood event and its consequences, presents information on local governmental policies in force that related to urban drainage, examines the response of governmental agencies and citizens to the flood event, and draws implications from the event that might help other communities that also live with the threat of such an event.

The federal government has greatly expanded its role in postflood research during recent years. In 1981 an interagency agreement among 10 federal agencies gave the Federal Emergency Management Agency (FEMA) the responsibility for assembling a "postflood hazard mitigation team" following presidentially declared flood disasters. FEMA has now performed about 20 such postflood hazard mitigation studies. These reports, which are to be prepared in draft form within 15 days after the declaration, are intended to provide timely and reasonable advice to federal, state, and local agencies in conducting recovery efforts so as to reduce future flood hazards.

The Austin flood of May 1981 was not declared a flood disaster by the President and therefore no FEMA study was undertaken. However, this report should serve a similar role as a FEMA report and should benefit hazard mitigation efforts in the future.

Jack E. Cermak
Chairman

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SUMMARY

Late in the evening of May 24, 1981, the city of Austin, Texas, experienced severe flooding of small creeks in the area, which resulted in the loss of 13 lives and costly damage to private and public property.

The flooding resulted from "very heavy" and "intense" thunderstorm rainfall, which was part of a general system of intense thunderstorms in the area. Contributing to the formation of the intense thunderstorms was the combination of a destabilizing upper-air trough, an influx of moist unstable air into the vicinity of a surface convergence line, and an ample amount of surface heat. The storm system remained nearly stationary during the period of most intense rainfall in northwest Austin.

Unusually good measurements of rainfall rates and streamflow indicate that the rainfall rates on Shoal Creek were close to those for a storm with a 100-year return period in the area. Flow measurements of Shoal Creek indicate that the streamflow and associated high-water marks correspond well with estimates previously made for the 100-year flood. On other watersheds in the area, point rainfall rates for durations of 60 minutes and 120 minutes were close to the expected 500-year rates.

Factors causing the severe flooding were:

1. Watersheds were saturated by moderate rainfall prior to the peak intensities that produced flooding.
2. The Shoal Creek watershed experienced a 100-year flood event.
3. Many homes along Shoal Creek built prior to adoption of current floodplain regulations were located within the 100-year floodplain.
4. Additional development had taken place in the upper portion of the watershed.

It has not yet been possible to evaluate the relative effect of these factors.

The response of citizens and governmental agencies in Austin during the flooding and soon afterward is graphically narrated in Chapter 5, "Local Response to Severe Flooding." This forms an exceptionally interesting and informative part of the report.

The flood experience of Austin leads to several conclusions about urban flood hazards and the response of a community to an emergency.

What is true for Austin should be generally valid for thousands of other cities throughout the world.

It is apparent that a community can deal effectively with the threat of flooding only to the extent that its citizens have a clear understanding and retain an awareness of the flood hazards. An understanding of the nature and extent of the hazards is generally not available to the average person. The facts must be developed by the appropriate level of government from past records and engineering analysis and then made available to citizens in a form that they can understand and remember.

The community must agree on policies to be followed in managing the flood hazards. The cost of sporadic flood damages can be reduced by creating open space along streams, by constructing channel improvements, by building detention storage, and by other measures, each of which has its own costs. The community must decide how far to go in reducing flood hazards, recognizing that even though the risk of flooding can be reduced, any economically feasible plan will not give complete protection against the risk of flood damage.

The public's memory of flood events is short. Thus a continuing education program related to flood hazards and how to cope with them should be implemented, working through the schools, information bulletins in utility bills, and periodic articles in newspapers and film clips on television. An early warning system to give quick and reliable information would provide the other element necessary for the proper response by citizens to emergencies.

The possibility of providing vital information in permanent form for high-hazard areas should also be explored. Permanent markers in prominent places showing high-water marks for floods of record or the limits of the 100-year floodplain would constantly remind those people with the greatest need to know of the hazard. Signs at low-water crossings could also indicate when the water level is too high to cross safely.

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THE FLOOD

National attention was focused on Austin, Texas, due to the severe local flooding of May 24-25, 1981, which caused loss of life and extensive property damage. This flood event in Austin represents extreme conditions in two respects:

1. This area, which is along the Balcones escarpment in central Texas, has experienced intense rainfall events in the past. For example, the Thrall storm of 1921, which had an intensity of 39 in. in 18 hours, and the Taylor storm of 1921, which had an intensity of 23 in. in 24 hours, were within 35 miles of Austin. The D'Hanis storm of 1935, which had an intensity of 20 in. in 3 hours, was 115 miles from Austin.
2. The drainage areas of the watersheds in Austin are small with short response times. Response times of the order of one hour gave little time for the community to react.

This chapter presents information about the flood event, including the meteorological conditions before and during the storm, the areal and temporal variation of precipitation, and the results of streamflow measurements in several watersheds.

METEOROLOGICAL CONDITIONS

A study was made of the surface and upper-air weather data from before and during the storm to determine the meteorological conditions responsible for the flash-flooding thunderstorms of May 24-25. The appendix gives a report of this study, which is briefly summarized here.

The morning synoptic analysis of May 24 suggested that the stage was set for the development of significant thunderstorm activity. An abundance of low- and mid-level moisture, coupled with a potentially unstable atmosphere and weak upward motion, contributed to the formation of many very intense thunderstorms in parts of Travis County and adjacent counties. The modest values of the level of free convection (LFC) taken from the 6 a.m. soundings suggested that slight lifting and/or heating of the moist layer of air would cause deep convection. Furthermore, the relatively low speeds of the "steering" winds indicated that any deep cells of convection spawned during the day would move very slowly.

The combination of a destabilizing upper-air trough, an influx of moist convectively unstable gulf air into the vicinity of a surface convergence line, and an ample amount of surface heat contributed to the rapid outbreak of very heavy thunderstorms on the afternoon of May 24.

The National Weather Service issued a Severe Thunderstorm Watch at 7:00 p.m. covering Austin and the adjacent counties to the north and west. The thunderstorm complex responsible for the flash floods in northwest Austin moved little during its seven-hour lifetime. At 7:20 p.m. radar pinpointed the core of a massive storm over the Shoal Creek watershed. Cloudtop heights varied between 40,000 and 45,000 ft, and for much of its life rainfall intensities from the storm varied between "very heavy" and "intense." At 10:26 p.m. the National Weather Service issued a Flash Flood Warning whereby people in Travis County were alerted to very rapid flooding of creeks and other flood-prone areas. By this time the prolific rain-producing thunderstorm complex had diminished to the status of a "heavy thunderstorm," meaning that rainfall rates had lessened to only 1 to 2 in. per hour.

PRECIPITATION

During the night of May 24-25, 1981, severe flooding occurred on many of the small watersheds in and around metropolitan Austin as a result of short-duration intense rainfall that in some locations exceeded 10 in. in a four-hour period. The major floods occurred along Shoal, Walnut, and Little Walnut creeks; substantial flooding took place also on Bee Creek and Waller Creek (see Figure 2.1).

Precipitation prior to the flooding was substantial. Almost one inch of rain fell over the Shoal Creek and Walnut Creek basins on May 23. By the evening of May 24, rainfall amounts ranging from about 1.2 to 2.4 in. had accumulated. Over many of the watersheds, the thin clay-loam soils overlying limestone bedrock must have been saturated, or nearly so. The intense rains that caused the floodings occurred mostly between 9:30 p.m. and midnight. Accumulated rainfall at rain gages located in the Shoal Creek, Walnut Creek, and Little Walnut Creek drainage basin is shown in Figure 2.2. It is clear that most of the rain fell between 10:00 and 11:00 p.m. The areal distribution of total precipitation over the region for the two days May 24 and 25 is shown in Figure 2.3. Figure 2.4 shows the rainfall intensities for durations of 60 minutes and 120 minutes at several locations and compares these with the intensity-duration frequency curves for Austin. This comparison indicates point rainfall intensities in the 100-year to 500-year frequency range.

STREAMFLOW

The streams in the area rose rapidly, commencing generally between 10:00 and 11:00 p.m. and peaking around midnight. Recessions also were rapid; by 3 a.m. on the morning of May 25, flows had receded in most channels

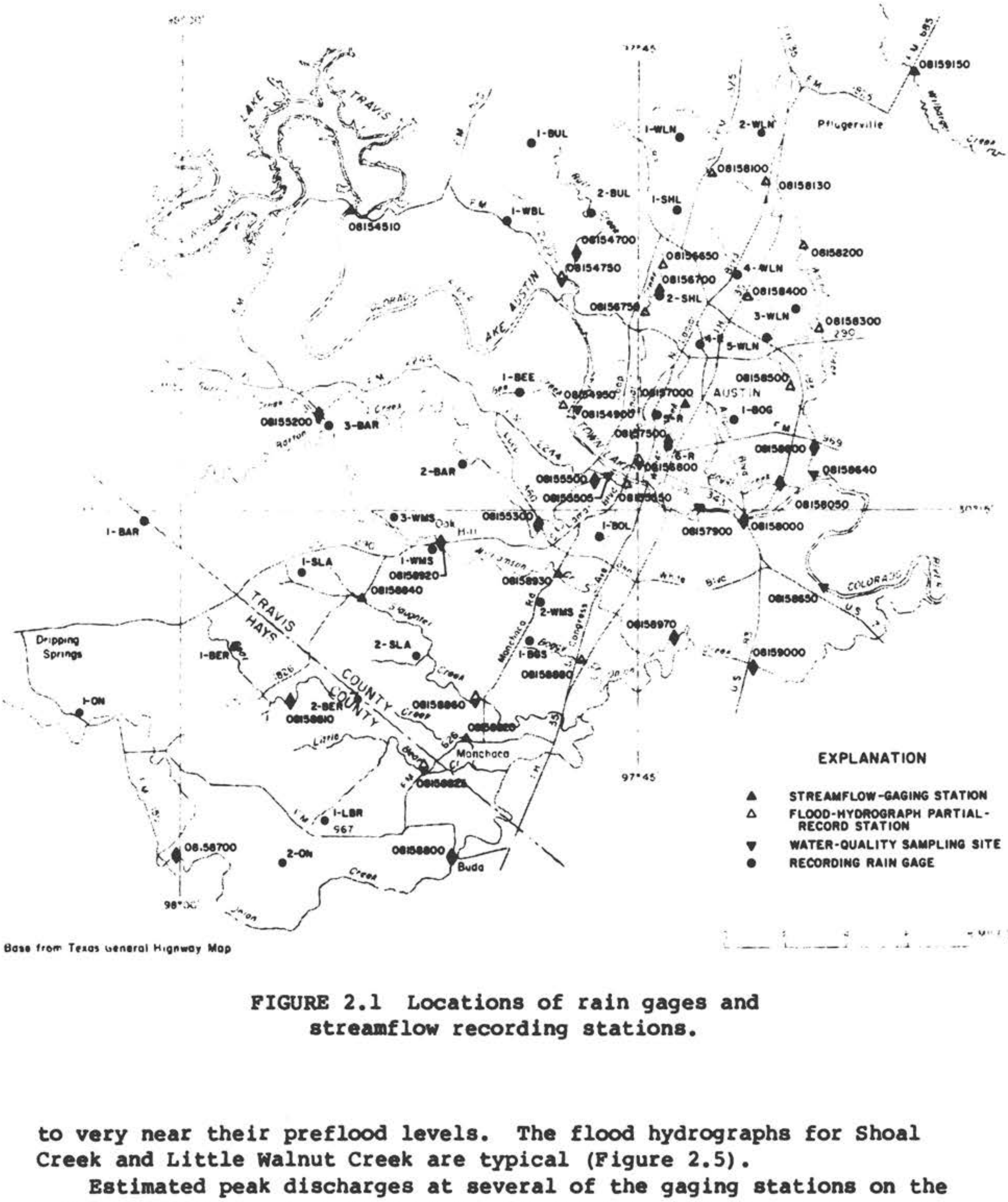

FIGURE 2.1 Locations of rain gages and streamflow recording stations.

to very near their preflood levels. The flood hydrographs for Shoal Creek and Little Walnut Creek are typical (Figure 2.5).

Estimated peak discharges at several of the gaging stations on the watersheds are given in Table 2.1. The locations of these gages and hydrologic data are given by Slade et al. (1981). Note that on Shoal Creek the flood wave moved downstream from Northwest Park to Twelfth Street with very little increase in peak flow. The rains responsible

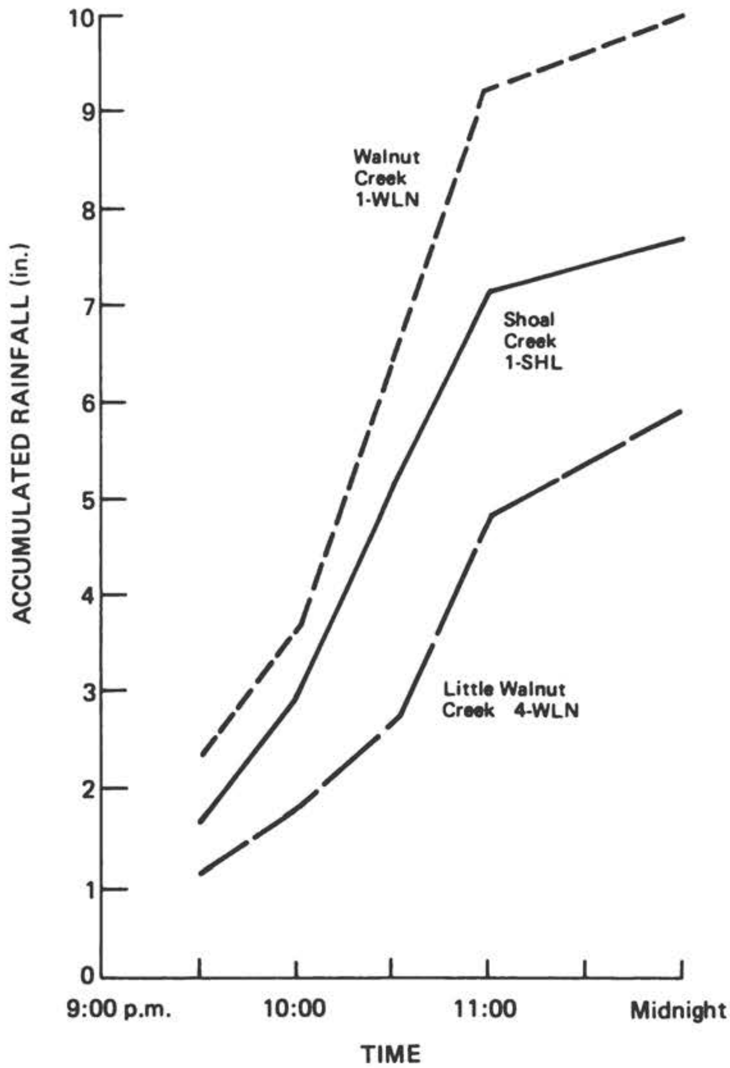

FIGURE 2.2 Accumulated rainfall in three rain gages (Source: Massey et al., 1982, Table 2).

for this flood occurred mainly on the upper 7 square miles of the watershed.

Hydrologic observations at the stations in Table 2.1 began in 1975 and 1976, except for Waller Creek, for which they began in 1954. Thus, except for Waller Creek, the hydrologic records are too short to permit estimates of flood frequencies at these sites by the usual methods of analysis. However, according to Massey et al. (1982), the floods probably were the greatest to occur in the Shoal Creek and Walnut Creek basins in at least 60 years.

The streamflow gages in the Shoal Creek, Walnut Creek, Waller Creek, and Bee Creek watersheds probably registered about the 100-year flood, which is the approximate return period for some of the recorded

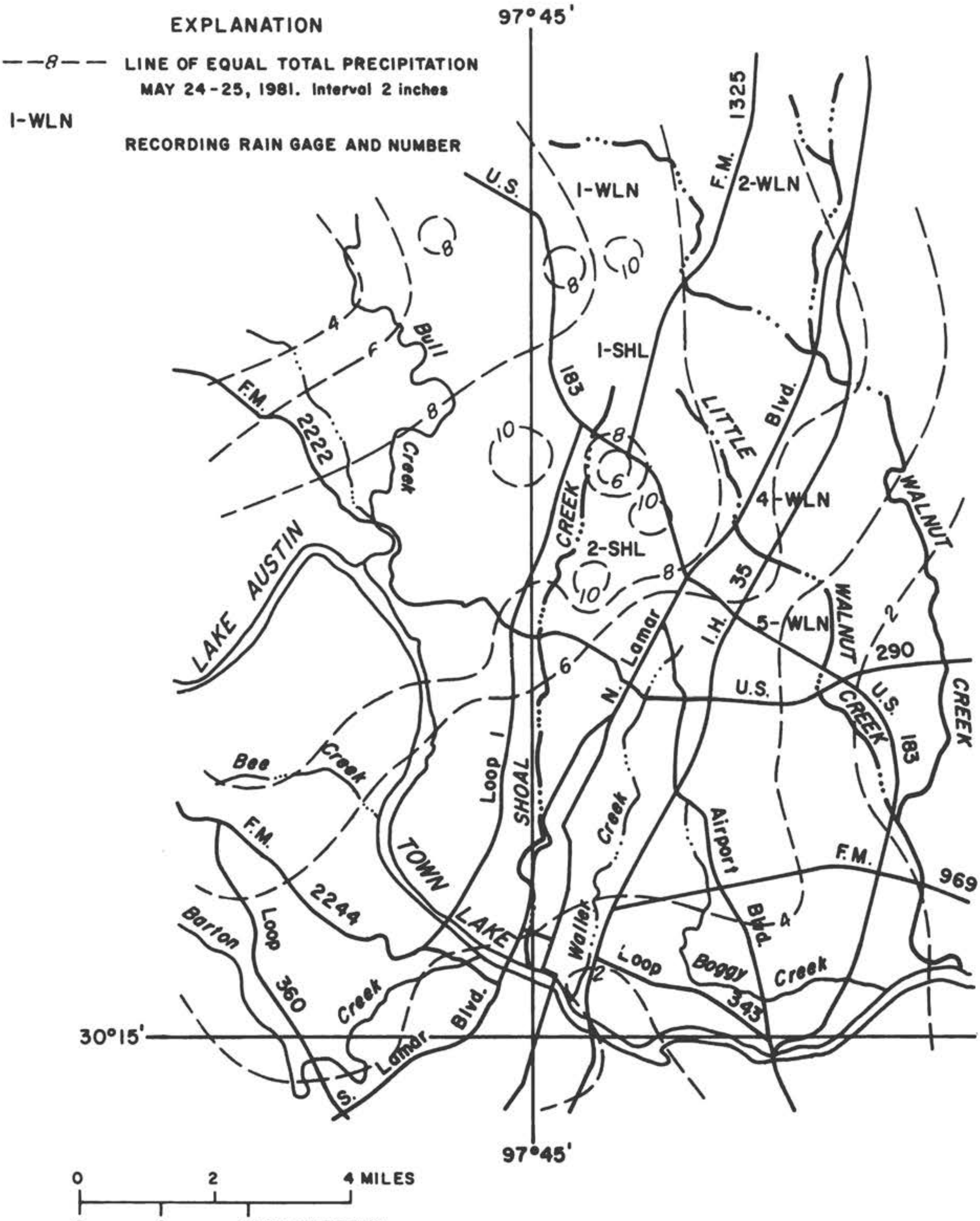

FIGURE 2.3 Isohyetal map of total precipitation (in.) on May 24-25, 1981, based on USGS measurements, the City of Austin network, and unofficial precipitation reports.

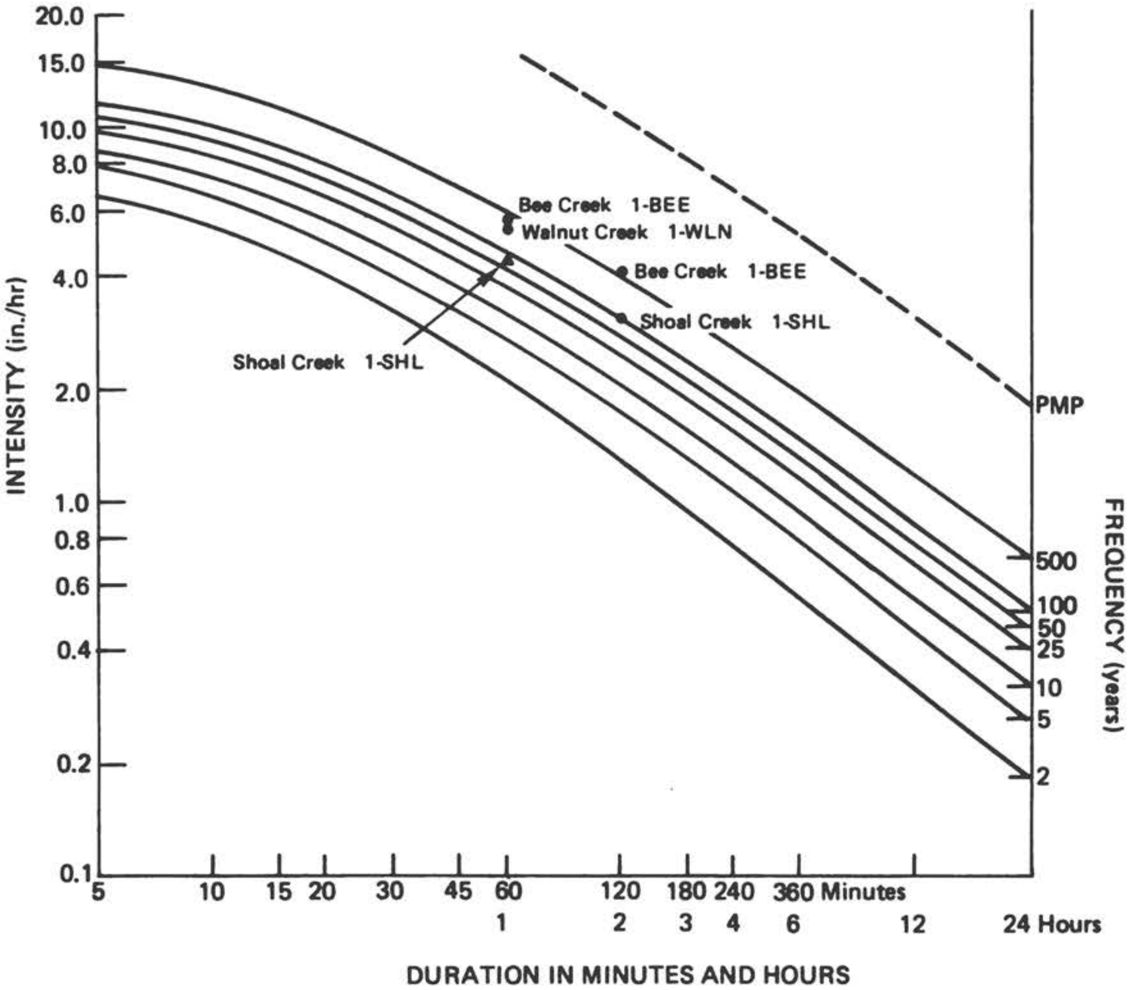

FIGURE 2.4 Rainfall curves for Austin, Texas.

precipitation (Figure 2.4). This recurrence interval is indirectly corroborated by the fact that the actual inundation boundaries of the flood conformed very closely to the predicted boundaries for the 100-year flood on Shoal Creek determined in floodplain studies by the City of Austin. The areal extent of flooding and other hydrologic data for the Shoal Creek and Walnut Creek watersheds are given by Massey et al. (1982).

The Bull Creek gage probably experienced a flood with a return period between 10 and 25 years. The gage on Little Walnut Creek at Interstate Highway 35 had about the 25-year flood, and the Manor Road site on Walnut Creek had a peak less than the 25-year flood.

Inspection of the channels after the flood showed that lateral channel migration as a result of the flood was minimal, probably because the channels are controlled largely by the limestone bedrock. Local

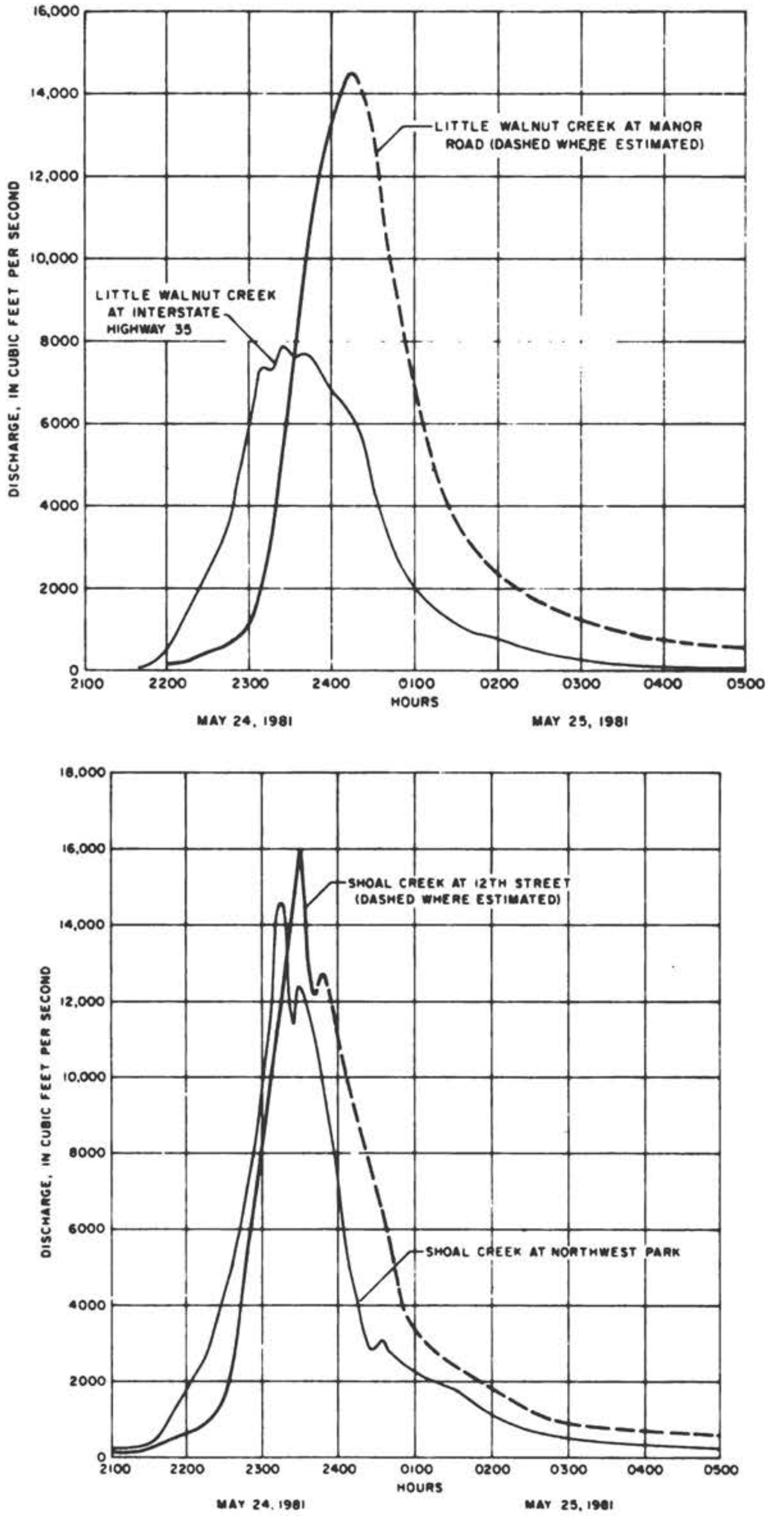

FIGURE 2.5 Typical flood hydrographs. (Source: Massey et al., 1982.)

TABLE 2.1 Peak Discharge Data for the Flood of May 24-25, 1981

Location	Drainage Area (square miles)	Datum of Gage is NGVD[a] of 1929 (ft)	Time of Maximum Discharge		Maximum	
			Date	Hour	Gage Height (ft)	Discharge (cfs)
Shoal Creek						
Steck Avenue	3.19	703.00	May 24	2255	10.63	5,100
Northwest Park	7.03	661.34	May 24	2315	18.00	14,600
White Rock Drive	7.56	642.60	May 24	2320	18.69	15,700
West Twelfth Street	12.8	455.33	May 24[b]	2330	23.22	16,000
Walnut Creek						
FM 1325	12.6	670.62	May 24[b]	2400	19.46	15,000
Dessau Road	26.2	553.44	May 25[b]	0030	26.20	21,600
Little Walnut Creek						
Highway 35	5.57	628.75	May 24	2325	12.00	7,900
Manor Road	12.1	473.82	May 25	0015	19.60	14,500
Waller Creek						
Thirty-eighth Street	2.31	555.44	May 24	--	10.50	5,000
Twenty-third Street	4.13	509.95	May 24	--	9.50	4,500
Bull Creek						
Loop 360	22.3	534.08	May 24	--	11.50	12,300
Bee Creek						
Westlake Drive	3.28	499.72	May 24	--	23.20	11,000

[a]National Geodetic Vertical Datum.
[b]Gaging station inundated by flood. Peak time estimated.

Source: U.S. Geological Survey, Austin, Texas.

bank erosion was apparent in many locations, but it was not severe. No bridges failed, but several sustained damage to abutments and approaches.

Most of the creeks carried large quantities of debris. In Shoal Creek, which flooded through parts of Austin's business district, many automobiles were swept into the channel, piling up against bridges or coming to rest in Town Lake (see Chapter 3). Considering the extraordinary amounts of debris carried by these flows, especially on Shoal Creek, it is indeed surprising that no bridges were destroyed.

3

THE CONSEQUENCES

The most serious consequences of the severe rainfall were the loss of life and the damage to private and public property. The rainfall also caused serious inconvenience to many people throughout Austin who were in their cars.

LOSS OF LIFE

Figure 3.1 shows the 10 locations where 13 people drowned during the flood. Six of the fatalities occurred when cars were washed into creeks at low-water crossings, five occurred when cars were washed off bridges, and two occurred in one of the houses on Jefferson Street, when two residents failed to leave until it was too late to reach higher ground safely.

In general, the common factor in nearly all the drownings was that they probably could have been avoided if the victims had better understood the potential risks from extreme flood conditions on the creeks. The high mortality rate was almost certainly due to the fact that nothing in recent experience had prepared people to anticipate and respect the violence of the rapidly rising waters.

PROPERTY DAMAGE

Property damage from the storm runoff occurred primarily along Shoal Creek, Walnut Creek, and its tributary Little Walnut Creek (see Figure 3.2) as those streams carried the floodwaters south through sections of Austin. There was also damage along Bee Creek and Dry Creek, which are located across the Colorado River to the southwest. Surveys conducted by the city immediately after the flood indicated that as many as 462 houses were affected in some degree, with the problems ranging in severity from minor inundation to complete destruction (McClellan, 1981).

Estimates submitted by the mayor of Austin to the governor of Texas in requesting disaster area designation set the dollar losses to residential damage at approximately $17.3 million, the private

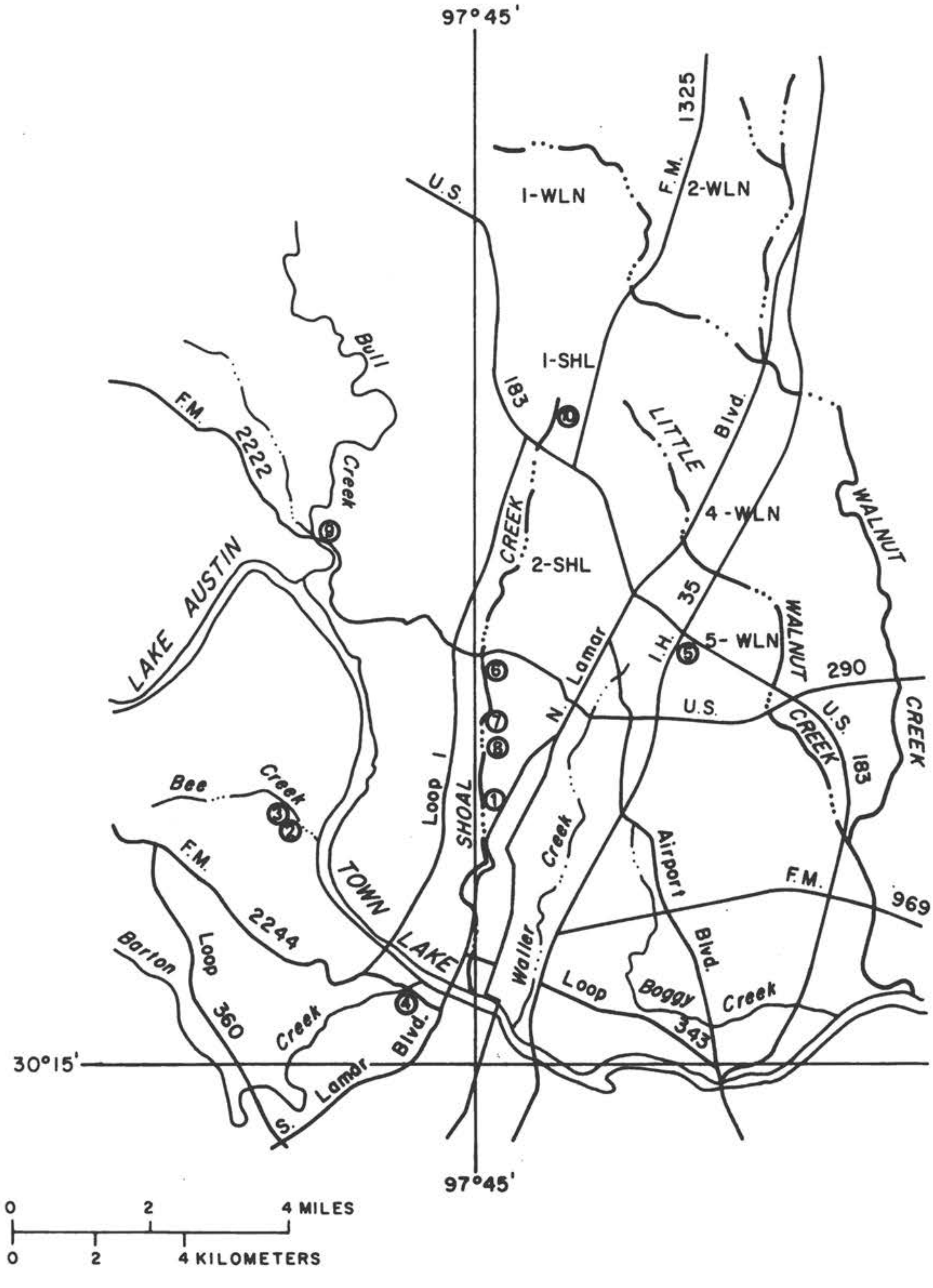

FIGURE 3.1 Fatality sites on May 24-25, 1981.

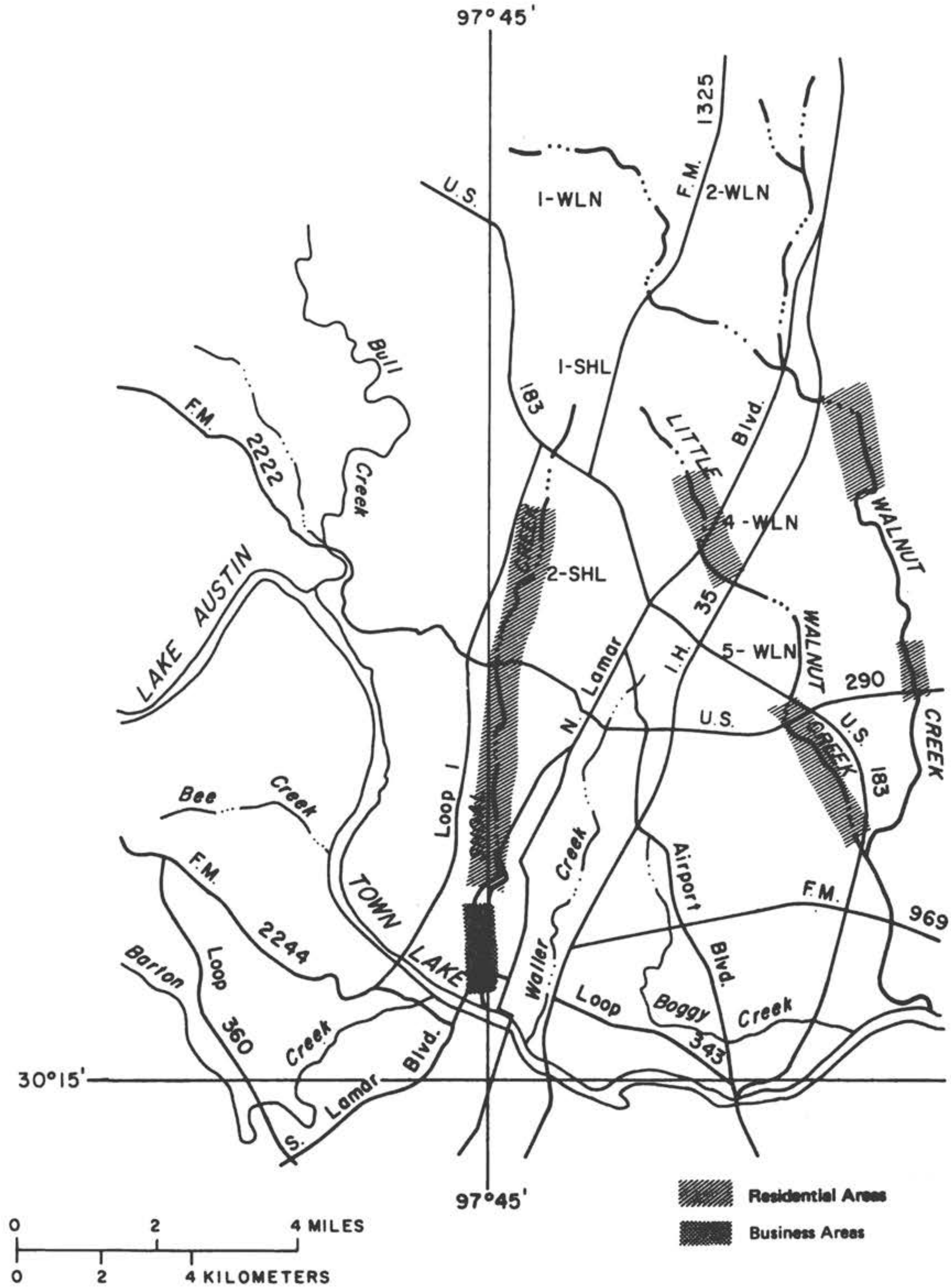

FIGURE 3.2 Damaged areas in Austin.

commercial losses at around $10.7 million, and the public property losses at $7.5 million, for a total of $35.5 million (McClellan, 1981).

Among the hardest hit areas were two blocks of houses on Jefferson Street, a street of modest homes along a section of Shoal Creek that receives runoff from most of the watershed. At the height of the flood, the living areas of the lowest houses on Jefferson Street were completely filled with water (see Figure 3.3). Farther south, in the 12 blocks immediately upstream from where Shoal Creek flows into the Colorado River, over 50 businesses were damaged, including several car dealerships with large inventories in parking lots on the creek bank. Damages to the automobile retailers were estimated at nearly $9 million, or about 84 percent of the total commercial loss (see Figures 3.4 through 3.7).

FIGURE 3.3 Washed-out first floor of a house on Tenth Street. (Photograph courtesy of the Austin American-Statesman.)

FIGURE 3.4
Automobiles
in the bed of
Shoal Creek.

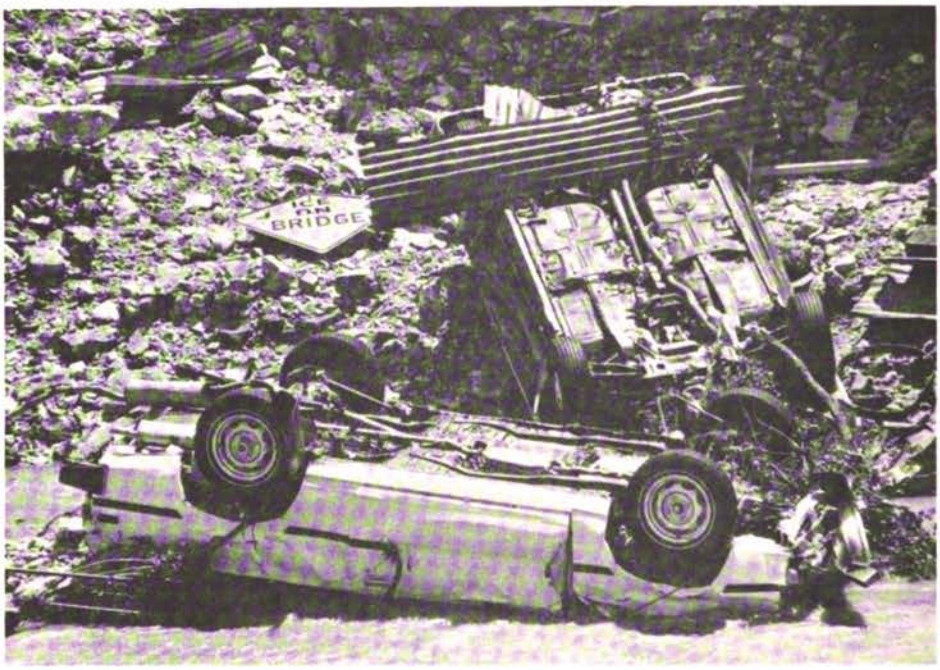

FIGURE 3.5 Debris and automobiles partially blocking railroad trestle.

FIGURE 3.6 Automobiles washed into creek.

FIGURE 3.7 Debris washed against water main crossing Shoal Creek.

4

LOCAL POLICIES FOR FLOOD HAZARD AREAS

The primary instrument of public policy relating to flood hazard areas in Austin is the Creek Ordinance, which was adopted in 1974 (City of Austin, 1974). The intent of the ordinance is twofold: (1) to require proper drainage engineering in any new developments so that adequate control of floodwaters is provided and (2) to preserve the local streams wherever possible in a natural and pleasant condition. Anyone who proposes to develop land inside the city limits or within the city's five-mile extraterritorial jurisdiction must obtain a waterway development permit if the area in question is adjacent to or is crossed by a waterway. There are two classes of permit, depending on the anticipated significance of the work. Class A permits are required where the Director of Engineering finds that there will not be a major impact on drainage and on the environment. Class B permits are required where major impact is foreseen. There is also provision for issuance of exemption certificates if the consequences of development are found to be insignificant.

To obtain a permit it must be shown that adequate provision is made for storm drainage, with due allowance for probable future increases in flow as additional streets and storm sewers are added. There must be satisfactory provision for erosion control during and after construction. Structures that will be in contact with moving water must be shown to have adequate strength. The proposed development must preserve the natural and traditional character of the land and waterway to the greatest extent feasible. And it must be shown that the new development will not result in additional identifiable adverse flooding of other property.

One key provision of the Creek Ordinance is that plans of proposed new developments must indicate the limits of flooding for a 25-year flood event, and that there must be no obstruction of that part of the stream. At the same time, it is also intended that the natural condition of the channel not be altered unless there is a very compelling reason to do so. A set of explanatory guidelines for the ordinance, published in 1974, emphasizes that enlargement of a stream channel or removal of trees and other vegetation will be considered only where there is no reasonable alternative (City of Austin Engineering Department, 1974). In effect, the ordinance as it is applied prohibits modification of a drainage course unless and until the applicant demonstrates substantial need and justification.

Also in effect is a Flood Plain Ordinance enacted in 1975 (City of Austin, 1979), which is incorporated as part of the city's building code and deals primarily with floodproofing of commercial structures that are to be built below or within 1 ft of the 100-year flood level. Taken together, the Creek Ordinance and the Flood Plain Ordinance establish the policy that there must be no construction below the 25-year flood level and no residential construction below a foot above the 100-year flood level, but that there can be commercial construction between the 100-year and 25-year levels if suitable flood-proofing techniques are applied.

By the time these ordinances were adopted (in 1974 and 1975), a substantial part of the Shoal Creek watershed had already been developed, with houses and commercial structures having been built along the creek when less stringent requirements for flood protection were in effect. The Flood Plain Ordinance recognizes this condition and provides that future enlargements or improvements to existing structres can be made only if the structure is made to conform with the requirements. It also provides that, if a structure is damaged to the extent of 50 percent of its value due to flooding or other causes, it cannot be reconstructed except in conformance with the regulations.

While not entirely incompatible, the two basic purposes of the Creek Ordinance are certainly mutually restrictive, in the sense that adequate storm drainage cannot always be provided while leaving the stream channels untouched. In actual practice, the desire for preservation of natural conditions must be balanced against the need to control flooding within new developments or in the present built-up sections of the city. To the extent that continuing growth in the past may have resulted in a need for increased capability to handle floodflows in the urbanized lower reaches of the creeks, the emphasis on avoiding changes in the stream channels can block effective engineering in some sections of the municipal storm drainage system. At the very least, the policy of not modifying a stream channel to increase its hydraulic capacity unless absolutely necessary is likely to inhibit improvements that may be needed in the older areas of the city, which generally lie downstream from the newer, developing areas.

5

LOCAL RESPONSE TO SEVERE FLOODING

INTRODUCTION

The policies discussed in the previous chapter were Austin's political response to the flood hazard prior to the flooding of May 24-25, 1981. Response to the hazard is not the same as response to actual flooding. The former is a response to a perception of potential loss and involves attempts to reduce or minimize that loss. The latter is a response to physical danger and involves attempts to evade that danger and help others evade it. A severe flood, especially if it has been some years since the most recent of its kind, is likely to alter the communal perception of the hazard and bring further changes in the political response.

In this chapter we outline the salient events of May 24-25, with emphasis on information and emergency operations systems; sketch the structure of decision and authority; point out certain features about the 13 deaths that night; note the low level of flood insurance coverage; and include a few anecdotal comments from Austin residents. Next we go back into history to describe the municipal experience with warning systems and the city's attempts to devise an adequate emergency response system. Then we comment on the stringent requirements the flash flood hazard imposes on the response system of a city such as Austin. We conclude by describing moves the city has made or is contemplating to improve its flood response capability.

THE FLOOD OF MAY 24-25

Although an inch of rain had fallen the night before and the ground was still wet, at noon on May 24 the sky over Austin was clear and blue. However, a cool front from the northwest had been stalled over central Texas for three days, and in the afternoon that front was met by a mass of warm moist air moving inland from the Gulf of Mexico. At 3:00 p.m. the National Weather Service, from its office at the Austin municipal airport, issued a Flash Flood Watch for the Texas Hill Country, including Austin. This information was sent out on the weather wire teletype to all subscribers, among whom are radio and television stations; also, it was broadcast over NOAA weather radio. At 5:10 p.m.

the Weather Service forecast an 80 percent probability of rain, noting the possibility of severe weather and heavy rain from thunderstorms; the Flash Flood Watch was repeated. A few minutes later (5:37 p.m.) a Severe Weather Statement was issued; radar showed moderate to heavy thunderstorms developing rapidly over central Texas west and southwest of Austin, whose residents were urged to watch carefully and be prepared for heavy rain.

James Dugan, who was in charge of the Austin office of the National Weather Service, issued eight more statements throughout the evening. For a variety of reasons, the information in these statements does not appear to have stimulated responsive action by the city or its residents. It was the Sunday evening before the Memorial Day holiday. The television and radio stations, as well as city offices, were minimally manned; indeed, most of the stations were being operated by a single person. Later in the evening, many of the stations were knocked off the air by lightning. And the citizens were not alert: they were in the middle of an enjoyable holiday; most of them had been through many thunderstorms, including the one of the previous evening; many had seen heavy rainfalls in Austin, preceded or accompanied by Weather Service "statements," that had resulted in inconvenience but not loss of life or significant property damage; and few had weather radios and even fewer were listening to them.

At 7:00 p.m., the sky now black and threatening, the darkness occasionally broken by lightning off to the west, Dugan activated the alarm tone over the weather radio (some weather radios will broadcast this tone even when turned off). At 7:35 p.m., with the storm moving slowly northeastward and dropping an estimated 1 to 2 in. of rain per hour (probably twice this, as rain gages later showed), weather radio warned that local urban flooding was likely and that "small streams may rapidly flood." At 8:00 p.m. this warning (not officially a Flash Flood Warning) was repeated, with a summary of the storm situation in the area west and (now) north of Austin.

At 8:30 p.m. came the first telephone call to the city's Electric Department to report loss of electrical power in residences because of lightning strikes. In the next few hours about 250 such calls came from 200 locations.

At 9:00 p.m. or a few minutes past, very heavy rainfall started pouring down on north and west-central Austin; it continued for two hours at rates up to 4-1/2 in. in a 60-minute period and then abruptly slackened to a gentle fall that continued through the night.

By this time John German, Director of the Department of Public Works, had been alerted to the growing emergency, as had Police Chief Frank Dyson. At 9:30 p.m. the Street and Bridge Division of the Public Works Department began to put up barricades at approaches to low-water crossings and streets in the floodplain, in an attempt to prevent unwary motorists from driving into floodwaters.

At 9:32 p.m. the first indication of flooding came from a telephone call to the Fire Department from Jollyville, 10 miles north of downtown Austin; the caller reported an automobile being swept away by water. Fire Chief Ed Kirkham and Assistant City Manager Guymon Phillips were notified at their homes that flooding had commenced. Also notified were radio and television stations, which are connected by a "hot line" to the police and fire departments.

By 9:50 p.m. other callers had reported widespread flooding in the northern part of the city. At about this time Kao Chin Lu, her Pontiac stalled in the rushing waters of a tributary of Walnut Creek, became the first victim of the flood, swept away after she had broken a window to escape from the car. The first report of flooding in the Shoal Creek basin came from the Allandale area. Torrential rainfall in this area had started at about 9:00 p.m.; Shoal Creek crested at Steck Avenue about 11:00 p.m. At 10:10 p.m. a report of flooding on Jefferson Street, four miles downstream from the Allandale area, indicated that the Shoal Creek drainage, which is constricted at its lower end, was being hit hard.

At 10:15 p.m. weather teletype reported flooding in progress, and at 10:26 p.m. a Flash Flood Warning was issued for Travis County. By this time major flooding was under way, Michael Villareal had been drowned when his pickup was washed into a drainage ditch at the intersection of Highway 35 and U.S. 183, and Bruce Engman was about to drive his Mercedes into Bee Creek while taking his baby-sitter home; she survived, he did not.

At 10:30 p.m. the Fire Department started to warn and evacuate persons in the areas of flooding and provide them with emergency shelter. Unlike the Police Department, which has only one central station, the Fire Department has 26 stations throughout the city and for this reason has been given a lead role in monitoring floods and tornadoes and in providing door-to-door warning and rescue service. Although warned, Carolyn Grove and her grown son Jeffrey did not leave their home on Jefferson Street; both were drowned, the only fatalities of the flood not related to stalled or washed-away automobiles. The exact time of the Grove deaths is not known; Shoal Creek crested near their home at about 11:30 p.m.

At 11:00 p.m. Palmer Auditorium was opened as a shelter facility. Heavy runoff into Lake Austin and a consequent swift rise in its level caused flood gates at Tom Miller Dam to be opened at this time. Released water from Lake Austin combined with floodwater from Shoal Creek to fill Town Lake, the next reservoir downstream, in short order. By 11:00 Town Lake was beginning to receive automobiles, both new and used, delivered to it by Shoal Creek. Between 11:30 p.m. and midnight the flood crest passed down Shoal Creek from Thirty-eighth Street to Nineth Street; Helen Durio was drowned in a Volkswagen on Bee Creek, Sally Dexter in a Mercury on Dry Creek South, and Les and Rita Genscy in a Cadillac on Shoal Creek (four others died that night in or near their cars, two on Shoal Creek and two on Bull Creek, but the times of death are not known). All units of the Fire Department were on duty by this time, as were the crews of the electric utility and public works departments. The National Weather Service extended the Flash Flood Warning until 2 a.m. and had its radar and other station equipment knocked out by lightning. The first victims arrived at the Palmer Auditorium shelter.

By 2:30 a.m. (May 25) the flood, as a hydrologic event, was over. As a human event, it was far from over.

COPING WITH THE FLASH FLOOD HAZARD

As do most cities struck by a damaging event of infrequent occurrence and brief warning, Austin found itself not as well prepared for the flood of May 24-25 as it would have liked. Although the danger of flash flooding in the Hill Country was well known, 26 persons having been killed by such floods less than three years before in the Kerville-Medina area about 90 miles southwest of Austin, the city had moved slowly to protect itself against the hazard.

Ways of coping with the flood hazard fall into four categories: (1) living with the hazard, (2) designing and building structures to mitigate the hazard, (3) controlling land use in flood hazard zones, and (4) providing insurance.

The first option calls for implementation and maintenance of an adequate flood forecasting and warning system coupled with an effective means of traffic control and evacuation. In the case of flash floods, a quick response of the appropriate local authorities is vital to the reduction of human casualties, as is appropriate response of the public to warnings and directives issued by those authorities. Austin has relied on reports from persons experiencing flooding to initiate municipal response.

Many cities require structures built in flood hazard areas to be designed to withstand inundation by moving water; they may also cause structures such as levees, storm sewers, retention dams, and diversion systems to be built to control floodwaters. Austin and Travis County, at the time they were accepted into the federal flood insurance program in 1975, adopted such structural regulations and policies, but most of the city had been built without attention to such protection measures in the floodplain. However, the city, in concert with the State Department of Highways and Transportation, had built a series of detention ponds in the upper Shoal Creek watershed prior to the storm.

Experts agree that it is only by controlling land use in the floodplain that flood losses can be eliminated rather than reduced. Floodplain use may be restricted to parks, open spaces, or buildings on stilts. Restrictions on developing flood-prone areas are possible either through purchases by the city or by legal agreements that preclude development on private lands. Following the flood, Austin allocated funds to purchase damaged homes along a section of Jefferson Street and other reaches of Shoal and Walnut creeks, with the intent of razing the structures and widening the creek channels to carry more floodwaters.

Partial protection against financial loss from flooding can come through insurance. About 50 years ago private insurers stopped writing flood insurance on property other than automobiles and (later) mobile homes. The National Insurance Act of 1968 authorized a national flood insurance program at highly subsidized rates. The Flood Disaster Protection Act of 1973 provided a strong incentive for communities to participate by denying direct federal assistance for activities in flood-prone areas until the local government has adopted a flood management program that includes land-use plans, control measures, subdivision planning, and building and health code requirements. No owner of property in flood-prone areas, however, is required to purchase flood insurance or to bring an existing structure (at the time of adoption of such measures) into compliance with requirements for new construction. The 1981 flooding revealed that only a small percentage of the residences and business structures in the flooded areas were covered by flood insurance. The Red Cross, from on-site interviews, estimated that 10 percent of the residences and 20 percent of the business establishments that suffered damage were insured against flooding. A private insurance agent estimated the number at "15 percent of those in the floodplain." Even a former City Engineer who had worked hard for local acceptance of the flood insurance program had no flood insurance on his residence, although he stated that he'd recommend it to any subsequent owner.

SOME PROBLEMS OF COPING WITH FLOODS IN AUSTIN

Austin city officials have recognized for a long while the importance of adequate disaster warning and a system of effective response to needs for evacuation, rescue, and emergency medical and police services. From 1958 to 1968 the city set up an outdoor warning system consisting of 17 sirens (city-wide) and a public address system (downtown and at the University of Texas campus only). About 1972 the city discontinued the warning system because of frequent false alarms and the expense of maintenance and expansion to keep pace with the city's rapid growth. In 1980 the city staff, at the request of the City Council, reviewed and modified an existing disaster preparedness plan. An ad hoc committee recommended the establishment of a permanent Emergency Operations Center that could be activated "at a moment's notice"; urged the development by the city of a public hazards education program, with major reliance on radio and television stations to alert the public; recommended that "all city employees normally out in the public should receive training on tornado and severe weather spotting"; and urged the creation of an Office of Disaster Management, drafting a proposed ordinance to accomplish this objective. The committee, after reviewing the warning systems of several other Texas cities, expressed strong reservations about their effectiveness. None of these recommendations had been implemented at the time of the May flood. However, a temporary Emergency Operations Center existed at 403 E. Fifteenth Street, the site of the city's Emergency Medical Services administrative offices, at the time of the May flood; it was activated then, as well as several times within the next month, when heavy rains again struck the city.

Most of Austin was built before the present regulations for building in the floodplain became effective. Prior to 1975 no rules for placing buildings in flood-prone areas existed. There were no regulations for runoff from large commercial parking lots until 1976. Much of the valuable land of the city lies in flood hazard areas. It would be extremely expensive for the city to buy such land and the structures on it to prevent its continued hazardous occupancy and use. Furthermore, it is difficult to find places in the parts of Austin built up prior to 1975 to put flood retention structures. A further problem is that of low-water crossings and bridges that are undersized. They can easily become blocked by debris and act more like dams than bridges. In Travis County outside Austin, according to County Engineer David Preble, there are about 80 such "hydraulically deficient" bridges and 119 low-water crossings. The city, which has been expanding rapidly through annexation, has found it financially difficult to replace low-water crossings with bridges as rapidly as county land is incorporated.

Heavy rains fell again in Austin on May 28, June 11, and June 13. On June 13 Onion Creek, which passes through the southern part of the city, flooded. The only organized flash flood warning system in the Travis County jurisdiction consists of rain and stream gages on Onion Creek and its tributaries manned by volunteers under the direction of the County Engineer. The system, designed by George Kush of the San Antonio office of the National Weather Service, covers 300 square miles. Although as much as 200 ft^3/s of surface flow in the Onion Creek basin can infiltrate into the underlying limestone, its effect was insignificant on the night of June 13, when precipitation in the basin and its prior saturation caused runoff to reach a rate of 46,200 ft^3/s. This brought flooding in Austin sufficient to cause the Fire Department, early on the morning of June 14, to order evacuation of the two low-lying areas. However, no lives were lost and property damage was modest.

The Onion Creek Warning Program, as it is called, did not work as well as it should have, according to County Engineer Preble, who identified three problem areas: activation responsibility, communication difficulties, and the interpretation and use of the information it provides. Clear definition of responsibility for activating the program was lacking. Telephone lines and radio communication frequencies became overloaded at the time when information should have been coming in promptly from the gaging stations.

A FALSE SENSE OF SECURITY?

A false sense of security based on the limitations of one's own experience may have been a factor in the 11 deaths on the night of May 24-25 related to automobiles. There were no deaths outside the urban and suburban areas that night, although it rained quite as hard west and north of town, and there were no such deaths within the city during subsequent flooding. In regard to the former, the County Engineer claimed that rural people know the hazard of low-water crossings during a storm and act prudently. In regard to the latter, the suddently sharpened sensitivity of the driving citizen and more effective barricading by police, firemen, and public works crews working together helped account for the lack of further fatalities.

Not only had the people of Austin little or no experience with flooding in their city as great as that of May 24-25, but probably few knew how easily an automobile can be floated and moved by a high-velocity stream of water. The size of objects movable by a stream is a function of its velocity, more than its discharge, a fact probably contrary to popular impression. Any educational program on flash-flooding should stress that shallow fast streams can move large objects a much deeper but slower stream could not budge.

WHY SO LITTLE FLOOD INSURANCE?

On the night of May 24-25, 528 residential and business structures suffered flood damage. Most were not covered by flood insurance. There appear to have been two main reasons for the low incidence of insurance: (1) a false sense of security and (2) lack of information and encouragement. Accidents happen to other people. Flood insurance, even highly subsidized, costs money. It had been more than 40 years since a flood had caused severe property damage in Austin, and it was then a flood of the Colorado River, not a "creek" flood. In the meanwhile there had been many thunderstorms, during which the nearby creek may have overreached its banks, but the water came up only to the first porch step or barely covered the big rock by the driveway. In other words, it had "never" happended, so it wouldn't happen. Why waste money on insurance? The low coverage limits under the emergency federal program, which Austin participated in until September 2, 1981, may have been a minor discouragement to buying the insurance.

Clearly, many property owners lacked information about flood insurance. Some quoted by reporters claimed they thought such coverage was part of their homeowner's policy; others assumed that the mortgage holder had taken out the insurance. Flood insurance coverage does not appear to have been made a condition of private loans on property in flood-prone areas, even after the city joined the federal insurance program in 1975. It should be noted that there was substantial opposition in Austin to the federal program; participation, defeated in 1970, was accepted in 1975 only after a determined "educational" effort by some who had favored it since before 1970. After the 1975 success there seems to have been no similar "selling" of the insurance itself. One trenchant reason came to light in this study: private insurance companies and agents, through whom the insurance is available, have little incentive to sell it.

Unlike other subsidized insurance programs, such as federal crop insurance, the flood insurance program is not managed by the private insurance business. Furthermore, no management percentage is diverted to that business, a portion of which could be allocated--as it is in the case of crop insurance--to the support of workshops and information kits for agents and to advertising of the insurance. In the case of flood insurance, these functions are contracted by the government to a management company. Interviews with insurance agents during this study indicated (1) that agents are not supported by their companies with informational and promotional campaigns designed to sell flood insurance, and (2) that the commissions allowed by government regulation are too low to bother with.

An important factor influencing the level of public awareness of the flood hazard in Austin is the rapid growth of the population since the latest severe flooding (from 87,930 in 1940 to 345,496 in 1980).

PAYING FOR THE FLOOD DAMAGE

As soon as the waters subsided, Austin residents started seeking help to pay the costs of repairing the flood damage. Only a small fraction of the costs was covered by existing insurance. For those who had flood insurance but suffered substantial losses, the limits of coverage prevented full recovery. In addition, commercial enterprises have no means of recovering, through insurance or otherwise, losses they sustain from being forced temporarily out of business--losses in sales during the stoppage and in customers diverted to competitors, losses in support of laid-off workers, and costs of putting together a new work force.

Some of the costs of rebuilding homes and business structures could be shifted to the national taxpayer through the subsidized interest rates of disaster loans granted by the Small Business Administration (SBA). The SBA Administrator can declare a disaster whenever, in one county, 25 homes or 5 businesses or any combination that equals 25 suffer at least 25 percent uninsured damage; upon such declaration, individuals and organizations within the county where damage occurred and adjacent counties become eligible recipients of SBA disaster loans. Loans are not available to the extent the damage was covered by insurance, and the loans require that flood insurance be purchased if available and the property was not already covered. By July 15, the SBA Administrator having promptly declared Travis a disaster county, SBA representatives in Austin had held 1,062 interviews and given out loan applications to each person interviewed; 825 of those interviewed claimed damage to homes, the remainder to business structures. On that same date the SBA had received 524 completed applications, of which 439 were for loans to repair or replace homes.

SBA disaster loans carry highly subsidized interest rates--3 percent for homes, 5 percent for businesses. National experience shows that 95 percent of all applications for SBA disaster loans on homes are approved. The SBA also provides loans, at 9.25 percent, to small businesses to permit the meeting of obligations that could have been met had the disaster not occurred; such loans cannot exceed $100,000.

Damage to public property could be repaired only at the expense of local taxpayers, unless a Presidential disaster declaration could be obtained, in which case federal funds might be obtained to cover some of the expense. Two vain attempts were made by the City of Austin, with the endorsement of the Governor of Texas, in the days following the May flooding to have a disaster declared by the President. It became obvious that the criteria used at the Presidential level were more restrictive than those employed by the SBA Administrator. Negative responses to the two pleas were interpreted by local officials to mean that "Austin can afford the repair costs; therefore, the federal treasury is not available." For purposes of a local bond election, repairs to city property were estimated at $9.6 million, with an additional $6 million deemed desirable for widening creeks and building retention ponds. Austin officials estimated that a property tax increase of one cent per hundred valuation would be needed to finance the repairs and improvements. The small community of West Lake Hills faced a 25 percent increase in its property tax to pay for repairs to public property, mainly streets. A bond proposal approved by Austin voters provided funds to purchase 16 residential parcels on Jefferson Street subject to flooding at 5- to 10-year intervals, as well as to widen the stream in that vicinity; four homes on Silverway Drive in order to widen Shoal Creek and lengthen a bridge at that place; and 12 properties on Elm Parkway to widen the channel in that area. Water detention ponds, dredging, and channel widening were proposed not only for Shoal Creek but for Little Walnut, Barton, Johnson, and Waller creeks. The City of Austin, when it found that no costs could be shifted to the federal level, calculated those costs carefully, not only for repairs but for improvements in its flood management capability, and presented them to the voters for acceptance or rejection.

ACCUSATIONS AND ASSESSMENT

Austin civic life has been enlivened for some years by skirmishes and battles beteen those who wish to encourage population and economic growth and those who see such growth as threatening the urban and suburban amenities they hold dear. Consequently, it was not surprising that voices were heard, soon after the waters subsided, charging that unbridled "development" was the major cause of the severe flooding. This hypothesis was presented as a conclusion in an article published in the July issue of the widely read Austin-based Texas Monthly magazine. This conclusion was attributed to unnamed architects and hydrologists. However, Raymond Slade of the U.S. Geological Survey and William Espey of Espey, Huston and Associates did not agree that development was the primary "culprit" causing the severe flooding. The damage to homes along Shoal Creek was great because these homes were built in the floodplain. Other important factors were (1) watersheds were saturated by moderate rainfall prior to the peak rain intensities that produced the flooding; (2) the Shoal Creek watershed experienced a 100-year flood; and (3) the homes along Shoal Creek were built prior to adoption of current floodplain regulations and were located within the 100-year floodplain even for a condition of little urban development. This view was also supported by Ramon Miguez of the City Engineer's office with the statement that the damage along Shoal Creek was probably considerably worse than it would have been had the affected part of the Shoal Creek floodplain been built to the present code. Some voices were raised against the environmentalists, or at least against those who, it was claimed, had kept the city from cleaning and widening stream channels in order that they be able to pass floodwaters more readily.

Recriminatory fire soon died down in favor of a serious assessment of Austin's flood hazard and what might be done to mitigate it. At the expert level this assessment was led by the city staff. At the lay level it was led by the city's daily newspaper, the Austin American-Statesman, which published a series of in-depth articles based on interviews with experts and concerned citizens. Review of these articles leads to the following tentative conclusions:

1. Austin's citizens generally recognize that they must live with the flash flood hazard and that land-use controls and structural flood management measures can be of limited practicability in those parts of the city already built because of the great costs involved in razing what already is in place.

2. They would like, however, to see such controls and structures in areas of new construction, many of which are in the upper reaches of drainage basins whose lower portions are heavily populated.

3. There is little inclination to blame city officials for lack of a formal warning system, but rather an acceptance of individual responsibility for alertness to hazards and appropriate response to information and advice.

The Austin broadcasters seem to have been uncomfortable with the poor performance of their stations on May 24, later urging the city to meet with them to discuss setting up a system for alerting and informing station personnel and, through them, the public at hazard during an emergency.

A final note on assessment of blame came from city public works officials interviewed, who pointed out that expenditures for improving the city's capability to cope with a flood lose support and priority as the most recent flood fades into memory. More and more, they say, "something else" tends to take precedence, frequently because that something else has an interest group pushing for it, whereas the flood management action may even have opposition, say, if it involves cleaning of stream channels.

THE STRUCTURE OF RESPONSIBILITY AND DECISION

Austin, unlike Travis County, has all the legal authority it needs to deal with the flood hazard. The city has authority to regulate and monitor land use and construction, not only within its borders but within its extraterritorial jurisdiction. Strangely, the county does not have authority to inspect buildings. Neither can the county require the filing of a plat for a new subdivision in its jurisdiction. The city's extraterritorial jurisdiction, to a considerable extent, represents extension of authority and supervision into a legal vacuum.

Texas law allows the Governor to delegate emergency authority to the mayors of large cities, who, by amendment to the Disaster Act of 1975, have authority to declare a disaster. In Austin the Mayor has delegated operational responsibility to the City Manager, who in turn has passed it on to the Assistant City Manager whose purview includes health and safety (in May-June 1981 this was Guymon Phillips). To facilitate coordination among city staff groups most apt to be involved in an emergency, an operational group called Emergency Medical Services (EMS) coordinates the Fire Department, the Police Department, the Health Department, and the City Hospital; the Director of EMS reports to the Assistant City Manager for health and safety. In an emergency, EMS staff form the cadre of an Emergency Operations Center, the nexus of information and decision.

A recent change in federal law allows properly constituted local emergency officials, such as Austin's Mayor or her delegate, to intercept the National Emergency Broadcast System for local needs. In other words, Austin city officials can commandeer local radio and television to transmit emergency messages to the people of the city. Local government also may use an emergency channel on cable television and can broadcast warnings on NOAA weather radio.

Although the city has sufficient authority to do what it wants to protect itself against losses from flash flooding, what it actually does will be determined by public perception of the hazard and public willingness to pay the cost of various levels of protection. These costs range from what it takes to inform the public so that individuals may take protective actions open to them to the very high expense of prohibiting building in and occupancy of floodplains and constructing subsidiary drainage systems.

IMPROVING AUSTIN'S CAPABILITY TO COPE WITH FLOODS

In the fall of 1981, Austin created the position of Emergency Management Officer and engaged Charles Harrison, who had been with the Federal Emergency Management Agency (FEMA) for nine years since retiring from the U.S. Air Force. At about the same time, the city allocated funds to the Fire Department to plan an automated flood warning system based on UHF transmission of data from rain and stream gaging stations previously put in place for the city by the U.S. Geological Survey and from other sensors installed for the system. For such a system to give effective warnings, it must yield useful information very quickly; to do this, precipitation and streamflow data will be fed to a computerized streamflow simulation model of Austin's drainage system, which can be used to reevaluate anticipated streamflow conditions every few minutes. Output from the hydrologic simulation model will provide estimates of the location and severity of flooding, upon which appropriate warnings and decisions can be based.

Under consideration in the fall of 1981 was the establishment by the city of a "911" analysis and decision center, to be separate from the existing Emergency Operations Center. To the 911 center would flow all relevant information--from the National Weather Service, from the simulation model, from telephoning citizens and amateur radio operators, from fire, police, and public works personnel, and from the news media. From the 911 center would flow instructions to the Emergency Operations Center and to local broadcasters for translation into messages for public dissemination. In addition to broadcast warnings, the new Emergency Management Officer has suggested the installation on high towers of strobe lights to attract the attention of drivers and all citizens in parts of the city where the electricity may fail; one color of light, say orange, would mean to turn on radio or television for warning information, while a second color, say blue, would mean to tune in for information vital to personal safety.

Now that Austin is in the regular program of national flood insurance, more realistic maximum coverages are available: $245,000 instead of $45,000 for single-family house and contents; $550,000 instead of $200,000 for a small business and its contents. However, actuarial rates (not subsidized) are charged for the additional coverage as well as for all coverage on new buildings.

Public awareness of flood hazards is clearly a major factor in reducing loss of life and property damage. Based on Austin's experience with the May 24-25, 1981, flood, loss of life could have been reduced had those people driving through floodwaters and across creeks been aware of the high probability that they were about to lose their lives. Prominent signs erected at danger points displaying the height of water for a 100-year flood and, where applicable, the number of lives lost at the location would help make the degree of danger apparent at the time and place most helpful to the driver.

Property damage in homes can often be significantly reduced by moving items a few feet above the floor. Again it would be helpful to put markers on the ground, where all could see, showing the limits of the highest flood previously experienced and the limits of the 100-year flood.

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PRINCIPLES OF FLOOD HAZARD IN URBAN AREAS

Flooding is the inundation of land by surface runoff from major rainfall. The extent and nature of damage from flooding vary greatly from place to place and from time to time depending on the physical characteristics of the watershed and the severity of the storm event. Some of the physical characteristics of the watershed that affect the amount and rate of surface runoff are the size, slope, and shape of the watershed; the drainage pattern; the soil material and depth; the amount of ponding; the ground cover in the watershed; and the degree of saturation of the watershed at the time of intense rainfall. The surface runoff produced by the storm event is influenced by the spatial and temporal distribution of precipitation intensity throughout the storm. From these basic concepts about flooding, it is apparent that the extent of flooding depends on a complex interaction of many factors.

Urbanization of an area may have a profound effect on the degree of flooding by changing the physical characteristics of a watershed. The most obvious effect of urbanization is the large increase in the amount of impervious cover in the form of roofs of houses and buildings, paved streets and sidewalks, and parking lots. Generally, these surfaces tend to shorten the time of runoff and increase the total amount of runoff by decreasing the rate of infiltration into the soil, where water can be held in storage and released slowly. However, the relative magnitude of this effect decreases as the intensity of the storm increases (U.S. Army Corps of Engineers, 1980).

Ponding, or detention storage, may be either increased or decreased by urbanization. The building of sidewalks and curbs and leveling for lawns may increase ponding, and green lawns may provide more infiltraion than does the natural vegetation, especially in semiarid areas where the natural vegetation is sparse much of the year. Ponding may be increased in urbanized areas by requiring the building of ponds in parks, creeks, and parking lots. Sometimes, inadequate bridge openings restrict the flow in a stream and inadvertently cause localized ponding. This may reduce flooding for some property located downstream from the bridge opening, but flooding may increase for property upstream of where the ponding occurs.

The changes in the drainage system due to urbanization usually speed up the rate of runoff, tending to increase the peak flows for an urbanized area. This is usually the case with storm sewers and improved channels, although some cities are incorporating detention storage in storm sewer systems and creeks to reduce the magnitude of peak flows.

The effects of urbanization may differ greatly depending on the characteristics of the watershed, the intensity of the storm, and antecedent moisture conditions in the watershed. It is commonly found that urbanization has increased the height of flooding, but in some instances urbanization has reduced the level of flooding--for example, in Dry Branch Creek in Fort Worth. It has not yet been possible to evaluate the effect of urbanization on the flooding in Austin from the Memorial Day flood because the watershed was saturated from the earlier rain and because the extreme intensity of the rainfall raises uncertainty about applying commonly used methods to evaluate the effects of urbanization. Additional studies involving more detailed watershed modeling may provide better answers to this question in the future.

It is clear, however, that in an urban area compromises must be made between property development and security from flooding. In many locations it is not practical to have total protection against flooding. There is always some risk that nature will produce an event that will exceed the capacity of the drainage system. The best solution will be found by seeking a proper balance between costs and benefits, recognizing that some degree of hazard will always be present. If citizens are brought to understand this fact, it should make a profound difference in the effectiveness of their efforts to develop proper facilities and organizational systems to deal with flood hazards.

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IMPLICATIONS

Review of the Austin flood experience of May 1981 leads to several conclusions about urban flood hazards and the manner in which a community comes to terms with those hazards. Basically, what is true in Austin should also be more or less valid for thousands of other cities throughout the world. The physical facts of the Austin flood may be unique in some respects, but the underlying principles of community preparedness and response to a flood disaster are not.

PUBLIC UNDERSTANDING AND AWARENESS

First, it is apparent that Austin, or any other urban area, can deal effectively with the threat of flooding only to the extent that its citizens have a reasonably clear understanding of the nature of the hazards and retain that understanding as part of their basic concept of the environment in which they live. People who truly believe that a creek will periodically get out of its channel will generally tend to be careful about what they place on the banks beside that channel. Those who understand how easily an automobile can be swept away by flowing water are much less likely to drive into a stream that has overtopped the roadway. If a family recognizes that their property might be flooded, they are better able to protect themselves and their investment.

In many cases this understanding of the nature and extent of the danger is something that is not readily available to the average person. Beyond the most fundamental generalities, a proper determination of flood hazards depends on access to records of past events and results of detailed engineering analysis. Typically, that kind of information will be developed only through governmental efforts, either at the local, state, or federal level. Any community that expects to handle flooding successfully must decide at the outset to learn the facts of the flood risks and make those facts available to the public. Without an adequate background of public awareness and support, it is doubtful that workable programs for security against flooding can be maintained.

CONFLICTING PERCEPTIONS AND POLICIES

The process of public education in this instance is not easy. It is characteristic of mankind not to want to hear bad news, and news about potential flooding is almost always bad. In Austin, as in other cities, a sizable segment of the public does not really know where flooding can be expected to occur or how serious it can be when it happens. Although the problem may have been investigated and may be understood by some departments of the city administration, that insight is not necessarily shared by the community at large. In the case of Shoal Creek, for example, a 1974 study of the 100-year flood condition had predicted closely the water levels experienced in May 1981 (URS/Forest and Cotton/Espey, Huston and Associates, Inc., 1974; Altman and Espey, 1981) but the actual event found its victims essentially unprepared.

In the aftermath of the flood, there followed a period of heightened concern and increased media coverage, highlighted by conflicting opinions about what caused the problem, where the blame should be placed, and what might be done to avoid similar difficulties in the future. Several months later, however, there was little expression of public concern and the city staff carried the responsibility for remedial actions with little support and some opposition from the public.

It is difficult to formulate consistent and effective public policy when the citizenry does not grasp the full extent of the problem and when public perceptions are not basically in agreement. In 1973 the Austin City Engineer recommended improvements to increase the hydraulic capacity of Shoal Creek. The proposal met with strong resistance from residents living along the creek, who objected to widening the channel and removing trees. Those disagreeing with the plan did not believe that the problem was serious enough to justify changing existing channel conditions in the suggested manner. At a public hearing called as a result of a petition to the City Council, there was emphatic opposition to "tampering with the creek." One participant read a poem urging that Shoal Creek not be changed to "Shoal Ditch," and some suggested the acceptance of flooding of the area for a few hours each year rather than changing the stream.

In recent times the belief that the natural drainage courses of the Austin area should be left as they are has apparently been more persuasive with the public and the city's policy makers than has the alternative concept that changes in the stream channels are needed to lessen the risks of flooding. This is seen most clearly in the city's Creek Ordinance, where channel improvements are viewed as acceptable only when shown to be unavoidable. With that policy as the basis of drainage administration, it is improbable that there will be significant modifications of the hydraulic conveyance characteristics of the channels, and opportunities to improve the ability to handle large floods may be limited to ineffective approaches.

RECOGNIZING REALITIES

The overriding reality in this instance is that Austin must continue to live with the flash flood hazard. The streams of the area rose out of their banks from time to time long before there was a city around them. Houses, buildings, and streets have now been built in many of the overbank areas that once were available for passage of the floodwaters. At street crossings and other places there has been encroachment on the channels themselves. For economic and political reasons, the city will not be rebuilt to eliminate the hazard. Growth will continue, and most parts of the local watersheds that are not now developed will become urbanized sooner or later.

It must also be recognized that there can be floods considerably more severe than anything so far experienced in the history of the city, including the events of May 24-25, 1981. In approximate terms, a probable maximum flood may produce peak flows three or four times larger than those of the 100-year flood. If the drainage system is overtaxed by a 100-year condition, there is significant probability of experiencing storms still more intense, with correspondingly greater hazard to people and property.

Austin faces the same facts of life as do most other communities in this regard. The problem of severe flooding has always been there. The urban environment makes it more challenging, because either structures are built in the flood paths or development tends to cause heavier runoff or both. It is obvious that there will continue to be flooding of homes, streets, and businesses at intervals in the future. The most logical response will be to recognize the threat, take all feasible measures to minimize the damages, and prepare to deal with the emergencies when they come.

BEING PREPARED

Because of the combination of a potential for very intense rainstorms and a network of small drainage basins, floods in Austin happen very quickly. Civic attention has been directed toward establishing an effective early warning system. Consideration may be given to electronic data processing with a self-improving hydrologic model and maintenance of a quick response capability among city personnel. The difficulty of keeping the quick response operable over a long period when there is no flooding could be alleviated by designing the system to cope with a range of emergencies and by running drills at random times to test the degree of readiness. The city has already taken a major first step in this respect by recognizing the need for centralized decision making and distribution of information and directives during emergencies.

A continuing education program related to flood hazards and how to cope with them should also be implemented, working through the city schools, information leaflets sent with utility bills, and periodic articles and film clips in local newspapers and on television. One of the most vivid lessons from the May 1981 flood is that far fewer lives would have been lost if people had been more alert and had recognized the probable severity of conditions as the storm developed. If the educational program served only to make the public more respectful of the inherent danger of flood events, it would have fulfilled a very worthwhile purpose. An early warning system to give quick and reliable information would provide the other necessary element for proper citizen response when such emergencies occur.

POLICIES IN HARMONY WITH NATURE

Ideally, any community should have as its goal the development of a long-range flood preparedness program based on sound facts and a realistic appraisal of the problem. This implies acceptance of the full extent of the potential hazards, as revealed by detailed engineering analysis, and hardheaded recognition of the inevitability of repeated losses wherever unprotected structures encroach on the flood path. When a city takes this approach, there is maximum incentive to mitigate the problem through attention to prudent and economically feasible land-use controls, construction practices, and flood management techniques. Realistic flood hazard regulations can be established and consistently enforced. Identifiable high-risk areas where development has already taken place can in some cases be converted to uses consistent with periodic flooding.* Additional protection can also be provided through engineering improvements. New developments in high-risk locations can be avoided altogether.

One of the most challenging steps in the process of coming to terms with the realities of urban flood hazards is to recognize the vulnerabilities that usually are present in many established areas of a city. Even under ideal circumstances, municipal drainage structures are generally designed to cope with storms considerably short of potential ultimate conditions. When the design storm is exceeded, the drainage network will be overloaded, often with serious consequences at critical locations in the system. Typically, there are also points of weakness in most city systems, where facilities that once were adequate or were based on less stringent criteria in earlier times may now be deficient.

A city's program of flood drainage management should include periodic surveys to identify such situations, and public awareness of them should be encouraged by placing signs or markers on the ground where they are visible to all who pass. These danger areas should be ranked according to the severity of the risk and the cost of reducing the risk. Steps should then be taken to reduce or eliminate the risk in a logical sequence as resources are available.

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*One reviewer of this report suggested that the Small Business Administration adopt a policy of not making subsidized loans available to people whose property on a floodplain is damaged in a flood. This, he said, would exert more pressure on property holders to protect themselves and their property from the threat of flood hazards.

It is also apparent that some areas of many cities will have to live with a continuing threat of occasional flood damage and should protect themselves with adequate insurance coverage. The insurance is available as a result of the existing federal requirements, but it is not always sought or easily purchased where it is needed. A need is clearly indicated for cities to encourage property owners in hazard areas to buy flood insurance, while at the same time encouraging local insurance agencies to sell such coverage.

At the heart of this entire process is the need to understand the physical facts of the problem and share those facts with the public at large. Almost inevitably this will require a certain amount of determination to keep the realities clearly in view and resist tendencies to minimize or ignore the true nature of the problem. Wherever communities can face flood control responsibilities on a factual basis in this manner, they can hope for a high degree of success in holding damages to a reasonable minimum and in meeting the emergencies satisfactorily when they occur.

APPENDIX

REPORT ON METEOROLOGICAL ASPECTS OF THE AUSTIN FLASH FLOOD OF MAY 24-25, 1981

by George Bomar, Texas Department of Water Resources

METEOROLOGICAL CONDITIONS PRIOR TO STORM DEVELOPMENT

Surface and upper-air weather data from as many as 12 hours before the onset of rains in the central Texas area were analyzed and studied to ascertain the evolution of meteorological conditions responsible for the development of flash-flooding thunderstorms in the Austin area on the evening of May 24, 1981.

Synoptic-Scale Analyses for 7:00 a.m. (CDT), May 24, 1982

A long-wave trough of low pressure in the upper atmosphere, with a major axis extending southwestward out of the central Rocky Mountains to Baja California and a secondary axis reaching across central Texas, was the principal element in the planetary circulation pattern affecting Texas on May 24, 1981 (Figure A.1). The major axis propagated eastward across the southwestern United States during the day and extended longitudinally across central Texas on the morning of May 25. As the trough surged eastward, it contributed to the formation of a weak low-pressure center with an associated cold front on the lee side of the southern Rockies about midday on May 24. By late afternoon on that day, the surface low was situated in the southern High Plains of Texas in the vicinity of Midland, and the cold front extended from the low center southwestward through the Big Bend area (Figure A.2).

It was not, however, the major axis of the long-wave trough and the weak cold front related to it that induced the flash-flooding rains in central Texas. The secondary or short-wave trough that stretched in arc-shaped fashion across Texas on May 24 was the primary impetus for the flash flood outbreak. While falls in pressure associated with this advance short wave were not as pronounced as those connected with the longer wave to the west, the wind shear and degree of cold air advection were much more marked with the shorter wave. The short-wave trough moved little on the day of May 24, and it disintegrated early on the following day, but not before it destabilized the atmosphere over central Texas on the afternoon when intense rainstorms caused catastrophic floods in parts of Austin.

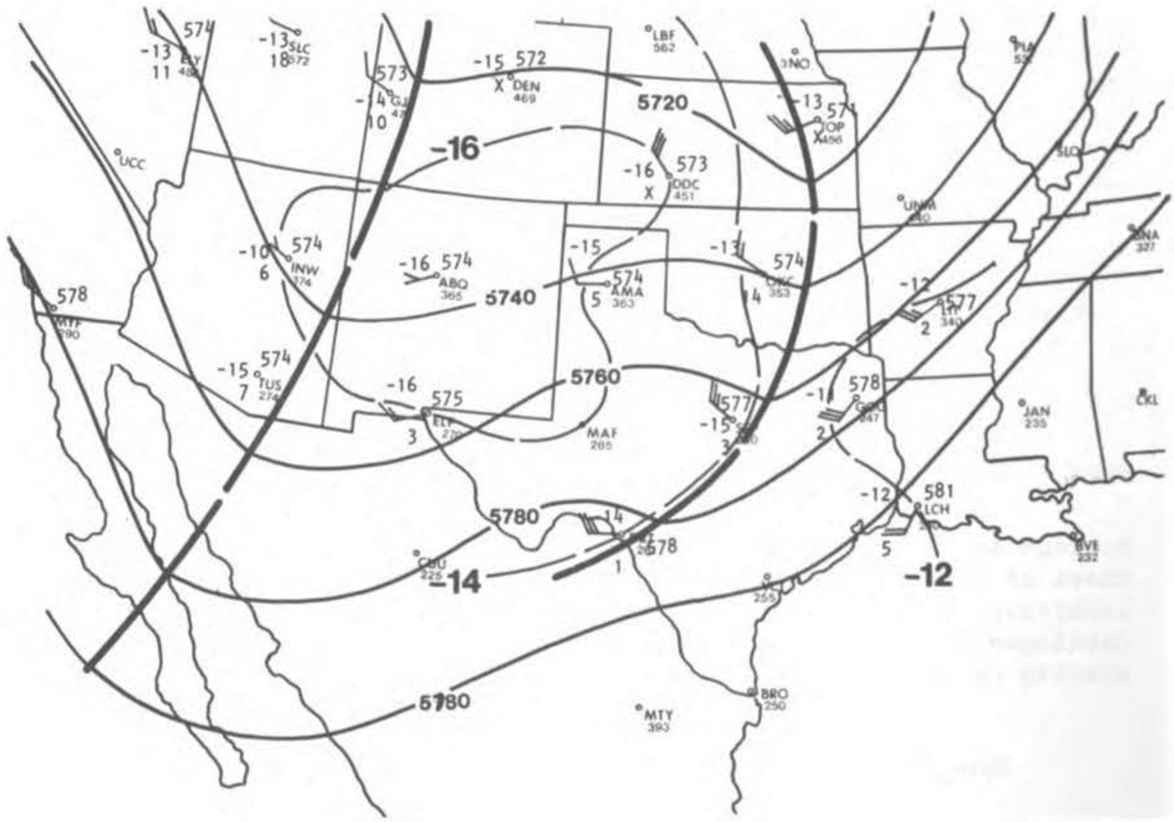

FIGURE A.1 500-mb analysis for 6 a.m. (CST), May 24, 1981. Height contours (drawn for every 20 m, 577 = 5770 m) and short-wave troughs are shown in black. Isotherms, shown as dashed lines, are for 2°C intervals.

Ample moisture characterized the lower half of the atmosphere over much of Texas on May 24. Very warm and moisture-laden air from the Gulf of Mexico streamed into that portion of Texas east of the Pecos River; at middle levels of the atmosphere, steady southwesterly winds transported appreciable amounts of moisture out of the eastern Pactific Ocean. The 500-mb analysis (Figure A.1) revealed considerable moisture at that level (approximately 19,000 ft above mean sea level) in practically all of the state. Indeed, as depicted by the plot of temperature and dew point for Longview in Figure A.3, the layer of moist air extended from about 700 to 400 mb, having a depth of approximately 14,200 ft. The 6:00 a.m. sounding taken at Del Rio showed the lower third of the atmosphere to be highly convectively unstable (Figure A.4). By lifting moist air near the surface to an altitude of just above 700 mb (or about 11,000 ft msl), virtually explosive growth of developing thunderstorms could be expected to occur. The unsettling influence of the upper-air short-wave trough moving through central Texas supplied the lift necessary for such phenomenal growth.

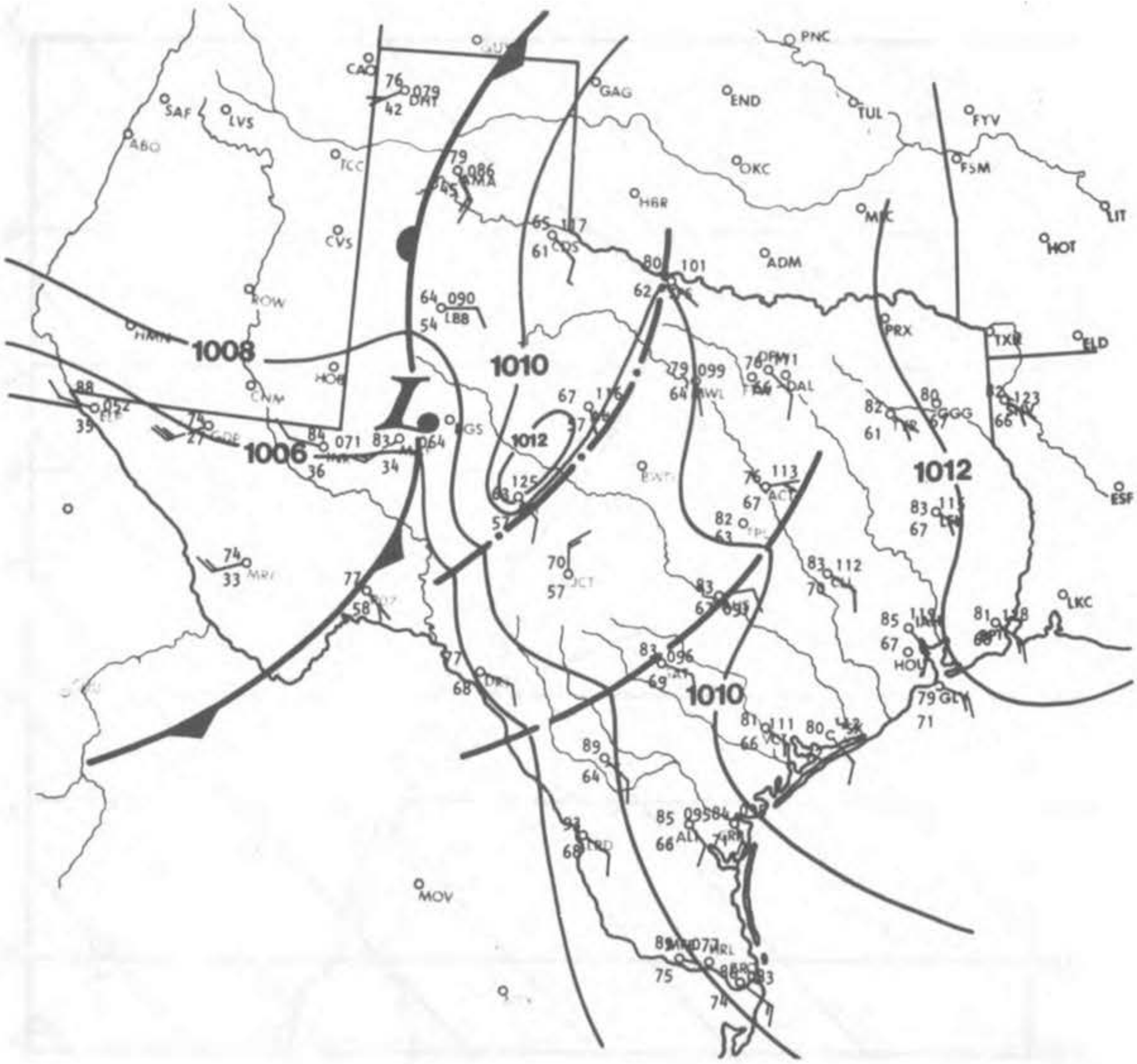

FIGURE A.2 Synoptic-scale surface analysis of weather conditions at 5 p.m. (CST), May 24, 1982. Isobars are at 2-mb intervals.

In summary, the May 24 morning synoptic analyses suggested that the stage was set for the development of significant thunderstorm activity in central Texas on that day. Modest values of the level of free convection (LFC) taken from the 6:00 a.m. soundings suggested that less than substantial lifting and/or heating of the moist layer of air would cause deep convection. Furthermore, the relatively low speeds of "steering" winds hinted that any deep cells of convection spawned during the day would move very slowly. Large amounts of precipitable water, combined with this projected slow storm movement, suggested that thunderstorms would have the potential of producing very substantial precipitation in localized areas.

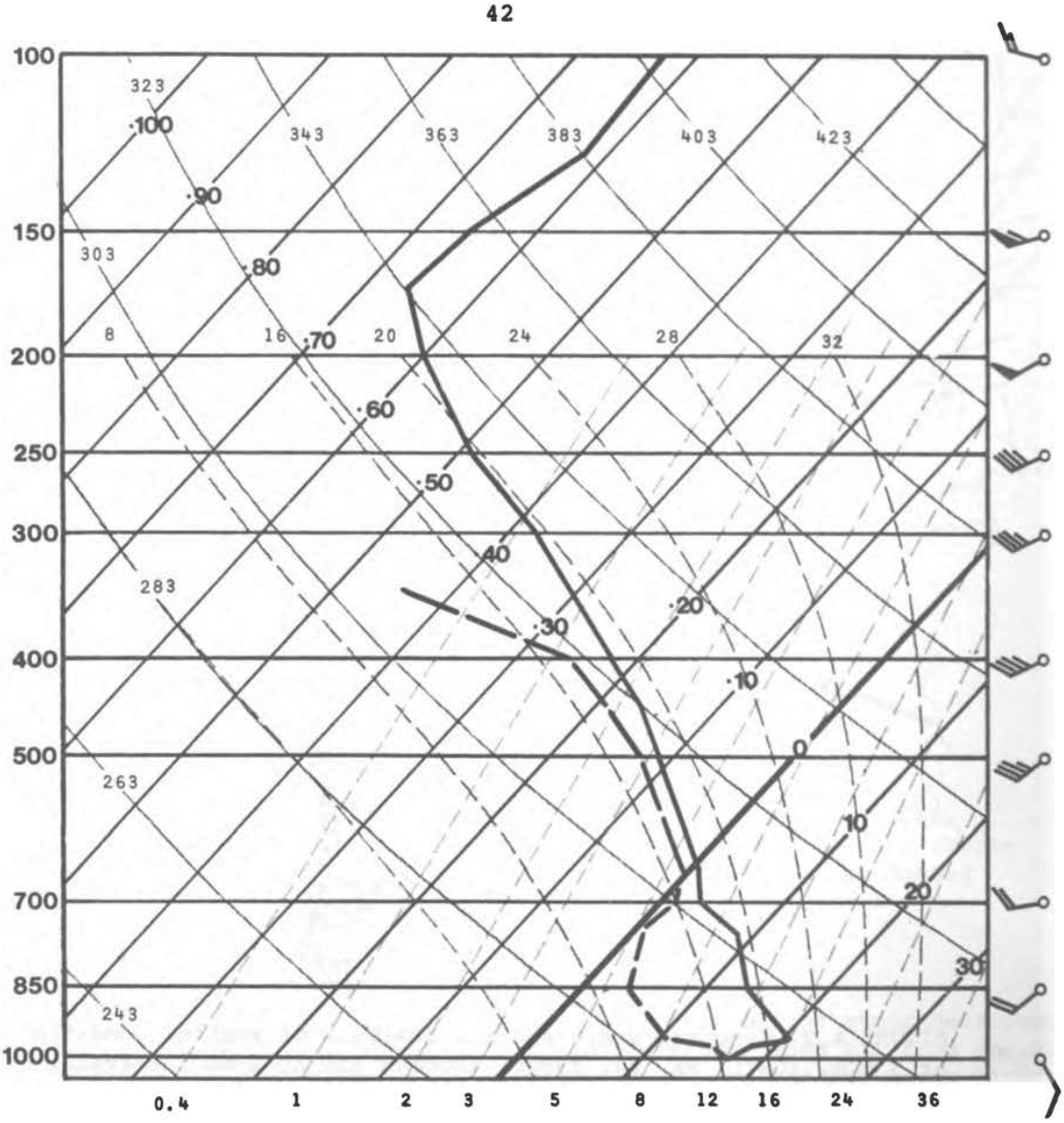

FIGURE A.3 Thermodynamic diagram depicting air temperature (solid) and dew point temperature (dashed) at various levels of the atmosphere above Longview at 6 a.m. (CST), May 24, 1981.

Localized Analysis of Events Prior to the Onset of the Heavy Rains

As shown by the time-series plot of surface weather conditions at Austin in Figure A.5, skies during much of the daytime of May 24 were fair to partly cloudy, with scattered clouds of the low-level cumuliform variety predominant from mid-morning until mid-afternoon.

As a result, plenty of sunshine elevated the temperature into the 80s not long after the noon hour; a modest increase in the moisture

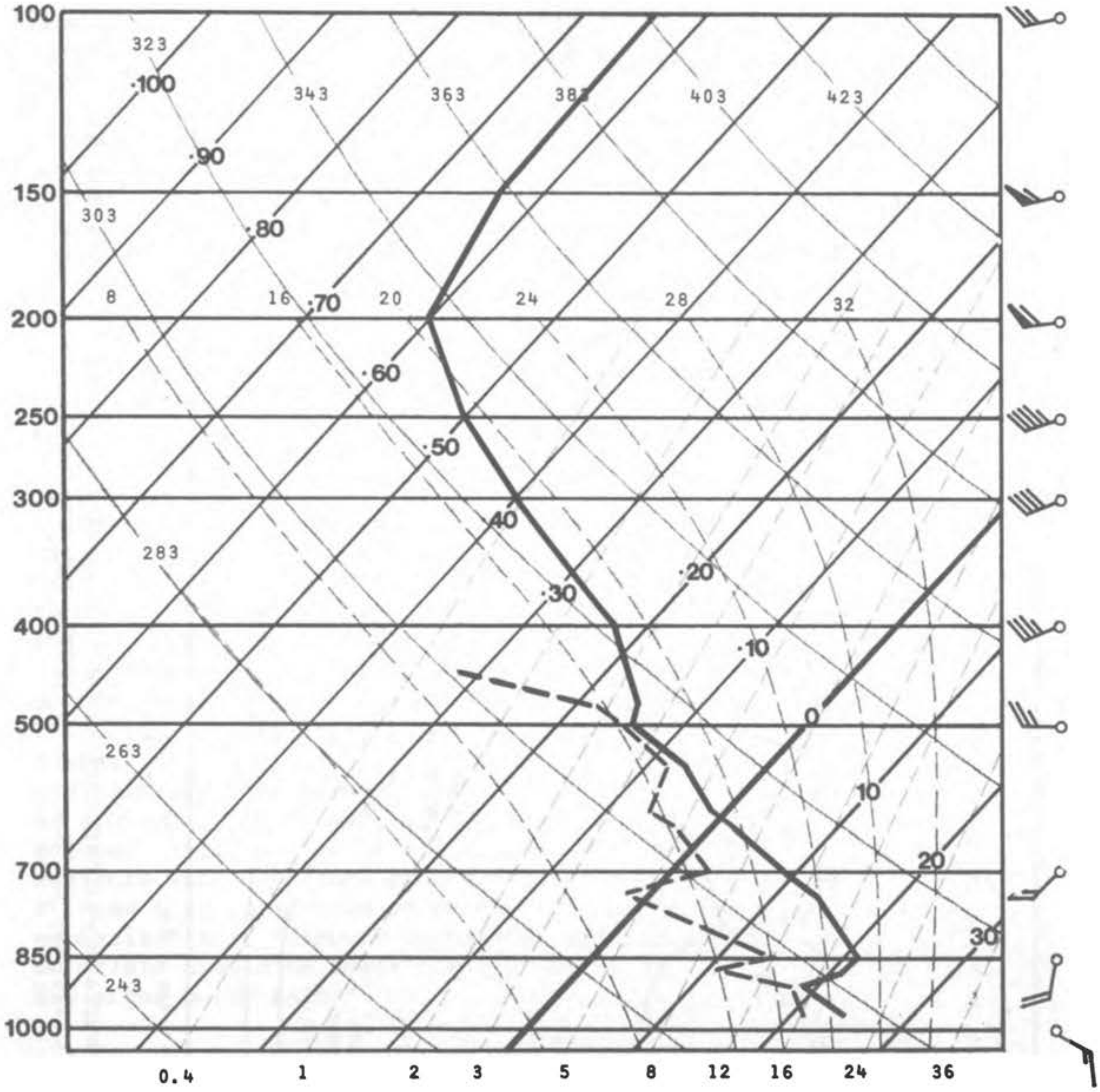

FIGURE A.4 Thermodynamic diagram depicting air temperature (solid) and dew point temperature (dashed) at various levels of the atmosphere above Del Rio at 6 a.m. (CST), May 24, 1981.

content of the surface layer of air was evidenced by a gradual increase in the dew point temperature, from the lower to the upper 60s during the same time. Surface winds throughout the daytime were mostly light (less than 10 mph) and variable in direction. The pressure declined after attaining its customary diurnal peak during the later morning, but the magnitude of its fall (nearly 0.20 in. in about eight hours) suggested that the passage of a surface weather disturbance was imminent.

The nature of this impending disturbance can be readily recongized

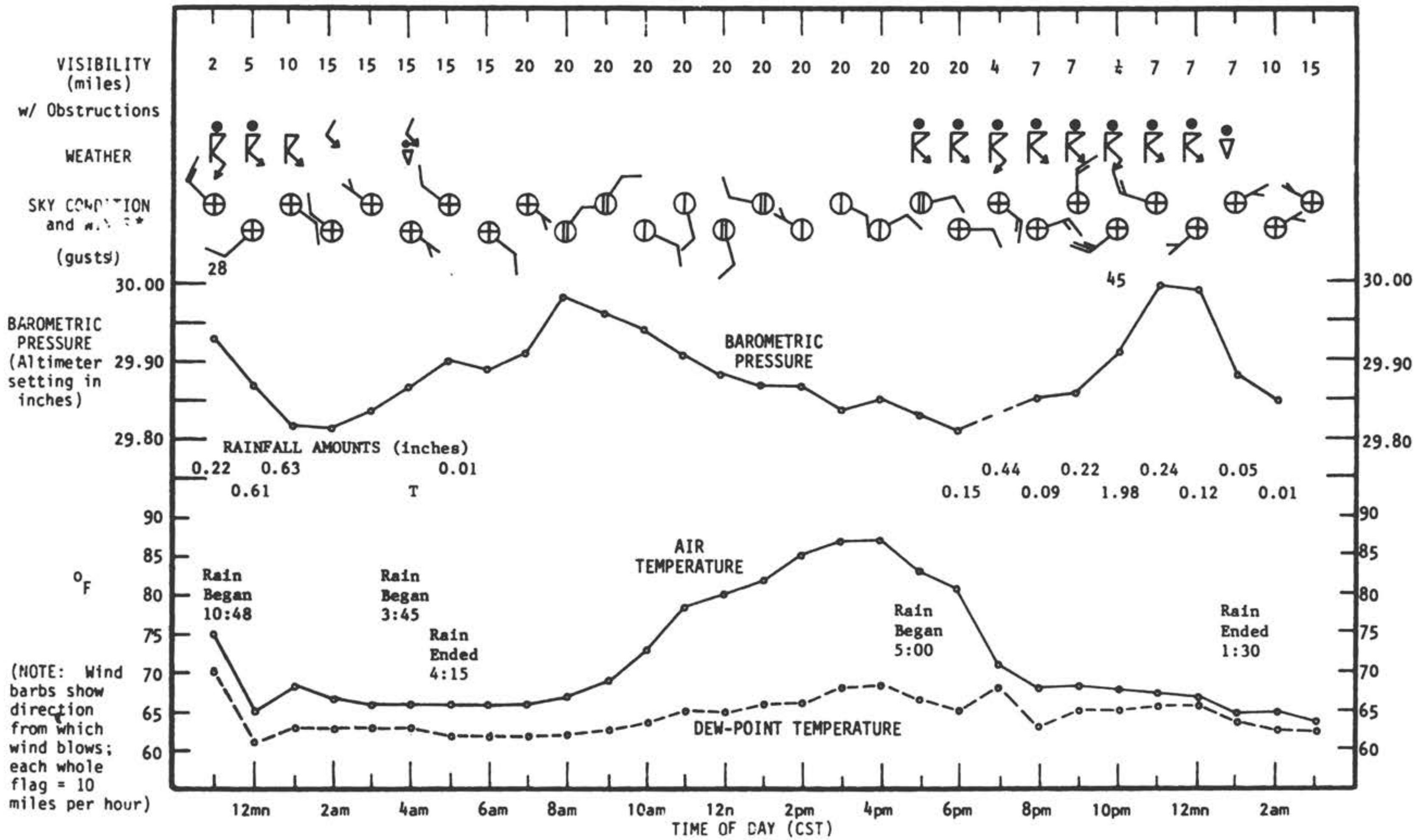

FIGURE A.5 Time-series plot of surface weather conditions as recorded at Austin's Municipal Airport during the period from 11 p.m. (CST), May 23, to 3 a.m. (CST), May 25, 1981.

from the analysis of surface data collected at 5:00 p.m. (CST), or not long after thunderstorms began cropping up in the vicinity of Austin. A well-defined surface trough line (indicated by the dashed line in Figure A.2) extended from just east of Waco (ACT) through Austin and San Antonio (SAT) to the Rio Grande south of Del Rio (DRT). Mostly southeasterly winds prevailed upstream of the surface trough, while easterly and northeasterly winds were common on the western side of the trough. The most convincing evidence of the trough was a favorable pressure field, in which Austin reported a sea level pressure of 1009.2 mb (shown as 091 in Figure A.2). It is known that the surface trough was not a feature induced by the developing thunderstorm activity, for similar wind and pressure patterns could be discerned several hours before the onset of the intense convection. Rather, the surface trough served as the depression into which warm, moist Gulf air flowed to supply the ingredients for the severe thunderstorm outburst. The presence of the upper-air trough mentioned earlier (the dashed line in Figure A.1) exacerbated the breakout of convection by inducing the unstable and moist air from the Gulf to rise to lofty levels. Of lesser concern to the Austin area, but noteworthy nonetheless, was the movement of a squall line (depicted by the dashed-dotted line in Figure A.2), extending from Wichita Falls (SPS) through Abilene (ABI) to San Angelo (SJT), and the weak area of cyclogenesis near Midland (MAF).

A rash of thunderstorms that moved through Austin and central Texas on the night of May 23-24 deposited rains generally amounting to 1/2 to 1-1/2 in. Consequently, with the ground wet from these nocturnal storms, any additional rainfall had the potential to cause flooding. Accordingly, the National Weather Service issued a Flash Flood Statement at 3:00 p.m. (CDT), May 24, advising residents of Austin and the adjacent Hill Country of the threat of flash floods. The special advisory warned persons planning outdoor activities near creeks and streams to stay advised of developing weather conditions, and it emphasized that "campers should not make camp close to creeks" and that motorists should be aware "of the danger at low water crossings during and after heavy rain."

METEOROLOGICAL CONDITIONS DURING THE TIME OF FLASH FLOODS

The combination of the destabilizing effect of an upper-air trough, the influx of moist and convectively unstable Gulf air into the vicinity of a surface convergence line, and an ample amount of surface heat contributed to the rapid outbreak of very heavy thunderstorms in and near Austin on the afternoon of May 24. Weather radar first recognized the presence of intense convection shortly before 5:00 p.m. (CDT); the National Weather Service observer at Austin Municipal Airport reported cumulonimbus and towering cumulus clouds forming along a line extending from the southwest to the northwest of the airport observation site. Thunder was first heard at the NWS site at 5:50 p.m., at which time lightning from cloud to ground was observed within the line of building thunderstorms to the west. Rain falling from the bases of several storm cells was visually spotted just before 6:00 p.m., and radar revealed the intensity of the rainfall to be "heavy." Rainfall was first observed at the airport weather station precisely at 6:00 p.m., and thunder was heard emanating from all directions. Most significantly, any movement of the intensifying thunderstorms could not be discerned.

Whereas widespread rain and thunderstorm activity cropped up in much of central Texas late in the afternoon, the most intense storms were confined to parts of Travis and nearby counties. Radar indicated at 6:19 p.m. that the huge thunderstorm cell just west of downtown Austin (labeled "A" in Figure A.6) had attained the status of "intense," suggesting that, at least in theory, rainfall rates from this system were in excess of 4-1/2 in. per hour. The top of the cell was measured at 45,000 ft msl. The downrush of cool air from this thunderstorm complex caused the temperature at the NWS station to dip to 71 degrees. Other showers and thunderstorms were growing rapidly in parts of the Hill Country when, at 7:00 p.m., the NWS issued a Severe Thunderstorm Watch covering Austin and the adjacent counties to the north and west of the city. The watch spoke of favorable conditions for the development of large hail and damaging winds in addition to very heavy rainfall.

The thunderstorm complex responsible for the tragic flash floods in the western sector of Austin moved little during its seven-hour lifetime. At 7:20 p.m. radar pinpointed the "core" of the massive storm a few miles northwest of the airport, or directly above the Shoal Creek watershed. Cloudtop heights varied between 40,000 and 45,000 ft, and for much of its life rainfall intensities fluctuated between "very heavy" and "intense." Pea- to marble-sized hail fell in parts of west and northwest Austin. Other very heavy thunderstorms cropped up in Burnet and Williamson counties (Figure A.7) and dished out damaging hail and strong, gusty winds. Then, at 10:26 p.m., the NWS issued a Flash Flood Warning to alert persons in Travis County to very rapid flooding of creeks, small streams, and other flood-prone areas. The special advisory warned, "Take all necessary precautions required. . . now!" By this time of the evening, the prolific rain-producing thunderstorm complex had diminished to the status of a "heavy thunderstorm," which meant that rainfall rates had lessened to only 1 to 2 in. per hour. Already, floodwaters were rampaging throughout the western sector of the city, inundating scores of homes along Shoal Creek and covering numerous streets and highways. The complex, as shown in Figure A.8, had drifted a few miles northeastward and, at 11:00 p.m. (CDT), was producing wind gusts of 45 mph and heavy rain at the airport. Its top remained at approximately 40,000 ft.

Remnants of the mammoth flash-flooding thunderstorm continued to produce light rainfall into the early-morning hours of May 25 in much of Travis County. Rainfall at Austin Municipal Airport did not cease until 2:30 a.m. (CDT). By that time, the heaviest thunderstorm activity was situated to the east of Austin, or generally along a line from Killeen through Round Rock and Elgin to Bastrop. The fact that widespread light rain continued to persist in much of central Texas east of a Marble Falls-Johnson City line attested to the quasistationary position of the upper-air short-wave trough. Skies over Austin remained overcast for the duration of the night as recovery efforts in the flood-hit areas of the city continued.

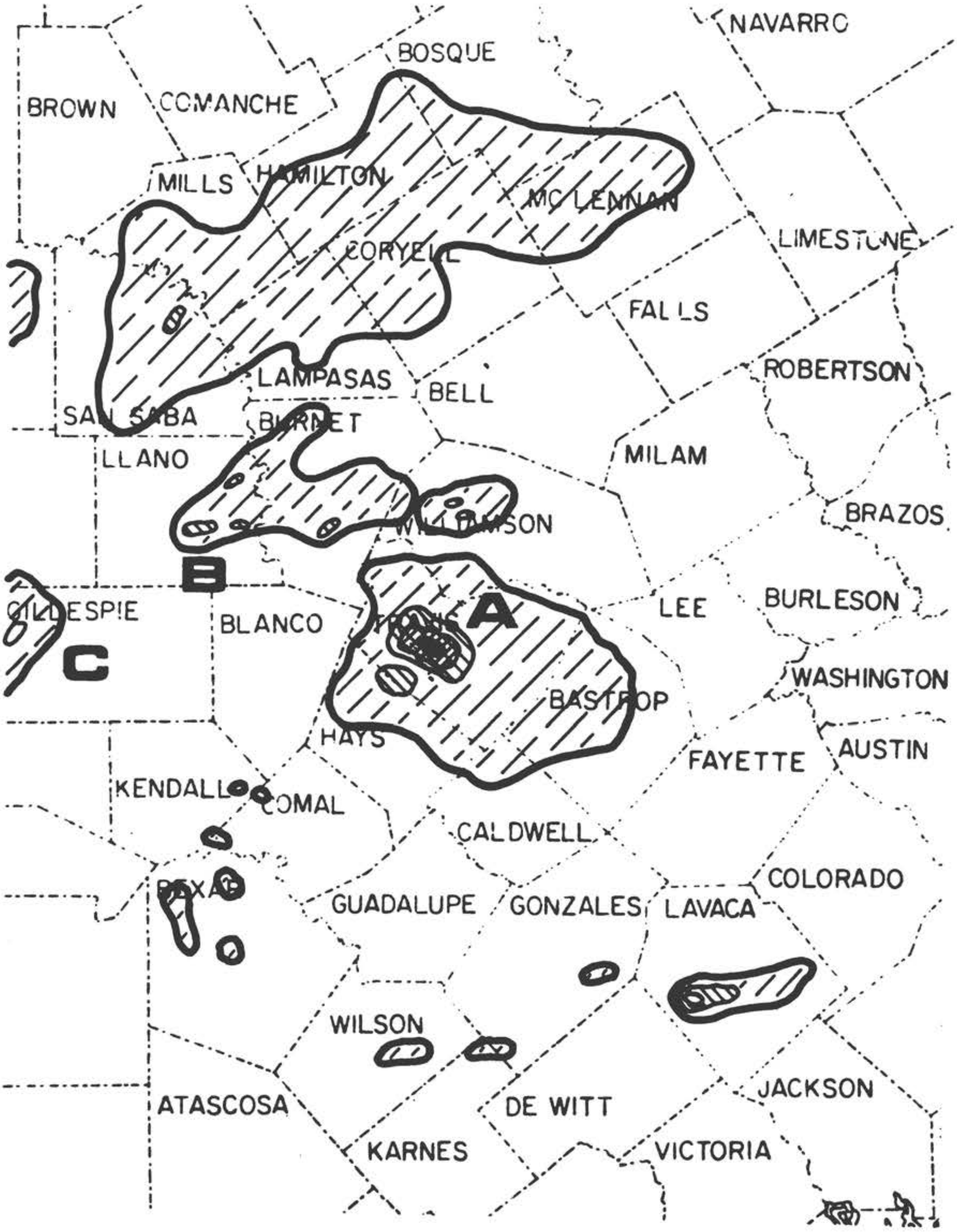

FIGURE A.6 Areas of precipitation discerned by weather radar at 6:19 p.m. (CDT), May 24, 1981. Measured cloudtop heights included cell "A" at 45,000 ft, cell "B" at 45,000 ft, and cell "C" at 30,000 ft.

FIGURE A.7 Areas of precipitation discerned by weather radar at 7:20 p.m. (CDT), May 24, 1981. Measured cloudtop heights included cell "A" at 40,000 ft, cell "D" at 45,000 ft, and cell "C" at 35,000 ft.

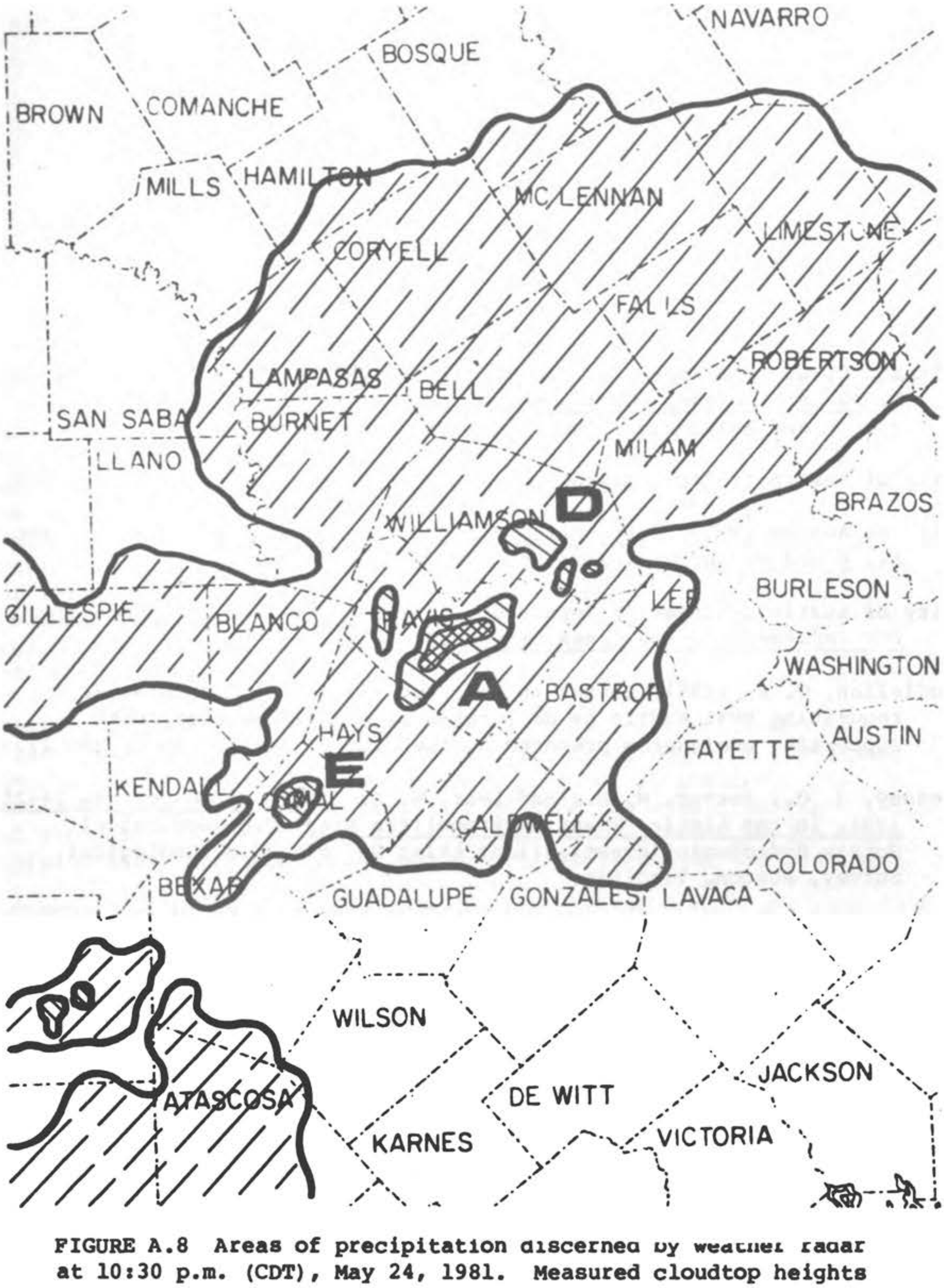

FIGURE A.8 Areas of precipitation discerned by weather radar at 10:30 p.m. (CDT), May 24, 1981. Measured cloudtop heights included cell "A" at 40,000 ft, cell "D" at 40,000 ft, and cell "E" at 42,000 ft.

REFERENCES

Altman, D. G., and Espey, W. H., Jr. (1981) The 24-25 May 1981 Flood Along Shoal Creek, Austin, Texas: Was It Predictable?, Espey, Huston and Associates, Inc., Austin, Texas, December.

City of Austin (1974) Ordinance No. 740307-I (Creek Ordinance), March 7.

City of Austin (1979) Uniform Building Code Amendments (1979 Ed.), Part XI, Flood Plain, Ordinance No. 75-0313-C.

City of Austin Engineering Department (1974) Guidelines and Procedures for Implementing the Creek Ordinance, July.

McClellan, C. K. (1981) Letter to Governor William P. Clements, Jr., requesting that Austin be designated as a disaster area, with supporting enclosures prepared by the City of Austin staff, May 27.

Massey, B. C., Reeves, W. E., and Lear, W. A. (1982) Floods of May 24-25, 1981, in the Austin, Texas, Metropolitan Area, U.S. Geological Survey Hydrologic Investigations Atlas No. 656, U.S. Geological Survey, Reston, Virginia.

Slade, R. M., Jr., et al. (1981) Hydrologic Data for Urban Studies in the Austin, Texas, Metropolitan Area, 1979, U.S. Geological Survey Open-File Report 81-628, U.S. Geological Survey, Reston, Virginia, 281 pp.

URS/Forrest and Cotton/Espey, Huston and Associates, Inc. (1974) Comprehensive Drainage Study, Shoal Creek Drainage Basin, October, Austin, Texas.

U.S. Army Corps of Engineers (1980) Walnut Creek Expanded Flood Information Study, General Report, Vol. 1, U.S. Army Corps of Engineers, Fort Worth District, Fort Worth, Texas.

BRIEF BIOGRAPHIES OF STUDY COMMITTEE MEMBERS

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NATIONAL RESEARCH COUNCIL REPORTS OF POSTDISASTER STUDIES, 1964-1982

Copies available from sources given in footnotes a, b, and c.

EARTHQUAKES

[a]The Great Alaska Earthquake of 1964:

- Biology, 0-309-01604-5/1971, 287 pp.
- Engineering, 0-309-01606-1/1973, 1198 pp.
- Geology, 0-309-01601-0/1971, 834 pp.
- Human Ecology, 0-309-01607-X/1970, 510 pp.
- Hydrology, 0-309-01603-7/1968, 446 pp.
- Oceanography and Coastal Engineering, 0-309-01605-3/1972, 556 pp.
- [a,c]Seismology and Geodesy, 0-309-01602-9/1972, 598 pp. PB 212 981
- Summary and Recommendations, 0-309-01608-8/1973, 291 pp.

[c]Engineering Report on the Caracas Earthquake of 29 July 1967 (1968) by M. A. Sozen, P. C. Jennings, R. B. Matthiesen, G. W. Housner, and N. M. Newmark, 233 pp., PB 180 548.

[c]The Western Sicily Earthquake of 1968 (1969) by J. Eugene Haas and Robert S, Ayre, 70 pp., PB 188 475.

[b,c]The Gediz, Turkey, Earthquake of 1970 (1970) by Joseph Penzien and Robert D. Hanson, 88 pp., PB 193 919.

[b,c]Destructive Earthquakes in Burdur and Bingol Turkey, May 1971 (1975) by W. O. Keightley, 89 pp., PB 82 224 007 (A05).

---

[a]Available from National Academy Press, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

[b]Available from Committee on Natural Disasters, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

[c]Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

[b,c]The San Fernando Earthquake of February 9, 1971 March 22, 1971) by a Joint Panel on San Fernando Earthquake, Clarence Allen, Chairman, 31 pp., PB 82 224 262 (A03).

[b,c]The Engineering Aspects of the QIR Earthquake of April 10, 1972 in Southern Iran (1973) by R. Razani and K. L. Lee, 160 pp., PB 223 599.

[b,c]Engineering Report on the Managua Earthquake of 23 December 1972 (1975) by M. A. Sozen and R. B. Matthiesen, 122 pp., PB 293 557 (A06).

[c]The Honomu, Hawaii, Earthquake (1977) by N. Nielson, A. Furumoto, W. Lum, and B. Morril, 95 pp., PB 293 025 (A05).

[b,c]Engineering Report on the Muradiye-Caldiran, Turkey, Earthquake of 24 November 1976 (1978) by P. Gulkan, A. Gurpinar, M. Celebi, E. Arpat, and S. Gencoglu, 67 pp., PB 82 225 020 (A04).

[b,c]Earthquake in Romania March 4, 1977, An Engineering Report, National Research Council and Earthquake Engineering Research Institute (1980) by Glen V. Berg, Bruce A. Bolt, Mete A. Sozen and Christopher Rojahn, 39 pp., PB 82 163 114 (A04).

[b,c]Earthquake in Campania-Basilicata, Italy, November 23, 1980, A Reconnaissance Report, National Research Council and Earthquake Engineering Research Institute (1981) by James L. Stratta, Luis E. Escalante, Ellis L. Krinitzsky, and Ugo Morelli, 100 pp., PB 82 162 967 (A06).

FLOODS

[b,c]Flood of July 1976 in Big Thompson Canyon, Colorado (1978) by D. Simons, J. Nelson, E. Reiter and R. Barkau, 96 pp., PB 82 223 959 (A05).

[b,c]Storms, Floods, and Debris Flows in Southern California and Arizona--1978 and 1980, Proceedings of a Symposium, September 17-18, 1980, National Research Council and California Institute of Technology (1982) by Norman H. Brooks et al., 487 pp., PB 82 224 239 (A21).

[b,c]Storms, Floods, and Debris Flows in Southern California and Arizona--1978 and 1980, Overview and Summary of a Symposium, September 17-18, 1980, National Research Council and California Institute of Technology (1982) by Norman H. Brooks, 47 pp., PB 82 224 221 (A04).

DAM FAILURES

[b,c]Failure of Dam No. 3 on the Middle Fork of Buffalo Creek Near Saunders, West Virginia, on February 26, 1972 (1972) by R. Seals, W. Marr, Jr., and T. W. Lambe, 33 pp., PB 82 223 918 (A03).

[b,c]Reconnaissance Report on the Failure of Kelly Barnes Lake Dam, Toccoa Falls, Georgia (1978) by G. Sowers, 22 pp., PB 82 223 975 (A02).

LANDSLIDES

[b,c]Landslide of April 25, 1974, on the Mantaro River, Peru (1975) by L. Lee and J. Duncan, 79 pp., PB 297 287 (A05).

[c]The Landslide at Tuve, Near Goteborg, Sweden on November 30, 1977 (1980) by J. M. Duncan, G. Lefebvre, and P. Lade, 25 pp., PB 82 233 693.

WINDSTORMS

[c]Lubbock Storm of May 11, 1970 (1970) by J. Neils Thompson, Ernest W. Kiesling, Joseph L. Goldman, Kishor C. Mehta, John Wittman, Jr., and Franklin B. Johnson, 81 pp., PB 198 377.

[c]Engineering Aspects of the Tornadoes of April 3-4, 1974 (1975) by K. Mehta, J. Minor, J. McDonald, B. Manning, J. Abernathy, and U. Koehler, 124 pp., PB 252 419.

[b,c]The Kalamazoo Tornado of May 13, 1980 (1981) by Kishor C. Mehta, James R. McDonald, Richard C. Marshall, James J. Abernathy, and Deryl Boggs, 54 pp., PB 82 162 454 (A04).