Floods in Central Texas, August 1–4, 1978

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1332

Report prepared jointly by the U.S. Geological Survey and the National Oceanic and Atmospheric Administration

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By E. E. SCHROEDER *and* B. C. MASSEY, U.S. Geological Survey, *and*
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GLOSSARY

Acre-foot (acre-ft). The volume of water required to cover 1 acre to a depth of 1 foot. It equals 43,560 cubic feet, 325,851 gallons, or 1,233 cubic meters.

Contents. The volume of water in a reservoir or lake. Content is computed on the basis of a level pool or reservoir backwater profile and does not include bank storage.

Convection cloud. A cloud which owes its vertical development, and possibly its origin, to convection.

Cubic foot per second (ft^3/s). A rate of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, flowing at an average velocity of 1 foot per second. It equals 28.32 liters per second or 0.02832 cubic meters per second.

Cubic foot per second per square mile [$(ft^3/s)/mi^2$]. The average number of cubic feet per second flowing from each square mile of area drained by a stream, assuming that the runoff is distributed uniformly in time and area. One cubic foot per second per square mile is equivalent to 0.01093 cubic meter per second per square kilometer.

Dew point (or dew temperature). The temperature to which a given parcel of air must be cooled at constant pressure and constant water-vapor content in order for saturation to occur.

Drainage area of a stream at a specific location. The contributing area of a stream, measured in a horizontal plane, bounded by topographic divides. Drainage area is given in square miles. One square mile is equivalent to 2.590 square kilometers.

Flash flood. A local and sudden flood which usually follows brief heavy precipitation.

Flood. Any high streamflow that overtops natural or artificial banks of a stream and overflows onto land not usually underwater and causes or threatens damage.

Flood peak. The highest value of the stage or discharge attained by a flood.

Flood profile. A graph of the elevation of water surface of a river in flood, plotted as ordinate, against distance, plotted as abscissa.

Flood stage. The approximate elevation of the stream when overbank-flooding begins.

Front. The interface or transition zone between two airmasses of different density.

Gaging station. A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained.

Isohyetal map. A map showing lateral distribution of precipitation and drawn as contours of equal rainfall depths.

Jet stream. High-velocity strong winds concentrated within a narrow stream high in the atmosphere.

Mean sea level. The annual mean sea level is the average of hourly heights of the tide from a calendar year of tidal record. This is referenced to the National Geodetic Vertical Datum of 1929.

Millibar (mb). A unit of pressure equal to 1,000 dynes per square centimeter.

National Geodetic Vertical Datum (NGVD). Formerly called Sea Level Datum of 1929. A geodetic datum derived from a general adjustment of the first order level nets of both the United States and Canada. In the adjustment, sea levels from selected tide stations in both countries were held as fixed. The year indicates the time of the last general adjustment. This datum should not be confused with mean sea level.

***N*-year precipitation (rain).** A precipitation amount which can be expected to occur, on the average, once every N years.

Precipitable water. The total atmospheric water vapor contained a vertical column of unit cross-sectional area extending from the surface up to a specified pressure level, usually 500 mb.

Rawinsonde. A radiosonde tracked by a radio direction-finding device to determine the winds aloft.

Recurrence interval. As applied to flood events, recurrence interval is the average number of years within which a given flood peak will be exceeded once.

Ridge. An elongated area of high atmospheric pressure.

Time of day expressed in 24-hour time. For example, 12:30 a.m. is 0030 hours, 1:00 p.m. is 1300 hours.

Unit discharge. The average number of cubic feet of water flowing per second from each square mile of area drained, assuming that the runoff is distributed uniformly in time and area.

Vorticity. A vector measure of local rotation in a fluid flow, defined mathematically as the curl of the velocity vector. In meteorology, vorticity usually refers to the vertical component of the vector.

CONVERSION OF INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

[Most units of measure used in this report are inch-pound units. The following factors may be used to convert inch-pound units to the International System of Units (SI).]

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer
degrees Fahrenheit (°F)	5/9 (F-32)	degrees Celsius (°C)
foot (ft)	.3048	meter
inch (in)	25.4	millimeter
knot (kn)	1.85	kilometer per hour
mile (mi)	1.609	kilometer
mile per hour (mph)	1.609	kilometer per hour
millibar (mb)	0.1	kilopascal (kPa)
nautical mile (nmi)	1.85	kilometer
square mile (mi^2)	2.590	square kilometer

FLOODS IN CENTRAL TEXAS, AUGUST 1-4, 1978

By E. E. SCHROEDER and B. C. MASSEY, U.S. GEOLOGICAL SURVEY, and EDWIN H. CHIN, NATIONAL WEATHER SERVICE, NATIONAL OCEANIC and ATMOSPHERIC ADMINISTRATION

ABSTRACT

Catastrophic floods caused by record rainfall occurred in central Texas during August 1–4, 1978. Torrential rain initiated by the remnants of tropical storm Amelia fell over south-central Texas during August 1–3, and very intense rain due to the interaction between the cold front and maritime air mass fell over north-central Texas on August 3–4. Rainfall of more than 48 inches near Medina in south-central Texas established a new United States record of extreme point rainfall for a 72-hour period.

Major flooding occurred on the Medina and Guadalupe Rivers. Severe to minor flooding occurred on the Brazos, Llano, Pedernales, and Nueces Rivers. Floods with recurrence intervals in excess of 100 years and record-setting peak discharges were observed at several streamflow stations.

Thirty three lives were lost and total damages reportedly exceeded $110 million.

INTRODUCTION

Catastrophic floods caused by intense rainfall occurred in central Texas during Aug. 1–4, 1978. The rain was initiated by remnants of tropical storm Amelia but was compounded by other meteorological factors. Torrential rain fell over the hill country area of south-central Texas during Aug. 1–3, and over the big country area of north-central Texas during Aug. 3-4. A maximum rainfall of more than 48 in. at a location 11 mi northwest of Medina (29°49′N. 99°15′W.) set a new extreme point rainfall record for a 72-hour period in the United States. A map of central Texas is shown in figure 1, and a map of Medina and vicinity (expanded scale) is shown in figure 2.

Major flooding occurred on the Medina River and its tributaries above Medina Lake and on the Guadalupe River and its tributaries above Canyon Lake. Moderate to severe flooding occurred on tributaries of the Nueces River, on Clear Fork Brazos River and its tributaries, and on the Llano and Pedernales Rivers, which are tributaries of the Colorado River. Peak discharges at several streamflow stations exceeded the historic peaks. The highest unit discharge observed was 3,010 $ft^3/s/mi^2$ from the 14.1-mi^2 drainage area of Spring Creek, which is a tributary of the Pedernales River.

Much of the extraordinary runoff was in the form of flash flooding. About half of the town of Medina was damaged, and many buildings in the city of Bandera farther downstream on the Medina River also were damaged. Medina Lake had 4 ft of flow over the spillway at maximum stage. In north-central Texas, 6 ft of water inundated the town of Albany on a tributary of Clear Fork Brazos River, forcing people to seek safety on roofs and trees. Floodwater opened gaps in the earthen dam of Albany Reservoir and overtopped the spillway at Lake Throckmorton. A total of 33 people lost their lives due to the floods. Property damages were estimated at $110 million.

This report presents the meteorlogical situations and the precipitation distributions that caused the floods and a description of the floods by basins with peak stages and discharges and flood-frequency estimates. Detailed discharge-hydrograph data, including historic maxima are presented in tabular form for 10 gaging stations. These should be of considerable value in assessing the risks involved in developing the flood plains of streams in the affected area.

This report was prepared jointly by the U.S. Geological Survey and the National Oceanic and Atmospheric Administration and in cooperation with the State of Texas and other agencies.

METEOROLOGICAL SETTINGS AND PRECIPITATION DISTRIBUTION

The disturbance that developed into tropical storm Amelia originated off the African coast as a tropical wave on July 19, 1978. It remained a weak system without much deep convection until it reached the central Caribbean Sea on July 26. On July 29, as the wave moved off the Yucatan Peninsula into the southwestern Gulf of Mexico, convection increased and the cloud mass took on a circular appearance on satelite pictures. By Sunday morning, July 30, the disturbance had turned toward the northwest and the cloud band structure had appeared. The track of Amelia is shown in figure 3, and surface analysis for the period July 30–August 4 is shown in figures 4A–F. All time mentioned in this report refers to central standard time (c.s.t.) unless stated otherwise. The surface analysis at 0600 July 30 (fig. 4A) indicated very flat

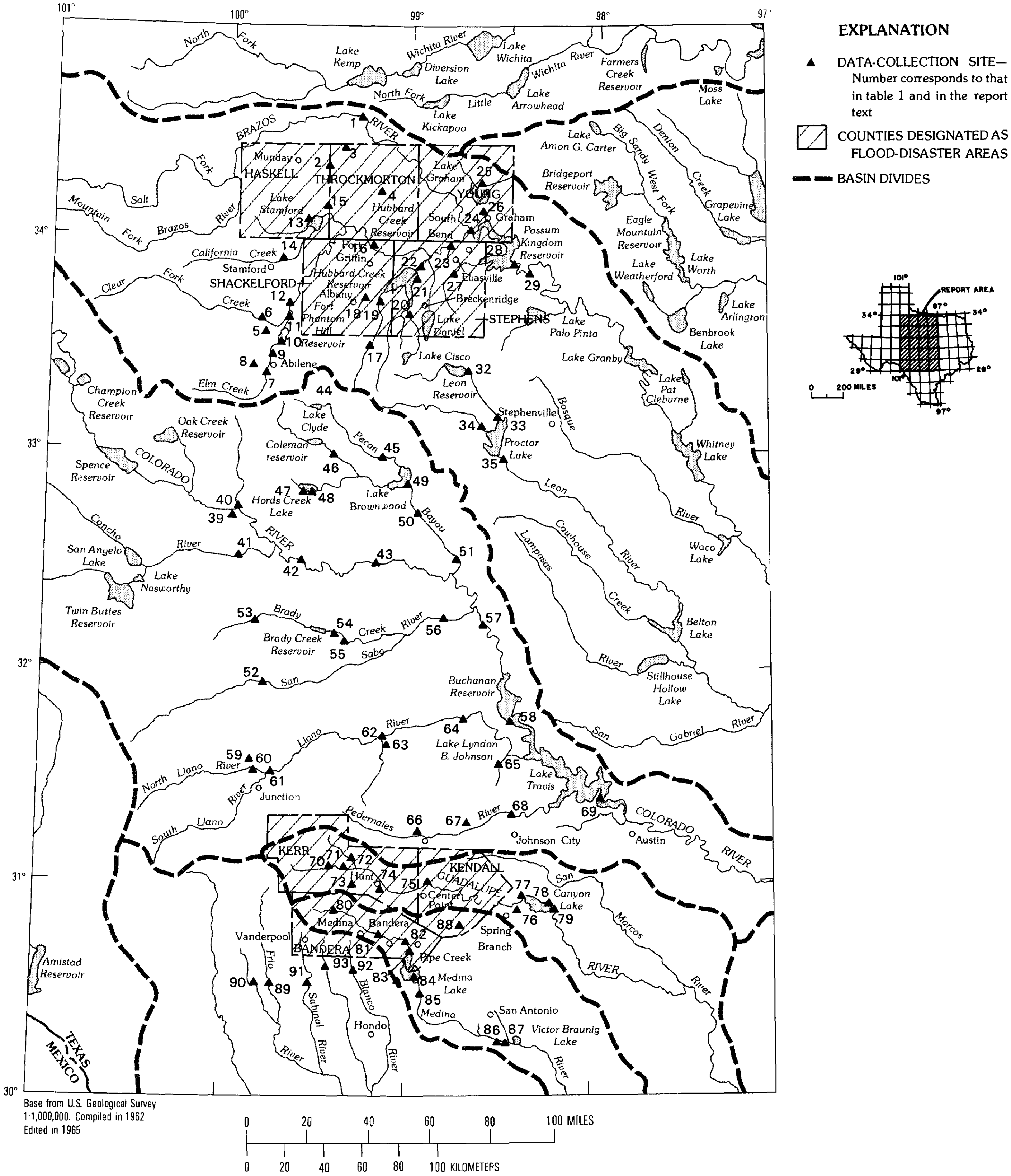


FIGURE 1.—Location of streamflow-data sites.

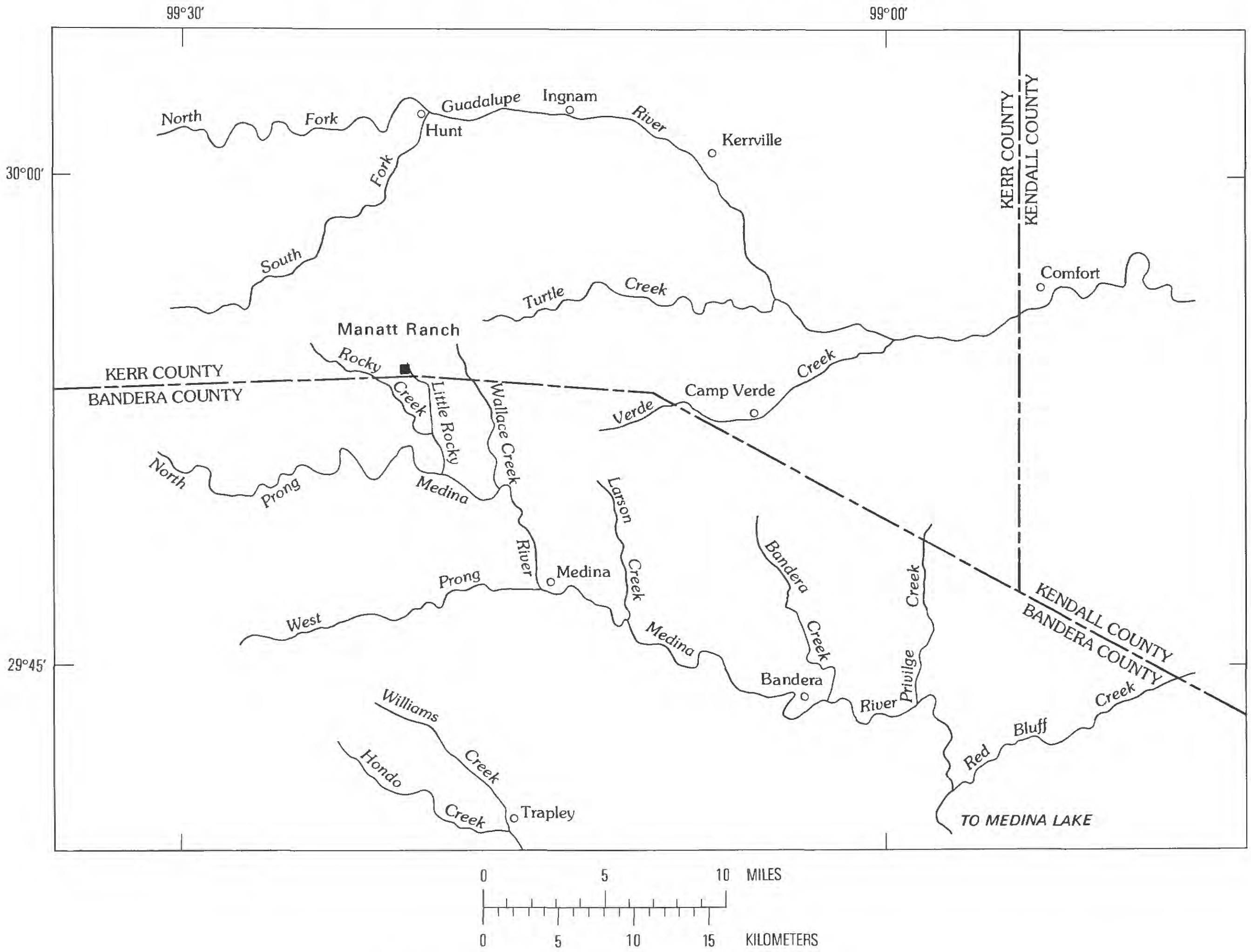


FIGURE 2.—Medina and vicinity in south-central Texas.

pressure gradient over Texas, with the coastal stations of Corpus Christi and Brownsville having light easterly winds with overcast sky. The low pressure center, which was to develop into Amelia, was centered in the western Gulf of Mexico at 23.5°N. 95°W. The corresponding 500–mb analysis (fig. 5A) showed a flat contour gradient with very light southeasterly winds of about 10 kn (knots) over the eastern two-thirds of Texas. A very weak low center was situated over north-central Mexico.

During the day of July 30, the low pressure center that was to develop into Amelia continued on a north-northwestward track at 10 mph. Before crossing the Texas coast north of Brownsville during the evening of July 30, this system reached tropical storm intensity, with winds in excess of 45 kn. The estimate of storm intensity was based on data obtained by reconnaissance flights through the storm. By 2200 July 30, Amelia was 40 mi north of Brownsville. During the night, Amelia continued on a northwesterly track and by 0600 Monday, July 31, was about 50 mi west by north of Corpus Christi at approximately 28.0°N. 97.8°W. The pressure gradient along the southwest Texas coast from near Brownsville to just east of Corpus Christi tightened during this period indicating a stronger onshore flow of warm moist air from the Gulf of Mexico. During July 31, the storm continued to drift northwestward while its circulation continued to weaken. The surface center of circulation could be traced inland to the west of San Antonio during the night of July 31–August 1, after which it was no longer identifiable. After the low was filled, the surface analysis at 0600 Tuesday, August 1 (fig. 4C) indicated continued onshore southeasterly flow and strong moisture advection. For example, with the wind southerly or southeasterly at Corpus Christi and vicinity on July 31 and August 1, warm maritime air with a mixing ratio of 22.5 grams of water vapor per kilogram of dry air near the surface was moving into south-central Texas. This predominantly southeasterly circulation pattern persisted throughout the life of the storm systems as can be seen from surface maps at 0600 August 2–4 (figs. 4D–F).

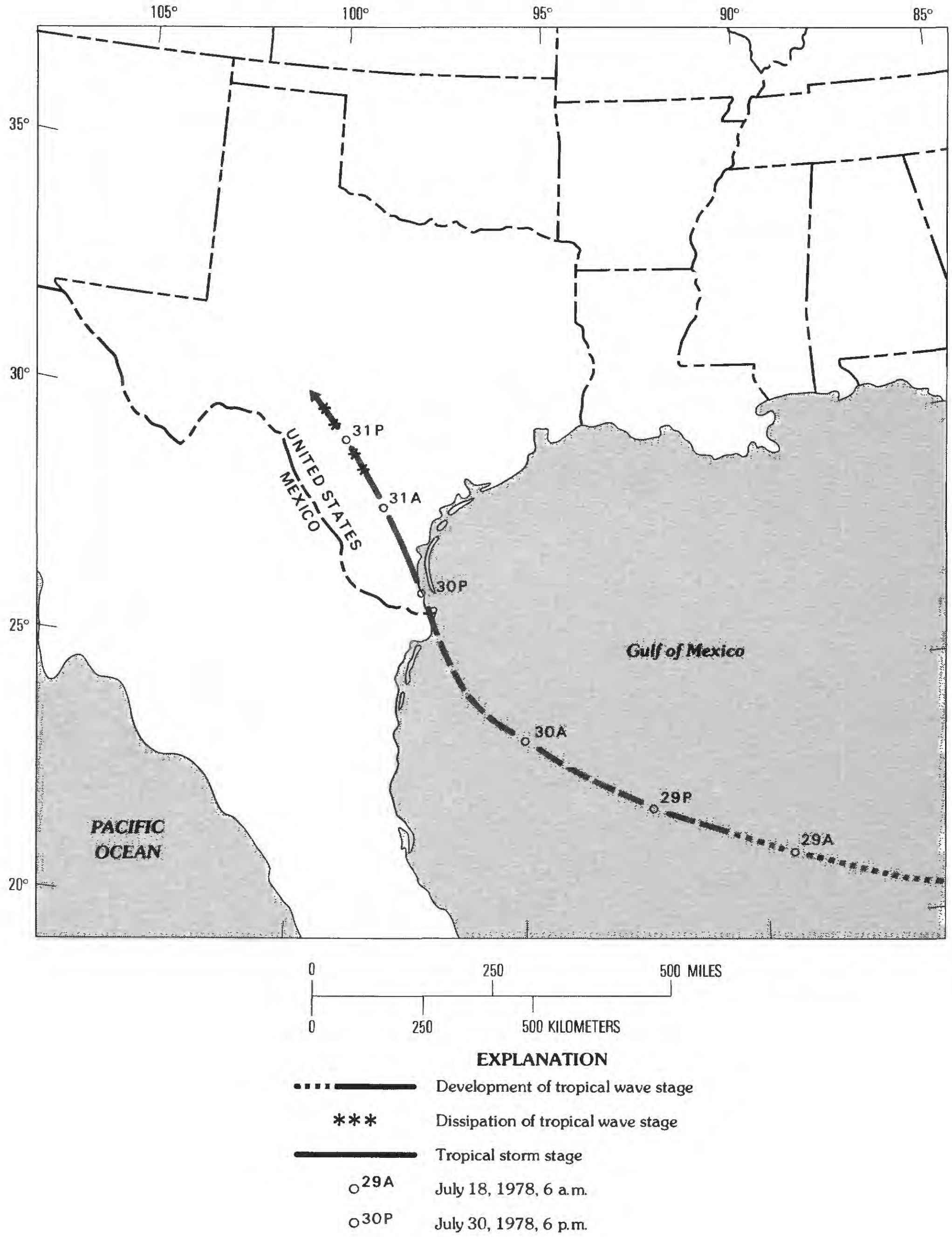
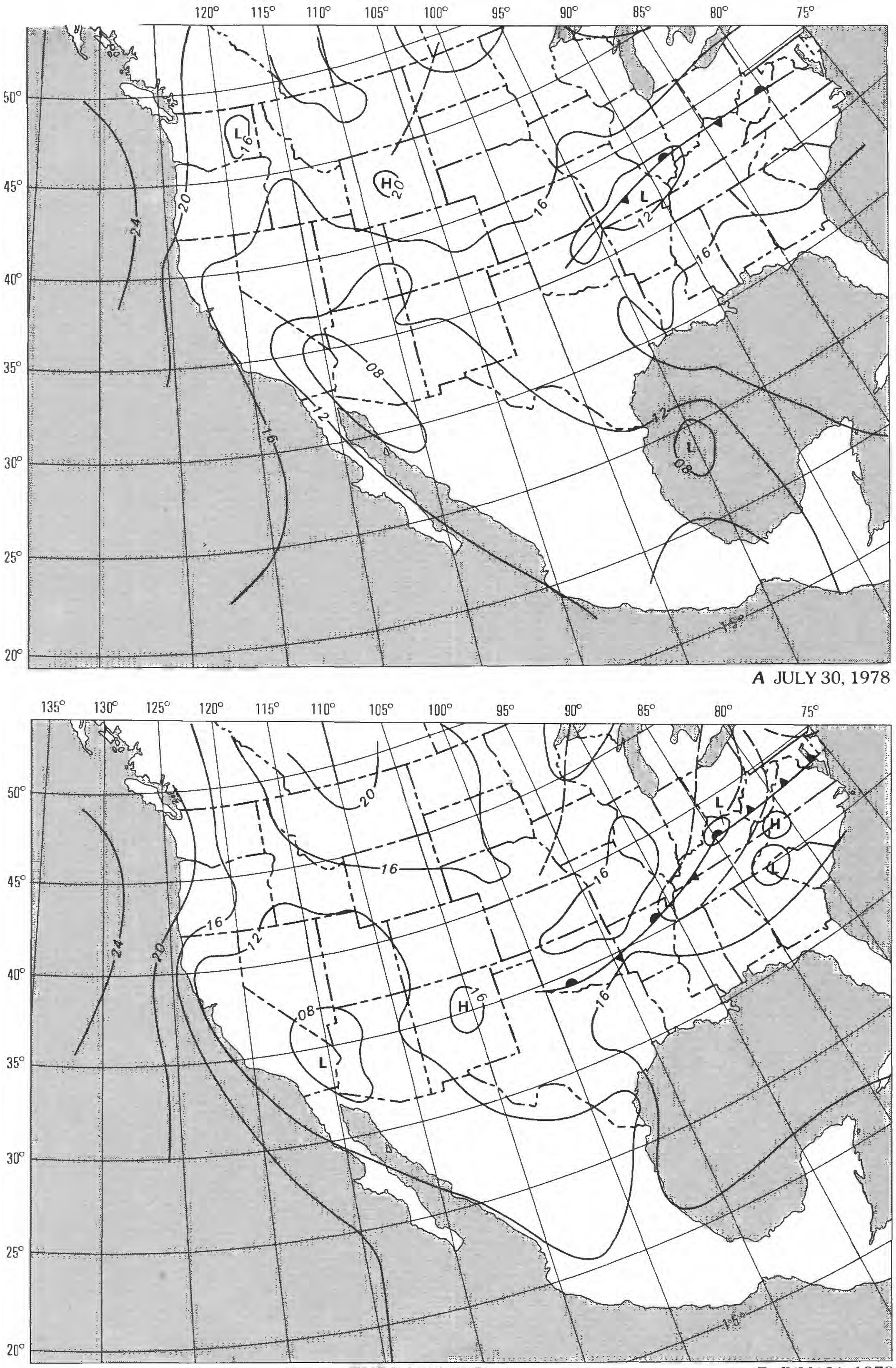


FIGURE 3.—Track of Amelia.

FIGURE 4(facing page).—Surface weather at 0600 c.s.t. *A*, July 30, 1978; *B*, July 31, 1978.



EXPLANATION

Cold front

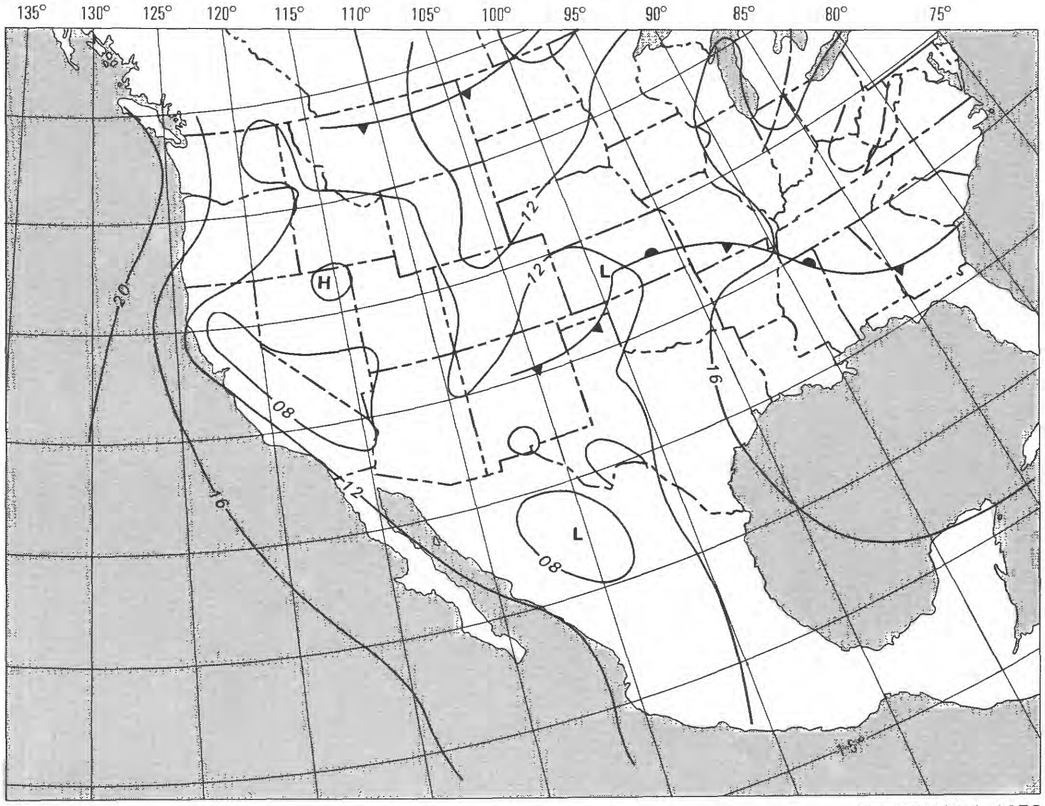
Warm front

Stationary front

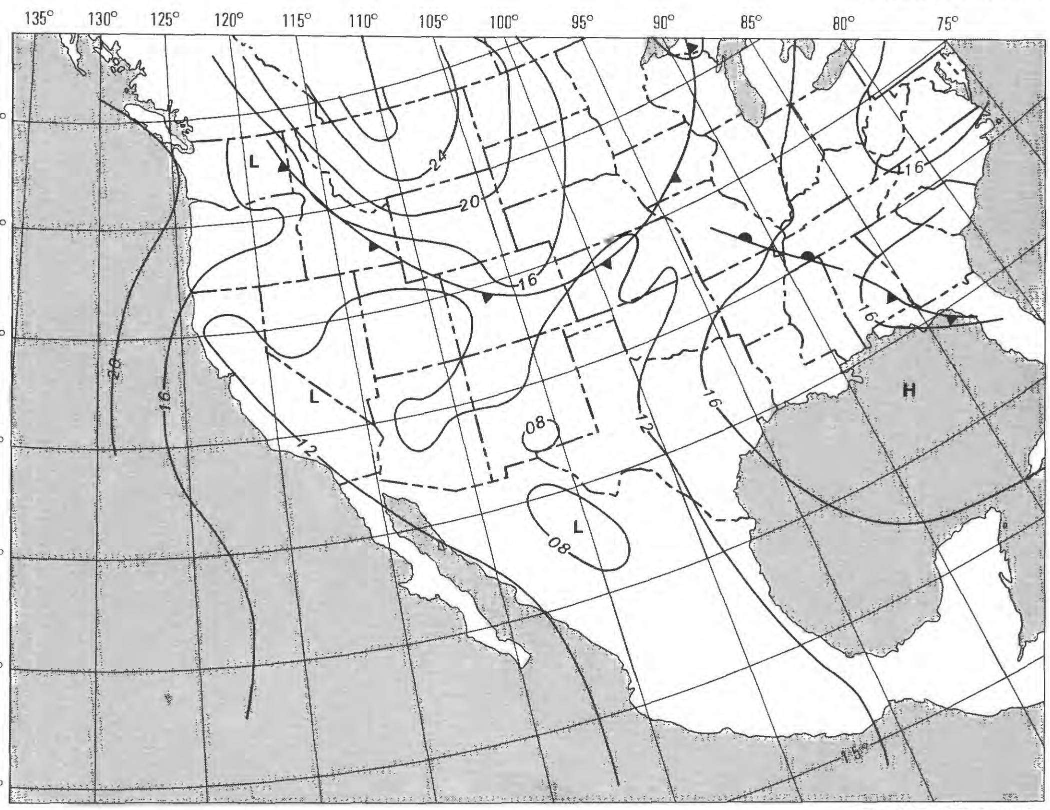
—08— Isobars. 08 stands for 1008 millibars, 12 stands for 1012 millibars

H Center of high pressure

L Center of low pressure



C AUGUST 1, 1978



D AUGUST 2, 1978

FIGURE 4.—Surface weather at 0600 c.s.t. *C*, August 1, 1978; *D*, August 2, 1978.

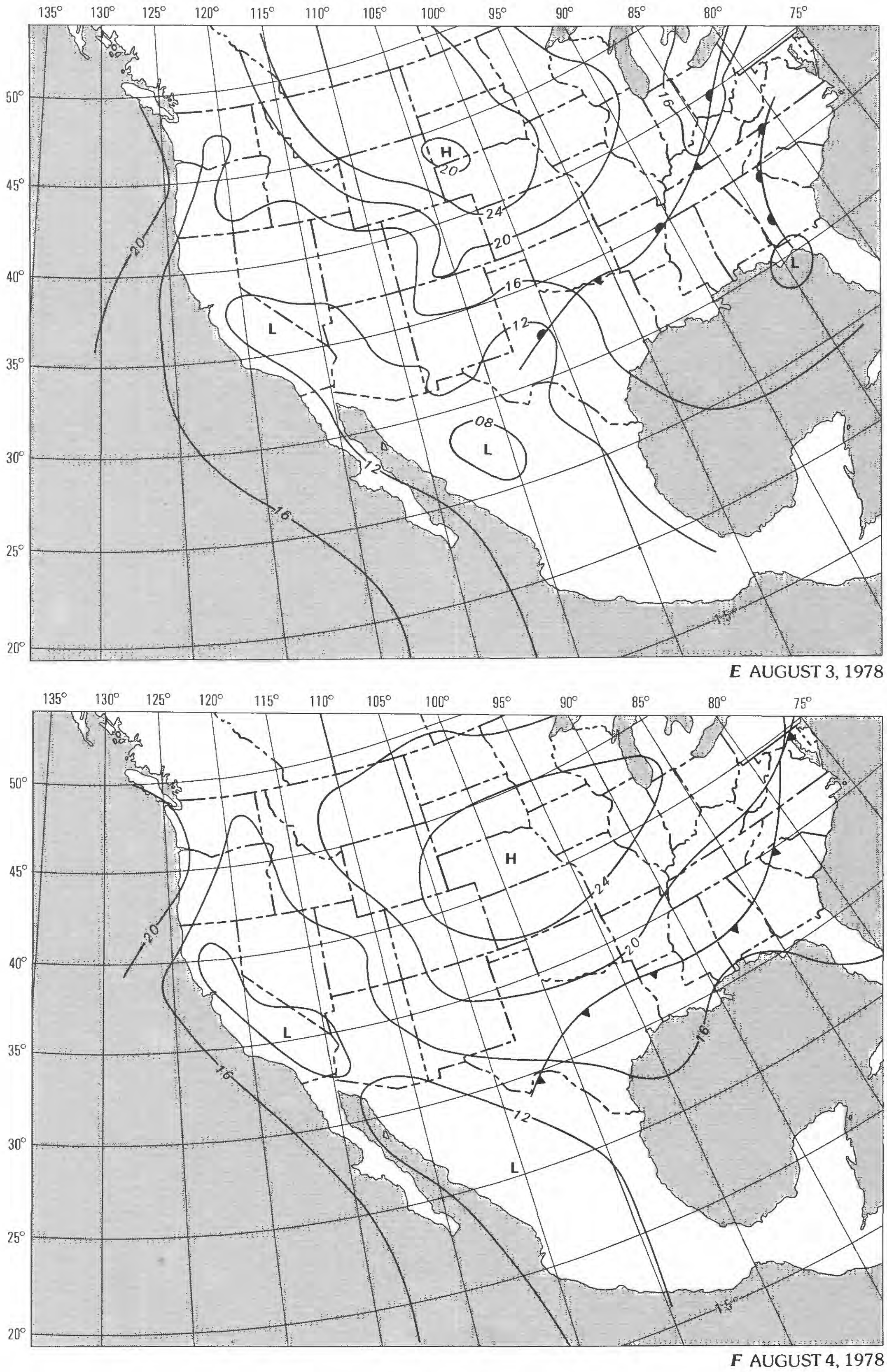


FIGURE 4.—Surface weather at 0600 c.s.t. *E*, August 3, 1978; *F*, August 4, 1978.

The evolution of the 500–mb circulation pattern from July 30–August 4 is shown in figures 5A–F. It was characterized by flat contour gradient and very light southerly wind during the entire storm period. It was not until the morning of August 4 that the winds picked up over central Texas. At 0600 August 1 a vorticity center (fig. 5C, marked with X) with the central value greater than $8x10^{-5}s^{-1}$ was located over northern Mexico just south of Del Rio, Texas. This vorticity center later migrated northward through the hill country and was over north-central Texas by the morning of August 3 (not shown). This vorticity center, combined with the remnants of Amelia and strong northward flow of moisture, all played a role in the extreme precipitation.

The evolution of dewpoint temperatures at Corpus Christi, San Antonio, and Abilene from July 31 to August 4, adjusted to 1,000–mb level for easy comparison, is shown in figure 6. A common measure of moisture used in many hydrometeorological studies is the persisting 12-hour 1,000–mb dewpoint. The surface dewpoints at observing stations are reduced to 1,000 mb adjusting the observed values at the moist adiabatic lapse rate. The persisting 12-hour 1,000–mb dewpoint then is the value that has been equaled or exceeded for a time interval of 12 consecutive hours. Studies have been conducted to determine smoothed regional and monthly values of this measurement of moisture (Environmental Science Services Administration, 1968). These values for Texas in late July and early August vary from just over 78°F (degrees Fahrenheit) near the coast to 58°F at Abilene. At Corpus Christi from the early afternoon of July 31 to midday of August 4, the dewpoint temperature was within a few degrees of this climatological extreme. In fact, the previous record was just slightly exceeded during the night of July 31–August 1 when the dewpoint temperature stayed at 79°F. At San Antonio and Abilene, the departures from the climatological extremes were slightly greater than at Corpus Christi. At San Antonio it was about 6°F below. Early in the period the dewpoint at Abilene was considerably below the extremes. It continued to increase as the moist air moved northward, and by the evening of August 3, was within about 9°F of the climatological extremes.

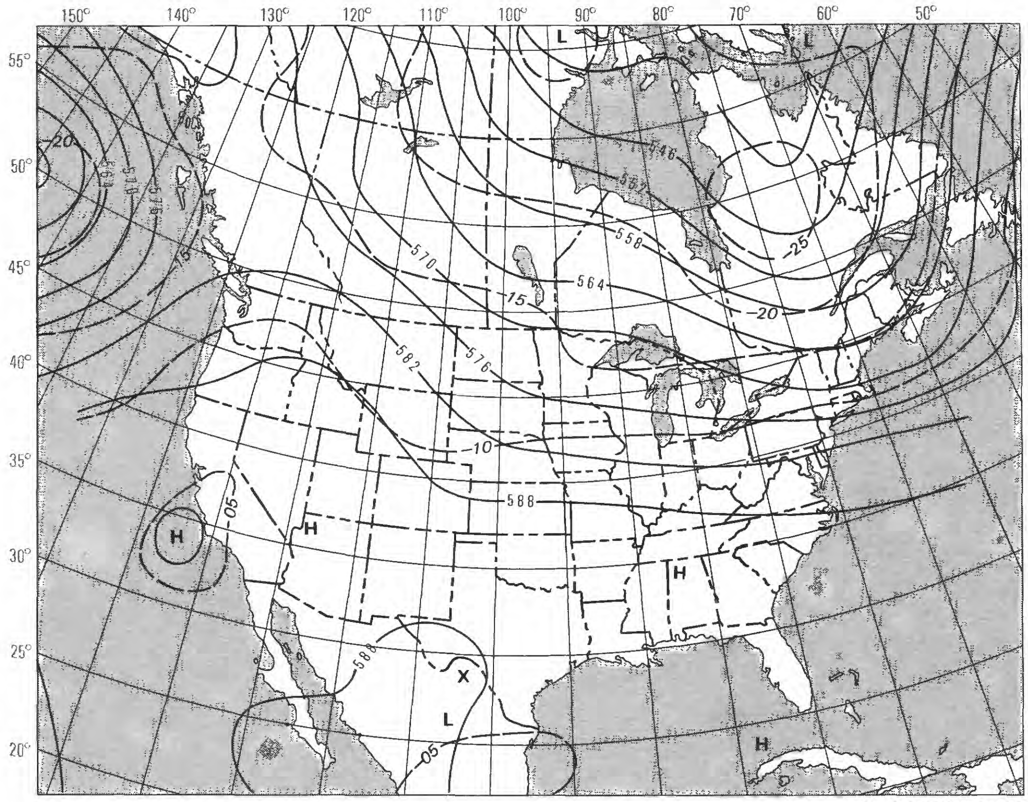
General comparison can also be made between dewpoint temperatures in figure 6 and the August mean dewpoint temperatures, also adjusted to 1,000 mb, which was 74°F at Corpus Christi, 70°F at San Antonio, and 67°F at Abilene (Environmental Science Services Administration, 1968). The observed dewpoints were considerably higher than the climatic values at Corpus Christi from the evening of July 31 through the morning of August 4 and also at Abilene from the afternoon of August 2 through the morning of August 4. This high moisture content was not limited to the surface level. The evolution of precipitable water from the surface to 500 mb in Texas and vicinity is shown in figure 7. High precipitable water content of 1.50 in. or more already covered coastal and southern Texas by the morning of July 31. By the morning of August 1, the southeastern two-thirds of Texas had precipitable water in excess of 1.50 in. By 0600 August 2, the area with precipitable water greater than 1.50 in. covered central Texas, while there was a reduction of precipitable water in other regions.

The rawinsonde station closest to the precipitation center in the north-central Texas region of the big country is located at Stephenville, approximately 75 mi east-southeast of Albany. The sounding at 0600 August 2 (at Stephenville) had total precipitable water of 1.72 in. from the surface to 500 mb. Precipitable water climatic statistics for Stephenville were not available for comparison. The nearest station with statistics available is at Fort Worth, 60 mi northeast of Stephenville. At Fort Worth, the mean monthly precipitable water for August was 1.41 in. with standard deviation of 0.30 in.

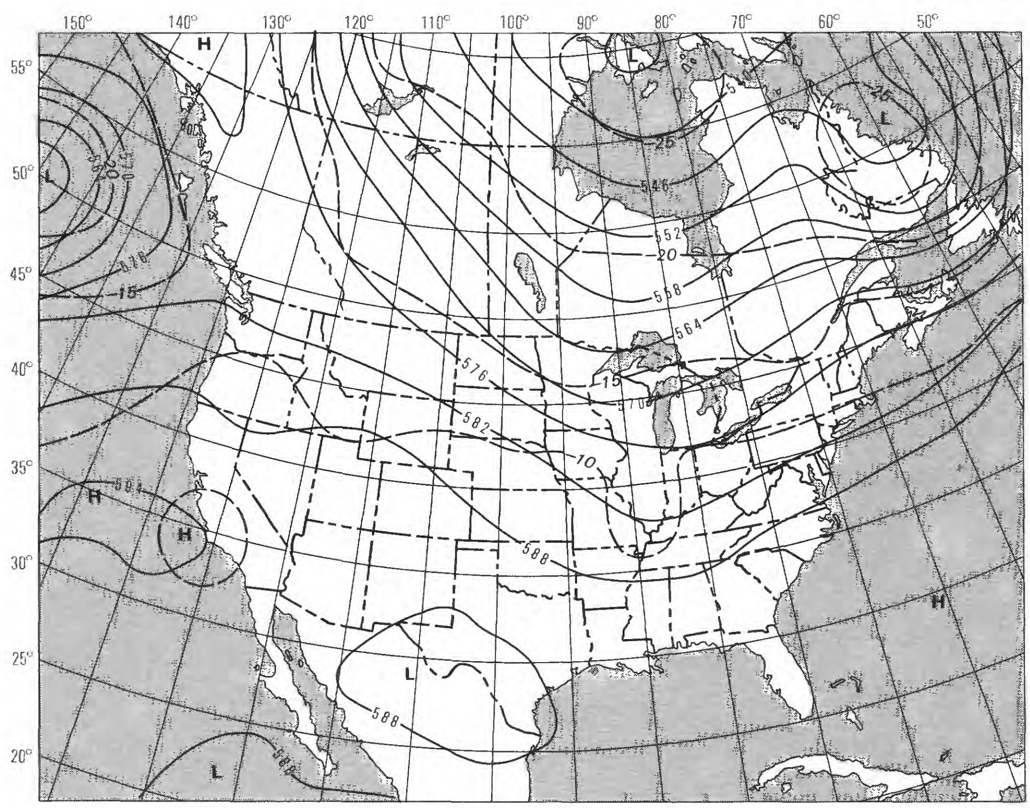
Temperature and trajectories at 850 mb for 0600 August 1 and August 2 are shown in figures 8A–B. For example, an air parcel arriving at 850 mb near Fort Worth during the morning of August 1 originated over the Gulf of Mexico about 40 mi east of Corpus Christi 24 h earlier. By inference, an air parcel arriving at 850 mb over the vicinity of Medina would have originated over a Gulf region further south. Both figures show that warm advection was prevalent and Gulf air was continuously being brought into central Texas.

The rawinsonde station near Victoria, Texas, is located upstream and to the southeast of the precipitation center of the hill country storm. Total precipitable water from the surface to 500 mb at Victoria was 1.97 in. at 0600 on both July 31 and August 1. For comparison, the corresponding mean August precipitable water at Victoria was 1.46 in. with standard deviation of 0.27 in. (Lott, 1976). The observed mean of semimonthly maxima of precipitable waters at 0600 for the last half of July was 1.83 in. with standard deviation of 0.18 in. and for the first half of August was 1.82 in. with standard deviation of 0.17 in. (Ho and Riedel, 1979). These climatic statistics, however, should be viewed with some caution because they were derived from a data sample of 7 years of data at Victoria (July 1966–December 1972) combined with 21 years of data at San Antonio (January 1946–June 1966). The maximum observed value for the period of record for the last half of July was 2.10 in. observed on July 22, 1972, and for August it was 2.26 in. observed on August 4, 1966. The observed precipitable water thus exceeds the average maximum values and were within 15 percent of the highest observed. Surface wind was southeasterly at 10 kn and the 500–mb wind over Victoria was southeasterly at 20 kn at 0600 both days. There is no doubt that very moist maritime air brought in by the prevailing southeasterly flow through midtroposphere was in place prior to the outbreak of the storm over the hill country during the night of July 31–August 1.

FIGURE 5(facing page).—500-mb analysis at 0600 c.s.t. *A*, July 30, 1978; *B*, July 31, 1978.



A JULY 30, 1978



EXPLANATION ***B*** JULY 31, 1978

L	Center of low pressure	——576——	Height contours in decameters. 576 stands for 5760 meters
H	Center of high pressure	— —*15*— —	Isotherms in degrees Celsius. −15 stands for −15° C

The heavy dashed line encloses **X**, a vorticity center with corticity greater than 8×10^{-5} sec.$^{-1}$

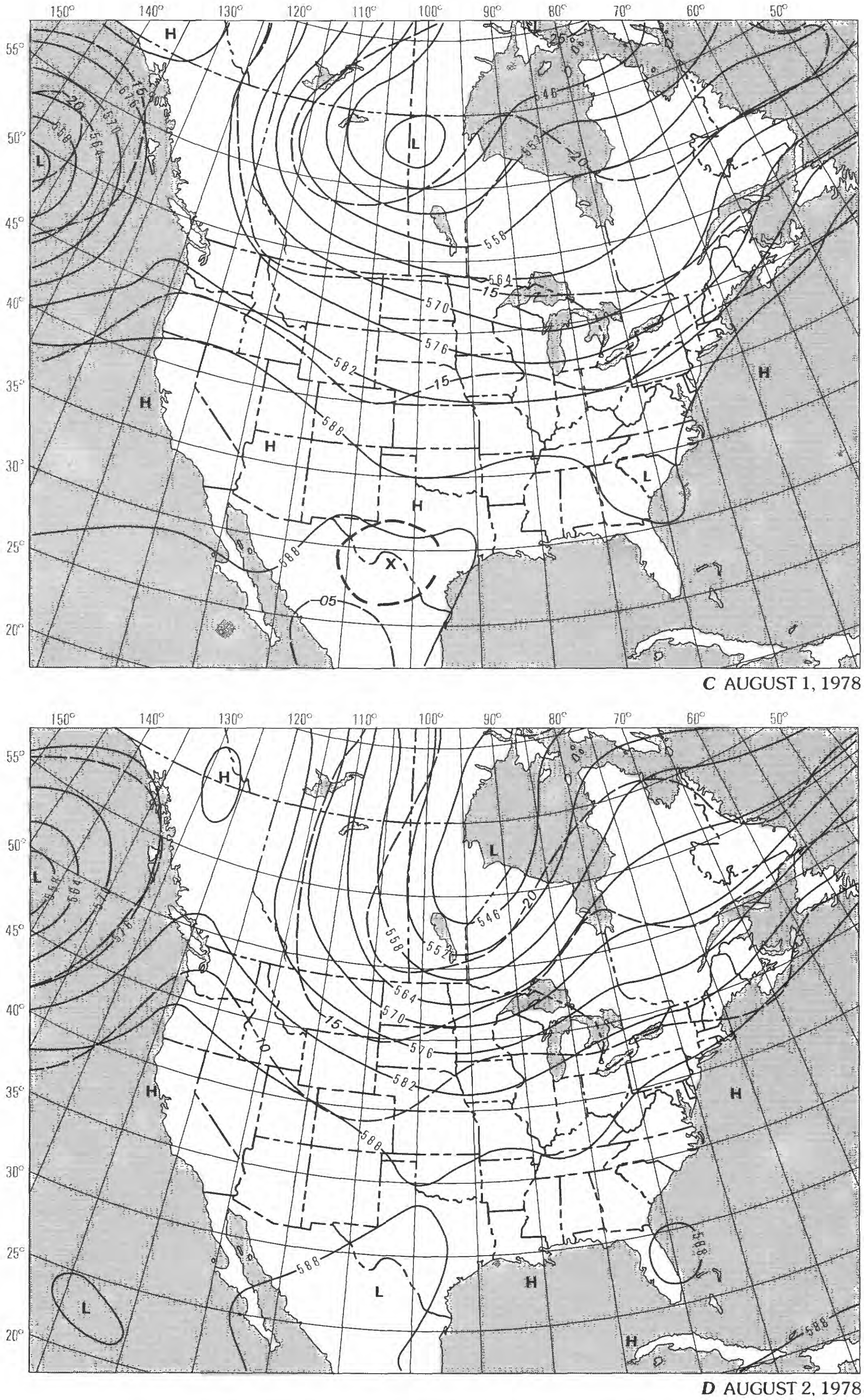
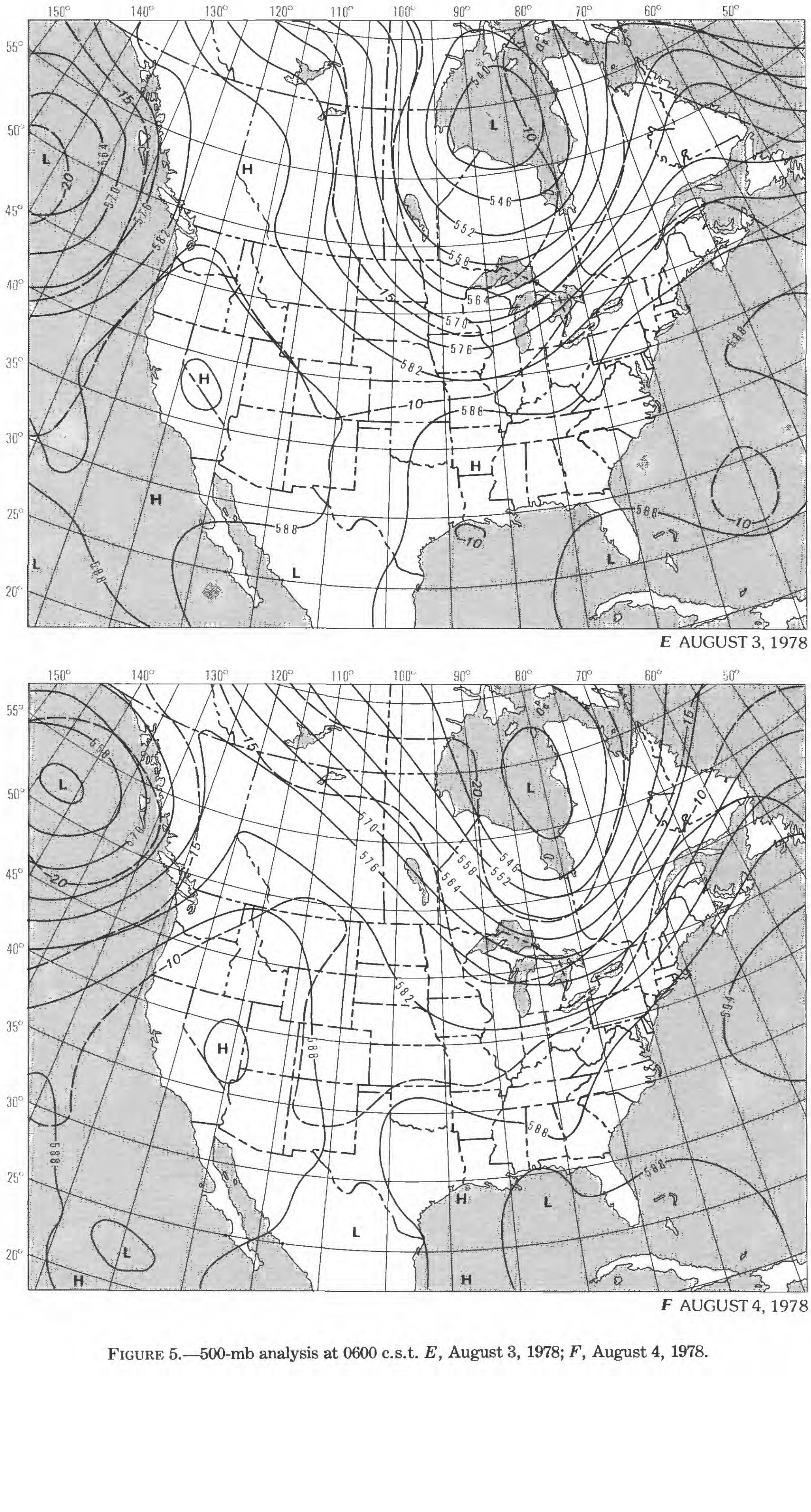


FIGURE 5.—500-mb analysis at 0600 c.s.t. *C*, August 1, 1978; *D*, August 2, 1978.



E AUGUST 3, 1978

F AUGUST 4, 1978

FIGURE 5.—500-mb analysis at 0600 c.s.t. *E*, August 3, 1978; *F*, August 4, 1978.

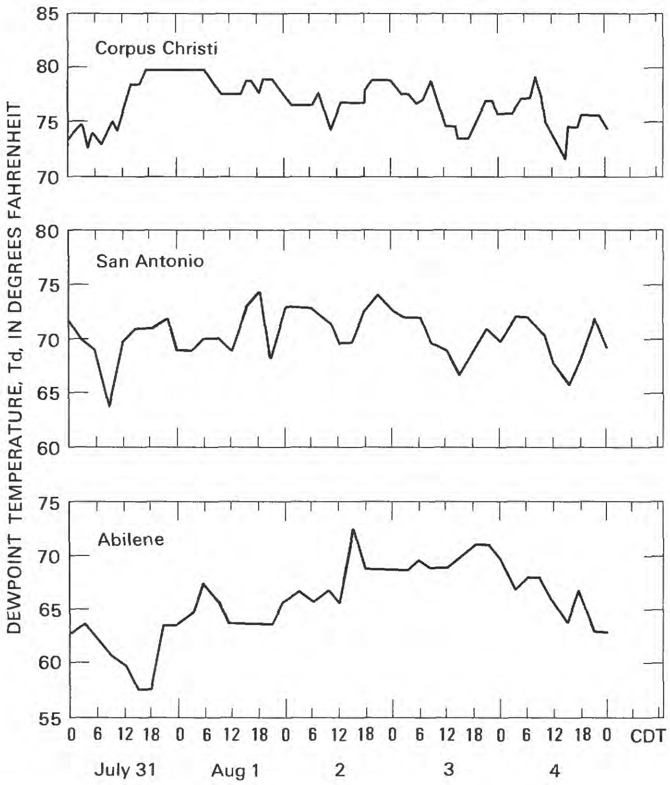


FIGURE 6.—Evolution of 1000-mb dewpoint temperature at Corpus Christi, San Antonio, and Abilene from July 31 to August 4, 1978.

Synoptic scale rising (sinking) motion provides an environment favorable (unfavorable) to the development of mesoscale convective systems. Floods resulting from convective storms that produce heavy rainfall are most unlikely to occur in an environment of strong synoptic scale subsidence and sinking motion. This is an example of the control exerted by the synoptic scale on smaller scale events. The 12-hour net vertical displacement for air parcels reaching 700 mb at 0600 and 1800 was positive (upward) over central Texas during July 31–August 5. The only brief interlude was 12 hours ending at 0600 August 2, when the net vertical displacement was downward over north-central Texas. This was at a time before there was significant weather over north-central Texas. This subsidence field in effect prevented moist low-level air from rising, thus building up the potential for intense convective activity later on. The net vertical displacement (north-central Texas) reverted to positive again after the morning of August 2 and prior to the storm outbreak in Albany and vicinity. This rising motion persisted and intensified during the evening of August 3 and throughout the morning of August 4.

The stability prognosis indicated a K Index greater than 32 over the hill country during the morning of July 31, increasing to more than 40 in the evening. The K Index is a measure of the air-mass moisture content and static stability, and is given by:

$$K=(T_{850}-T_{500})+T_{d},850-(T_{700}-T_{d},700)$$

where T and T_d are temperature and dew point, respectively, in degrees Celsius; and the subscripts denote pressure level, in millibars. The larger the K Index of the air mass, the more unstable the air mass is. In general, a K Index greater than 35 is associated with numerous thunderstorms; an index smaller than 20 with no thunderstorms.

The 12-hour net vertical displacement of an air parcel arriving at 700–mb level over southeastern Texas in the evening of July 31 was 20 mb. This corresponded to a synoptic scale rising motion of 0.5+ cm/sec (centimeter per second). By itself, this was a moderate rising motion, but it was a relative maximum. Figure 9 shows these two parameters at 1800 July 31, just prior to the first rain event over the hill country. By Tuesday morning, the vorticity center formerly over Mexico had crossed the Texas border. The moisture envelope also reached as far north as the Balcones Escarpment, which runs from the Del Rio area to San Antonio and northeastward to Austin. This is an uplift zone where surface elevation rises some 800 ft in about 10 mi and marks the beginning of the rough terrain that froms the Edwards Plateau.

With the meteorological factors so favorable, convective storms developed and rain began to fall during the night of July 31–August 1 over the eastern part of the hill country through the San Antonio area. The rain continued during the morning, spreading northwestward. Total rainfall amounted to 4–5 in. which primed the area where much heavier rain would fall later. The Manatt Ranch, about 11 mi northwest of Medina on the upper tributary of Little Rocky Creek, which is tributary to the Medina River, had 5 in. during this first burst. The city of Kerrville, 18 mi north-by-east from Medina, received 6 in. during this initial rain.

Convective activity over the hill country diminished sharply during the afternoon of Tuesday, August 1. By Tuesday evening, however, convection intensified over southern Texas and slowly spread northward toward the hill country. By 2200, the first light rainfall moved into the Medina and Guadalupe River watersheds. Satellite pictures revealed that the large area of convection in south-central Texas had diminished partially in late evening. But by midnight Tuesday, new cells had developed within the decaying area, about 40–50 mi west of San Antonio. These new cells grew rapidly in size and intensity and moved very slowly through Bandera, Kerr, Gillespie, and Kendall Counties, producing torrential rain in the early morning hours of Wednesday, August 2. The rains diminished later in the morning, but Manatt Ranch received over 31 in. of rain during this second major rainfall burst. The city of Medina received more than 24 in. Headwater regions of the Guadalupe River centered around Kerrville received over 11 in.

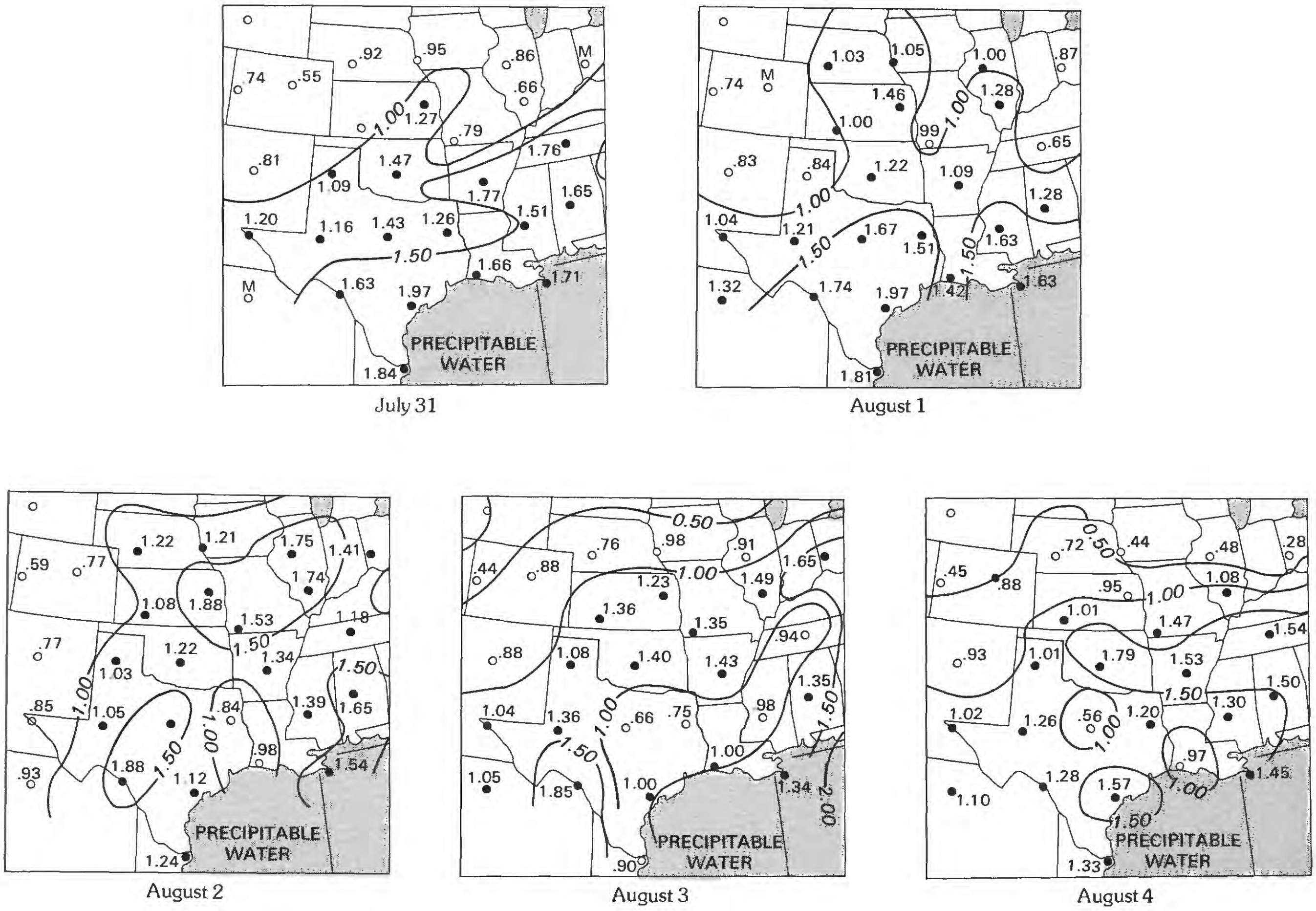
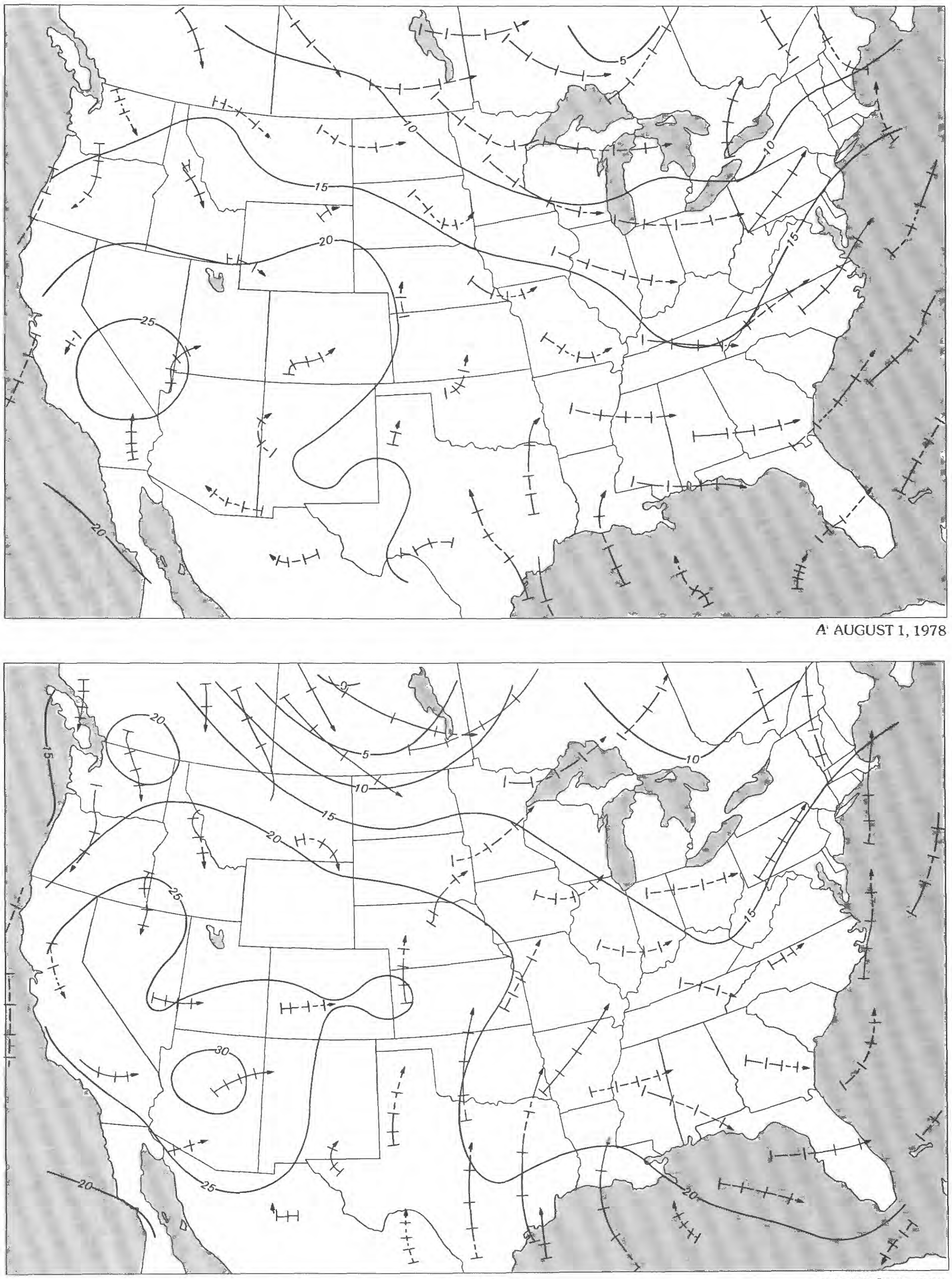


FIGURE 7.—Evolution of precipitable water from surface to 500-mb at 0600 c.s.t., July 31 to August 4, 1978.

Rain continued during much of Wednesday at a slightly reduced rate and over a more northern region—north and northwest of the upper Guadalupe and Medina basins, but by about 1900, scattered convective showers started further south in northwestern Bandera County. Around 2230, satellite IR (infrared) imagery showed that the cells started to intensify and expand rapidly, spreading northeastward over central Kerr County, western Gillespie and southeastern Mason Counties. The precipitation center, with rainfall exceeding 20 in., was located in west-central Gillespie County. Rainfall was heaviest from just prior to midnight to the early morning of Thursday, August 3. Manatt Ranch was again in the path of the storm and had an additional 12 in. of rain during this third and last major rain burst over the hill country. Therefore, in 3 days ending August 3, the Manatt Ranch had a total rainfall of more than 48 in. This set a new United States record for extreme point rainfall in 72 hours although most of the rain at the Manatt Ranch fell within 52 hours. Hunt 10W recorded 7.5 in. during this burst, while nearby Ingram received nearly 16 in. Medina, which recorded 24 in. of rain the previous night, had only 0.6 in. during the night of August 2–3, revealing the northward progression of the storms. The areal rainfall distribution of the second major burst during August 2 and the third major burst during August 3 over the hill country is shown in figure 10.

The National Weather Service operates an S-band WSR–57 weather radar at Hondo, about 45 mi south-southeast from the maximum precipitation area centered in a grid square 30 nmi on a side (900 nmi^2) enclosing the Manatt Ranch. The accumulated rainfall from 1830 August 1 to 0730 August 2, conservatively estimated from radar Video Integrator Processor (VIP) levels for this grid square, was about 11 in. The same conservative estimate from 1850 August 2 to 0530 August 3 was about 20 in. (Moore and Smith, 1979). This suggested that areal average rainfall was much heavier on the second night than on the first night. A more detailed analysis as represented by figure 10, indicated that the center (periphery) of the maximum storm rainfall was indeed over the ranch on the first (second) night, with a major portion of area of heaviest rain outside (inside) of the grid square on the first (second) night. This may partly explain the apparent difference between the time of maximum point

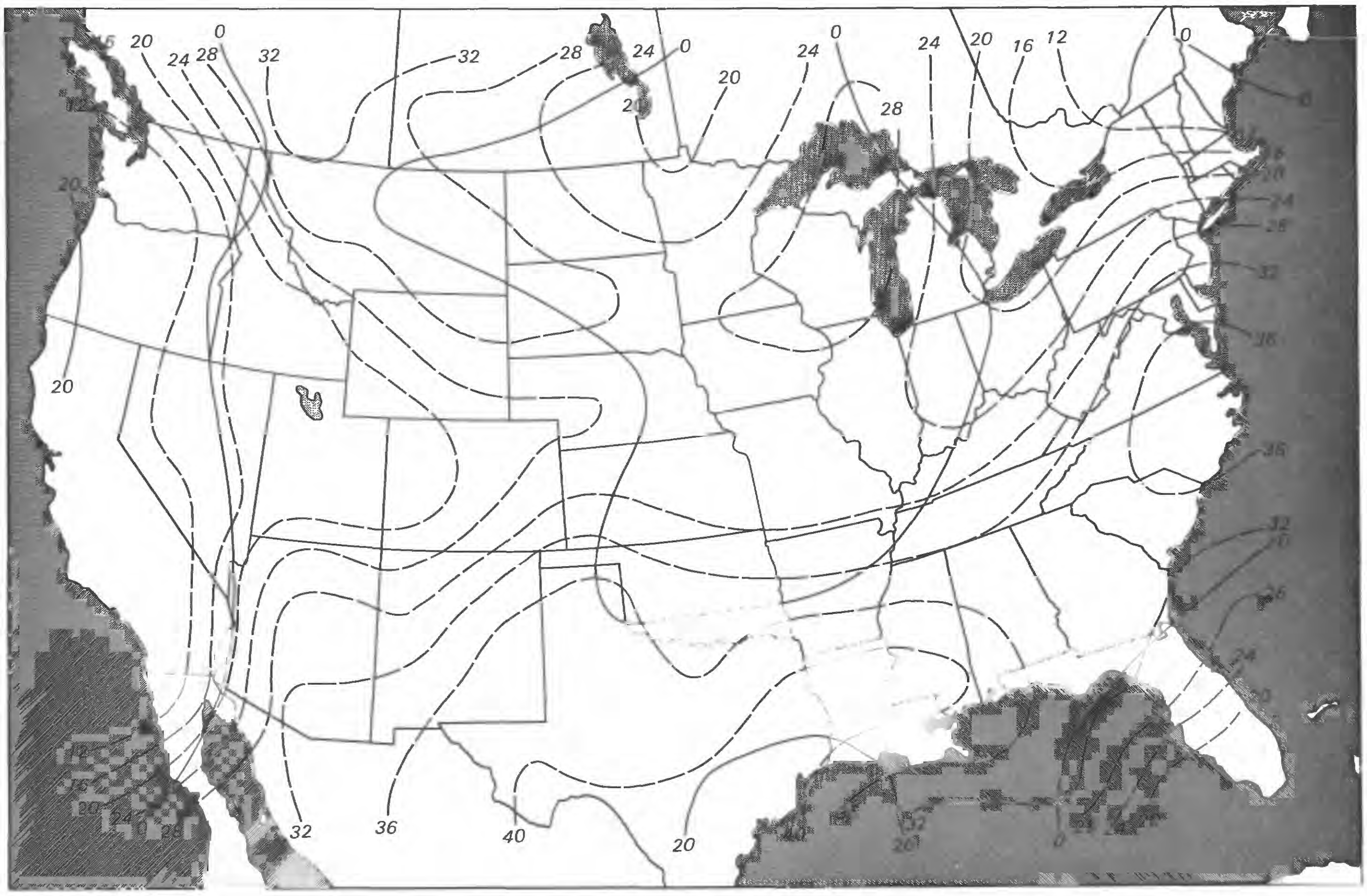


EXPLANATION

—25— 850-mb temperature, in degrees Celsius

├┤┤┤► 24-hour trajectories, in 6-hour increments

FIGURE 8.—850-mb temperature and 24-h trajectory valid at 0600 c.s.t. *A*, August 1, 1978; *B*, August 2, 1978.



EXPLANATION

0 ——— 0 Net vertical displacement of air parcels, in mb/12-hours

12 — — 12 K index, in degrees Celsius (°C)

FIGURE 9.—700-mb, 12-hour net vertical displacement and K Index valid at 1800 c.s.t., July 31, 1978.

rainfall at Manatt Ranch (31 in. the night of August 1–2) and the time of maximum areal rainfall estimated by radar (the night of August 2–3).

The prevailing south or southeasterly flow over the Gulf Coast and central Texas persisted through August 4. By the morning of August 1, the warm maritime air mass was advancing into north-central Texas. A further increase in dewpoint occurred at Abilene during August 2–3 (fig. 6), indicating strong local moisture convergence. An area of strong vorticity ($>8\times10^{-5}s^{-1}$) was now situated over north-central Texas. The surface analysis showed that a cold front, which earlier had extended from Idaho and Colorado, through Kansas eastwards, had now passed the panhandle area. Ahead of this front, a trough formed briefly and the pressure dropped noticeably along the trough. By 2111 August 3, the cold front had reached north-central Texas and briefly became stationary, but started to move southward again as a cold front by the early morning of August 4.

Strong convection due to the interaction between this front-trough system and the maritime air mass coming from the south produced heavy rain in Haskell, Throckmorton, and Shackelford Counties in the big country (north-central Texas) beginning during the early morning of August 3. Rain was most intense during the evening and night of August 3–4. Major portions of these three counties received amounts greater than 10 in. in 2 days. Some areas of Shackelford County had more than 25 in., with a maximum of 32.5 in. 3 mi west of Albany.

Albany is a ranch town of 2,000 people situated on the north bank of a tributary to the Brazos River. Shackelford County, like most of the big country that surrounds Abilene, is considerably flatter and drier than the hill country. It is mostly an area of wide open space devoted to large-scale farming and ranching. The terrain is not particularly hilly, elevations range from 1,300 to 1,900 ft above NGVD. Moist tropical air masses occasionally penetrate this deep into

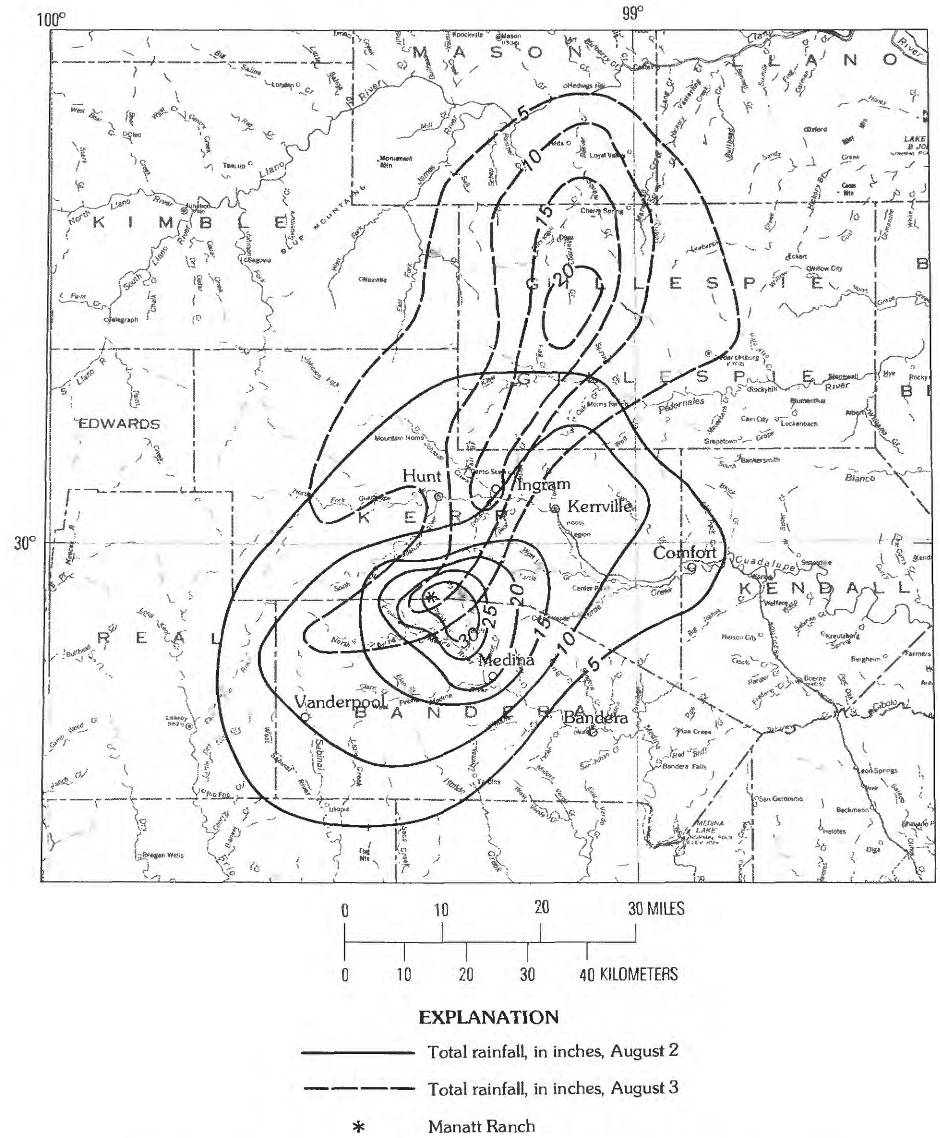


FIGURE 10.—Isohyetal analysis for south-central Texas, August 2–3, 1978.

Texas, but excessive rainfall and flash flooding are somewhat less common and usually less severe than in the hill country or coastal region.

The NOAA Geostationary Operational Environmental Satellite (GOES) is constantly looking at the earth's cloud pattern from 22,500 mi in space in an earth synchronous orbit. The GOES image was very valuable during this meteorological event to reveal that high-level outflow persisted even after the surface low had vanished. However, quantitative precipitation estimates using the Schofield-Oliver technique (Schofield and Oliver, 1977) were found to be considerably lower than the observed amount. The original technique was designed for short-lived isolated thunderstorms with large updrafts and rapidly expanding anvils. Long-lived, slow-moving large-area thunderstorm systems such as those that occurred over the Texas hill country during August 2–3 or over the Texas big country during August 3–4, are associated with strong, steady-state updrafts and outflows. The subsidence outside the rainshaft causes the anvil to erode at its outer edge as fast as new cloud material arrives at the tops of the storm. Heavy rain could fall continuously without any visible sign of anvil expansion. Also a slow-moving thunderstorm cluster could remain in the same area for 3 or more hours, as did the thunderstorm systems that yielded torrential rain over the hill country during August 1–3 and over the big country during August 3–4.

As a result, large areas become greatly saturated and there is no longer any dry air entrainment into the sides of individual updrafts in the center of the cluster. Entrainment of dry air not only reduces the moisture content of the

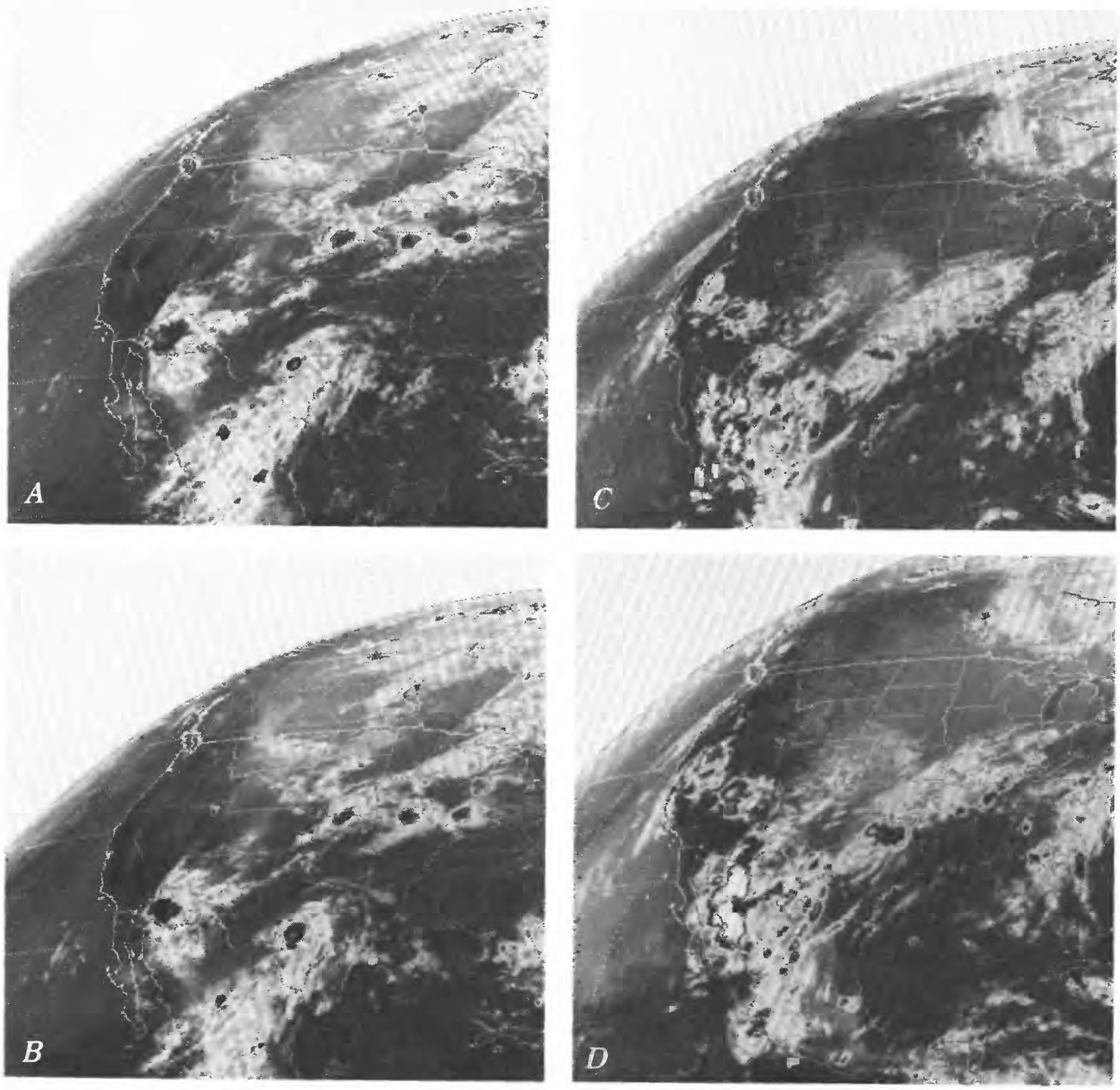


FIGURE 11.—GOES infrared imagery. *A*, 0100 c.s.t., August 2, 1978; *B*, 0200 c.s.t., August 2, 1978; *C*, 1930 c.s.t., August 3, 1978; *D*, 2030 c.s.t., August 3, 1978.

rising column but also tends to produce a lapse rate of temperature for the saturated parcel greater than the saturated adiabatic lapse rate to reduce the buoyancy forces and inhibit further cumulus growth. Without this inhibitive factor, convective cells in the central part of a storm system would be able to produce much more rain than isolated thunderstorms.

Schofield and Oliver (1980) proposed an improved rainfall estimation procedure based mainly on the experience of applying rainfall estimation technique to the storms over central Texas under discussion. Using satellite IR imagery and taking into account the saturated environment factor, they estimated a rainfall of 11.05 in. at 4.5 mi northwest of

Medina during the 6½ hours ending 0400 August 2. However, this still represented an underestimate of about 4.5 in. The reason for the difference is that by its nature, GOES IR rainfall estimation is approximately an 80-km^2 (square kilometer) areal average, while surface observation can be a point maximum.

Klazura (1971) measured drop-size distributions in warm cumuli over southeast Texas. He confirmed the expectation that the higher the cloud builds, the broader the droplet-size spectrum and the larger the concentration of large drops; this in turn leads to a highly efficient collision-coalescence process for rain formation. The enhanced GOES IR images at 0100 and 0200 August 2 and again at 1930 and 2030 August 3 are shown in figures 11A–D. These were time periods when each storm had rapid development. The growth of the cumulonimubus towers was evident. At 2030 August 3 the storm over north-central Texas had a cloudtop temperature of -80°C (degrees Celsius), which translated to a cloudtop height exceeding 55,000 ft. Comparable heights were reached by cloud towers associated with the hill country storm. The radar summary issued by the National Weather Service indicated that an echo top of 40,000 ft was observed over the hill country at 0530 August 4. The existence of high cloud tops and high echo tops suggested high precipitation efficiencies. The difference in cloud heights between those reported by radar summary and those sensed by satellite radiometer in this instance is, of course, due mainly to the difference in time of observation. However, even if observation time is the same for the same cloud, radar summary usually reports a lower height than that reported by satellite observation. This is because radar detects large precipitation-size particles such as rain drops or graupels but cannot detect much smaller, supercooled cloud droplets and small ice crystals near the cloud top where temperatures are sensed by satellite IR radiometer.

The disastrous Texas floods of August 1–4, could be recognized as the result of two separate major storms of different origin and distinguishable time and geographical context but with some shared features. The presence of very moist maritime air that originated in the Gulf of Mexico and the presence of positive vorticity advection preceded the outbreak of both storms. In the case of the storm of August 1–3 over the hill country, moist Gulf air mass initially was brought into south-central Texas by the cyclonic circulation of the remnant of tropical storm Amelia. Considerable rain fell over the Texas Coastal Plains and over part of the hill country during the night of July 31–August 1. The very unstable atmospheric structure with high K Index remained over south-central Texas as well as the continuation of warm air advection after filling of Amelia. There was an established pattern throughout the duration of the storm that convective activity would subside during the day but would reinvigorate as evening approached. During the nights of both August 1–2 and August 2–3, thunderstorms developed over the southern part of the hill country. Satellite IR pictures showed that as the cells grew, merged, and then slowly moved northward against the Balcones Escarpment, orographic lifting enhanced the release of convective instability thus increasing rainfall intensity. Major contributions to rainfall for the hill country storm were observed on these two nights.

The storm of August 3–4 over the big country resulted from the interaction of a cold front with the maritime air mass that penetrated deeply into north-central Texas. This deep penetration of maritime air was the result of the persistent southeasterly flow field through a deep layer for at least 2 days prior to the storm outbreak over Albany and vicinity during the early morning hours of August 3. Orography was not a factor for the August 3–4 storm; rainfall covered a larger area than that of the hill country storm. The major contribution of the storm rainfall was in a single major rainburst during the night of August 3–4.

Selected mass rainfall curves at locations near each precipitation center are shown in figure 12. Rainfall curves for Hunt 10W and Stamford 2 were derived from recording gages, other curves were constructed from bucket survey data with limited time resolution. It is clear, however, that the rainfall rates were intense. For example at the northern center, a total amount of 32.5 in. fell at Albany 3W, but 23 in. of the total fell during an 8-hour period ending at 0200 August 4. Isohyetal analyses of the storm centered near Medina is shown in figure 13A and for the storm centered near Albany in figure 13B.

Preliminary depth-area-duration analysis of the hill country storm with a maximum centered near Medina is shown in figure 14A and for the big country storm with a maximum centered near Albany is shown in figure 14B. A comparison with the areal rainfall of historic storms with those that occurred during the summer of 1978 over central Texas (Shipe and Riedel, 1976) is given in table 1.

It is evident from the depth-area-duration analyses that the storms of August 1978 were indeed extraordinary. Rainfall in the Medina storm established summer season records over 100-mi^2 areas for durations of 6, 12, and 48 hours and over 200-mi^2 areas for durations of 6 and 12 hours. The Albany storm was characterized by a record-setting 24-hour rainfall over 100-mi^2 and 200-mi^2 areas. It should be noted, however, that the period of comparison in table 1 covers June to August only; the September 8–10, 1921, storm centered in Thrall, Texas, for example, was not included. Comparisons between the extreme point rainfalls in these recent storms and corresponding 100-year return period amounts (Hershfield, 1961; Miller, 1964) are shown in table 2. The rare intensity of the storms is apparent.

Comparisons between the maximum at Manatt Ranch with the most extreme point rains known in the United States for 6- to 72-hour durations are shown in table 3. The last line lists the world record rains for 1, 2, and 3 days observed at Cilaos, La Reunion, an island east of Madagascar

TABLE 1.—*Comparison of maximum storm rainfalls with that of historical storms over central Texas in the summer season.*

Area (mi^2)	Duration (hours)	Greatest on record (central Texas)		Depth (in.)	
		In.	Date	Medina center (Aug. 1-3, 1978)	Albany center (Aug. 2-4, 1978)
100	6	12.7	(June 27-July 4, 1936)	15.4*	8.7
	12	16.5	(June 28-30, 1940)	20.0*	16.0
	24	25.8	(June 30-July 2, 1932)	24.0	27.3*
	48	30.0	(June 27-July 1, 1899)	31.6*	30.0
100	6	12.2	(June 27-July 4, 1936)	13.8*	8.2
	12	15.6	(June 28-30, 1940)	17.7*	15.0
	24	23.8	(June 30-July 2, 1934)	21.5	25.5*
	48	29.5	(June 27-July 1, 1899)	28.5	28.1
1,000	6	10.9	(June 27-July 4, 1936)	9.1	6.4
	12	12.3	(June 27-July 4, 1936)	12.0	11.5
	24	21.1	(June 27-July 1, 1899)	15.0	19.6
	48	27.1	(June 27-July 1, 1899)	20.3	21.7

* Denotes record-setting event in the summer season.

TABLE 2.—*Comparison between storm rainfalls and 100-yr amounts*

Location	100-year 24-hour rain (in.)	Storm 24-hour rain (in.)	100-year 3-day rain (in.)	Storm 3-day rain (in.)
Medina 11NW	9.05	30* (ending 0600 Aug. 2, 1978)	11.4	>48 (52 hours Aug. 1-3, 1978)

Location	100-year 24-hour rain (in.)	Storm 24-hour rain (in.)	100-year 2-day rain (in.)	Storm 2-day rain (in.)
Albany 3W	8.8	29.05 (Aug. 4, 1978)	10.0	30.25 (48 hours Aug. 3-4, 1978)

* Approximate.

TABLE 3.—*Comparison of extreme point rainfalls in the United States and the world.*

Storm	Duration (hours) Amount (in.)					
	6	12	18	24	48	72
Smethport, Pa. (July 17-18, 1942)	+30.8	34.3				
Thrall, Tex. (Sept. 8-10, 1921)			36.4	38.2	39.7	
Yankeetown, Fla. (Sept. 3-7, 1950)				38.7	43.1	45.2
Manatt Ranch (Aug. 1-3, 1978)						>48 (52 hours)
Cilaos, La Reunion (Mar. 15-18, 1952)				73.62	98.42	127.56

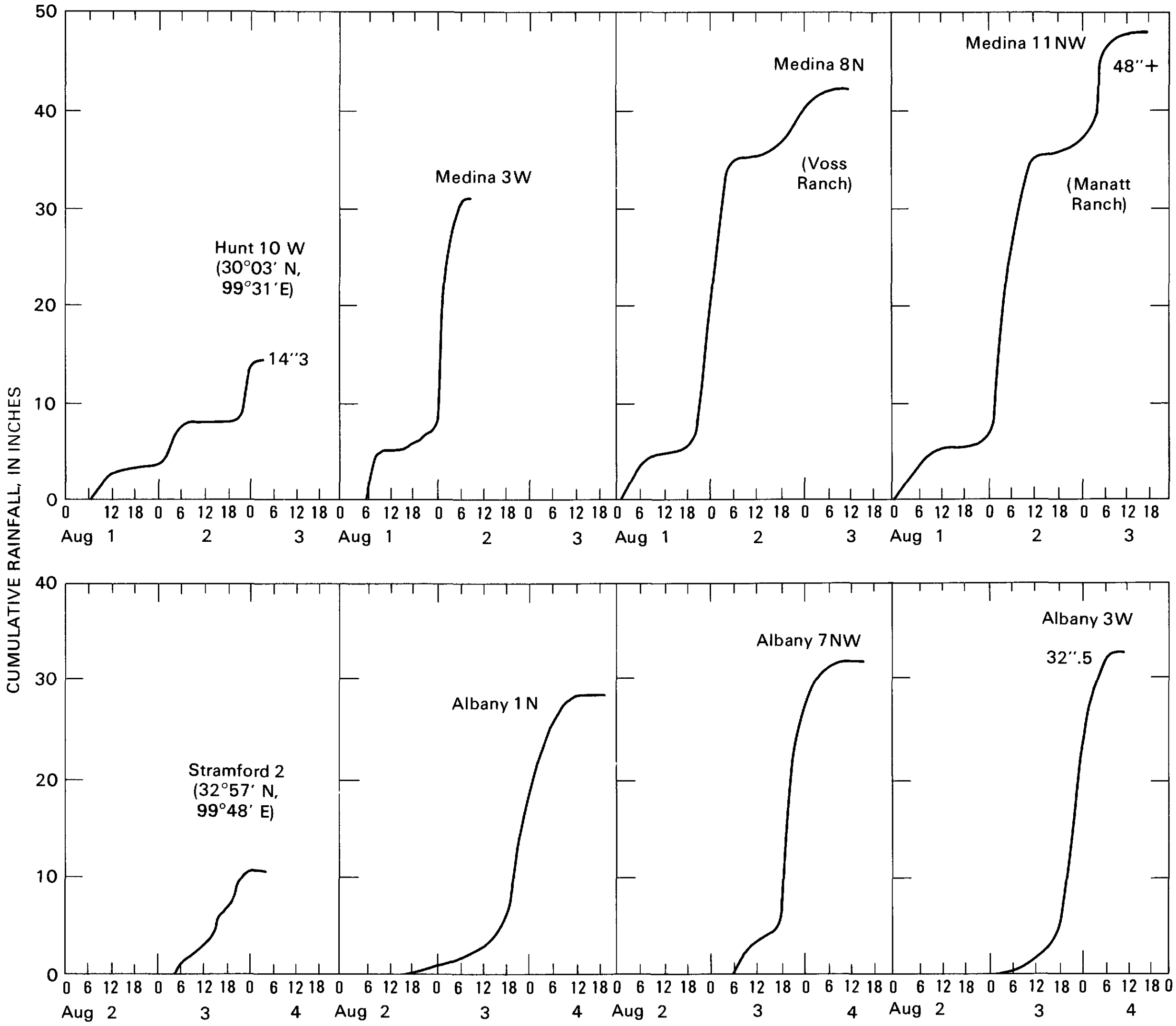


FIGURE 12.—Mass rainfall curves at selected rain gages, August 1–4, 1978.

in the Indian Ocean, where elevations rise to 10,000 ft in 10–15 mi from the shore (Paulhus, 1965).

Rainfall extremes set the very lowest limit to estimates of probable maximum precipitation (PMP). The record of more than 48 in. observed during August 1–3, 1978, 11 mi northwest of Medina in the hill country reached 95 percent of the all-season probable maximum precipitation (PMP) for 72 hours and 10 mi^2 at that location (Schreiner and Riedel, 1978) and will constitute important input in future PMP studies.

DESCRIPTION OF THE FLOODS

Flooding to some degree occurred in an area of approximately 25,000 mi^2 in parts of the Nueces, Guadalupe, Colorado, and Brazos River basins. A summary of flood stages and discharges for selected sites is given in table 4; the locations of the sites are shown in figure 1. The locations of discontinued streamgaging stations and miscellaneous discharge-measurement sites are given in table 5.

NUECES RIVER BASIN

During the early part of the storm on August 1, substantial rain fell on the headwaters of the Sabinal River, Hondo Creek, and Seco Creek in the Nueces River basin. The greatest 24-hour amount recorded by the National Weather Service in this basin was at Vanderpool in Bandera County, where a total of 11.53 in. fell in the 24-hour period ending at 0700 August 2. Sharp rises occurred on many streams, but flooding was minor.

TABLE 4.—*Summary of flood stages and discharges*

Map number	WRD station number	Stream and place of determination	Contributing drainage area (mi^2)	Period of known floods	Maximum flood previously known			Maximum during August 1978 flood			Recurrence interval (years)
					Date	Stage (feet)	Discharge (ft^3/s)	Date (1978)	Stage (feet)	Discharge (ft^3/s)	
		BRAZOS RIVER BASIN									
1	08082500	Brazos River at Seymour	5,972	1906-78	Sept. 28, 1955	23.00	71,200	Aug. 5	14.20	28,200	--
2	0808.700	Millers Creek near Munday	104	1883-1978	June 15, 1930	>18.0	1/	Aug. 4	17.53	34,600	>100
3	08082800	Millers Creek Reservoir near Bomarton	240	1974	June 3, 1977	1,309.89	2/3,440	Aug. 6	1,335.30	2/34,480	--
4	08082900	North Elm Creek near Throckmorton 3/	3.58	1966	Apr. 30, 1966	26.28	1,350	Aug. 4	30.6	5,000	>100
5	08083240	Clear Fork Brazos River at Hawley	1,416	1915	1932	4/	1/	Aug. 4	14.64	2,540	--
6	08083245	Mulberry Creek near Hawley	205	1932	1957	16.0	1/	Aug. 4	13.98	1,770	--
7	08083300	Elm Creek near Abilene	133	1963	Sept. 18, 1974	18.68	4,570	Aug. 3	13.26	1,830	--
8	08083400	Little Elm Creek near Abilene	39.1	1903	1913	15.0	1/	Aug. 3	9.50	1,340	--
9	08083420	Cat Claw Creek at Abilene	13.0	1970	Sept. 18, 1974	6.41	1,200	Aug. 3	6.60	1,310	--
10	08083470	Cedar Creek at Abilene	119	1970	Sept. 18, 1974	12.54	4,670	Aug. 3	11.93	3,830	--
11	08083500	Fort Phantom Hill Reservoir near Nugent	470	1940	May 25, 1957	58.7	2/89,910	Aug. 6-10	48.4	2/50,370	--
12	08084000	Clear Fork Brazos River at Nugent	2,199	1876	1876	30.0	1/	Aug. 4	9.97	2,840	--
13	08084500	Lake Stamford near Haskell	368	1953	Sept. 9-10, 1962	1,416.6	2/74,100	Aug. 5	1,422.18	2/103,600	--
14	08084800	California Creek near Stamford	478	1897	June 10, 1962	29.6	1/	Aug. 4	31.00	40,000	>100
15	08085300	Humphries Draw near Haskell 3/	3.51	1966	Aug. 5, 1971	19.41	1,840	Aug. 4	19.36	1,830	10
16	08085500	Clear Fork Brazos River at Fort Griffin	3,988	1876	Sept. 1900	38.0	1/	Aug. 4	38.88	149,000	>100
17	08086050	Deep Creek at Moran 3/	228	1888	June 6, 1961	25.6	1/	--	21.80	13,000	10
18	08086150	North Fork Hubbard Creek near Albany	39.3	1940	June 10, 1940 July 18, 1953	21.0	1/	Aug. 4	23.3	103,000	>100
19	08086212	Hubbard Creek below Albany	613	1966	Jan. 21, 1968	25.10	27,200	Aug. 4	41.41	330,000	>100
20	08086290	Big Sandy Creek above Breckenridge	280	1949	May 16, 1949 July 20, 1953 Apr. 29, 1957	24.6	1/	Aug. 4	21.86	5,140	--
21	08086400	Hubbard Creek Reservoir near Breckenridge	1,085	1962	Feb. 3, 1975	1,183.61	2/327,200	Aug. 5	1,188.06	2/401,500	--
22	08086500	Hubbard Creek near Breckenridge	1,089	1925	July 20, 1953	34.2	1/	Aug. 5	30.66	14,600	--
23	08087300	Clear Fork Brazos River at Eliasville	5,697	1877	Sept. 1900 May 1, 1957	35.0	1/	Aug. 6	37.04	68,000	>100
24	08088000	Brazos River at South Bend	13,107	1876	1876	36.2	1/	Aug. 6	41.50	78,100	25
25	08088300	Briar Creek near Graham	24.2	1900	Sept. 1955	15.2	1/	Aug. 5	.78	1.6	--
26	08088400	Lake Graham near Graham	221	1958	Apr. 30, 1970	1,077.77	2/61,120	Aug. 5	1,067.61	2/36,090	--
27	08088450	Big Cedar Creek near Ivan	97.0	1964	July 8, 1968	22.39	9,590	Aug. 5	4.11	3.0	--
28	08088500	Possum Kingdom Reservoir near Graford	14,030	1941	Oct. 5, 1941	1,001.0	2/743,700	Aug. 12	999.69	2/564,800	--
29	08089000	Brazos River near Palo Pinto	14,245	1876	1876	5/	1/	Aug. 8	22.93	54,500	--
30	08092600	Brazos River at Whitney Dam near Whitney	16,950	1853	May 9, 1922	45.0	1/	Aug. 10	12.81	6/5,710	--
31	08098290	Brazos River near Highbank	20,870	1909	Dec. 1913	42.0	1/	Aug. 13	5.90	4,000	--
32	08099000	Leon Reservoir near Ranger	259	1955	June 13, 1967	1,382.2	2/5/40,640	Aug. 6-8	1,369.80	2/20,000	--
33	08099100	Leon River near De Leon	479	1908	May 1908	19.3	1/	Aug. 4	2.47	17	--
34	08099300	Sabana River near De Leon	264	1890	May 1908	24.0	1/	Aug. 4	8.80	617	--
35	08099400	Proctor Lake near Proctor	1,259	1963	Jan. 26, 1968	1,174.84	2/137,500	Aug. 4-7	1,154.48	2/31,170	--
36	08109500	Brazos River near College Station	30,033	--	--	--	--	Aug. 18	--	7/4,120	--
37	08114000	Brazos River at Richmond	35,441	1852	Dec. 10, 1913	51.2	1/	Aug. 20	6.90	3,850	--
38	08116650	Brazos River near Rosharon	35,773	1884	Dec. 11, 1913	56.4	1/	Aug. 21	13.29	3,270	--

See footnotes at end of table.

TABLE 4.—*Summary of flood stages and discharges*—Continued

Map number	WRD station number	Stream and place of determination	Contributing drainage area (mi²)	Period of known floods	Maximum flood previously known: Date	Maximum flood previously known: Stage (feet)	Maximum flood previously known: Discharge (ft³/s)	Maximum during August 1978 flood: Date (1978)	Maximum during August 1978 flood: Stage (feet)	Maximum during August 1978 flood: Discharge (ft³/s)	Recurrence interval (years)
		COLORADO RIVER BASIN									
39	08126500	Colorado River at Ballinger	5,240	1882	1884	36.0	1/	Aug. 3	23.95	16,600	--
40	08127000	Elm Creek at Ballinger	471	1904	Aug. 1906 Oct. 13, 1957	8/14.50 14.20	1/ 50,000	Aug. 3	9.17	23,400	15
41	08136500	Concho River at Paint Rock	5,132	1853	Sept. 17, 1936	43.4	301,000	Aug. 3	19.11	12,700	--
42	08136700	Colorado River near Stacy	11,160	1882	Sept. 18, 1936	64.59	356,000	Aug. 4	22.50	35,700	--
43	08138000	Colorado River at Winchell	11,700	1882	Sept. 19, 1936	62.20	1/	Aug. 5	31.88	29,600	--
44	08140600	Lake Clyde near Clyde	37.9	1970	May 28, 1975	1,873.4	2/6,370	Aug. 4	1,875.50	2/7,420	--
45	08140700	Pecan Bayou near Cross Cut	532	1900	1908	26.5	1/	Aug. 4	24.90	16,200	
46	08140800	Jim Ned Creek near Coleman	333	1961	May 6, 1969	9.08	5,020	Aug. 4	5.77	1,830	--
47	08141000	Hords Creek Lake near Valera	48	1948	May 1, 1956	1,906.86	2/12,790	Aug. 5	1,887.90	2/3,570	--
48	08141500	Hords Creek near Valera	53	1900	July 3, 1932	23.0	1/	Aug. 3	11.06	2,360	--
49	08143000	Lake Brownwood near Brownwood	1,535	1933	May 2, 1956	1,431.4	2/192,300	Aug. 16-24, 29, 30	1,424.4	2/138,500	--
50	08143500	Pecan Bayou at Brownwood	1,614	1900	July 3, 1932	--	9/235,000	Aug. 4	1.05	47	--
51	08143600	Pecan Bayou near Mullin	2,034	1967	Jan. 23, 1968	29.26	13,700	Aug. 3	6.50	1,690	--
52	08144500	San Saba River at Menard	1,151	1880	June 6, 1899	23.3	1/	Aug. 2	17.36	35,400	25
53	08144800	Brady Creek near Eden	97	1884	July 1938	15.8	1/	Aug. 3	1.3	2.1	--
54	08144900	Brady Creek Reservoir near Brady	513	1963	Sept. 24, 1971	1,747.7	2/40,880	Aug. 3	1,738.12	2/21,570	--
55	08145000	Brady Creek at Brady	575	1882	July 23, 1938	29.1	86,000	Aug. 2	8.31	536	--
56	08146000	San Saba River at San Saba	3,042	1899	July 23, 1938	39.3	203,000	Aug. 3	28.38	27,000	--
57	08147000	Colorado River near San Saba	17,720	1878	July 23, 1938	63.2	224,000	Aug. 4	22.59	28,100	--
58	08148000	Lake Buchanan near Burnet	18,370	1937	Jan. 24, 1968	1,020.8	2/1,010,000	Aug. 8	1,011.94	2/814,700	
59	--	Bear Creek at Interstate Highway 10 near Junction 10/	155	1936	Sept. 16, 1936	--	31,300	Aug. 3	--	81,000	--
60	08148500	North Llano River near Junction 3/	914	1875	Sept. 16, 1936	29.2	94,800	Aug. 2	23.50	64,800	10
61	08150000	Llano River near Junction	1,874	1875	June 14, 1935	43.3	319,000	Aug. 2	22.14	76,700	--
62	08150700	Llano River near Mason	3,280	1875	June 14, 1935	--	11/388,000	Aug. 3	21.35	92,500	--
63	08150800	Beaver Creek near Mason	218	1963	May 16, 1965	13.58	23,200	Aug. 3	24.00	66,900	>100
64	08151500	Llano River at Llano	4,233	1879	June 14, 1935	41.5	380,000	Aug. 3	25.61	139,000	15
65	08152000	Sandy Creek near Kingsland	327	1881	Sept. 11, 1952	34.2	163,000	Aug. 2	8.89	3,610	--
66	08152800	Spring Creek near Fredericksburg 3/	15.2	1967	Aug. 28, 1974	8.42	7,530	Aug. 3	17.0	42,500	>100
67	08153100	Cane Branch at Stonewall 3/	1.37	--	--	--	--	Aug. 3	--	<10	--
68	08153500	Pedernales River near Johnson City	947	1859	Sept. 11, 1952	42.5	441,000	Aug. 3	24.9	127,000	25
69	08154500	Lake Travis near Austin	25,250	1940	May 18, 1957	707.4	2/1,770,000	Aug. 4	662.9	2/868,200	--
		GUADALUPE RIVER BASIN									
70	08165300	North Fork Guadalupe River near Hunt	168	1900	July 1, 1932	37.3	140,000	Aug. 3	26.8	39,300	--
71	08165500	Guadalupe River at Hunt	288	1900	July 2, 1932	36.6	206,000	Aug. 2	23.5	62,900	10
72	08166000	Johnson Creek near Ingram	114	1852	July 2, 1932	35.0	138,000	Aug. 3	21.4	73,900	60
73	--	Turtle Creek at State Highway 16 near Kerrville 10/	26.5	--	--	--	--	Aug. 2	--	32,700	--
74	08166300	Turtle Creek tributary near Kerrville 3/	.46	--	--	--	--	--	11.2	605	--
75	08167000	Guadalupe River at Comfort	838	1848	July 1869	40.3	1/	Aug. 2	40.9	240,000	>100
76	08167500	Guadalupe River near Spring Branch	1,315	1859	1869	53.0	1/	Aug. 3	45.25	158,000	>100

See footnotes at end of table.

TABLE 4.—*Summary of flood stages and discharges*—Continued

Map number	WRD station number	Stream and place of determination	Contributing drainage area (mi^2)	Period of known floods	Maximum flood previously known: Date	Maximum flood previously known: Stage (feet)	Maximum flood previously known: Discharge (ft^3/s)	Maximum during August 1978 flood: Date (1978)	Maximum during August 1978 flood: Stage (feet)	Maximum during August 1978 flood: Discharge (ft^3/s)	Recurrence interval (years)
77	08167600	Rebecca Creek near Spring Branch	10.9	1885	Sept. 1952	25.5	1/	Aug. 1	2.06	1.5	--
78	08167700	Canyon Lake near New Braunfels	1,432	1962	Apr. 22, 1977	917.96	2/ 460,400	Aug. 4	12/ 930.61	2/ 588,400	--
79	08167800	Guadalupe River at Sattler	1,436	1962	Feb. 11, 1975	8.18	13/ 5,390	Aug. 5	8.31	5,850	--
80	--	North Prong Medina River near Medina 10/	67.5	1932	July 1, 1932	--	40,200	Aug. 2	--	123,000	--
81	08178900	Bandera Creek tributary near Bandera 3/	.27	--	--	--	--	Aug. 2	10.9	120	--
82	08179000	Medina River near Pipe Creek	474	1880	1919	43.0	14/ 115,000	Aug. 2	49.6	281,000	>100
83	08179100	Red Bluff Creek near Pipe Creek	56.3	1905	Sept. 27, 1964	22.64	46,900	Aug. 2	3.7	160	--
84	08179500	Medina Lake near San Antonio	634	1913	Sept. 16, 1919	1,078.0	2/ 288,000	Aug. 2	1,076.67	2/ 281,000	--
85	08180500	Medina River near Rio Medina 3/	650	1922	July 15, 1973	23.2	28,600	Aug. 2	20.0	20,100	--
86	08180800	Medina River near Somerset	967	1890	July 17, 1973	29.39	30,500	Aug. 4	22.35	12,800	--
87	08181500	Medina River at San Antonio	1,317	1939	July 17, 1973	43.59	31,900	Aug. 4	29.95	1,030	--
88	08183900	Cibolo Creek near Boerne	68.4	1892	Sept. 27, 1964	19.15	36,400	Aug. 2	3.65	462	--
		NUECES RIVER BASIN									
89	08195000	Frio River at Concan	405	1869	July 1, 1932	34.44	162,000	Aug. 2	6.9	3,350	--
90	08196000	Dry Frio River near Reagan Wells	117	1875	1880	33.0	1/	Aug. 1	5.23	1,500	--
91	08198000	Sabinal River near Sabinal	206	1892	July 2, 1932	33.0	1/	Aug. 2	19.43	23,200	--
92	08200000	Hondo Creek near Tarpley	86.2	1907	June 17, 1958	28.2	69,800	Aug. 2	13.10	13,200	--
93	08201500	Seco Creek at Miller Ranch near Utopia	43.1	1901	June 17, 1958	16.4	52,600	Aug. 2	8.40	10,600	--

1/ Discharge not determined.
2/ Contents in acre-feet.
3/ Discontinued site, see table 2.
4/ The maximum stage since 1915 occurred in 1932 and the second highest stage occurred in 1959, 2,510 feet.
5/ The maximum stage occurred in 1876 and was several feet higher than flood of June 16, 1930, 30 feet, 95,600 ft^3/s.
6/ Stage and discharge data at site 08093100.
7/ At site 6.5 miles downstream.
8/ Backwater from Colorado River.
9/ Prior to completion of Lake Brownwood.
10/ Miscellaneous site, see table 2.
11/ At site 17 miles downstream.
12/ Elevation at 2400 hours.
13/ Maximum since closure of Canyon Dam on July 21, 1962.
14/ From rating extended above 32,000 ft^3/s on basis of slope-area measurement of 64,000 ft^3/s.

GUADALUPE RIVER BASIN

The drainage area of the Guadalupe River above Canyon Lake received the first of the heavy rainfall during the night of August 1 and the morning of August 2. The storm cell, which was centered just west of Kerrville in Kerr County, produced rainfall amounts that resulted in severe flooding on the Guadalupe River and all of its local tributaries. On August 2, the flood crest on the Guadalupe River at Comfort (site 75, fig. 1) exceeded by 0.6 ft the previously known maximum, which occurred in July 1869. When the crest reached the Spring Branch gaging station (site 76) on August 3, the peak discharge had attentuated from 240,000 ft^3/s at Comfort to 160,000 ft^3/s at Spring Branch. Secondary peaks occurred at both stations. A discharge hydrograph for Guadalupe River at Comfort is shown in figure 15, and data are presented in table 6. A discharge hydrograph for Guadalupe River near Spring Branch is shown in figure 16, and data are presented in table 7.

Canyon Lake contained all of the flood runoff from the Guadalupe River basin above the dam, so no damage occurred below Canyon Lake. The contents of Canyon Lake increased from 362,200 acre-ft at 2400 August 1 to 588,400 acre-ft at 2400 August 4. This was the maximum storage since closure of the dam on July 21, 1962.

MEDINA RIVER BASIN

A second cell of the storm that caused flooding in the Guadalupe River basin was centered near Medina in Bandera County where the North Prong and the West Prong of the Medina River join. The official total rainfall near the storm's center was in excess of 48 in., which resulted in a catastrophic flood on the headwaters of the Medina River. A peak discharge of 123,000 ft^3/s from a drainage area of 67.5 mi^2 was recorded at a miscellaneous site (site 80) on the North Prong Medina River about 10 mi upstream from Medina. The maximum flood discharge probably occurred a short distance downstream from the confluence of the North Prong and West Prong of Medina River.

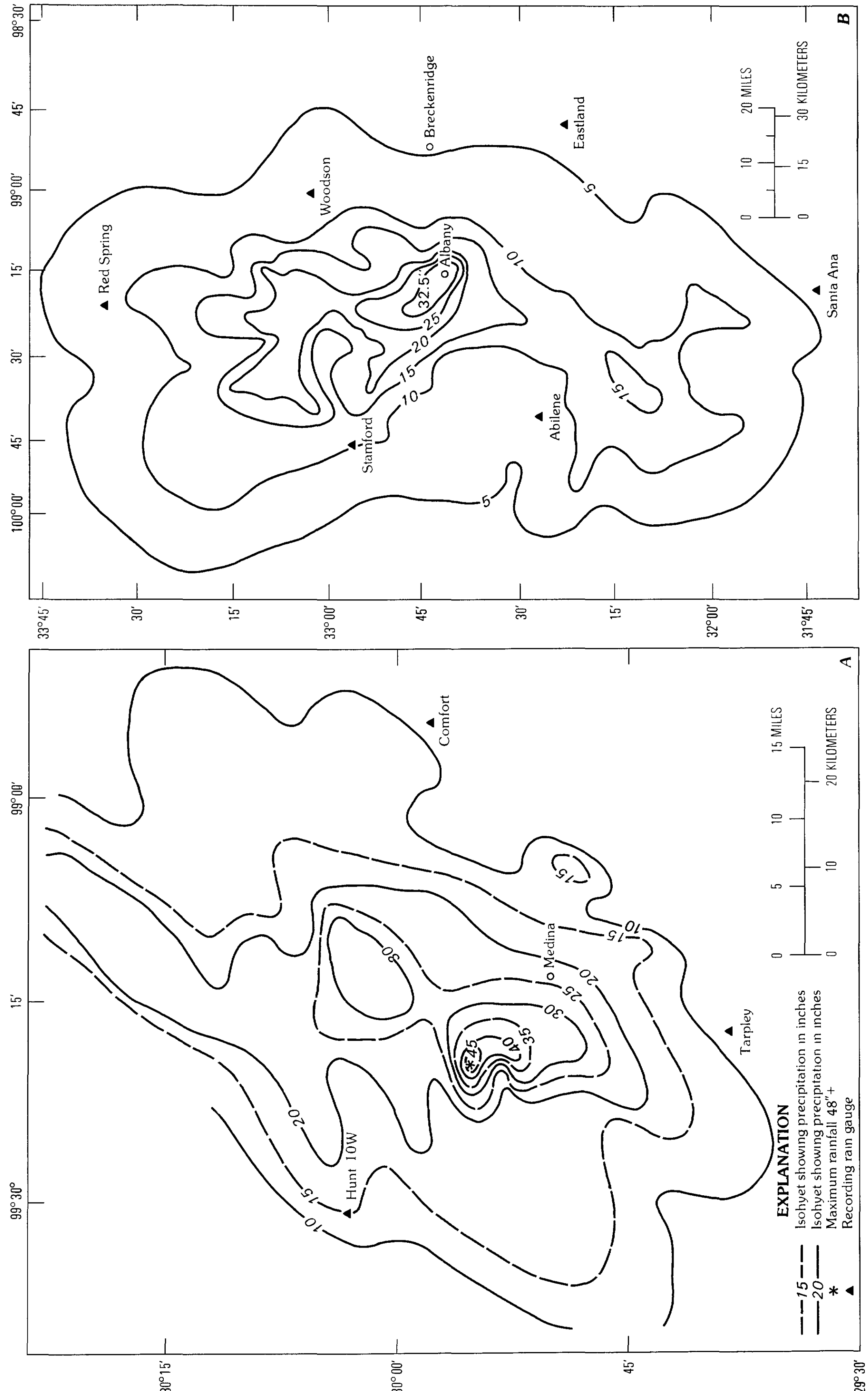


FIGURE 13.—Isohyetal analyses for storm centered near: *A*, Medina; *B*, Albany.

TABLE 5.—*Locations of discontinued stream-gaging stations and miscellaneous discharge-measurement sites*

Map number	Station number	Name and location
		BRAZOS RIVER BASIN
4	08082900	North Elm Creek near Throckmorton. Lat 33°10'50", long 99°22'05, Throckmorton County, Hydrologic Unit 12060101, at culvert on State Highway 24, and 11.3 miles (18.2 kilometers) west of Throckmorton.
15	08085300	Humphries Draw near Haskell. Lat 33°10'40", long 99°34'30", Haskell County, Hydrologic Unit 12060101, at culvert on State Highway 24, and 9.3 miles (15.0 kilometers) east of Haskell.
17	08086050	Deep Creek at Moran. Lat 32°33'33", long 99°10'11", Shackelford County, Hydrologic Unit 12060105, at downstream side of bridge on U.S. Highway 380, 0.8 mile (1.3 kilometer) north of Moran, and 10.8 miles (17.4 kilometers) upstream from Hubbard Creek.
		COLORADO RIVER BASIN
59	--	Bear Creek at Interstate Highway 10 near Junction. Lat 30°31'57", long 99°50'11", Kimble County, Hydrologic Unit 12090202, 1.3 miles (2.1 kilometers) upstream from Interstate Highway 10, 1.5 miles (2.4 kilometers) upstream from mouth, and 3.4 miles (5.5 kilometers) west of Junction.
60	08148500	North Llano River near Junction. Lat 30°31'06", long 99°48'39", Kimble County, Hydrologic Unit 12090202, 1,000 feet (305 meters) upstream from remains of old Wilson Dam, 2.1 miles (3.4 kilometers) northwest of Junction, and 4 miles (6 kilometers) upstream from confluence with South Llano River.
66	08152800	Spring Creek near Fredericksburg. Lat 30°18'10", long 99°03'20", Gillespie County, Hydrologic Unit 12090206, downstream side of bridge on U.S. Highway 290, and 11 miles (18 kilometers) west of Fredericksburg.
67	08153100	Cane Branch at Stonewall. Lat 30°14'07", long 98°39'21", Gillespie County, Hydrologic Unit 12090206, at culvert on U.S. Highway 290 at Stonewall, and 0.6 mile (1.0 kilometer) upstream from Pedernales River.
		GUADALUPE RIVER BASIN
73	--	Turtle Creek at State Highway 16 near Kerrville. Lat 29°57'41", long 99°12'35", Kerr County, Hydrologic Unit 12100201, 0.1 mile (0.2 kilometer) upstream from Lambs Creek, at State Highway 16 and 9.0 miles (14.5 kilometers) southwest of Kerrville.
74	08166300	Turtle Creek tributary near Kerrville. Lat 29°58'11", long 99°11'02", Kerr County, Hydrologic Unit 12100201, at culvert on Farm Road 2771, and 5.9 miles (9.5 kilometers) south of Kerrville.
80	--	North Prong Medina River near Medina. Lat 29°51'49", long 99°22'18", Bandera County, Hydrologic Unit 12100302, 0.5 mile (0.8 kilometer) upstream from Lima School, and 12.0 miles (19.3 kilometers) upstream from mouth.
81	08178900	Bandera Creek tributary near Bandera. Lat 29°50'51", long 99°06'12", Bandera County, Hydrologic Unit 12100302, at culvert on Farm Road 689, and 10 miles (16 kilometers) north of Bandera.
85	08180500	Medina River near Rio Medina. Lat 29°29'53", long 98°54'16", Medina County, Hydrologic Unit 12100302, on left bank 233 feet (71 meters) upstream from bridge at Haby's crossing, 4.2 miles (6.8 kilometers) northwest of Rio Medina, and 10.4 miles (16.7 kilometers) upstream from San Geronimo Creek.

TABLE 6.—*Data for gaging station 08167000 Guadalupe River at Comfort*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 1 -	0900	4.10	50	Aug. 2 -	1000	38.82	203,000	Aug. 3 -	1400	27.83	69,200
	1500	4.14	56		1100	36.07	161,000		1600	23.67	39,900
	1600	4.36	103		1200	34.19	137,000		1800	19.87	21,700
	1700	6.12	1,040		1500	30.89	98,600		2100	16.45	12,000
	1800	8.25	1,990		1800	26.23	56,400		2400	14.52	7,870
	1900	9.85	2,760		2100	21.36	28,000				
	2400	11.26	3,580		2400	17.58	14,600	Aug. 4 -	0600	12.31	4,520
									1200	10.88	3,330
Aug. 2 -	0300	11.74	3,960	Aug. 3 -	0300	15.20	9,260		2400	9.00	2,340
	0400	13.24	5,710		0500	19.38	20,100				
	0500	15.85	10,700		0600	30.76	97,200	Aug. 5 -	1200	8.00	1,770
	0600	22.97	36,000		0700	33.98	134,000		2400	7.49	1,450
	0700	30.98	99,500		0800	35.08	148,000				
	0800	37.55	183,000		0900	34.87	145,000	Aug. 6 -	1200	7.18	1,260
	0900	40.90	240,000		1100	33.00	122,000		2400	7.04	1,170

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	74,200	44,400	19,800
1940 to July 1978-------------	27,300	13,700	6,840

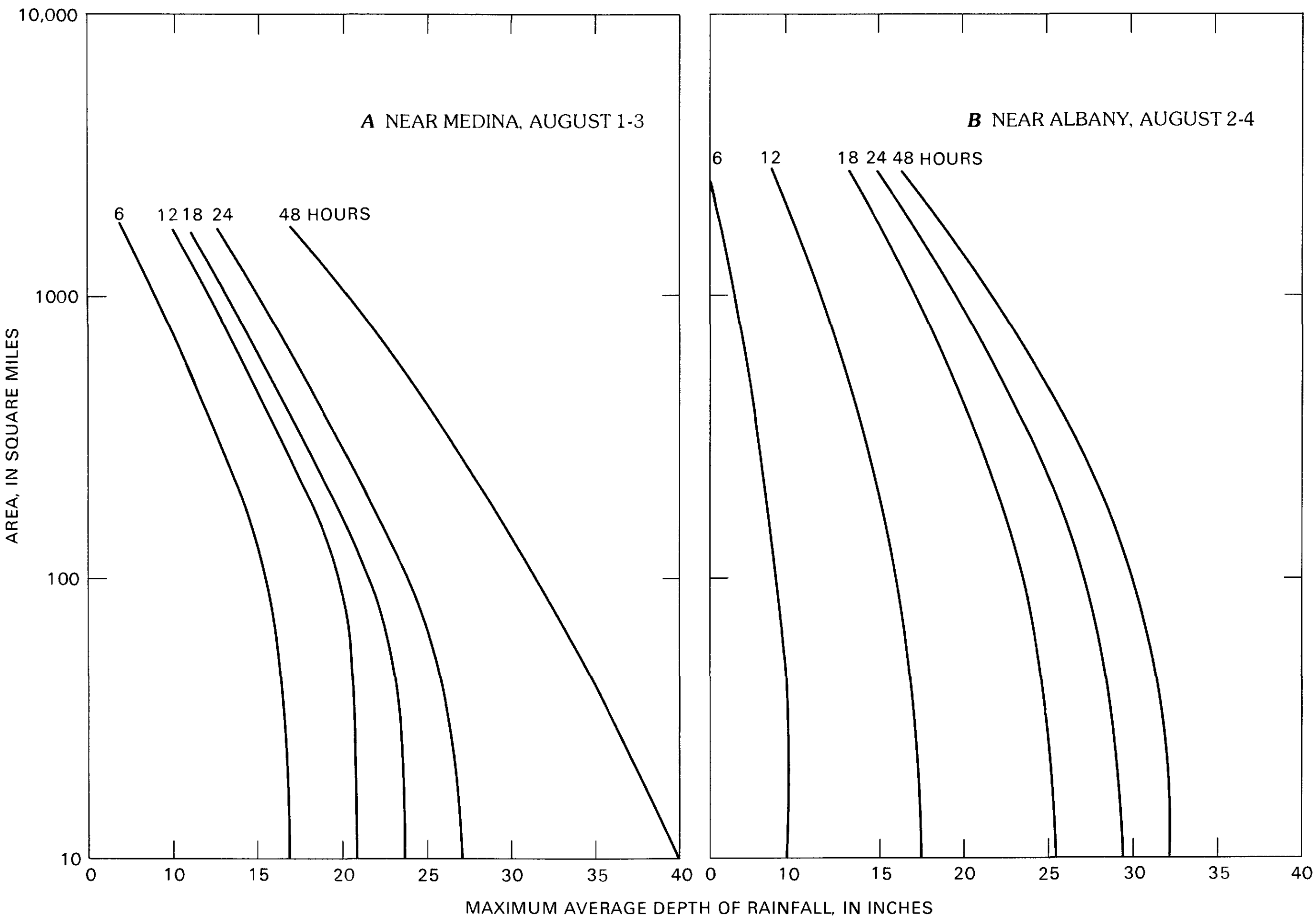


FIGURE 14.—Depth-area duration analysis for storm centered near: *A*, Medina; *B*, Albany.

TABLE 7.—*Data for gaging station 08167500 Guadalupe River near Spring Branch*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 1 -	0300	2.20	40	Aug. 2 -	2400	34.00	54,400	Aug. 4 -	0200	40.60	118,000
	1200	2.37	64						0300	39.40	108,000
	2400	2.55	95	Aug. 3 -	0100	37.80	94,500		0800	32.30	56,300
					0200	42.00	130,000		1200	27.80	36,400
Aug. 2 -	0300	2.57	99		0300	45.25	160,000		1600	21.40	21,300
	0600	2.77	144		0400	44.40	152,000		2000	14.00	10,400
	1000	3.07	232		0800	38.00	96,100		2400	11.00	6,920
	1100	3.90	611		1200	32.70	58,800				
	1200	5.10	1,290		1900	25.60	30,100	Aug. 5 -	0400	9.40	5,340
	1400	6.60	2,320		2000	28.00	37,000		1200	8.00	4,100
	1600	8.25	3,580		2200	32.60	58,100		2400	6.90	3,240
	1800	10.95	6,050		2400	37.00	88,300				
	2000	17.70	14,400					Aug. 6 -	1200	5.87	2,420
	2200	25.30	27,600	Aug. 4 -	0100	39.20	106,000		2400	5.85	2,400

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	76,500	43,200	20,100
1923 to July 1978-------------	66,100	32,700	14,900

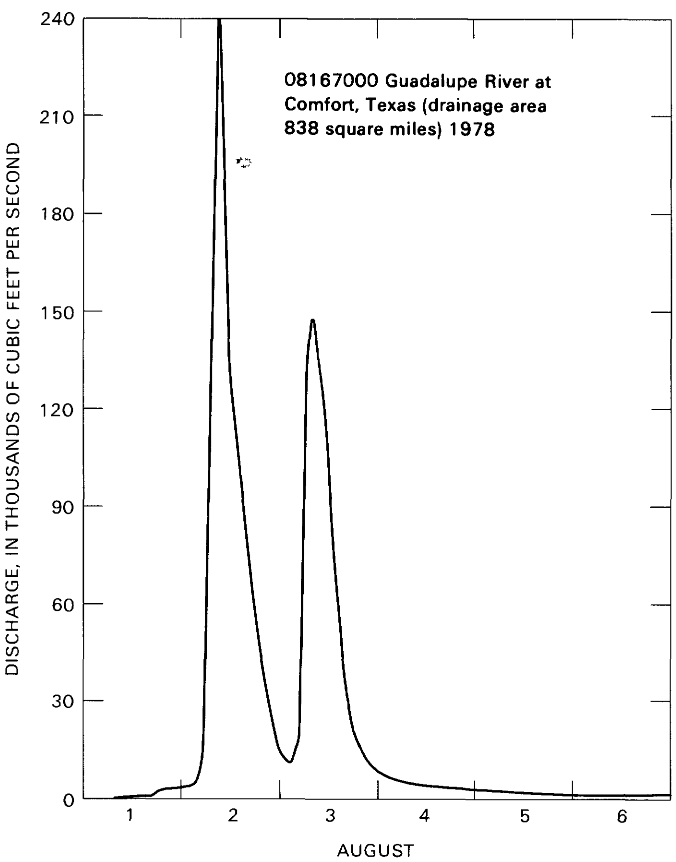


FIGURE 15.—Discharge hydrograph of Guadalupe River near Comfort for August 1–6, 1978.

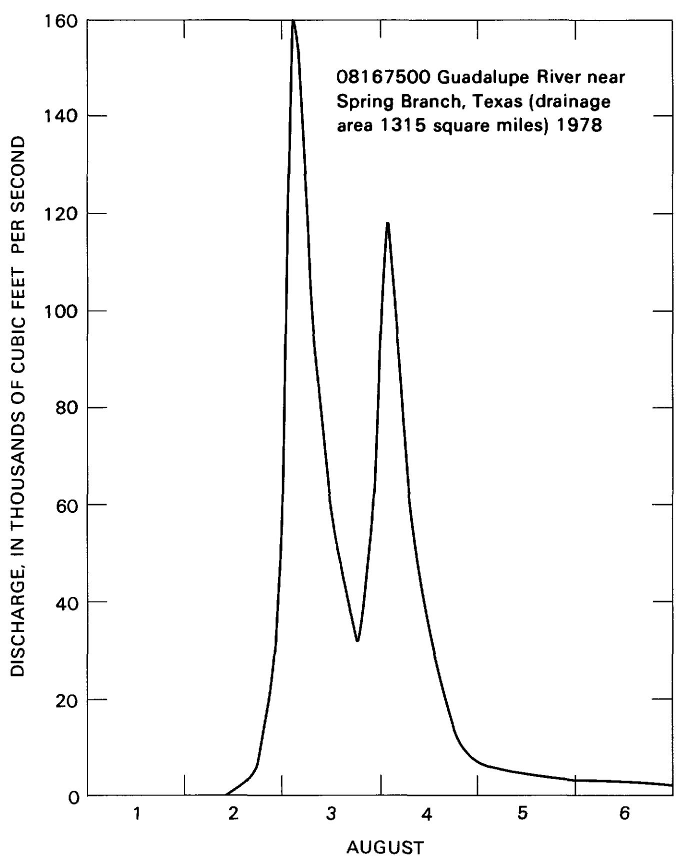


FIGURE 16.—Discharge hydrograph of Guadalupe River near Spring Branch for August 1–6, 1978.

TABLE 8.—*Data for gaging station 08179000 Medina River near Pipe Creek*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 1 -	0600	3.88	16	Aug. 2 -	1200	45.00	160,000	Aug. 3 -	2400	10.70	6,710
	1200	3.96	26		1300	38.70	95,100				
	1900	3.96	26		1400	33.20	64,200	Aug. 4 -	1200	8.60	4,260
	2400	4.22	60		1600	25.20	36,100		2400	7.80	3,450
					1900	18.40	19,800				
Aug. 2 -	0300	4.20	57		2400	15.55	14,300	Aug. 5 -	1200	7.15	2,840
	0400	7.10	1,060						2400	6.65	2,410
	0500	8.20	1,810	Aug. 3 -	0200	15.00	13,300				
	0700	9.75	3,230		0300	20.70	24,900	Aug. 6 -	1200	6.15	2,000
	0800	11.65	5,360		0400	23.00	30,400		2400	5.80	1,720
	0900	27.95	39,000		0500	21.20	26,000				
	1000	43.60	119,000		1200	15.80	14,700	Aug. 7 -	1200	5.45	1,460
	1100	49.60	281,000		1800	13.40	10,600		2400	5.20	1,260

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	41,700	20,100	9,640
1924 to July 1978--------------	23,000	15,000	7,900

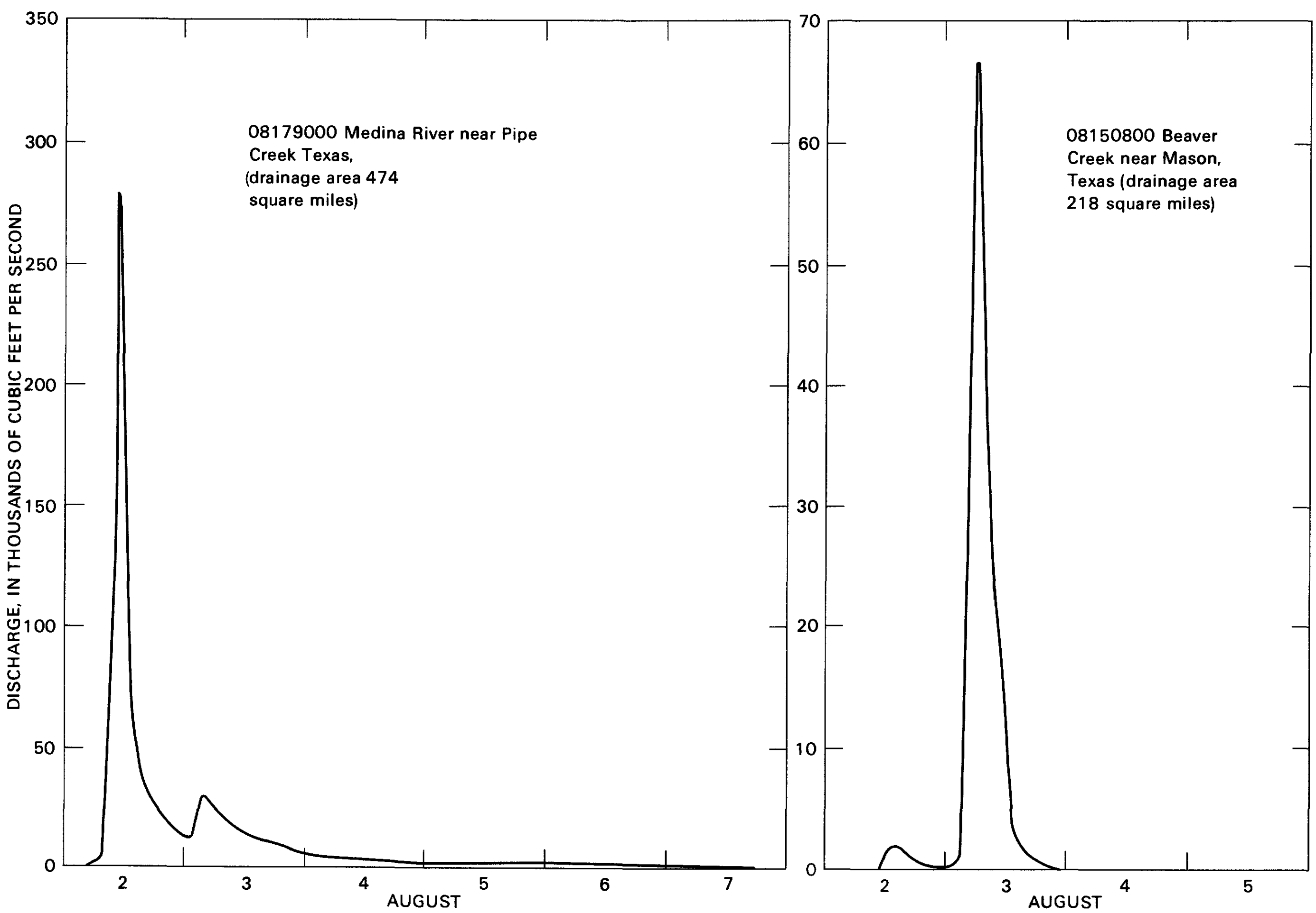


FIGURE 17.—Discharge hydrographs of Medina River near Pipe Creek for August 2–7, 1978, and Beaver Creek near Mason for August 2–5, 1978.

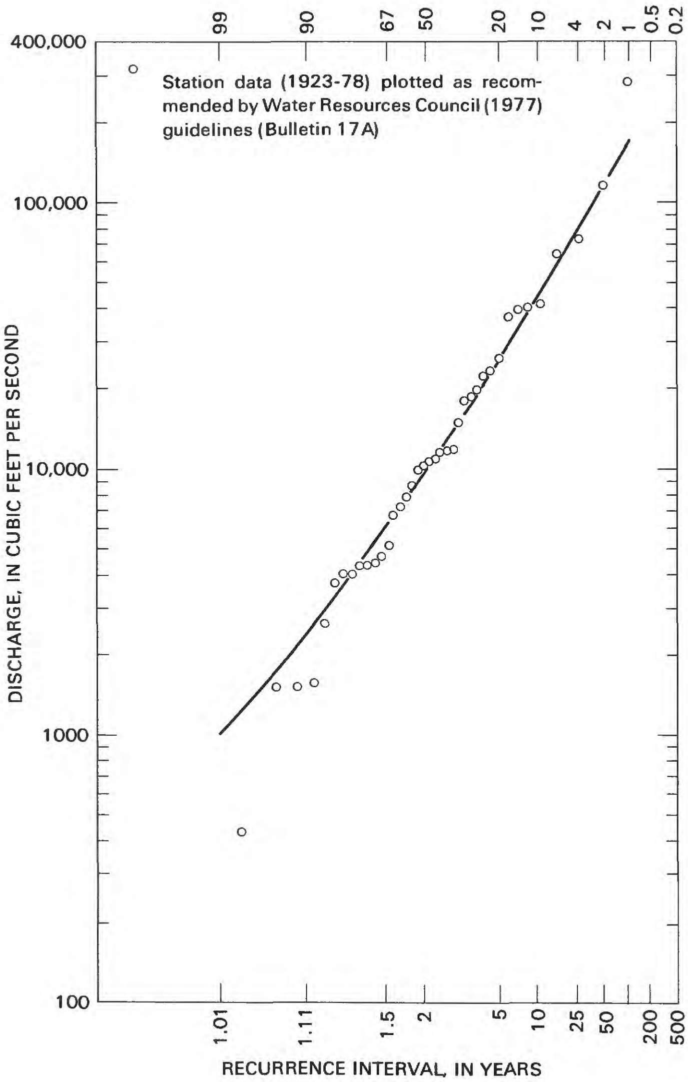


FIGURE 18.—Log-Pearson Type III frequency curve for Medina River near Pipe Creek.

The flood crest reached the stream-gaging station Medina River near Pipe Creek (site 82) on August 2, and exceeded by more than 6 ft the previously known maximum stage since 1880, which occurred in 1919. The peak discharge was 281,000 ft^3/s. A discharge hydropgraph for this station is shown in figure 17, and data are presented in table 8. An analysis of the annual peak-flow data for this site shows that a discharge of 281,000 ft^3/s has a recurrence interval greatly in excess of 100 years (fig. 18). Red Bluff Creek (site 83), which flows into the Medina River just below the Pipe Creek gaging station, received very little runoff and had a peak discharge of only 160 ft^3/s on August 2.

Medina Lake near San Antonio (site 84) reached a stage of 1,076.67 ft, with 4 ft of flow over the spillway at the maximum stage. Storage in Medina Lake increased from 188,200 acre-ft at 0800 August 1 to 281,000 acre-ft at 1900 August 2.

One of the most striking indications of the severity of the flood was the destruction of massive cypress trees that lined the low-water banks of the Guadalupe and Medina Rivers and many of the tributaries. These trees ranged in size up to 6 ft in diameter, and the larger trees were estimated to be as much as 600 years old (oral commun., David Riskin, Botanist, Texas Parks and Wildlife Department, September 1978). Entire stands of these picturesque trees were either uprooted or snapped off and floated downstream. Hundreds were left scattered along the flood plains (fig. 19) or lodged in huge piles of debris along the channel banks and beneath the highway bridges. Many of the trees that were not uprooted were left partially down and stripped of their bark and foliage (fig. 20).

In this area of central Texas, older trees develop an extensive system of large lateral roots because tap roots cannot penetrate the limestone bedrock beneath the shallow topsoil. When the receding floodwaters became too shallow to maintain free flotation of the uprooted trees, the lateral roots carved distinctive ruts in the soil as the trees were moved along the flood plain. These straight narrow ruts defined the direction of flow.

COLORADO RIVER BASIN

PEDERNALES RIVER

Heavy rainfall was not as widespread in the Colorado River basin as in the Guadalupe and Medina River basins. The highest unit runoff observed during this storm occurred on Spring Creek, which is tributary to the Pedernales River. Spring Creek, a short distance upstream from the station Spring Creek near Fredericksburg (site 66), had a peak discharge of 42,500 ft^3/s from a 14.1-mi^2 drainage area. The

FIGURE 19.—Cypress tree uprooted by floodwaters on the Medina River.

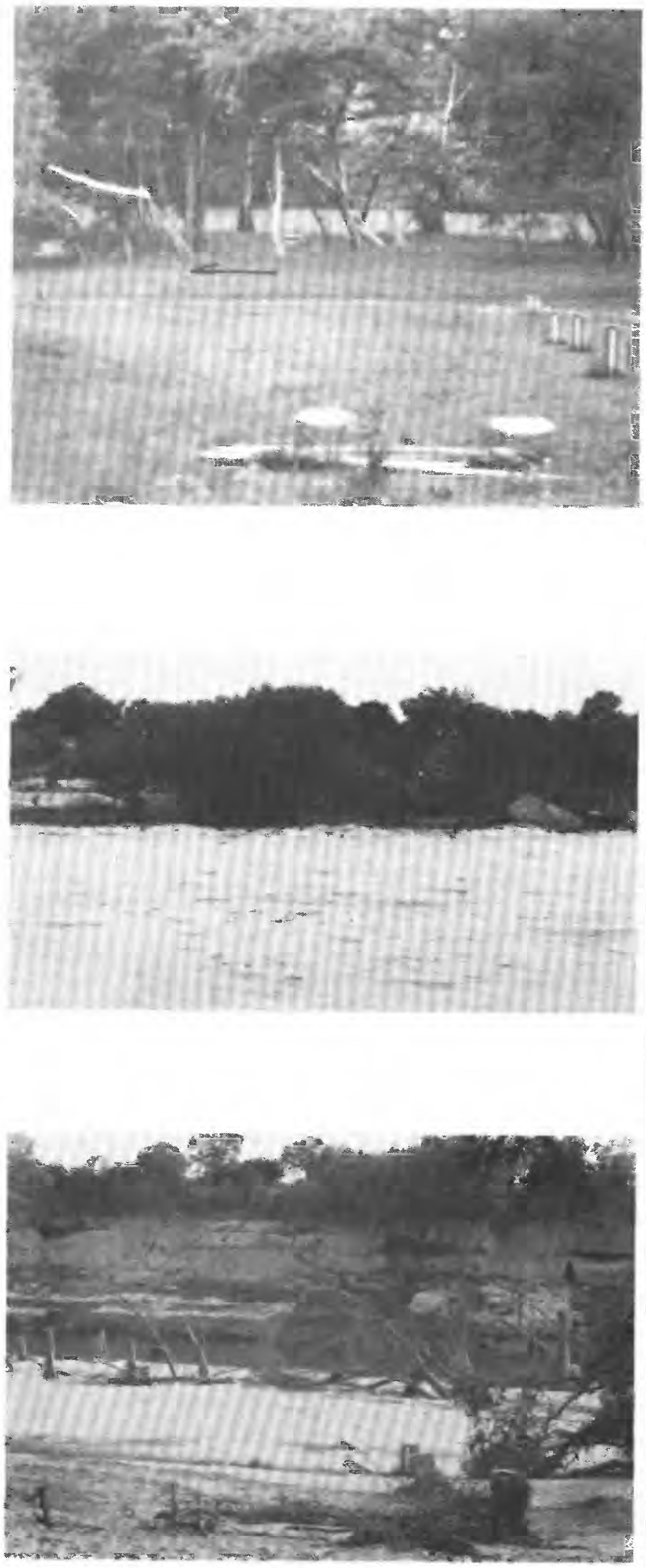


FIGURE 20.—Medina River near Pipe Creek, before, during, and after the flood.

unit discharge was 3,010 $ft^3/s/mi^2$, which is equivalent to 4.67 in. of runoff per hour at the time of the peak. Overbank flooding occurred on the Pedernales River upstream from the gaging station near Johnson City (site 68), but the flood crest was 17.6 ft lower than the crest of the September 1952 flood.

LLANO RIVER

Rainfall in the Llano River basin generally was 5 in. or less except in several small areas near Junction. The peak discharge on Bear Creek (site 59), which is tributary to the North Llano River just northwest of Junction, was 81,000 ft^3/s from a drainage area of 155 mi^2. The floodwaters on Bear Creek inundated Interstate Highway 10, which was closed for several hours. At the gaging station on Beaver Creek near Mason (site 63), another tributary to the Llano River, the recorded peak stage of 24.00 ft was over 10 ft higher than the previous maximum in 1965, and the peak flow rate was 66,900 ft^3/s. The discharge hydrograph for Beaver Creek near Mason is shown in figure 17, and data are presented in table 9.

BRAZOS RIVER BASIN

On August 3, a new storm developed in the Brazos River basin. During the 24-hour period ending at 0700 August 4, a total of 29.05 in. of rain was recorded by the National Weather Service at Albany in Shackelford County. Record-breaking floods occurred on the Clear Fork Brazos River and on Hubbard Creek and other tributaries of the Clear Fork Brazos River. A peak discharge of 103,000 ft^3/s from a drainage area of 39.3 mi^2 was recorded at North Fork Hubbard Creek near Albany (site 18) on August 4. The unit discharge of 2,620 $ft^3/s/mi^2$ was one of the highest ever recorded in Texas for a drainage area of this size. The streamflow station Hubbard Creek below Albany (site 19) had a peak discharge of 330,000 ft^3/s from a drainage area of 613 mi^2. Discharge hydrographs for North Fork Hubbard Creek near Albany and Hubbard Creek below Albany are shown in figure 21, and data are presented in tables 10 and 11, respectively.

The contents of Hubbard Creek Reservoir near Breckenridge (site 21) increased from 185,800 acre-ft at 2400 August 2 to a maximum of 401,500 acre-ft at 0800 August 5. The reservoir effectively contained the floodwaters from the Hubbard Creek basin although it was not designed for flood control. Sufficient storage capacity was available in the reservoir to contain the flood wave with only moderate releases, which prevented more serious flooding downstream on the Clear Fork Brazos River. The streamflow station Hubbard Creek near Breckenridge (site 22), downstream from the reservoir and about 11 mi upstream from the Clear Fork Brazos River, had a peak discharge of only 14,600 ft^3/s.

TABLE 9.—*Data for gaging station 08150800 Beaver Creek near Mason*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 2 -	0100	1.85	1.2	Aug. 2 -	2400	3.76	270	Aug. 3 -	1300	5.97	4,060
	0300	1.98	3.8						1400	5.25	2,840
	0500	2.10	7.7	Aug. 3 -	0200	3.82	281		1600	4.35	1,420
	0800	2.30	18		0300	5.29	1,100		1800	3.76	770
	1000	2.72	58		0400	13.37	23,500		2000	3.35	470
	1100	4.54	590		0500	18.91	43,600		2200	3.03	308
	1200	5.54	1,360		0600	24.00	66,900		2400	2.77	211
	1300	6.22	2,310		0700	20.00	48,200				
	1500	6.07	2,070		0900	13.90	25,200	Aug. 4 -	0200	2.56	151
	1800	5.07	912		1100	11.10	16,700		0600	2.28	93
	2100	4.23	440		1200	9.00	10,900		1200	2.00	59
									2400	1.68	40

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	12,800	4,500	1,940
1964 to July 1978--------------	5,040	2,090	919

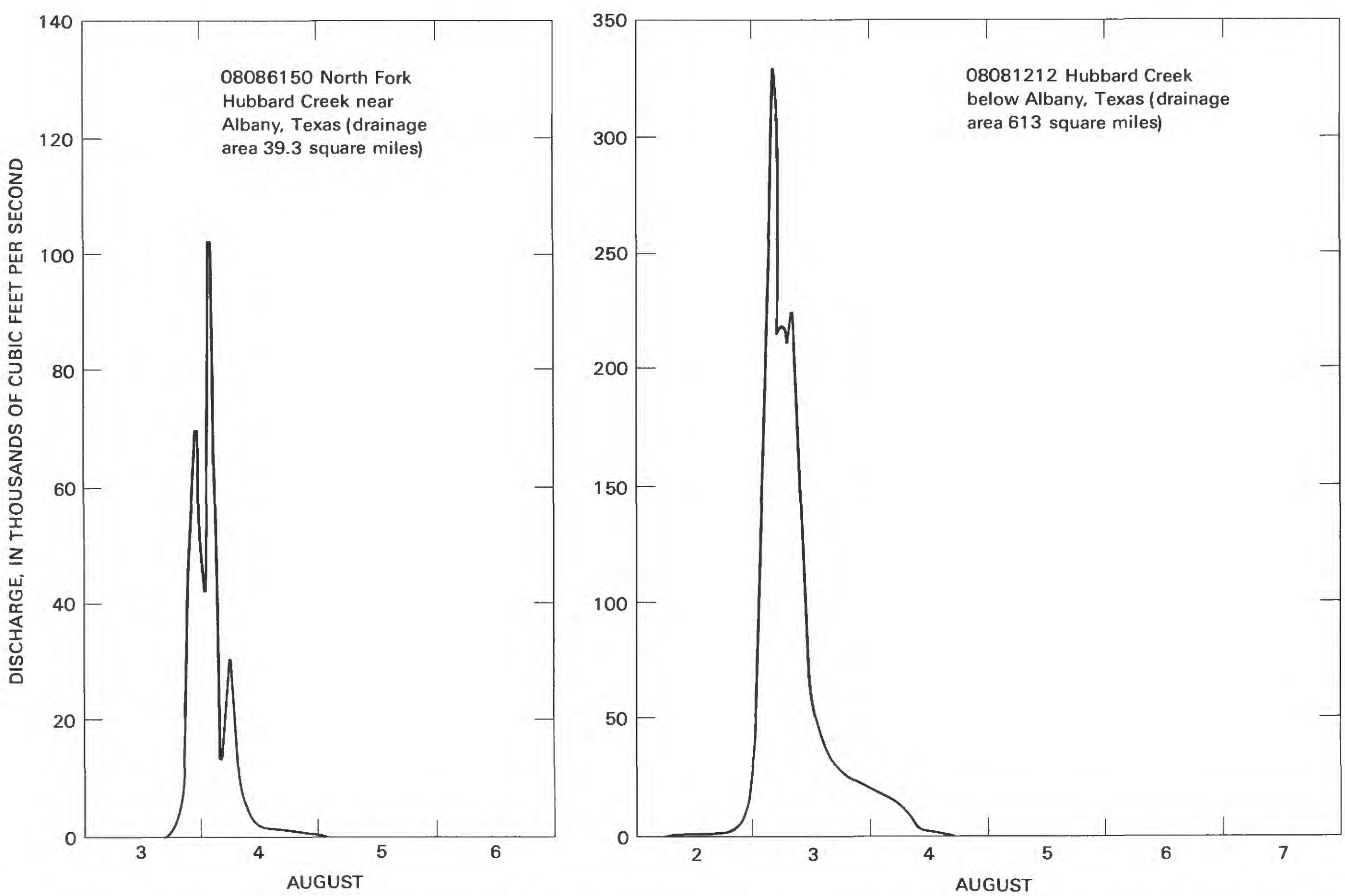


FIGURE 21.—Discharge hydrographs of North Fork Hubbard Creek near Albany for August 3–6, 1978, and Hubbard Creek below Albany for August 2–7, 1978.

TABLE 10.—*Data for gaging station 08086150 North Fork Hubbard Creek near Albany*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 3 -	1100	1.95	0.00	Aug. 3 -	2400	22.80	53,600	Aug. 4 -	1000	11.00	4,080
	1300	2.74	9.2						1100	7.20	1,670
	1400	2.93	25	Aug. 4 -	0100	22.55	42,000		1200	5.40	816
	1600	2.98	31		0200	23.30	103,000		1300	4.50	456
	1800	3.18	58		0300	22.70	48,600		1800	3.73	207
	1900	6.60	1,360		0400	21.20	13,000		2400	3.38	115
	2000	12.00	4,780		0500	21.10	12,800				
	2100	19.60	10,100		0600	22.30	30,700	Aug. 5 -	0600	3.24	82
	2200	22.70	48,600		0700	21.50	13,600		1200	3.13	63
	2300	23.05	70,200		0800	16.00	7,460		2400	3.01	42

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	13,100	6,640	2,860
1964 to July 1978--------------	1,570	754	361

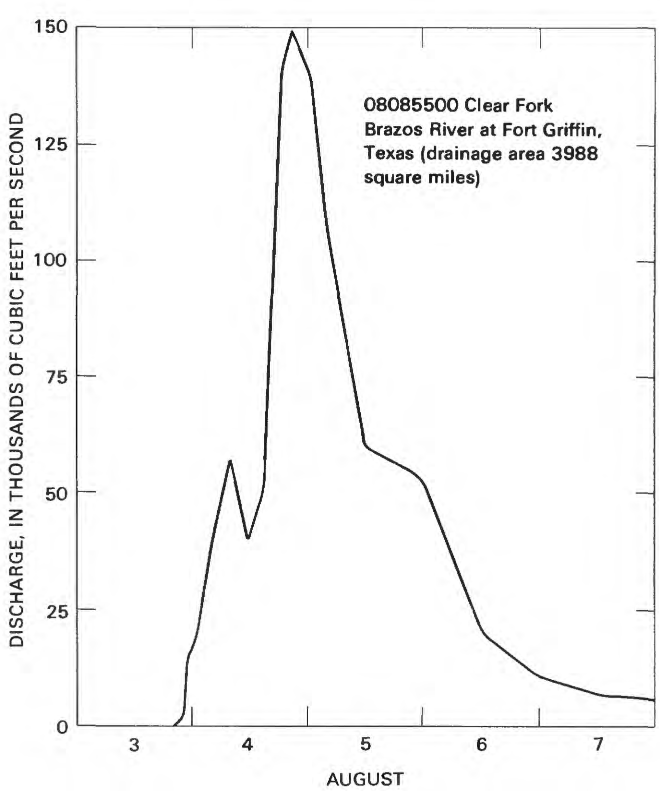


FIGURE 22.—Discharge hydrograph of Clear Fork Brazos River at Fort Griffin for August 3–7, 1978.

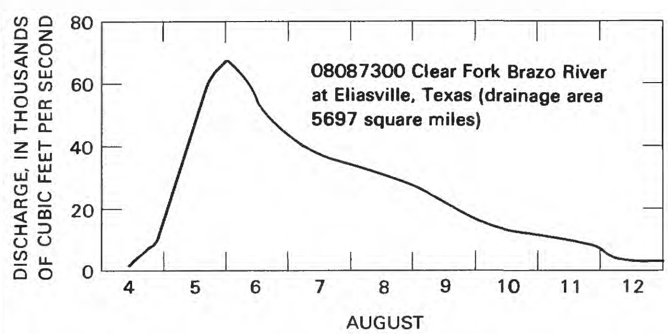


FIGURE 23.—Discharge hydrograph of Clear Fork Brazos River at Eliasville for August 4–12, 1978.

Serious flooding developed on the Clear Fork Brazos River as a result of heavy runoff from tributaries upstream from Hubbard Creek. California Creek near Stamford (site 14), which has a drainage area of 478 mi², had a peak discharge of 40,000 ft³/s. The gaging station on the Clear Fork Brazos River at Fork Griffin (site 16) recorded a peak discharge of 149,000 ft³/s, and the stage exceeded the previously known maximum stage by 0.88 ft. When the flood crest reached the gaging station at Eliasville (site 23), 13.2 mi upstream from the main stem of the Brazos River, the peak discharge had attentuated to 68,000 ft³/s. A discharge hydrograph for Clear Fork Brazos River at Fort Griffin is shown in figure 22, and data are presented in table 12. A discharge hydrograph for Clear Fork Brazos River at Eliasville is shown in figure 23, and data are presented in table 13.

TABLE 11.—*Data for gaging station 08086212 Hubbard Creek below Albany*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 3 -	0400	3.31	0.00	Aug. 4 -	0300	39.89	189,000	Aug. 5 -	0600	23.30	14,400
	0600	3.81	3.8		0400	41.41	330,000		0800	18.00	7,920
	1200	4.04	6.9		0430	41.15	300,000		1000	11.40	2,970
	1300	7.37	681		0500	40.29	218,000		1200	9.40	1,840
	1500	8.13	1,020		0600	40.33	221,000		1800	7.80	942
	1800	9.74	1,980		0700	40.19	210,000		2400	7.19	657
	2100	12.72	3,760		0730	40.39	226,000				
	2200	18.01	7,890		0800	40.01	196,000	Aug. 6 -	1200	6.52	391
	2300	23.88	15,300		1000	38.11	112,000		2400	6.04	250
	2400	30.17	26,300		1200	35.72	56,000				
					1500	32.44	33,700	Aug. 7 -	1200	5.65	164
Aug. 4 -	0100	35.79	56,700		1800	29.94	25,900		2400	5.40	122
	0200	38.29	118,000		2400	27.67	21,600				

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	94,700	34,400	14,800
1967 to July 1978--------------	20,100	14,600	6,670

TABLE 12.—*Data for gaging station 08085500 Clear Fork Brazos River at Fort Griffin*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 3 -	2100	1.54	0	Aug. 4 -	1700	38.10	108,000	Aug. 6 -	2400	28.05	10,400
	2200	6.28	1,360		1900	38.81	142,000				
	2300	19.20	13,900		2100	38.88	149,000	Aug. 7 -	1200	21.55	7,340
	2400	25.20	16,900		2400	38.76	141,000		2400	16.15	5,160
Aug. 4 -	0100	28.81	20,800	Aug. 5 -	0400	38.18	107,000	Aug. 8 -	1200	13.17	4,040
	0500	35.66	43,200		1200	36.75	59,600		2400	11.48	3,360
	0800	36.56	57,000		2400	34.40	28,600				
	1200	35.58	39,500					Aug. 9 -	1200	10.18	2,850
	1500	36.32	52,000	Aug. 6 -	1200	32.80	20,800		2400	9.19	2,500

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	72,800	53,500	25,400
1925 to July 1978--------------	30,800	24,000	15,300

TABLE 13.—*Data for gaging station 08087300 Clear Fork Brazos River at Eliasville*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 4 -	0030	7.56	0.04	Aug. 5 -	1800	36.63	61,900	Aug. 8 -	2400	30.51	27,500
	0500	7.84	.93		2400	36.98	67,100				
	0600	7.98	4.3					Aug. 9 -	1200	27.83	21,900
	0700	8.25	29	Aug. 6 -	0100	37.04	68,000		2400	24.53	16,100
	0900	8.72	132		0200	36.93	66,300				
	1000	9.10	289		0600	36.71	63,100	Aug. 10-	1200	22.01	12,700
	1100	10.25	1,160		1200	36.08	54,500		2400	20.37	11,300
	1200	11.29	2,920		1800	35.48	47,400				
	1400	12.40	4,570		2400	34.92	43,300	Aug. 11-	1200	18.22	9,630
	1900	16.90	8,650						2400	15.20	7,310
	2400	24.19	15,600	Aug. 7 -	1200	34.05	37,600				
					2400	33.24	34,800	Aug. 12-	0400	12.28	4,420
Aug. 5 -	0600	31.70	30,200						1200	11.23	2,820
	1200	35.44	47,100	Aug. 8 -	1200	32.10	31,300		2400	10.83	2,040

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	55,200	46,400	30,700
1917 to July 1978--------------	32,400	23,200	16,600

Some tributaries to the Brazos River upstream from the Clear Fork Brazos River also experienced high rates of runoff. Millers Creek near Munday (site 2), which has a drainage area of 104 mi^2, had a peak discharge of 34,600 ft^3/s. Discharge hydrographs for Millers Creek near Munday and California Creek near Stamford are shown in figure 24, and data are presented in tables 14 and 15, respectively.

The streamflow gaging station on the Brazos River near South Bend (site 24), 1.8 mi downstream from the Clear Fork Brazos River, has a peak discharge of 78,100 ft^3/s. Although this discharge was exceeded by a flood that occurred in May 1941, the peak stage (41.5 ft) was the greatest to occur since at least 1876. Because of changes in the stage-discharge relationship, the peak stage of the August 1978 flood exceeded that of May 1941 by about 14 ft.

Major flooding occurred along the Brazos River from South Bend to Possum Kingdom Reservoir. Possum Kingdom Reservoir was 6.6 ft below the normal pool level before the heavy runoff began. Releases from the reservoir by the Brazos River Authority, in anticipation of the approaching flood wave, reduced the crest of the flood and effectively prevented a more serious flood from occurring downstream.

Flood damages in the Brazos River basin downstream from Possum Kingdom Reservoir were minimal. Flooding did not occur on the Brazos River downstream from Lake Whitney, where sufficient storage capacity was available to contain the floodwaters.

MAGNITUDE AND FREQUENCY OF THE FLOODS

The relationship of flood-peak magnitude to the probability of occurrence, or recurrence interval, generally is referred to as a flood-frequency relation. The probability of occurrence is the percent chance of a given flood magnitude being exceeded in any 1 year. The recurrence interval, which is the reciprocal of the probability of occurrence multiplied by 100, is the average number of years between exceedances. It is emphasized that the recurrence interval is an average interval and that the occurrence of floods is assumed to be random in time; no schedule of regularity is implied. The occurrence of a flood having a 50-year recurrence interval (2-percent chance of occurrence) is no guarantee, therefore, that a flood of equal or greater magnitude will not occur the following year, or even the following week.

TABLE 14.—*Data for gaging station 08082700 Millers Creek near Munday*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 4 -	0300	0.52	0	Aug. 4 -	1400	17.53	34,600	Aug. 5 -	2400	12.63	790
	0400	.52	1.0		1500	17.34	30,600				
	0500	1.01	2.0		1600	17.05	25,400	Aug. 6 -	0600	11.27	589
	0600	2.76	32		1800	16.32	15,600		1200	8.35	366
	0800	3.96	82		2200	15.58	8,910		1800	4.49	114
	0900	5.84	216		2400	15.40	7,690		2400	3.08	42
	1000	8.45	372								
	1100	10.94	555	Aug. 5 -	0600	14.95	5,280	Aug. 7 -	0600	2.53	25
	1200	13.86	2,080		1200	14.18	2,750		1800	1.99	13
	1300	17.07	25,700		1800	13.52	1,530		2400	1.78	9.9

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	8,730	4,160	1,790
1964 to July 1978--------------	973	802	376

TABLE 15.—*Data for gaging station 08084800 California Creek near Stamford*
[Gage height, in feet, and discharge, in cubic feet per second, at indicated time, 1978]

Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge	Date	Hour	Gage height	Discharge
Aug. 3 -	1000	6.38	0.44	Aug. 4 -	0200	29.25	15,700	Aug. 5 -	0600	24.82	4,640
	1100	6.67	6.3		0400	30.20	24,800		0900	21.00	2,500
	1200	7.38	44		0600	30.94	38,600		1200	15.20	941
	1400	8.40	107		0700	31.00	40,000		1500	12.25	485
	1600	10.33	270		0800	30.92	38,200		2000	10.13	251
	1800	13.14	600		1200	30.07	23,000		2400	9.38	185
	2000	16.31	1,190		1500	29.34	16,400				
	2200	24.38	4,260		2000	28.14	10,500	Aug. 6 -	0400	8.37	105
	2400	27.90	9,670		2400	27.17	7,550		0800	7.73	64
									1200	7.33	40
									2400	7.30	38

Period	*Highest mean discharge, in cubic feet per second, for the indicated number of consecutive days* 1	3	7
August 1978--------------------	20,400	7,860	3,380
1963 to July 1978--------------	5,820	4,950	3,040

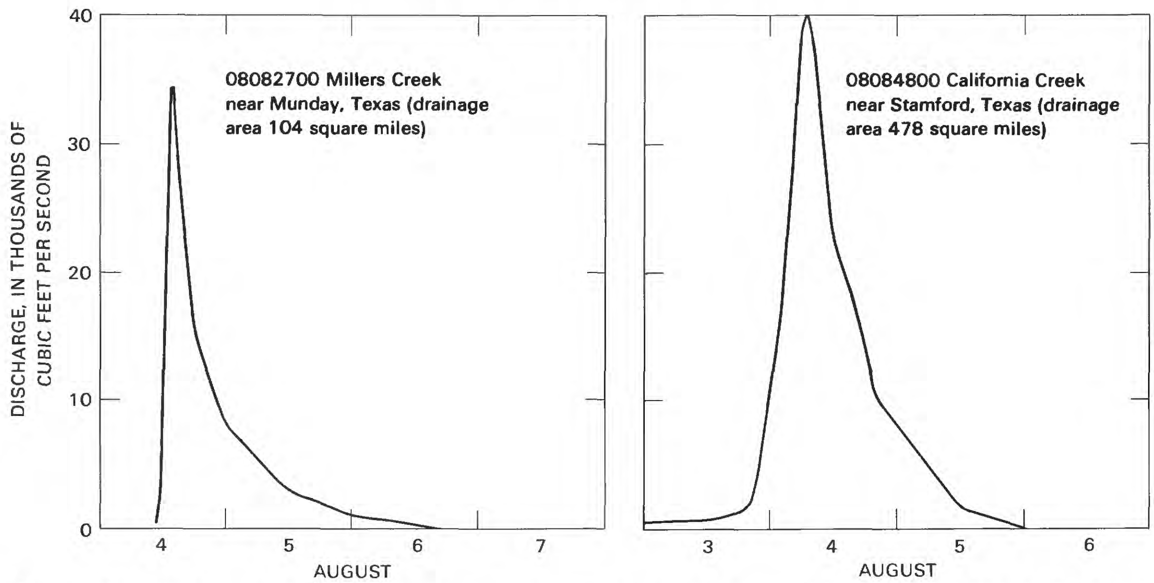


FIGURE 24.—Discharge hydrographs of Millers Creek near Munday for August 4–7, 1978, and California Creek near Stamford for August 3–6, 1978.

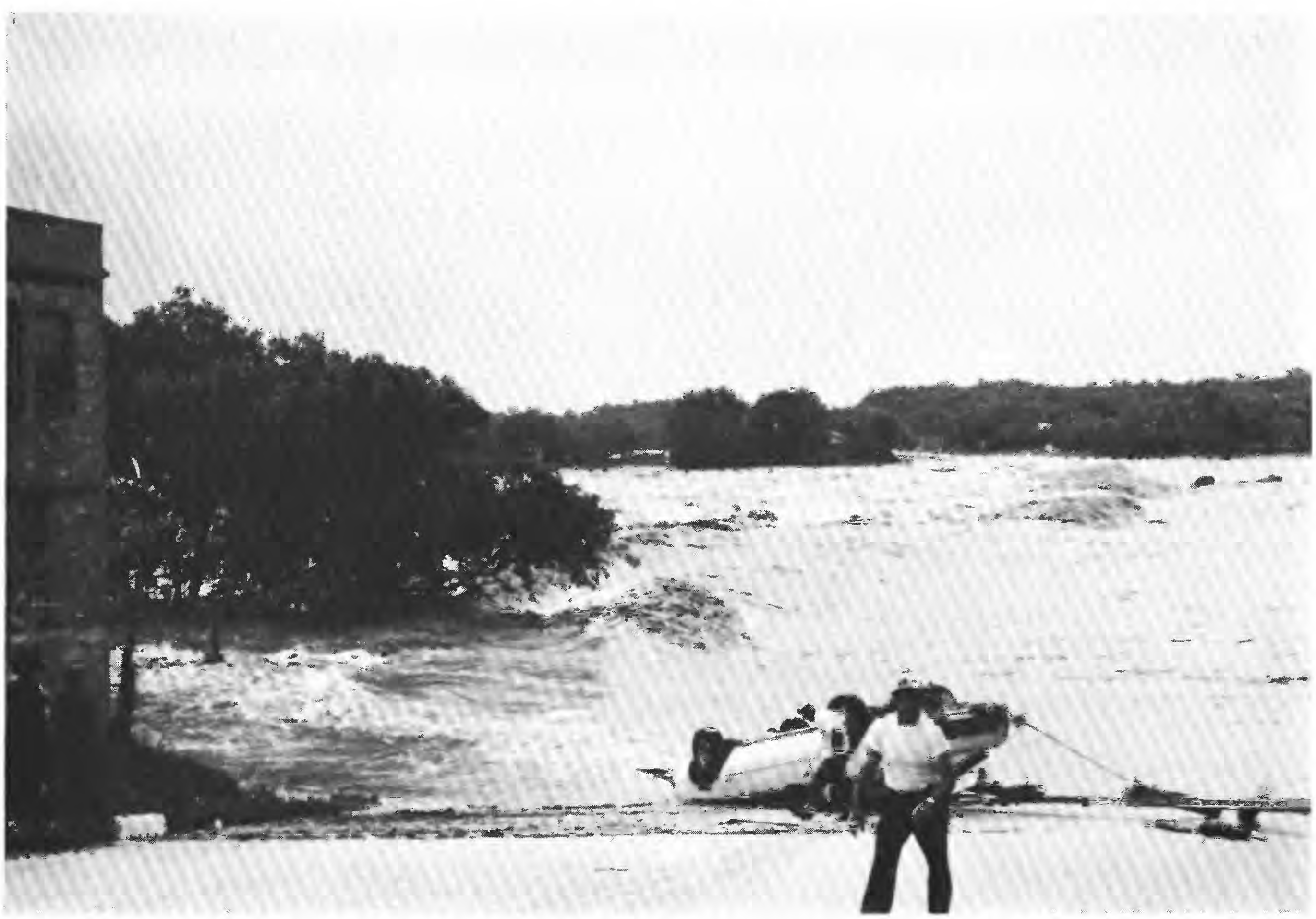


FIGURE 25.—Inundation of State Highway 173 and the Medina River bridge at Bandera.

FIGURE 26.—State Highway 290 flooded by Spring Creek near Fredericksburg.

Recurrence intervals of peak discharges on the Clear Fork Brazos River, Guadalupe River above Canyon Lake, and Medina River above Medina Lake were greater than 100 years. The peak discharge for Spring Creek near Fredericksburg (site 66) was 3.8 times the magnitude of the 100-year regional flood. Flood-frequency data are presented in table 4 for all stations in the flood area that experienced floods with frequencies of 10 years of more.

FLOOD DAMAGE

Seventeen counties in central Texas sustained widespread damages from the floods associated with tropical storm Amelia (National Oceanic and Atmospheric Administration, 1978). Eight of these counties (Bandera, Kendall, and Kerr Counties in south-central Texas, and Haskell, Shackelford, Stephens, Throckmorton, and Young Counties in north-central Texas) were declared flood-disaster areas by the Federal government. Ironically, Bandera, Kendall, and Kerr Counties had been declared drought-disaster areas prior to the floods.

In Bandera, Kendall, and Kerr Counties, 25 people were drowned, about 150 people were injured, and property damages were estimated to be at least 50 million dollars. About 175 homes were destroyed or damaged. Public utilities were disrupted in much of the area and many roadways and bridges were heavily damaged. The bridge on State Highway 173 over the Medina River at Bandera, which was designed to withstand the 50-year flood, was inundated by 18 ft of water (fig. 25). The damage to livestock and crops, to farm and ranch facilities, and to farm and pasture lands was extremely heavy.

Much damage was sustained in Gillespie and Kimble Counties in south-central Texas. Two people were drowned when Spring Creek inundated the bridge on State Highway 290 west of Fredericksburg (fig. 26). Many roadways, bridges, and farm and ranch lands were extensively damaged.

In Haskell, Shackelford, Stephens, Throckmorton, and Young Counties in the Brazos River basin in north-central Texas, the flood damage was comparable to the damage in south-central Texas. Six people were drowned, four were injured, and property damages were estimated to be at least $62 million. About 750 homes and 75 businesses were destroyed or damaged (fig. 27), and the damages to livestock, crops, and farm and ranch lands were extremely severe. In Haskell County alone, these damages were estimated to be about $30 million.

In the total area affected by the storm, 33 people were drowned and 154 were injured. Property damages were estimated to be more than $110 million.

FIGURE 27.—Aerial view of the Brazos River in flood at Graham.

SUMMARY

The catastrophic floods in central Texas during August 1–4, 1978, were the result of two separate major storms of different origin and distinguishable time and geographical context but with some shared features. The presence of very moist maritime air that originated in the Gulf of Mexico and the presence of positive vorticity advection preceded the outbreak of both storms. In the case of the storm of August 1–3 over the hill country of south-central Texas, moist Gulf air initially was brought into the area by the cyclonic circulation of the remnant of tropical storm Amelia. The storm of August 3–4 over the upper Brazos River basin in north-central Texas resulted from the interaction of a cold front with the maritime air mass that penetrated deeply into north-central Texas.

Major flooding of the hill country in south-central Texas occurred on the Medina River and its tributaries above the Medina Lake and on the Guadalupe River and its tributaries above Canyon Lake. Moderate to severe flooding occurred on tributaries of the Nueces River, on Clear Fork Brazos River and its tributaries, and on the Llano and Pedernales Rivers, which are tributaries of the Colorado River. Peak discharges at several streamflow stations exceeded the historic peaks. The highest unit discharge observed was 3,010 $ft^3/s/mi^2$ from the 14.1-mi^2 drainage area of Spring Creek, which is a tributary of the Perdanales River. In the upper Brazos River basin in north-central Texas, 6 ft of water inundated the town of Albany on a tributary of Clear Fork Brazos River. Floodwater opened gaps in the earthen dam of Albany Reservoir and overtopped the spillway at Lake Throckmorton.

Thirty-three lives were lost and total damages reportedly exceeded $110 million.

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