FLOODS IN KANSAS CITY, MISSOURI AND KANSAS, SEPTEMBER 12-13, 1977

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

U.S. DEPARTMENT OF THE INTERIOR • U.S. DEPARTMENT OF COMMERCE

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1169

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By LELAND D. HAUTH and WILLIAM J. CARSWELL, JR., U.S. Geological Survey, and EDWIN H. CHIN, National Weather Service, National Oceanic and Atmospheric Administration

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CONTENTS

ILLUSTRATIONS

TABLES

GLOSSARY

Bed material. The sediment mixture of which the moving bed is composed.

Continuous-record station. A site on a stream where continuous records of discharge are obtained.

Cubic feet per second (ft^3/s). The rate of discharge; one ft^3/s is the rate of discharge of a stream having a cross-sectional area of 1 square foot and an average velocity of 1 ft per second:

$1\ ft^3/s = 0.646$ million U.S. gallons per day, 28.32 L/s or 0.02832 m^3/s.

Dew point (or dew point 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.

Fine material. That part of the total stream sediment load composed of sizes not found in appreciable quantities in the bed material; normally, the silt and clay sizes (less than 0.062 mm).

Flood hydrograph. A graphical representation of a stream's fluctuation in flow (in cubic feet per second) arranged in chronological order.

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 a flood, plotted as ordinate, against distance, measured in the upstream direction, plotted as abscissa.

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

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

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

Jet stream. Relatively strong winds concentrated within a narrow stream in the atmosphere.

Miscellaneous site. A site where data pertaining to a specific hydrologic event are obtained.

Moist tongue. An extension or protrusion of moist air into a region of lower moisture content.

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

Particle size. The diameter of a particle measured by settling, sieving, micrometric, or direct measurement methods.

NGVD. National Geodetic Vertical 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 adjustments, sea levels from selected tide stations in both countries were held as fixed.

Particle-size distribution. The relative amount of sediment sample having a specific size, usually in terms of percent by weight finer than a given size, *D* percent.

Radiosonde. A miniature radio transmitter that is carried aloft (as by an unmanned balloon) with instruments for broadcasting humidity, temperature, and pressure.

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

Rainfall mass curve. A graph of the accumulated rainfall depth, plotted as an ordinate, against time or duration of storm, plotted as abscissa; the curve represents total precipitation depth throughout the storm.

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. For example, a 50-year flood discharge will be exceeded on the average of once in 50 years. In terms of probability, there is a 2-percent chance that such a flood will occur in any year.

Ridge. An elongated area of relatively high atmospheric pressure.

Saturation. The condition in which the partial pressure of water vapor is equal to its maximum possible partial pressure under the existing environmental conditions.

Sediment. Solid particles usually derived from rocks or earth material that have been or are being transported laterally or vertically from one or more places of origin.

Sounding. A single complete radiosonde observation of the upper atmosphere.

Squall line. Any nonfrontal line or narrow band of active thunderstorms; a mature instability line.

Total Total Index. A measure of air mass static stability, TT, given by: $TT = T_{850} + T_{d,850} - 2T_{500}$
where T and T_d are temperature and dew point, respectively, in degrees Celsius; and the subscripts denote pressure level in millibars. A Total Total Index exceeding 50 is favorable to the occurrence of severe thunderstorms.

Through. An elongated area of relatively low atmospheric pressure.

Vapor pressure. The pressure exerted by the molecules of a given vapor; in meteorology, this term is used exclusively to denote the partial pressure of water vapor.

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 inch-pound units	*by*	*To obtain SI units*
inches (in.)	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
yards (yd)	0.9144	meters (m)
miles (mi)	1.609	kilometers (km)
nautical miles (nmi)	1.85	kilometers (km)
knots (kn)	1.85	kilometers per hour (km/h)
acres	4,047	square meters (m^2)
acres	0.4047	hectares (ha)
square miles (mi^2)	2.590	square kilometers (km^2)
acre-feet (acre-ft)	1,233	cubic meters (m^3)
acre-feet (acre-ft)	1.233×10^{-3}	cubic hectometers (hm^3)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
gallons (gal)	3.785×10^{-3}	cubic meters (m^3)
degrees Fahrenheit (°F)	$5/9\ (F - 32)$	degrees Celsius (°C)

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By LELAND D. HAUTH and WILLIAM J. CARSWELL, JR., U.S. Geological Survey,
and EDWIN H. CHIN, National Weather Service, National Oceanic and Atmospheric Administration

ABSTRACT

The storms of Sept. 12–13, 1977, delivered as much as 16 in. of rain, with average rainfall exceeding 10 in. in the Kansas City metropolitan area. Twenty-five lives were lost, many were left homeless, and damages exceeded $80 million.

Data obtained by the National Weather Service and the U.S. Geological Survey indicate that two record-setting rainstorms occurred within 24 hours. The first storm, in the early morning, thoroughly soaked the local drainage basins. The second storm, centered along the Brush and Round Grove Creek basins, resulted in a devastating flash flood. Peak discharges were determined during and after this major flood at gaging stations and selected miscellaneous locations. Streamflows and flood volumes in many locations far exceeded estimated values for the 100-year flood.

INTRODUCTION

Outstanding floods occurred on streams in the Kansas City, Mo.-Kans., area as a result of two separate rainfall events occurring 8–12 h apart, each of which exceeded the 100-year 24-h rainfall. A total of up to 16 in. of rain fell in some sections of the metropolitan area. The first storm saturated the ground and caused a greater part of the second rainfall to run off, resulting in peak discharges well in excess of the 100-year recurrence interval in some areas.

These storms extended over parts of western Missouri, northeastern Kansas, and southeastern Nebraska. However, the heaviest rainfall was in Kansas City and vicinity. The metropolitan area received an average rainfall in excess of 10 in. for the two events. The heaviest rain fell east of the city, just south of Independence, Mo., and along Brush Creek to the south and west, including its headwater areas in Kansas.

Peak discharges were computed for many locations by indirect methods, because the rapid rise and fall of the floodwaters did not permit real-time measurement with current meters. These computations were made after the flood from data that was obtained by carefully measuring high-water marks and the geometry of the hydraulic structures and channels.

Twenty-five persons lost their lives and damages exceeded $80 million. Although many homes and businesses suffered losses throughout the storm area, the major economic damage occurred in the Brush Creek basin of Missouri and Kansas and within the lower Blue River basin downstream from the mouth of Brush Creek (see fig. 2). Upstream from the U.S. Geological Survey gaging station on Brush Creek, the Country Club Plaza received national attention because of extensive flood damages to its numerous shops.

PURPOSE AND SCOPE

This report is one of a continuing series of joint flood reports undertaken by the National Weather Service in the National Oceanic and Atmospheric Administration of the Department of Commerce, and by the U.S. Geological Survey in the Department of the Interior.

Data collected by the National Weather Service document the meteorological settings associated with the extreme precipitation and the distribution of rainfall. Materials presented in this report include related weather maps, atmospheric soundings, rainfall mass curves, and ishoyetal analyses.

Streamflow data collected by the U.S. Geological Survey present surface runoff including rates of flow and total flood volume. These data include peak stages and discharges, discharge hydrographs, water-surface profiles of selected stream reaches, and flood volumes. Elevations are referred to National Geodetic Vertical Datum of 1929 (NGVD).

Compilation of all pertinent meteorological and hydrological analyses related to the flood in this one report is intended to provide convenient reference for hydraulic planning. Analysis of such outstanding flood events can aid in promoting prudent development within any river basin where the threat of severe flooding exists.

ACKNOWLEDGMENTS

Elevations for water-surface profiles of Brush Creek, Rock Creek (Kans.), Blue River, and Little Blue River were provided by the U.S. Army Corps of Engineers, Kansas City District. The Corps also provided personnel for field assistance. Photographs of the Plaza area were taken by Frederick Solberg, Jr., and William H. Batson, Kansas City Star photographers.

DESCRIPTION OF THE FLOOD AREA

This report encompasses the Kansas City metropolitan area and extends 15 mi eastward. This area comprises about 1,000 mi² (fig. 1). The region most affected by the storm consisted of drainage basins of the Blue River with Brush Creek as one of its tributaries, the Little Blue River, and Sni-A-Bar Creek, all emptying into the Missouri River within a 40-mi reach (fig. 2).

Streamflows shown in this report reflect runoff from both urban and rural areas. The metropolitan area includes approximately 60 percent of the area shown in figures 1 and 2. The Brush Creek basin (main site of the Plaza area damage) is completely urbanized, while the Sni-A-Bar Creek basin is rural. The other drainage basins included in this report lie somewhere between these extremes, with only part of each basin being urbanized.

METEOROLOGICAL SETTING AND PRECIPITATION DISTRIBUTION

At 1800 c.s.t., Sept. 11, 1977, a weak Low was located over western Kansas. A warm front associated with the Low was about 300 mi southwest of Kansas

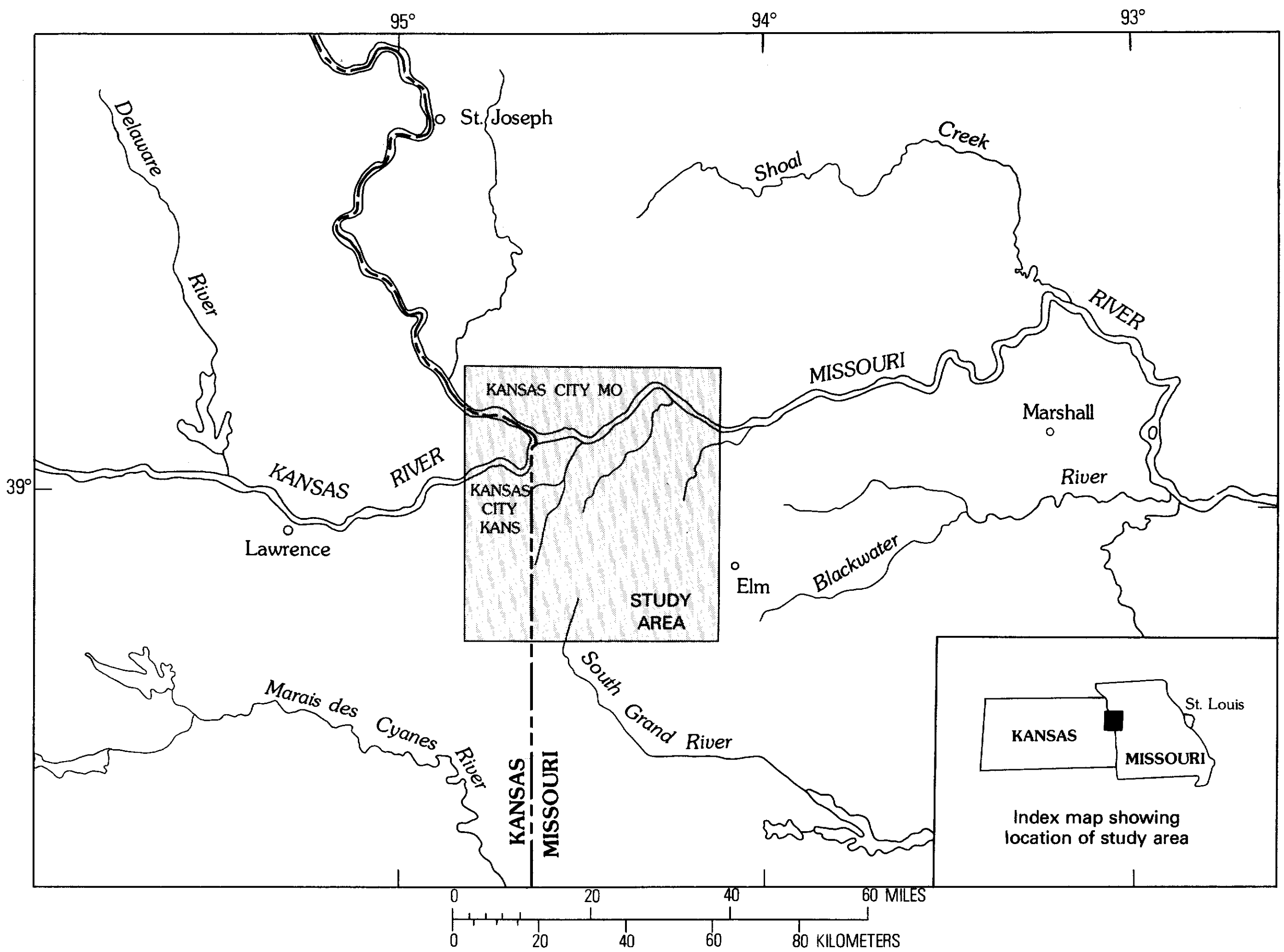


FIGURE 1.—Location of area of flooding in Missouri and Kansas.

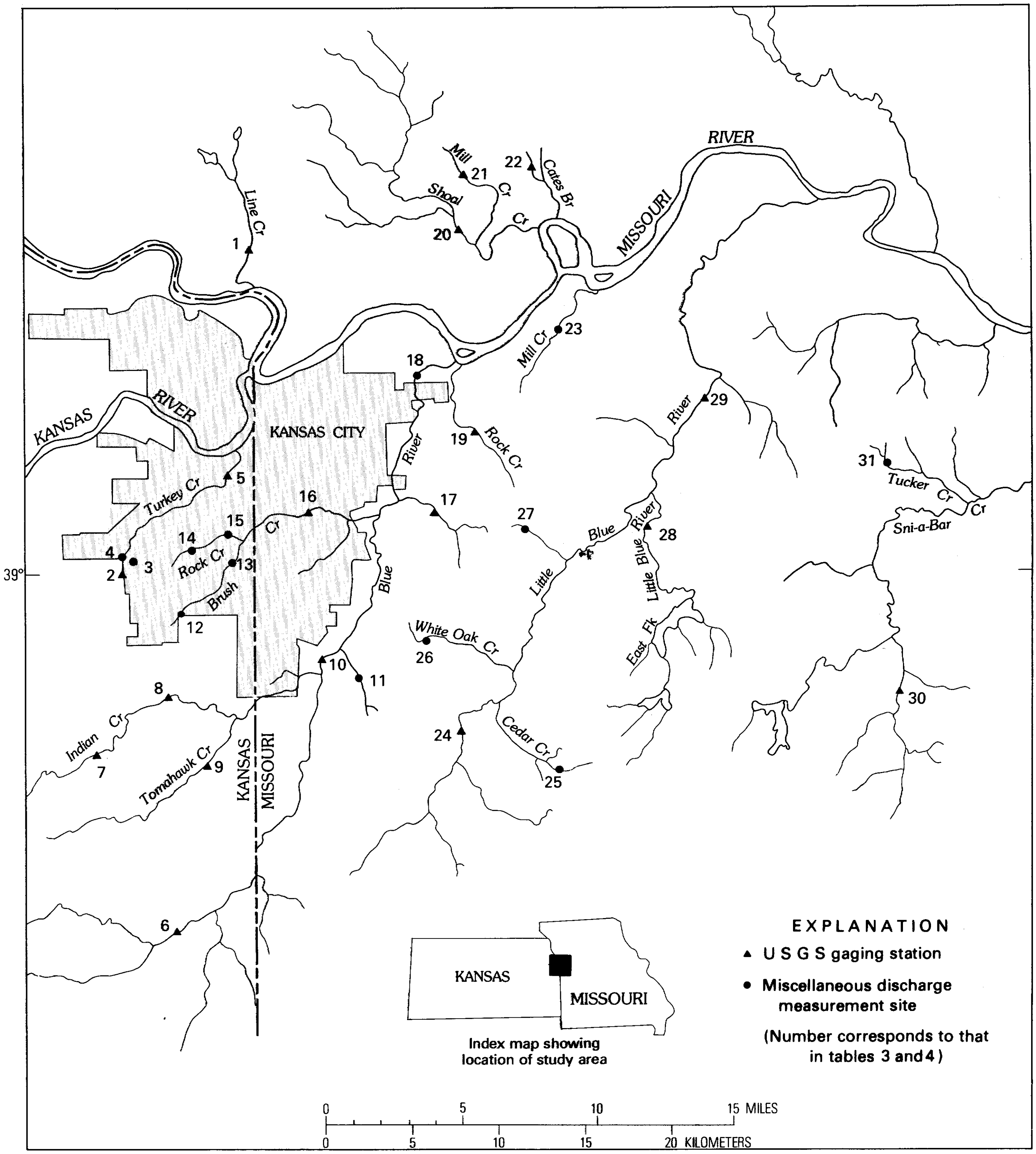


FIGURE 2.—Flood area and location of flood-determination points.

City. During that night, the wind field over the southern Great Plains was characterized by a low-level jet with strongest southwesterly winds impinging aloft on the sloping frontal surface south of the Kansas City area. Strong warm advection brought in warm moist air below the 700-mb level into eastern Kansas and western Missouri. By 0600 c.s.t., Sept. 12, the warm advection had extended to the 500-mb level. The arrival of the warm moist air mass was indicated by a very small dew-point depression of 1°C at both 850-mb and 700-mb levels in the vicinity of Kansas City in the morning. As the northwesterly flow of colder air from the mountain states met the warm moist gulf air coming from the southeast, a cold front was formed. This cold front was associated with the Low centered over western Kansas. The Low with its associated frontal system gradually progressed eastward towards Kansas City. The surface, 700-mb, and 500-mb analyses at 0600 c.s.t. are shown in figures 3*A*, 3*B*, and 3*C*, respectively.

Temperature, moisture, and wind distributions in the upper atmosphere are routinely probed by rawinsonde at selected stations. The rawinsonde station nearest to Kansas City is at Topeka, Kans. Upper-air soundings there for 0600 and 1800 c.s.t., Sept. 12, are shown in figure 4. Figure 4*A* shows that the air was moist through a deep layer from the surface up to 570 mb, capped by a dry layer. Strong warm advection existed from the surface to above 700 mb. The inversion below 800 mb indicated a diffuse frontal transition zone. This was consistent with the fact that the surface front was south of Topeka at that

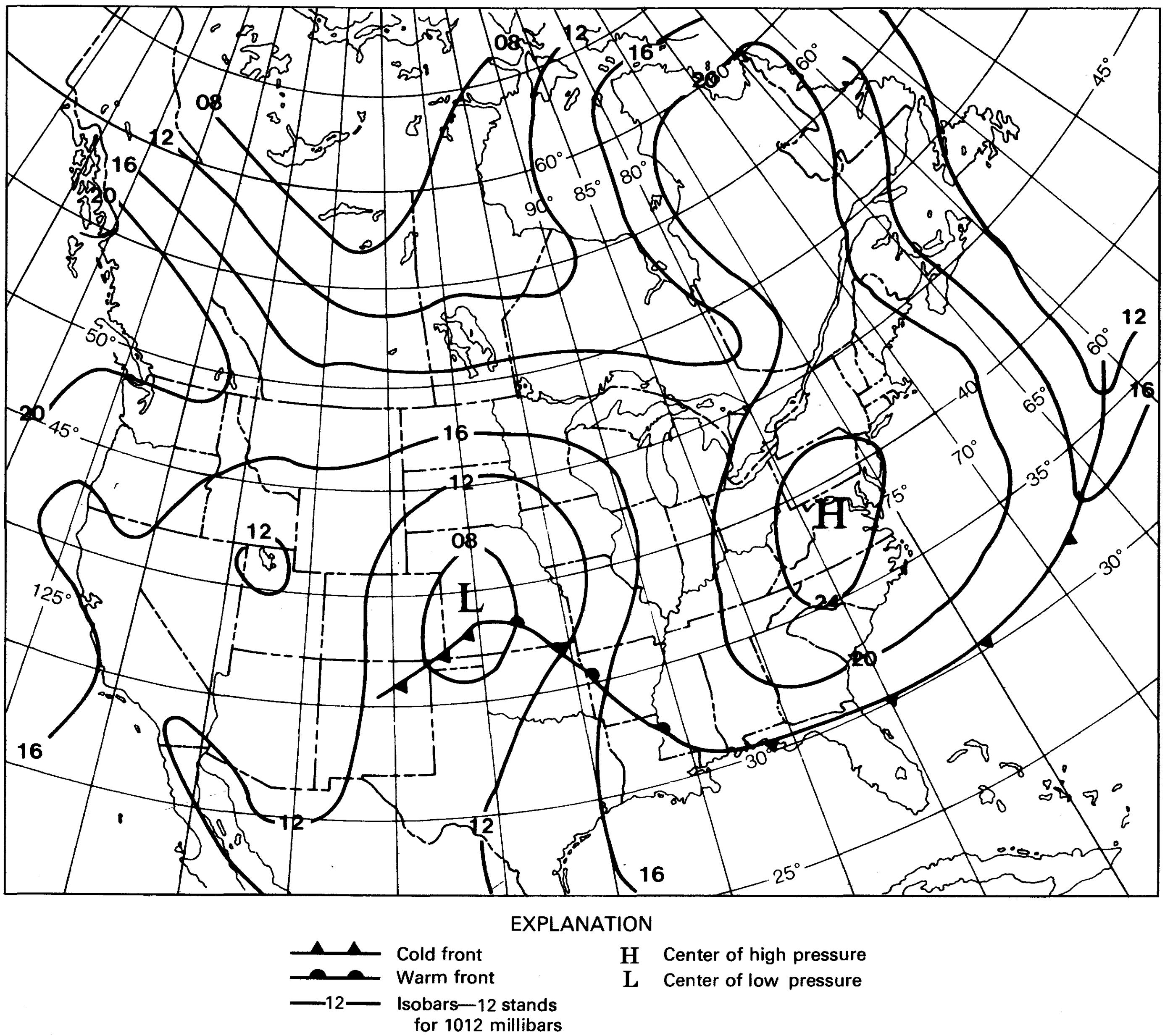
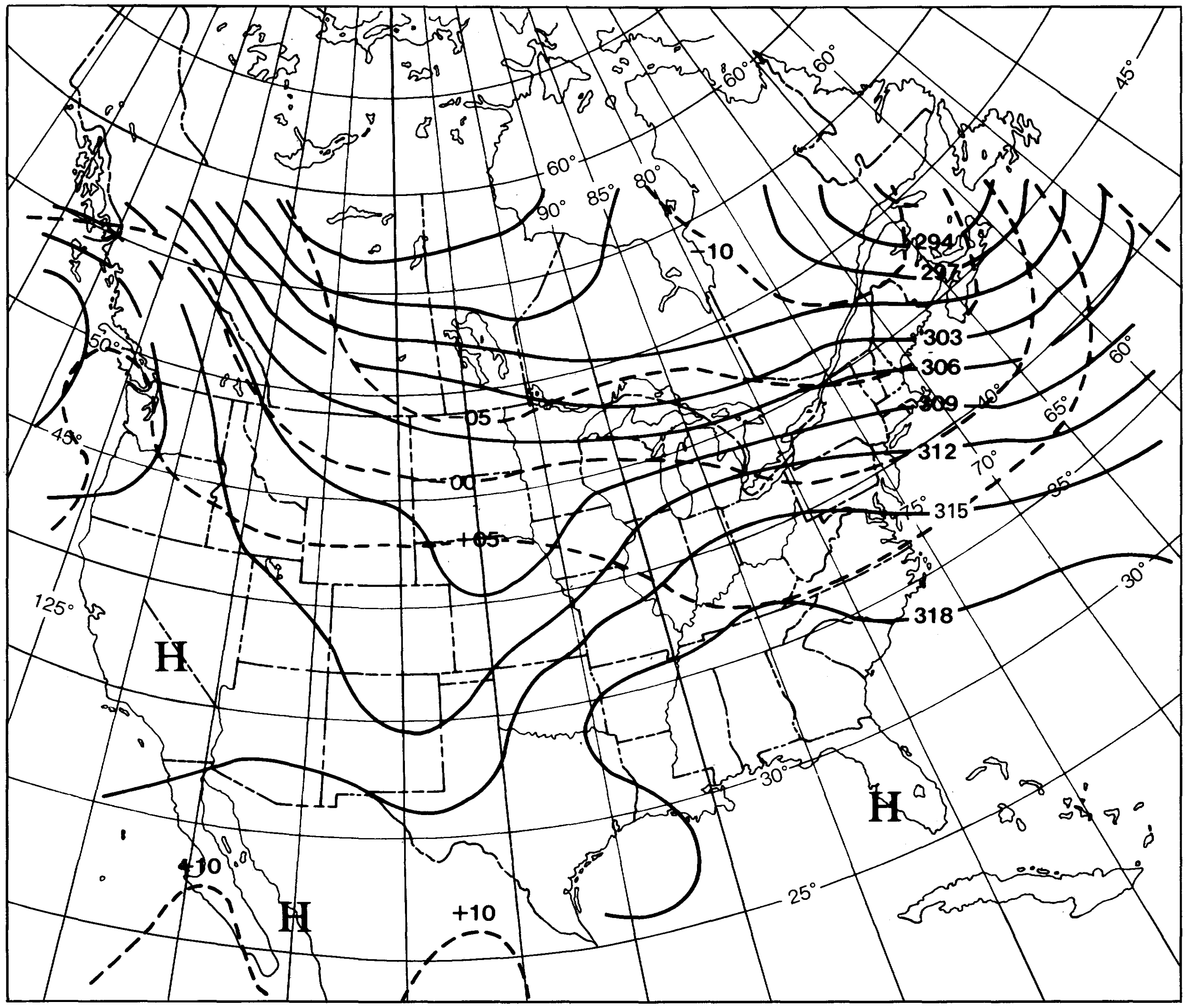


FIGURE 3.—*A*, Surface analysis 0600 c.s.t., Sept. 12, 1977.



EXPLANATION

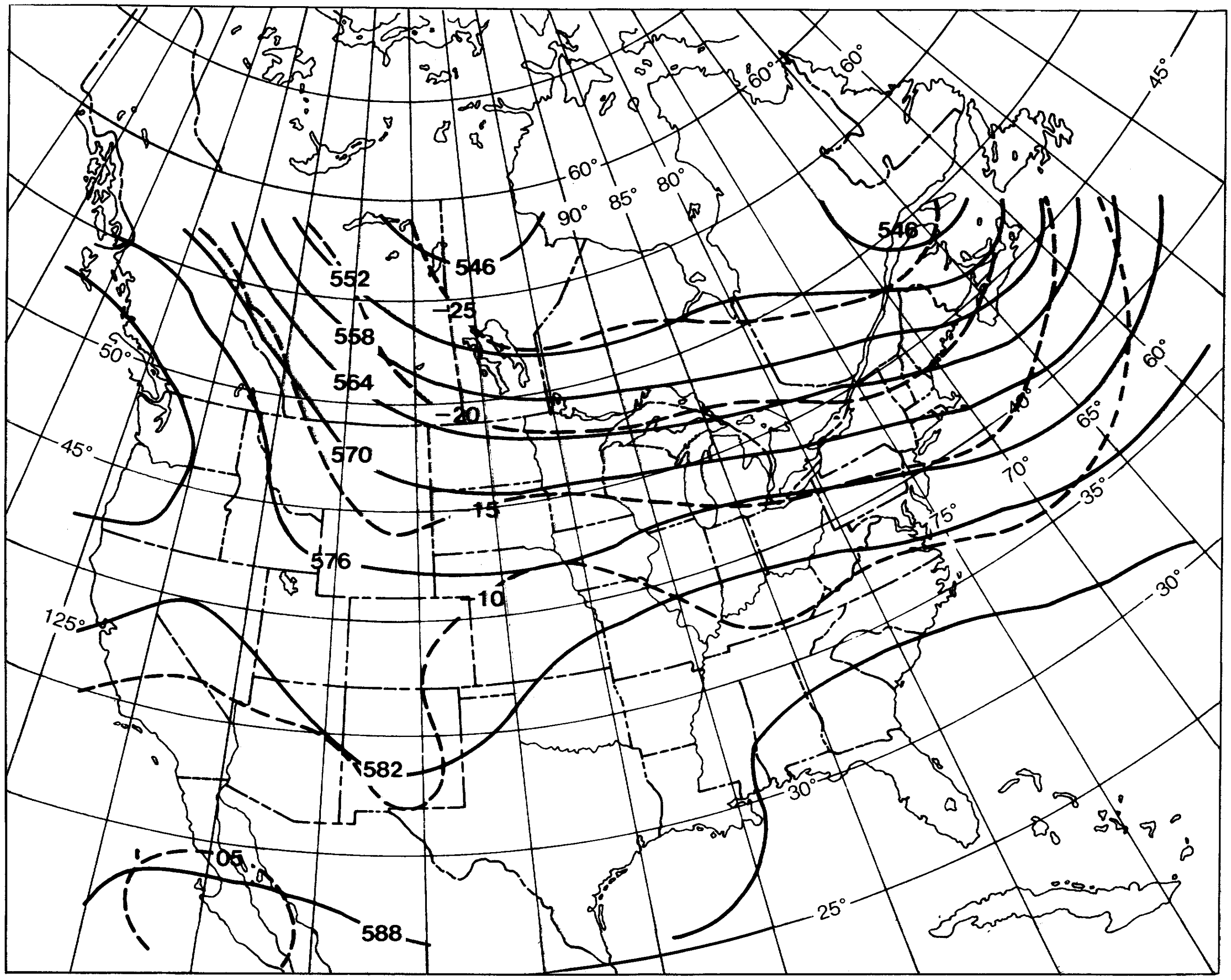
—306— Contour in decameters
306 stands for 3060 meters

H Center of contour height

--+10-- Temperature, degrees Celsius

FIGURE 3.—Continued. *B*, 700-mb analysis 0600 c.s.t., Sept. 12, 1977.

ime (fig. 3*A*). Figure 4*B* shows a moderately moist lower and midlayer capped by an inversion at about 670 mb and a very dry layer above. These soundings indicated that the low level southerly flow brought in moist air from the Gulf. Aloft the advection of much drier air from the northwest by the midtropospheric jet stream provided another ingredient for generation of instability. The presence of an inversion around 670 mb at 1800 c.s.t. prevented deep convective overturning initially so that a progressive increase of instability could occur. Instead of being inhibiting factors, these are, in fact, contributing factors favorable to the development of intense convection. Even though Topeka, Kans., was not at the center of storm rainfall, the soundings should represent atmospheric structure in the fringe area during the latter part of the first storm (fig. 4*A*) and prior to the beginning of the second storm (fig. 4*B*).



EXPLANATION

—576— Contour in decameters 576 stands for 5760 meters

– –10– – Temperature, degrees Celsius

FIGURE 3.—Continued. *C*, 500-mb analysis 0600 c.s.t., Sept. 12, 1977.

The integrated 12-h vertical displacement of the air parcel terminating at 700 mb indicates the degree of large-scale atmospheric vertical motion. Sinking motion, or subsidence, is generally associated with good weather. On the other hand, vigorous rising motion provides a favorable environment for storms to develop. 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 it is. In general, a K Index greater (less) than 35 (20) is associated with numerous (no) thunderstorms. Both parameters are computed using the NWS Three-Dimensional Trajectory Model in a 24-h forecast mode. The evolution of these parameters in the vicinity of Kansas City over the 48-h period is shown in table 1.

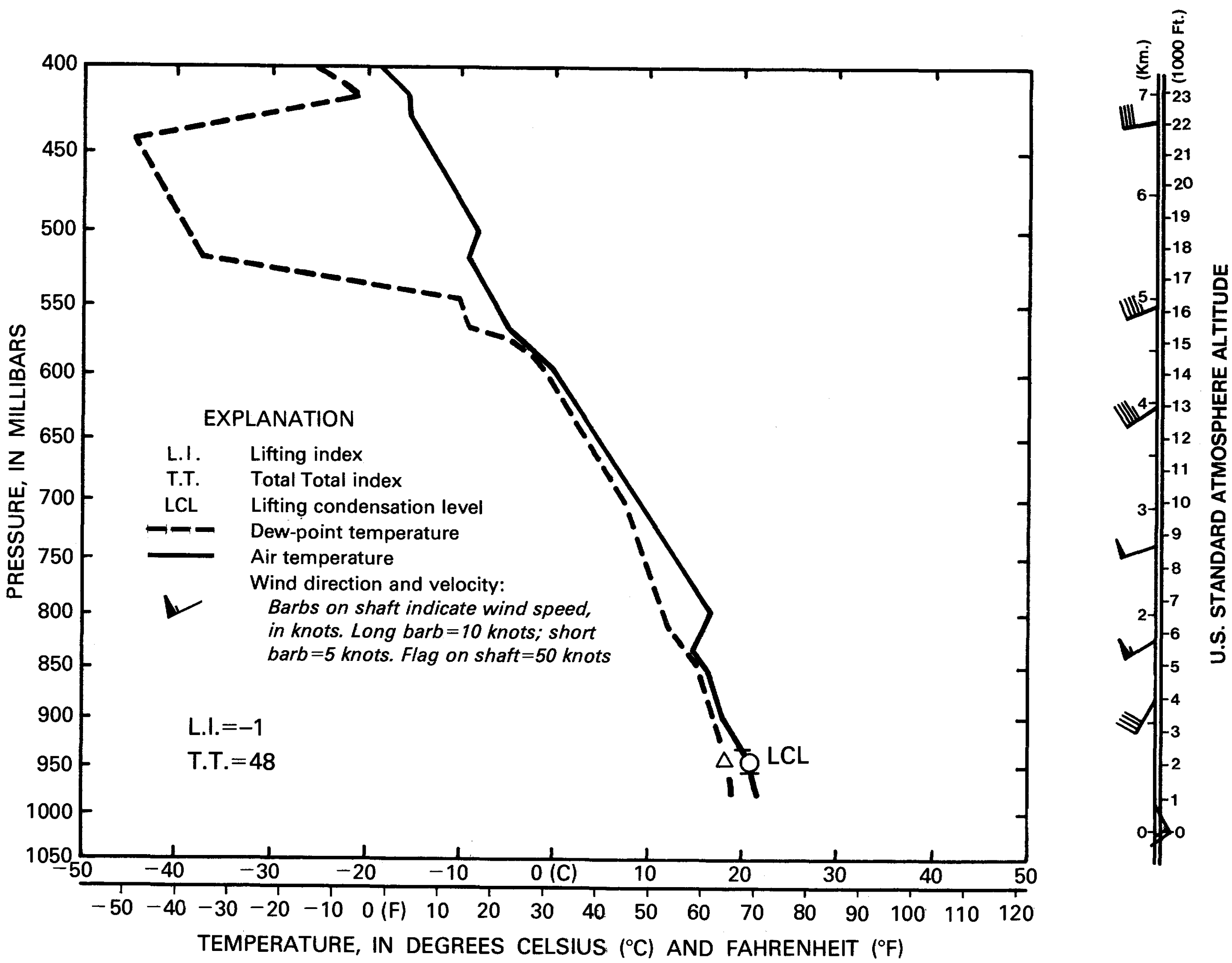


Figure 4.—*A*, Rawinsonde profile at Topeka, Kans., 0600 c.s.t., Sept. 12, 1977.

Table 1.—*K Index and 12-h net vertical displacement at Kansas City vicinity, September 10–12, 1977*

[All times in c.s.t.]

	Sept. 10	Sept. 11		Sept. 12	
	1800	0600	1800	0600	1800
K Index (°C)	10	12	20	36	41
Vertical Displacement (mb/12 hr)	−10	<20	20	>20 <40	>40

Note: Upward (downward) vertical displacement is positive (negative).

The atmosphere in the Kansas City area became progressively unstable on Sept. 12, 1977, as the data indicates (table 1). At the same time, the atmosphere became increasingly more moist. The mean relative humidity from the surface to approximately 490 mb for an air column increased from 25 to 85 percent over a 48-h period ending at 0600 c.s.t., Sept. 12, 1977. Precipitable water is defined as the total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between the surface to a specific level, usually 500 mb. The precipitable water over Kansas City increased from 0.4 in. to about 1.8 in. during the same period, approaching the climatological maximum of 2.0 in. in the first half of September. The monthly mean precipitable water there for September is 0.95 in. (Lott, 1976), about one-half of the observed amount. The mixing ratio is defined as the mass of water vapor per unit mass of dry air in the mixture. The interpolated mean mixing ratio in the lowest 100 mb at

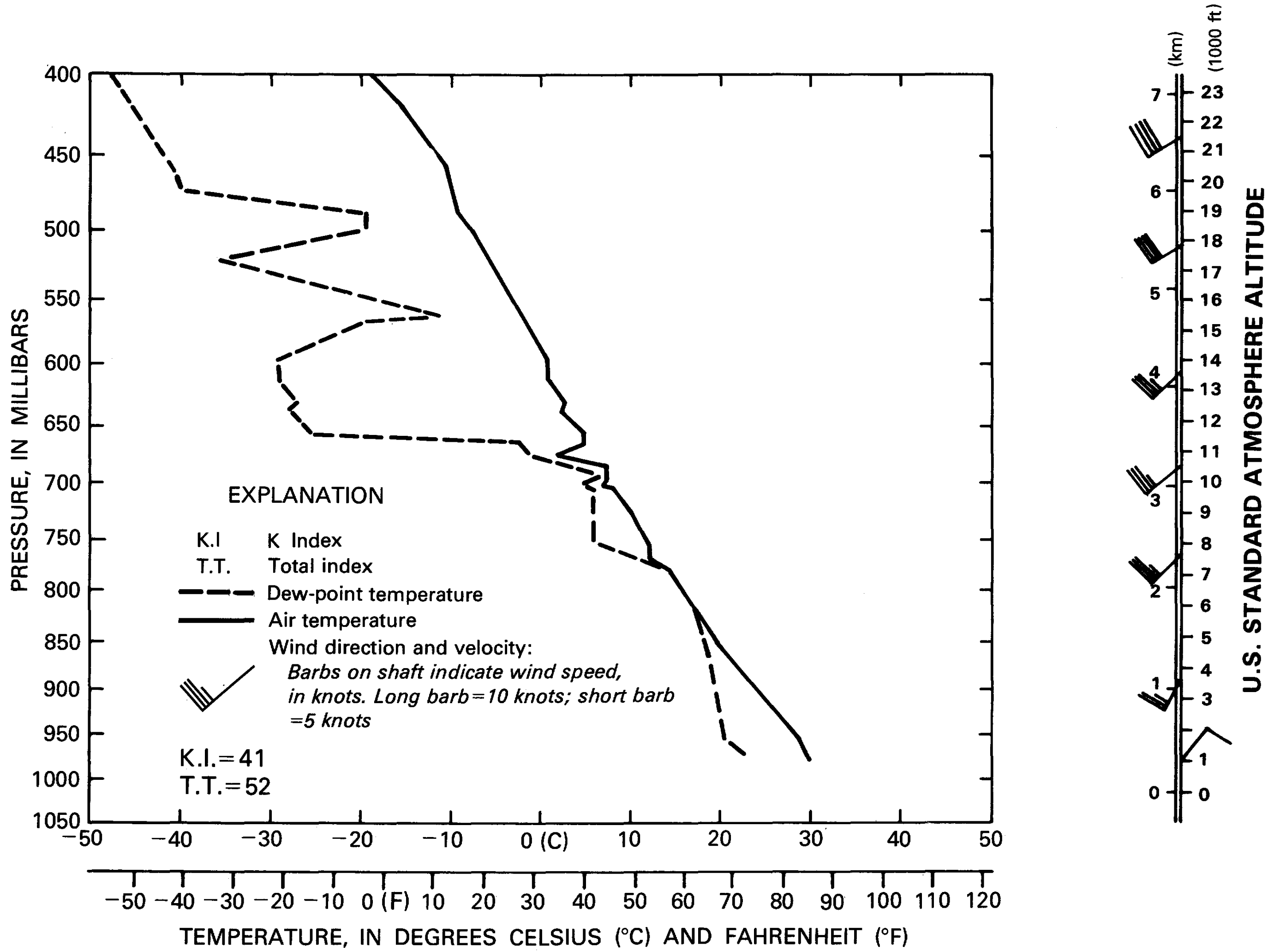


Figure 4.—Continued. *B*, Rawinsonde profile at Topeka, Kans., 1800 c.s.t., Sept. 12, 1977.

0600 c.s.t., Sept. 12, in the Kansas City region was 13.8 g/kg. For comparison, a value ranging from 12 to 14 g/kg is usually associated with a typical Great Plains severe storm (Maddox, 1976).

With the air increasingly moist and unstable, and with strong low-level wind impinging on the frontal surface aloft in the Kansas City vicinity, the first burst of heavy rain began in the very early morning of September 12. The rate of rainfall was intense at some gages: in north Kansas City, 2.20 in. of rain fell in a one-half hour period ending at 0150 c.s.t. This first storm lasted about 6 to 7 hours. The observed 6-in. maximum amount exceeded the 100-yr 6-h rainfall of 5.8 in. (Hershfield, 1961). The areal average near Kansas City also exceeded 5 in. Rainfall from this first storm ended by 0700 c.s.t.; it completely saturated the soils of the local drainage basins, but by itself did not cause any damage.

Near the end of the first rain period and during the initial period of no rain, fog was observed. This indicated the existence of a temperature inversion with its base near the ground. This condition was brought about by the warm front that was then just south of Kansas City. Evaporative cooling by raindrops falling into initial cooler air near the ground raised the dew point until fog was formed. Since the surface wind was light, the fog persisted until diurnal heating raised the temperature into the 70's (°F) in the early afternoon. This rain-cooled air mass extended from central Missouri to eastern Kansas; its southern boundary became a zone of convective activities and was situated south of Kansas City at 1800 c.s.t. Between storms there was an interlude of sunshine; and the atmospheric pressure began to change. At the Kansas City International Airport it fell from 1012.4 mb at 0700 to 1003.5 mb at 1800

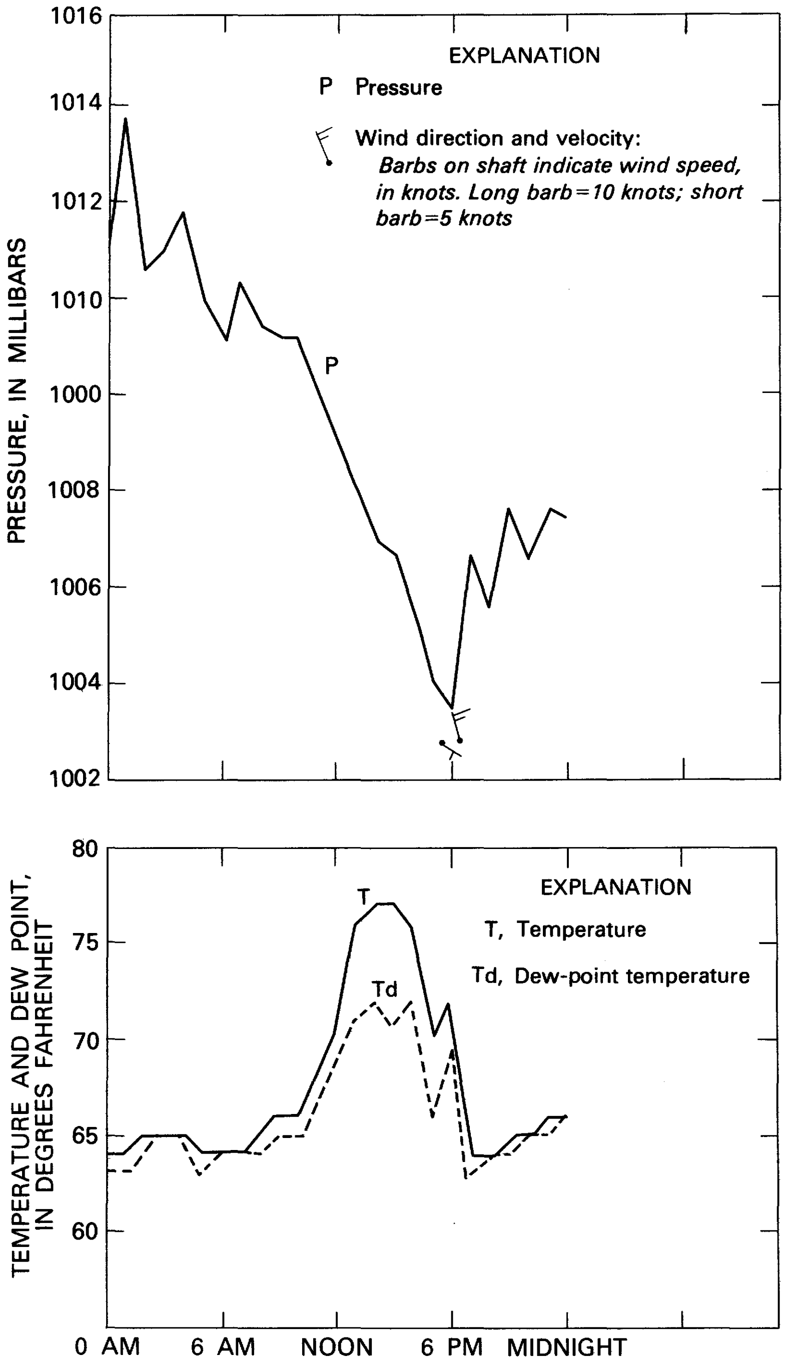


FIGURE 5.—Temperature, dew point, and pressure at Kansas City International Airport on Sept. 12, 1977. Wind speeds and directions near 6 p.m. are shown.

c.s.t.; then it began to rise. Temperature also dropped 5°F in only 45 minutes, ending at 1830 c.s.t. In the same period, surface wind shifted from 140° at 5 kn to 340° at 20 kn gusting to 32 kn (fig. 5). These observations indicated a cold front passage, just prior to 1830 c.s.t. Figure 6 shows the positions of surface fronts and 500 mb jet at 1800 c.s.t., Sept. 12, 1977—the time just prior to the beginning of the second major storm. Areas with 1000-mb dew point temperature equal to or greater than 70°F are shaded. Dashed line encloses an area with K Index greater than 36, indicating high instability. Kansas City was

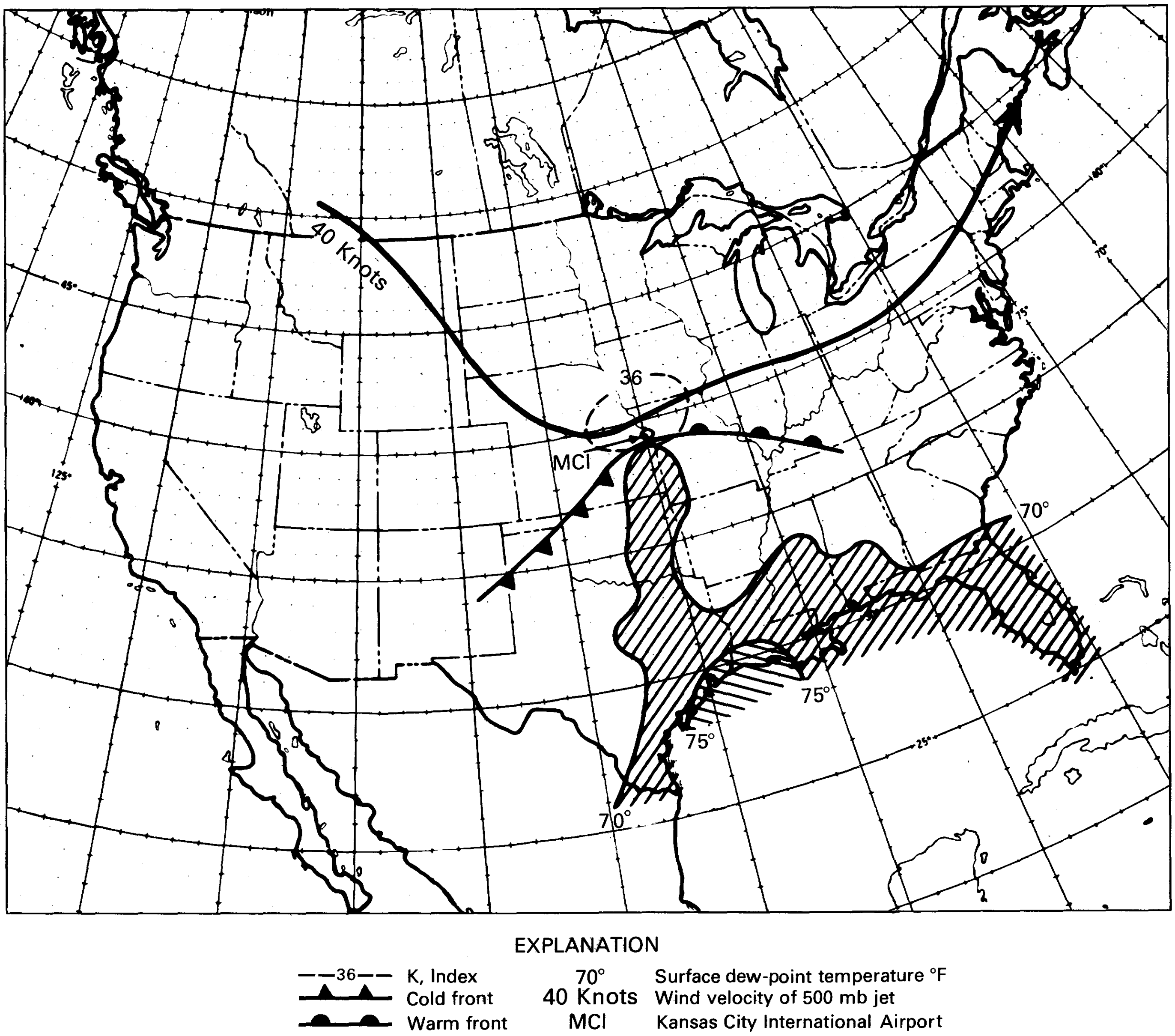


FIGURE 6.—Surface fronts, moist tongue, and 500 mb jet, 1800 c.s.t., Sept. 12, 1977. Crosshatched areas denote areas with surface dew-point temperature exceeding 70° or 75°F, as shown.

also located just north of the warm sector and at the tip of a moist tongue.

All the ingredients necessary for the occurrence of significant convection were present. The upward vertical motion associated with the tropospheric jet passing just to the north of Kansas City provided a triggering mechanism for releasing the instability. Convective clouds grew rapidly in this favorable environment. Cumulonimbus tower soon grew to a height exceeding 15 km (9.3 mi) with cloud top temperature dropping to below −80°C (−112°F) and rain began to fall over soil already saturated by the morning storm. By 2000 c.s.t., torrential rain had been falling over the metropolitan area for 2 hours. A more detailed description of both storms using information derived from satellite imagery is presented in a later section.

Isohyetal maps of total storm rainfall for the Kansas City vicinity and for affected areas of Missouri, Kansas, and Nebraska are shown in figures 7 and 8, respectively. Rainfall mass curves for selected rain gages are shown in figure 9. A maximum depth-area analysis for storm duration of 24 hs is shown in figure 10*A*. The metropolitan area is well covered by

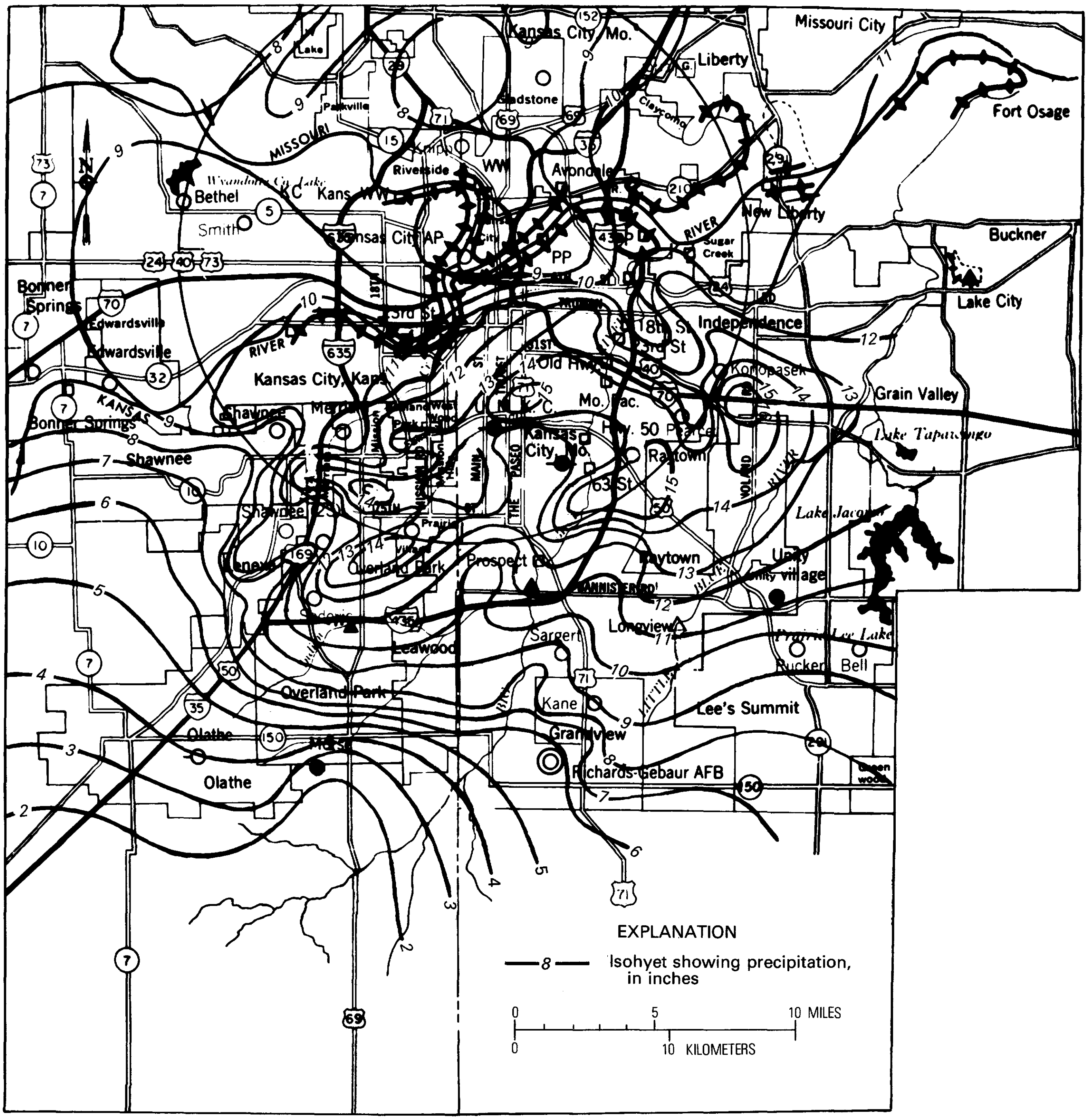


FIGURE 7.—Isohyetal map, storm of Sept. 12–13, 1977, Kansas City and vicinity.

rain gages. At the Kansas City International Airport, 8.82 in. fell on September 12, while the total storm rainfall there was 9.39 in. over a 36-h period. This latter amount exceeded the 100-year 2-day rainfall of 8.8 in. Maximum storm rainfall of 16.15 in. observed to the south of Independence over approximately a 36-h period exceeded the 100-year 10-day rain of 13.0 in. (Miller, 1964). Supplementary rainfall data were collected through an intensive bucket survey conducted by the National Weather Service, Central Region, helped by personnel from the National Severe Storm Forecasting Center and the U.S. Army Corps of Engineers, Kansas City. These data are listed in table 2.

TABLE 2.—*Supplementary rainfall data, storms of Sept. 12–13, 1977, in northeastern Kansas, northwestern Missouri, and southeastern Nebraska*

MOST OF THE RAIN OCCURRED IN ABOUT 25 HOURS E.G., INDEPENDENCE,MO,RECORDER, 3 MILES NORTH OF THE 16 INCH CENTER,INDICATED 11.03 IN. FROM 1 AM SEPT 12 TO 2 AM 13 SEPT,OUT OF A STORM TOTAL OF 11.11 INCHES. THE RAIN IN THE METROPOLITAN KANSAS CITIES OCCURRED PRIMARILY IN TWO BURSTS, THE FIRST FROM 1 TO 6 AM ON THE 12TH AND THE SECOND FROM ABOUT 8 AM THE 12TH TO 2 AM THE 13TH. THE BAND OF HEAVY RAINFALL EXTENDED FROM SOUTH OF GRAND ISLAND(HASTINGS NE) TO NEAR COLUMBIA MO. WITH MAX AMOUNTS AND DAMAGE IN THE KANSAS CITY AREA AND EASTWARD TO NEAR ODESSA MO. THE REPORTS ARE PROVIDED IN TWO LISTINGS (1) FEDERAL EMPLOYEES PRIMARILY NWS C OF E AND NESS AND (2) FROM PUBLIC REPORTS RECEIVED BY MAIL.

COUNTY	STATE	TWP	RGE	SECTION	STORM TOTAL	RAIN GAGE	REMARKS-OBS.,LOCATION
CLAY	MO	51N	33W	27 SE 1/4	7.87	CL-VU	ALEXANDER, 425 NW 58TH
CLAY	MO	51N	33W	1 NW1/4	9.48	WEDGE	ARNS,GLADSTONE 3N
CLAY	MO	51N	33W	25 SW1/4	9.15	WEDGE	AUDSLEY, 5614 MANOR DR
CLAY	MO	51N	32W	31 NE 1/4 NW1/4	8.60	WEDGE	DOSWELL, N.KC
CLAY	MO	50N	33W	11 NW 1/4	8.50	5 IN	HALMSTED,N.KC
CLAY	MO	51N	31W	7 NE 1/4	10.8	USDA	LIBERTY MO, TOWN SQ.
CLAY	MO	51N	33W	13 SE 1/4	9.11		MOHLER,7214 N.WOODLAND
CLAY	MO	51N	33W	25 SE1/4 NW1/4	9.22	WEDGE	PHILLIPS,6003NWOODLAND
CLAY	MO	51N	32W	29 SW 1/4	8.75	WEDGE	ZAJDEL, N.KC
JACKSON	MO	48N	33W	7 NE1/4	14.6	ALL-W	BALKE, 71ST &JEFFERSON
JACKSON	MO	47N	33W	5 NW 1/4	9.13	WEDGE	BASKIN,112 E 109 TER.
JACKSON	MO	48N	32W	9 SE1/4	13.15	5 IN	DARRAH,RAYTOWN
JACKSON	MO	49N	32W	9 SE1/4SE1/4	12.88	WEDGE	GAYLORD
JACKSON	MO	49N	33W	12 SW 1/4	12.5	STD	JOHNSON,2626 OAKLEY
JACKSON	MO	47N	33W	17 NW1/4 NW1/4	8.45	WEDGE	KANE,GRANDVIEW
JACKSON	MO	49N	32W	33 NW 1/4 NE1/4	13.08	WEDGE	KERR,511 NORTHERN
JACKSON	MO	49N	32W	15 NE1/4 SW1/4	12.98	WEDGE	KONOPASEK
JACKSON	MO	49N	32W	15 SW 1/4	12.87	WEDGE	LEMON,3201 ENGLEWOOD T
JACKSON	MO	47N	33W	14 NW1/4	8.47	WEDGE	LEMON,708 DUTCH RD.
JACKSON	MO	48N	32W	30 NE 1/4	11.75	5 IN	MATHEWS,8407 EAST 91ST
JACKSON	MO	48N	33W	29 SW 1/4	9.35	WEDGE	MONDSCHEIN,9747 WALNUT
JACKSON	MO	48N	30W	23 SE 1/4 NW 1/4	10.45	ALL-W	MULLER,GRAIN V. 8S
JACKSON	MO	49N	32W	26 NW1/4	16.15	WEDGE	NELSON,LEES SUMMIT
JACKSON	MO	47N	32W	2 NE1/4	9.75	WEDGE	NEUMAN,LEES SUMMIT 5W
JACKSON	MO	48N	33W	30 NE 1/4	9.27	5 IN	REED, 616 W 89TH
JACKSON	MO	49N	32W	3 NE1/4	10.94	CL-VU	ROCK CR. NET.CE
JACKSON	MO	49N	32W	11 SE1/4	12.83	CL-VU	ROCK CR. NET.CE
JACKSON	MO	49N	32W	15 NE1/4	13.86	CL-VU	ROCK CR. NET.CE
JACKSON	MO	49N	32W	16 SW1/4NW1/4	11.30	CL-VU	ROCK CR. NET.CE
JACKSON	MO	49N	32W	22 SE1/4	16.22	CL-VU	ROCK CR. NET.CE
JACKSON	MO	48N	32W	19 NE 1/4	13.05		ROCKWOOD,RAYTOWN
JACKSON	MO	48N	31W	34 SW1/4 NW1/4	10.0	WEDGE	RUCKER,LEES SUMMIT
JACKSON	MO	47N	33W	3 NW1/4 SE1/4	8.88	WEDGE	SARGERT,4009RED BRIDGE
JACKSON	MO	49N	31W	26 SE 1/4	13.77	CL-VU	SPITTLER,BLUE SPRGS
JACKSON	MO	49N	32W	13 SW1/4	14.5	STD	SWEENEY, 3408 S.HOCKER
JACKSON	MO	48N	32W	3 SE1/4NW1/4	14.53	CL-VU	VOCHATZER,12201 E 61 T
JACKSON	MO	48N	33W	31 NE 1/4	10.15		WEINRICH, 1100 W.100 T
JACKSON	MO	48N	33W	8 SW1/4	13.32	WEDGE	WERTMAN,405E.71ST.TER
JOHNSON	KS	12S	24E	27 SW1/4NW1/4	10.8	ALL-W	CALABRESE,8208 NOLAND
JOHNSON	KS	12S	25E	4 NW1/4	11.23	5 IN.	CASTO,ROELAND PK
JOHNSON	KS	12S	24E	1 NW1/4	10.58	WEDGE	CRAIG, SHAWNEE
JOHNSON	KS	11S	24E	25 NE1/4 SW1/4	9.18	WEDGE	DECAIGNY,1642S,51ST
JOHNSON	KS	13S	24E	10 NW 1/4	9.82	CL-VU	GRAY, OVERLAND PK
JOHNSON	KS	12S	24E	11 NW 1/4	8.95	RRG	HAHN, SHAWNEE
JOHNSON	KS	13S	24E	1 SW1/4	10.99		HALES
JOHNSON	KS	12S	25E	15 SW 1/4	14.3	CL-VU	HUGHES, MISSION HILLS
JOHNSON	KS	13S	25E	4 NW1/4	11.5	CL-VU	KNUDSEN,OVERLAND PK
JOHNSON	KS	12S	25E	33 SW1/4	11.38	WEDGE	LEE LARSON 95TH&ROE
JOHNSON	KS	13S	25E	6 NE1/4	11.12	CL-VU	MEAUX,7508 W 95TH TER
JOHNSON	KS	13S	25D	4 NW 1/4	11.0	ALL-W	OSTBY, 4812 W. 97 TER
JOHNSON	KS	12S	24E	27 SW1/4NW1/4	10.8	ALL-W	PROENZA,8210 HAUSER
JOHNSON	KS	12S	25E	31 NW1/4	13.68	6 IN	SCHOENI,8524 W 88TH T.
JOHNSON	KS	13S	24E	2 SW1/4	9.81	WEDGE	SEDOVIC
JOHNSON	KS	12S	25E	29 NE 1/4	14.78	WEDGE	WEISS
PLATTE	MO	51N	34W	23 NW 1/4	9.67	CL-VU	HENDERSON,PARKVILLE 2N
PLATTE	MO	51N	34W	27 SW 1/4	9.67	WEDGE	JOHNSTON,PARKVILLE 2W
PLATTE	MO	50N	33W	4 NE1/4S1/2	8.80	WEDGE	KNIPP,400 WOODLAND RD
PLATTE	MO	53N	35W	9 NW1/4	8.71	CL-VU	LONGSDORF,WESTON 6E
PLATTE	MO	51N	34W	11 SW 1/4	8.44	5 IN	REMBOLDT,WEATHERBY L.
PLATTE	MO	51N	33W	17 NE 1/4 SW 1/4	8.81	WEDGE	WILLIAMS, WAUKOMIS
WYANDOTTE	KS	10S	23E	26 NW1/4 NE1/4	9.17	WEDGE	SMITH,2906 N56TH
JOHNSON	KS	12S	24E	4 NE1/4	10&	10 IN	14113 W 48 TER
JOHNSON	KS	12S	24E	11 SE1/4	12.80	VICTOR	10715 W 61ST
JOHNSON	KS	12S	24E	12 NW1/4 NE1/4	11.00	5 IN	5713 KESSLER
JOHNSON	KS	12S	24E	24 NE1/4 NW1/4	10.81	6 IN	7018 GRANDVIEW
JOHNSON	KS	12S	24E	25 SW1/4	9.50	4 IN	86TH&FARLEY
JOHNSON	KS	12S	24E	33 NE1/4	10.58	5 IN	8966 PARK
JOHNSON	KS	12S	25E	2 NW1/4 NW1/4	12.5	5 IN	4937 GLENDALE RD
JOHNSON	KS	12S	25E	4 SW1/4	10	5 IN	4101 W 53 TER
JOHNSON	KS	12S	25E	5 SE1/4	11.6	5 IN	5631 BEVERLY
JOHNSON	KS	12S	25E	8 NW1/4 NW1/4	10.90	TRU-C	6320 W 57 TER
JOHNSON	KS	12S	25E	9 NW 1/4	13.10	VICTOR	5400 CEDAR
JOHNSON	KS	12S	25E	10 NE 1/4 SW 1/4	13.3	11 IN.	6041 WINDSOR DR
JOHNSON	KS	12S	25E	10 NW1/4 NW1/4	12.50		6001 LOCKTON LANE
JOHNSON	KS	12S	25E	17 NW1/4	11.75	SPF	6212 WALMER
JOHNSON	KS	12S	25E	17 SE 1/4 NW 1/4	15	AIR-G	6408 W. 67TH
JOHNSON	KS	12S	25E	20 SE 1/4 SE 1/4	12.85	TAYLOR	5603 W. 77TH TER.
JOHNSON	KS	12S	25E	21 NE1/4	12.63	WEDGE	7412 ELMONTE
JOHNSON	KS	12S	25E	22 SW1/4NE1/4	13.8		7604 CHADWICK
JOHNSON	KS	12S	25E	29 SE1/4	14.48	5 IN	8427 WALMER
JOHNSON	KS	12S	25E	30 NW1/4 SE1/4	11.50	4 IN	8316 W 81ST
JOHNSON	KS	12S	25E	32 SE1/4SE1/4	11.40	SPF	5600 W 92ND PL
JOHNSON	KS	13S	24E	2 NW 1/4	11.65	11 IN.	10210 W.92ND PLACE
JOHNSON	KS	13S	24E	2 NE1/4	5.08	WEDGE	10116 W 98TH
JOHNSON	KS	13S	24E	3 SW1/4	9.82		13019 W 102ND ST
JOHNSON	KS	13S	24E	5 SE1/4 SW1/4	11.48	WEDGE	6417 W 101ST
JOHNSON	KS	13S	24E	36 NE1/4	2.30		
JOHNSON	MO	13S	25E	27 NE1/4	8.2	5 IN	12747 OVERBROOK RD.
WYANDOTTE	KS	10S	24E	27 SE1/4SE1/4	9.05	RAIN-M	6420 PARKVIEW
WYANDOTTE	KS	11S	23E	23	9.31	USDA	1313 EDWARDSVILLE DR
WYANDOTTE	KS	11S	25E	28 SW1/4NE1/4	11.15	VICTOR	2100 S.10TH
WYANDOTTE	KS	11S	25E	34 SE1/4	11	ACU-R	4608 FISHER ST
CLAY	MO	51N	32W	30 SE1/4NW1/4	8.25		5907 N HOWARD
CLAY	MO	51N	32W	33 SE1/4	10.5		4912 WINCHESTER
CLAY	MO	51N	33W	2 SE1/4	9.27	10 IN.	8816 N.CHARLOTTE
CLAY	MO	51N	33W	8 NW1/4	8.7	6 IN.	8741 N.HIGHLAND
CLAY	MO	51N	33W	12 NW1/4NE1/4	9.73	VICTOR	8928 N.PROSPECT
CLAY	MO	51N	33W	23 NE1/4NW1/4	7.60		7010 N.HOLMES
JACKSON	MO	47N	30W	1 NE1/4NE1/4	8.0		LONE JACK, MO
JACKSON	MO	47N	31W	25 SE1/4 NE1/4	7.8		3908 SEQUOIA
JACKSON	MO	47N	32W	19 NW 1/4	8.95	TRU-C	13146 SYCAMORE
JACKSON	MO	47N	33W	3 SW1/4 SE1/4	8	5IN	10612 WALROND
JACKSON	MO	47N	33W	25 SW1/4	7.50	6 IN.	129TH & 71 HWY
JACKSON	MO	48N	31W	1 NE1/4	12.7	6IN	1312 SKYLINE DR
JACKSON	MO	48N	32W	19 NE1/4	11.65	TRU-C	8412 JAMES A REED RD
JACKSON	MO	48N	33W	3 NE1/4	12.70&	5 IN	5929 KENSINGTON
JACKSON	MO	48N	33W	5 SE 1/4	12.95	VICTOR	5619 ROCKHILL RD
JACKSON	MO	48N	33W	8 SE1/4	13.52	6IN	7423 HOLMES
JACKSON	MO	48N	33W	11 NW1/4	15	11 IN.	SWOPE PK, GREENHOUSE
JACKSON	MO	48N	33W	16 SW1/4	10.80		8400 EUCLID
JACKSON	MO	48N	33W	17 NE1/4	14.60	5 IN.	920 E.76TH TER.
JACKSON	MO	48N	33W	18 NW1/4	12.70	OHIO	1105 W 77TH STREET
JACKSON	MO	48N	33W	18 SW1/4 NW1/4	8.5		7909 WARD PARKWAY
JACKSON	MO	48N	33W	21 NE1/4	11.21	TRU-C	8601 GARFIELD
JACKSON	MO	48N	33W	31 NE1/4	10.50	5 IN.	9815 JARBOE
JACKSON	MO	48N	33W	32 NE 1/4 NW 1/4	10.5	609B	10026 WALNUT DR
JACKSON	MO	49N	30W	3 SW1/4SW1/4	11.0		BUCKNER 4S
JACKSON	MO	49N	30W	35	10.58	6 IN.	GRAIN VALLEY, MO
JACKSON	MO	49N	32W	32 SE 1/4 NE 1/4	11.5	6 IN.	115 N. OVERTON AVE
JACKSON	MO	49N	32W	32 SE1/4NW1/4	15.58	WEDGE	8905 E. 55TH
JACKSON	MO	49N	33W	1 CENTER	13.0	10 IN.	1032 FULLER
JACKSON	MO	49N	33W	25 NE 1/4	14.0	5 IN.	7061 E.47TH ST
JACKSON	MO	49N	33W	32 NE1/4NE1/4	12.75	6 IN.	5441 HOLMES
JACKSON	MO	49N	33W	36 SE1/4	13.83	VIC.	6501 E. 58TH
JACKSON	MO	50N	30W	22 NE 1/4	10.0	CL-VU	BUCKNER BANK
JACKSON	MO	50N	31W	30	11.60	WEDGE	17804 REDWOOD DR.
JACKSON	MO	50N	32W	32 SW1/4 SW1/4	12.2	TAYLOR	8728 ROBERTS
JACKSON	MO	50N	33W	32 SW1/4	9.10	5 IN.	307 N. GRAND
JACKSON	MO	50N	33W	35 SE1/4	9.33	6 IN.	404 N HARDESTY
JACKSON	MO	51N	30W	34 SW1/4SW1/4	10.8		SIBLEY 1W
JACKSON	MO	51N	32W	29 NE1/4 SW1/4	9.35	SPF	5209 E.60TH TER.
JACKSON	MO	51N	32W	31 SE 1/4	9.5		3904 NE 49TH TER.
JOHNSON	MO	44N	27W	4	6.1	6 IN.	HOLDEN 6SE
JOHNSON	MO	46N	28W	27 NE 1/4	5.0	5 IN.	HOLDEN 3N
LAYFAYETTE	MO	48N	26W	15 SW1/4	9.58		
LAYFAYETTE	MO	48N	26W	17 NW1/4SW1/4	10.5		ODESSA 8ESE
LAYFAYETTE	MO	48N	28W	27 SW1/4	10.25	6 IN.	
LAYFAYETTE	MO	48N	29W	3 NE1/4	13.4		BATES CITY 1.5W
LAFAYETTE	MO	49N	25W	6 WEST	8.15		HIGGINSVILLE WATER PLT
LAYFAYETTE	MO	49N	27W	13 NE1/4	9.00		MAYVIEW,MO.
LAYFAYETTE	MO	49N	28W	3 SW1/4	9.5		ODESSA 5NNW
LAYFAYETTE	MO	49N	28W	15 SE1/4	12.0		ODESSA 3NNW
LAYFAYETTE	MO	50N	28W	15 SW1/4SE1/4	9.00		WELLINGTON MO.
PLATTE	MO	51N	33W	28 NE1/4	7.7	WEDGE	5906 HUTSON RD.
PLATTE	MO	51N	34W	25 SE1/4SE1/4	8.75	5 IN.	1131 N. 36TH ST.
RAY	MO	51N	29W	23 SE1/4	9.60		BANK OF ORRICK
RAY	MO	52W	29W	1	8.9	5 IN.	EXCELSIOR SPGRS 5E

& POSSIBLE OVERFLOW OR SPLASH OUT

RAIN GAGES
CL-VU,ALL-W 4 IN.DIA.FUNNEL,APPROX. 12 IN. CAPACITY PLASTIC
RRG UNIV. RECORDER
STD STANDARD NWS NON-RECORDER
WEDGE APPROX. 6 IN. PLASTIC
5 IN. PLASTIC 5 IN. CAPACITY
ACU-R ACU-RITE
OHIO OHIO THERM. RAIN GAGE
RAIN-M RAINMASTER
SPF SPRINGFIELD
TAYLOR
TRU-C TRUE CHECK
VIC. VICTORY
VICTOR--5 IN CAPACITY
609B / AIR-G. AIRGUIDE

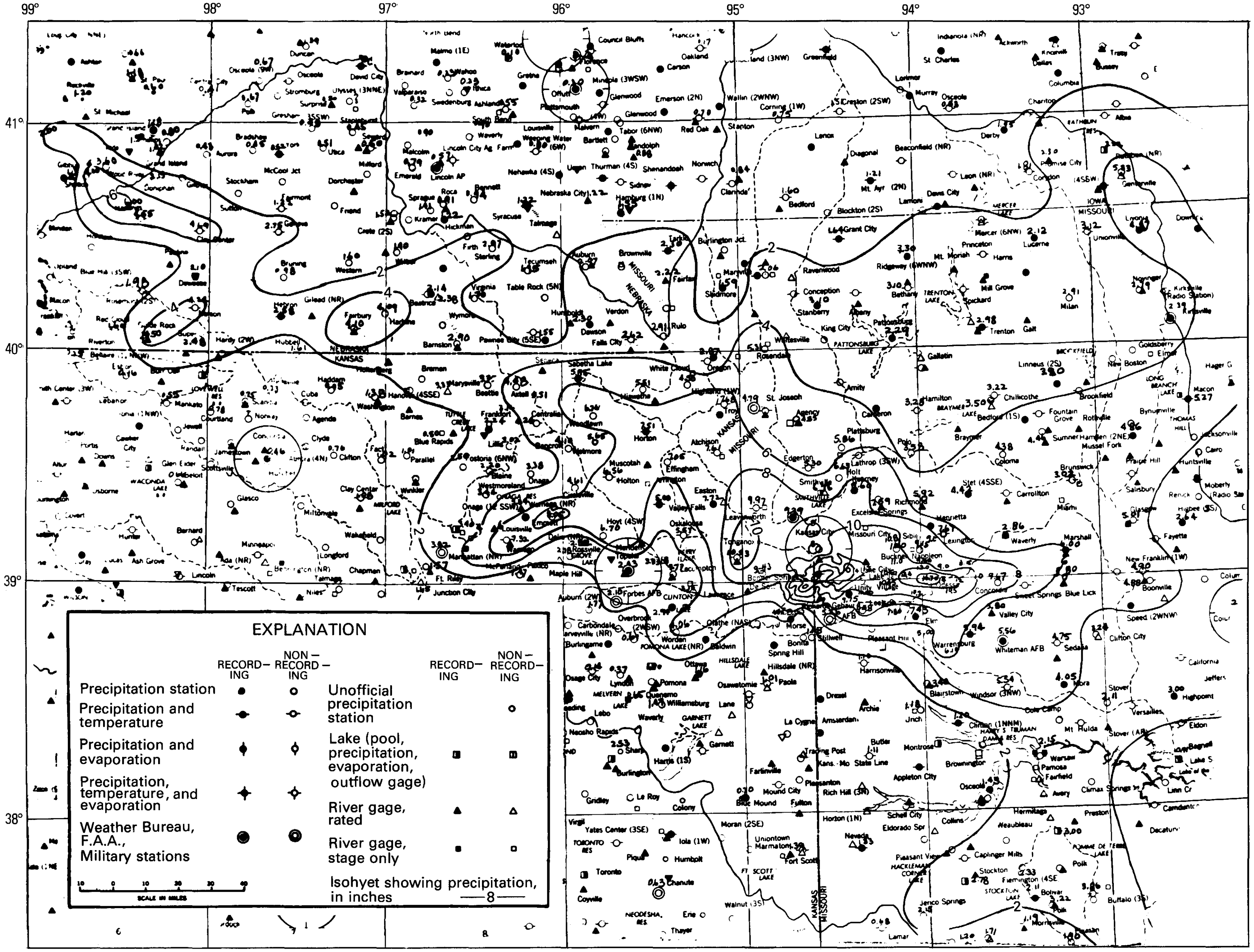


FIGURE 8.—Isohyetal map of total rainfall for Sept. 11–13, 1977, in southeastern Nebraska, northeastern Kansas, and north-central Missouri.

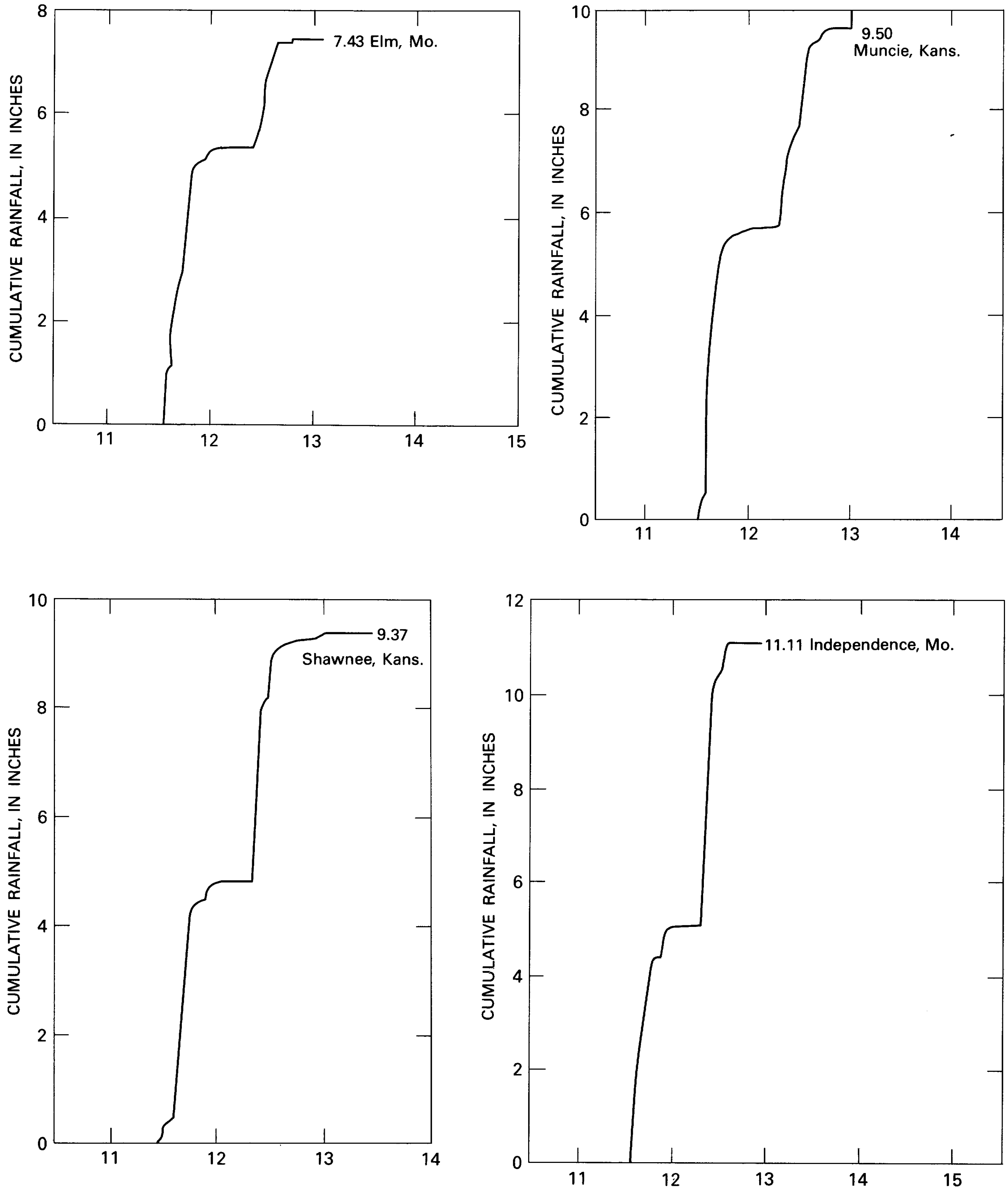


Figure 9.—Mass rainfall curves at four selected raingages, Sept. 11–14, 1977.

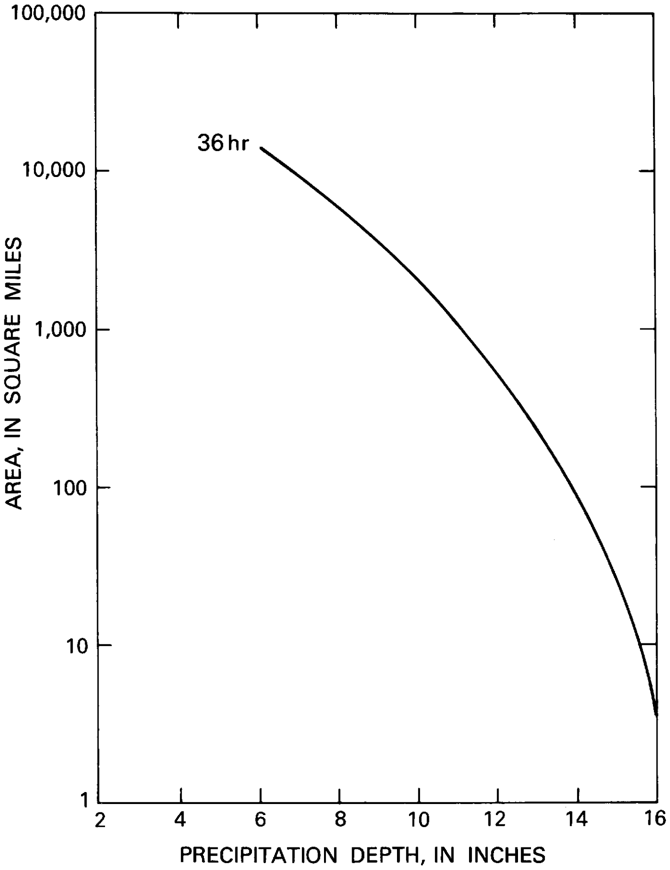


FIGURE 10.—*A*, Depth-area analysis for 36-h duration for storm precipitation, Sept. 12–13, 1977.

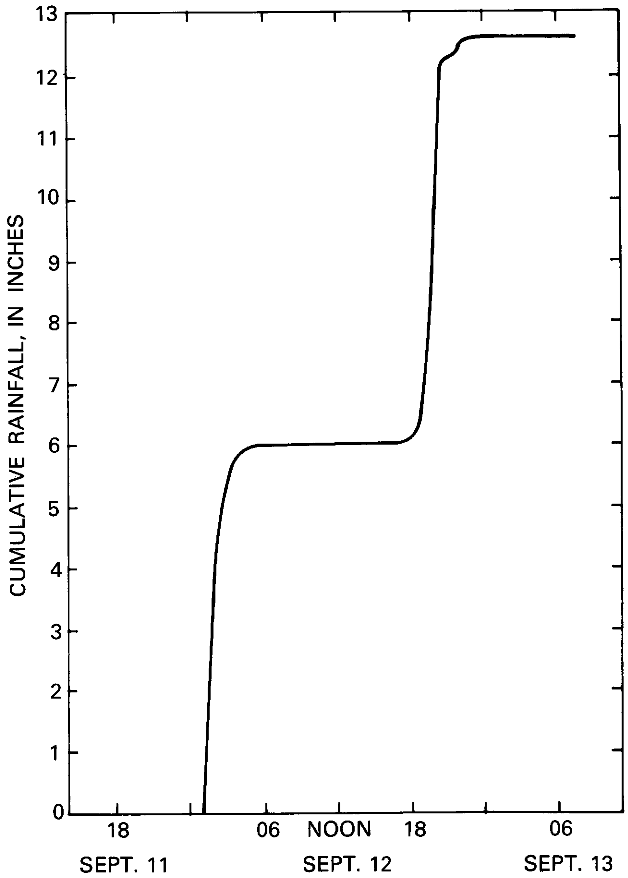


FIGURE 10.—Continued. *B*, Composite rainfall mass curve derived from satellite infrared imagery, Sept. 11–13, 1977.

Most of the rain fell on Kansas City and vicinity in a 24-h period from 0100 c.s.t., Sept. 12, to 0100 c.s.t., Sept. 13, 1977. The first burst occurred from 0100 to 0700 c.s.t., Sept. 12. The second burst occurred from 1830 c.s.t., Sept. 12, to 0100 Sept. 13. Within this framework, considerable variation in the time distribution of rain exists among different gages. The band of considerable rainfall extended from Hastings, Nebr., to near Columbia, Mo. Within this band, the 8-in. isohyet enclosed an area from Leavenworth, Kans., to Concordia, Mo. (fig. 8). Flood damage was maximal in the Kansas City area.

PRECIPITATION ESTIMATIONS USING SATELLITE INFRARED IMAGERY

The Geostationary Operational Environmental Satellite (GOES) System including the Synchronous Meteorological Satellite (SMS) provides an ideal platform where rain-producing weather systems ranging from convective storms through squall lines to frontal zones can be continuously monitored. However, GOES sensors do not "see" rain directly. All precipitation is accompanied by cloudiness, but not all clouds yield precipitation. In order to "see" rain, we must choose a sensing wavelength that can penetrate clouds or at least be able to distinguish a clear separation of precipitating clouds from all others. At certain portions of the microwave band ($\lambda > 10^4\ \mu$) of the electromagnetic spectrum, thin, nonprecipitating clouds become fairly transparent and raindrops can be detected. This differentiation is not possible in the visible (0.55 to 0.70 μ) and infrared channels 10.5 to 12.6 μ) sensed by the GOES Visible and Infrared Spin Scan Radiometer (VISSR).

One of the earlier attempts to obtain a quantitative rainfall estimation was made by Follansbee (1973). Using one afternoon cloud's coverage picture from a polar-orbiting satellite, he made rainfall estimates over an area the order of 10^5 km^2 (38,600 mi^2) by considering the summed ratios of coverages by cumulonimbus, nimbostratus, and cumulus congestus, each weighted by an empirical coefficient. This method is only appropriate where and when rainfall is due to convective storms produced by diurnal heating. In general, however, the evolution of cloud system is too swift for one picture to be representative for a whole day. During recent years, several improved schemes have been devised. It should be mentioned that Cheng and Rodenhuis (1977) found that the instantaneous state of clouds in a satellite imagery and region of precipitation, as indicated by radar echoes, was not well correlated.

Woodley and his group at the National Hurricane and Experimental Meteorology Laboratory (of NOAA) did much of the groundwork in rainfall estimation using satellite data (1972). They found that the rain-producing clouds are bright and cold on the satellite image by virtue of their greater thickness. They also pointed out that instead of a snapshot, a complete "time-exposure" is needed to track a cloud mass of interest. Since the same brightness or cloud top temperature can indicate quite different rainfall, an accurate estimate of rainfall amount depends on whether the cloud mass is growing or decaying. The life stages of the cloud system can be identified only from a sequence of satellite pictures. Clouds with expanding cold tops in the infrared (IR) or bright clouds in the visible imagery correspond to the incipient and mature stage of storm development and produce more rainfall than those not expanding. Clouds with contracting bright area or cold top correspond to the decaying stage of a storm and are associated with little or no rainfall. Most of the significant rainfall occurs in the upwind at the anvil-level portion of a convective system. The highest and coldest clouds form where the thunderstorms are most vigorous and the rain heaviest. These cold clouds get thinner downwind and become warmer as the anvil material blows away from its origin over the updraft (Woodley and others, 1972).

Rain estimates using satellite imagery have been made and verified in Florida using gage-adjusted radar estimates of precipitation as ground truth (Griffith and others, 1978). The results show considerable overestimation by the satellite method. But accuracy appears to be a function of the total time period under consideration. Both error and standard deviation of estimates decrease when estimates are accumulated for 6 h or longer. Based on the relationships between rainfall and satellite cloud imagery found by Woodley's group, Schofield and Oliver (1977) proposed an empirical method for making quantitative estimations of half-hourly rainfall, mainly from infrared imagery that can be applied operationally in near real-time. Satellite rainfall estimation made in the current study (fig. 10*B*) is based on this empirical method.

The extreme rainfall that caused the Kansas City flash flood of September 1977 came as two storms, each of about 6- to 8-h duration and separated by a period of no rain of 8–12 h. Within each storm, rainfall intensity varied considerably. Selected GOES infrared imagery pictures for the two storms are shown in figure 11.

Characteristics of these two storms as revealed by these pictures are summarized separately.

Specific features of the infrared imagery of the first storm (fig. 11*A*, *B*, and *C*) :

1. Kansas City was located near the edge of the anvil at 0100 c.s.t., Sept. 12. Anvil is defined as that portion of a cumulonimbus (Cb) cloud system where cloud top temperature T_t is less than −32° (−25.6°F).

2. Protruding Cb turrets with cloud top temperature T_t colder than −80°C (−112°F) existed near Kansas City from 0100 to 0230 c.s.t. They propagated eastward afterwards and disappeared by 0400 c.s.t.

3. Turrets went through considerable expansion between 0130 and 0200 c.s.t., indicating occurrence of intense rainfall in this period.

4. Maximum cloud top temperature gradient $-\nabla T_t$ reached near Kansas City was at 0230 c.s.t. estimated to be 39°C/50 km (70°F/30 mi) toward the northeast.

5. By 0330, active turret had moved to the east of Kansas City and T_t over Kansas City increased to between −58°C (−72°F) and −62°C (−80°F), signifying the beginning of storm decay and reduction of rainfall intensity there.

6. Dissipating stage continued past 0400 c.s.t., but with little rain indicated after 0500 c.s.t.

Specific features of the infrared imagery of the second storm (figs. 11*D*, *E*, and *F*) :

1. At 1800 c.s.t., Sept. 12, Kansas City was located at the edge of the anvil topping the cumulonimbus cloud mass to the north.

2. Protruding turret with cloud top temperature T_t less than −80°C (−112°F) was already in existence at 1800 c.s.t. Area of turret remained the same until 1830, but then started to expand.

3. The most rapid expansion occurred between the period 1930 to 2030 c.s.t.; this corresponded to the time of most vigorous convective activity and most intense rainfall.

4. The anvil level wind was southwesterly about 50 kn. Between 1930 and 2030 c.s.t., the turret area

actually expanded upwind. This signaled an abundant moisture inflow and vigorous rising motion to the southwest of Kansas City—over Johnson County and Brush Creek headwaters in Kansas.

5. Maximum cloud top temperature gradient $-\nabla T_t$ reached near Kansas City was at 2030 c.s.t. estimated to be 48°C/25 km (84°F/15 mi) toward the north. This gradient was more than twice as steep as that reached in the first storm. Quantitative relationship between $-\nabla T_t$ and rainfall has not been established, but qualitatively there is a positive correlation between them, and the maximum rainfall intensity of the second storm was greater than that of the first storm.

6. Cold turret began contraction after 2030 c.s.t. This contraction initially affected the Kansas portion of the storm system. The turret over and to the northeast of Kansas City, Mo., was maintained past 2200 c.s.t.

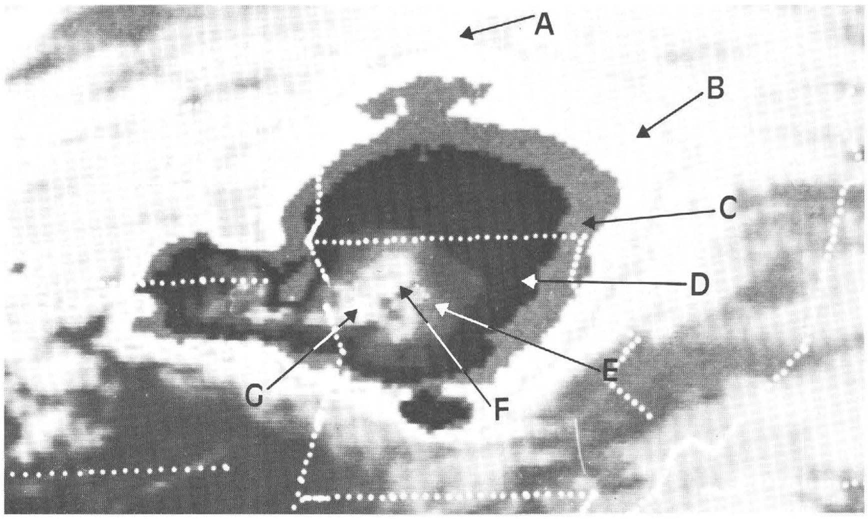
When locating the highest and, therefore, coldest top of thunderstorm on a map, a correction for displacement error of satellite-sensed cloud top must be made. This correction is necessary because, except at the subpoint, the line of sight from the satellite sensor to the cloud top is slanted. The amount of correction depends on the height of the cloud top and its longitude and latitude differences from those of the subpoint. For example, at 2030 c.s.t., Sept. 12, the coldest top north of Kansas City (fig. 11*B*) was estimated at a height of 53,000 ft, to map its true geographical position, it should be displaced toward southeast by a distance of 12 miles.

Based on the analysis of the infrared characteristics of the storm and using the method in NOAA Technical Memorandum NESS 86, we constructed a composite rainfall mass curve (fig. 10*B*). From the users' point of view, the quality of an infrared imagery is characterized by three parameters: the spatial resolution or instantaneous field of view, the temporal resolution or the time between consecutive looks at the same spot, and temperature resolution or the ability to discern a cloud against the earth background by virtue of the temperature difference between the two. These three parameters are not mutually independent. For example, to increase the spatial resolution by reducing the field of view would degrade temperature and temporal resolutions. Thus, the design of the Visible and Infrared Spin Scan Radiometer (VISSR) aboard GOES represents an optimal trade-off among these three parameters.

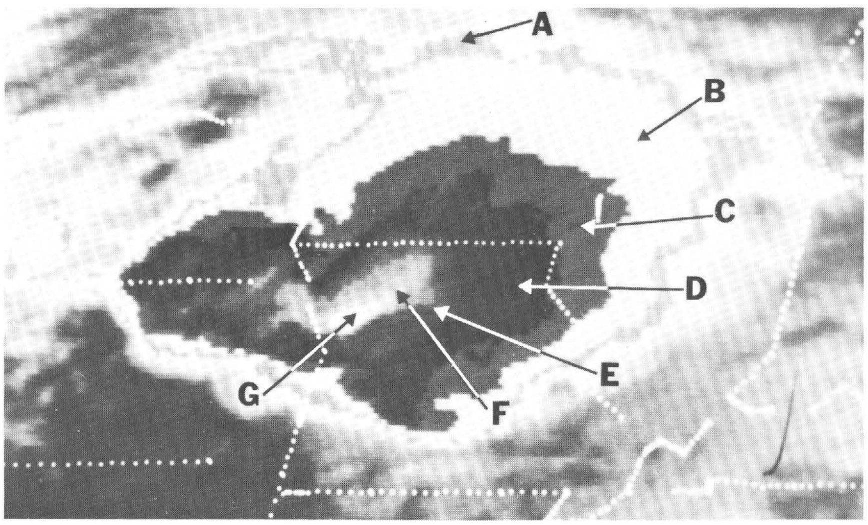
The present GOES infrared imagery has a spatial resolution of 9 km (5.6 mi) at the satellite subpoint at 0.5° N., 75.0° W. This resolution degrades the farther the sensed area lies from the subpoint. Therefore, the derived mass curve (fig. 10*B*) represents the time distribution of rainfall over an area approximately 100 km^2 (about 39 mi^2) where rainfall was heaviest. It should not be compared with any mass curve of specific gages in figure 9, but instead should be compared with depth-area-duration analysis. A storm depth-area analysis for a duration of 36 hours is shown in figure 10*A*. This is based on the isohyetal analysis of "ground truth" data from rain gages and a bucket survey. Comparison of figure 10*B* to rainfall amounts at 39 mi^2 in figure 10*A* shows that figure 10*B* underestimated the maximum rainfall by 1.4 in. This represents a 10 percent underestimation. The possible reasons for this are not discussed here. It is evident, however, that the composite mass curve derived from GOES infrared imagery (fig. 10*B*) is not inconsistent with the conventional depth-area-duration analysis (fig. 10*A*).

Weather radar coverage for the Kansas City area was provided by a WSR–57 radar at the National Severe Storm Forecast Center in Kansas City and by a WSR–74C radar at Topeka, both operated by National Weather Service. The radar Video Integrator and Processor (VIP) provides automatic contouring of the varying radar echo intensity which is used to estimate instantaneous rainfall rate. Detailed time sequence of radar scope displays are archived in film form at NOAA's National Climatic Center at Asheville, N.C., and are not presented here. Radar data indicated that precipitation of the second storm first began to the north and west of metropolitan area and then moved southward. This is consistent with the satellite pictures in figures 11*D*, *E*, *F*. The storm reached Kansas City downtown area by 1830 c.s.t.

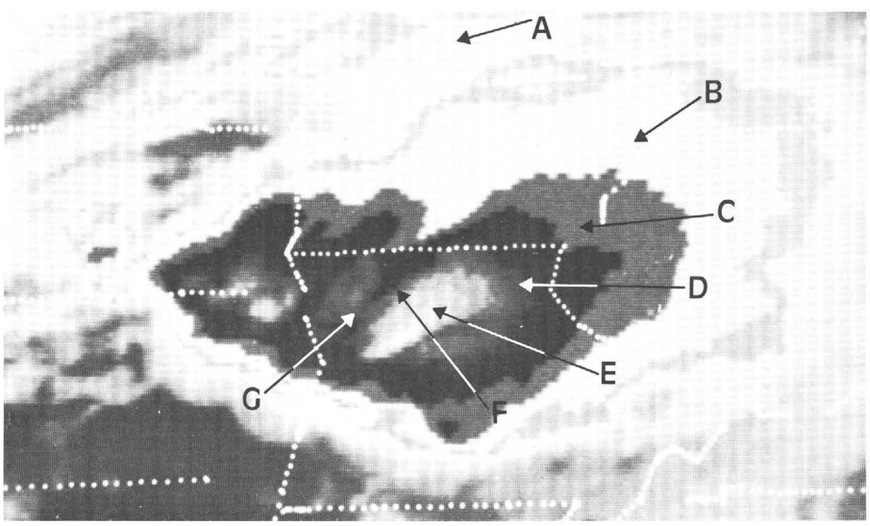
In the Great Plains, it is not uncommon for a flood to result from new rainfall on succeeding nights. Normally, such subsequent heavy rainfall has a tendency to occur in an area downwind from the earlier events. What distinguished the 1977 Kansas City flood was that the two bursts of heavy rains fell on nearly the same location. In fact, in the satellite infrared imagery, the cumulonimbus turret actually propagated upwind toward southwest in the early stage of the second storm. During about 6½ h, this second storm released up to 7 in. of rainfall on the previously saturated area. This amount again exceeded the 100-year 6-h rainfall value. All streams and creeks rose rapidly and almost simultaneously as the rain fell. It was this second burst of heavy rain that caused havoc. Even with drainage basins as small as those involved, a shift of the heaviest rain of



A.—0100 c.s.t., Sept. 12, 1977.

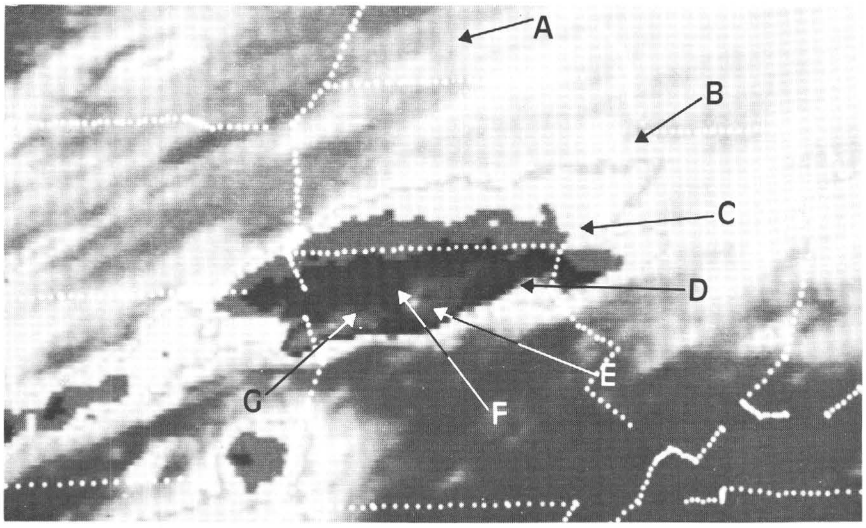


B.—0200 c.s.t., Sept. 12, 1977.

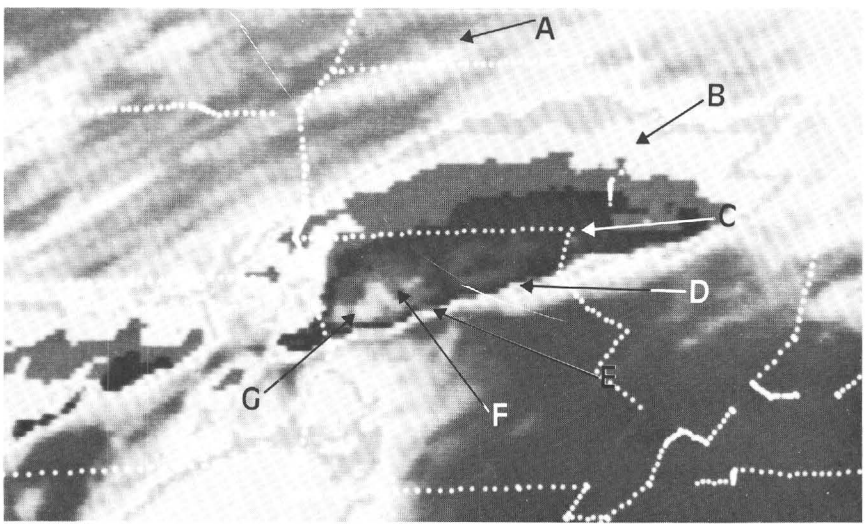


C.—0300 c.s.t., Sept. 12, 1977.

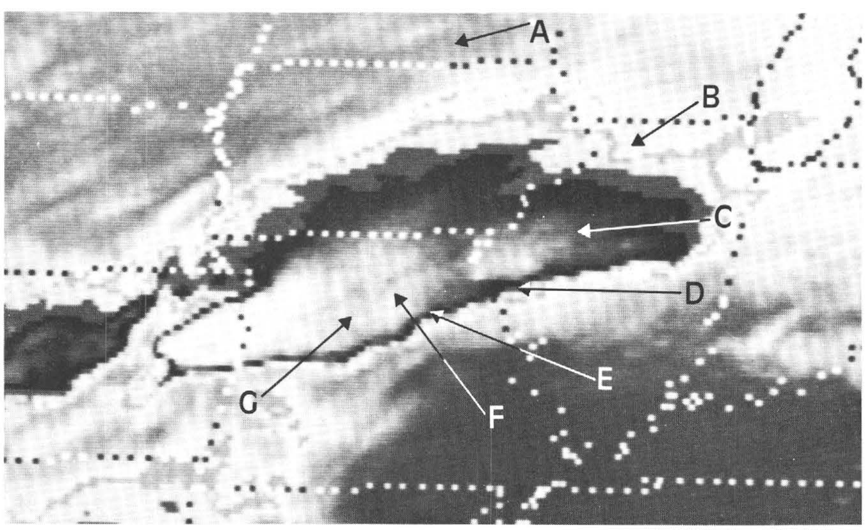
FIGURE 11.—GOES infrared imagery for first storm (11*A*, *B*, *C*) and second storm (11*D*, *E*, *F*). All pictures are enhanced by use of M_B curve to increase the contrast of cloud top temperature differences. To convert different shading into temperature ranges, use the scale shown in figure 11*B*, where A: $-32 \rightarrow -41$°C; B: $-41 \rightarrow -52$°C; C: $-52 \rightarrow -58$°C; D: $-58 \rightarrow -62$°C; E: $-62 \rightarrow -71$°C; F: $-71 \rightarrow -80$°C; G: below -80°C.



D.—1830 c.s.t., Sept. 12, 1977.



E.—1930 c.s.t., Sept. 12, 1977.



F.—2030 c.s.t., Sept. 12, 1977.

FIGURE 11.—Continued.

either storm of only a few miles apart would have greatly reduced the intensity of the flood. The fact that the axis of heavy rain in the second storm also lay WSW-ENE, approximately along the direction of Brush Creek and the adjacent small basins, further aggravated the severity of the resulting flash flood.

DESCRIPTION AND MEASUREMENT OF FLOODS

FLOOD DAMAGES

Water damage was widespread in nearly every drainage basin in the area. Because of the high rainfall intensities that occurred during the storm, hillside runoff flooded garages and basements of buildings in some areas located well above the flood plains.

High-rainfall intensity, however, was not the sole cause of flood damage in the study area. Only 10 hours apart, both rainfall periods exceeded the 100-year 24-h rainfall frequency depth. The first rainfall period saturated the ground. This saturated soil, together with large impervious urbanized areas forced much of the second storm rainfall to become surface runoff, since it could not infiltrate the ground. All these conditions, together with the high rainfall intensities, added to the magnitude of the total runoff.

The greatest damage to commercial property occurred in the Brush Creek and lower Blue River basins. In the Brush Creek basin, many shoppers had parked their cars in underground sections of multilevel parking lots and along streets that were inundated during the flood. Mission Shopping Center in Mission, Kans., was inundated by floodwaters from steep hillside slopes and overbank flow from Rock Creek, a tributary in the Brush Creek basin. Shops and stores in the Country Club Plaza of Kansas City,

FIGURE 12.—Brush Creek, after flood crest, looking north on J. C. Nichols Parkway at Ward Parkway, at Country Club Plaza, Kansas City, Mo.

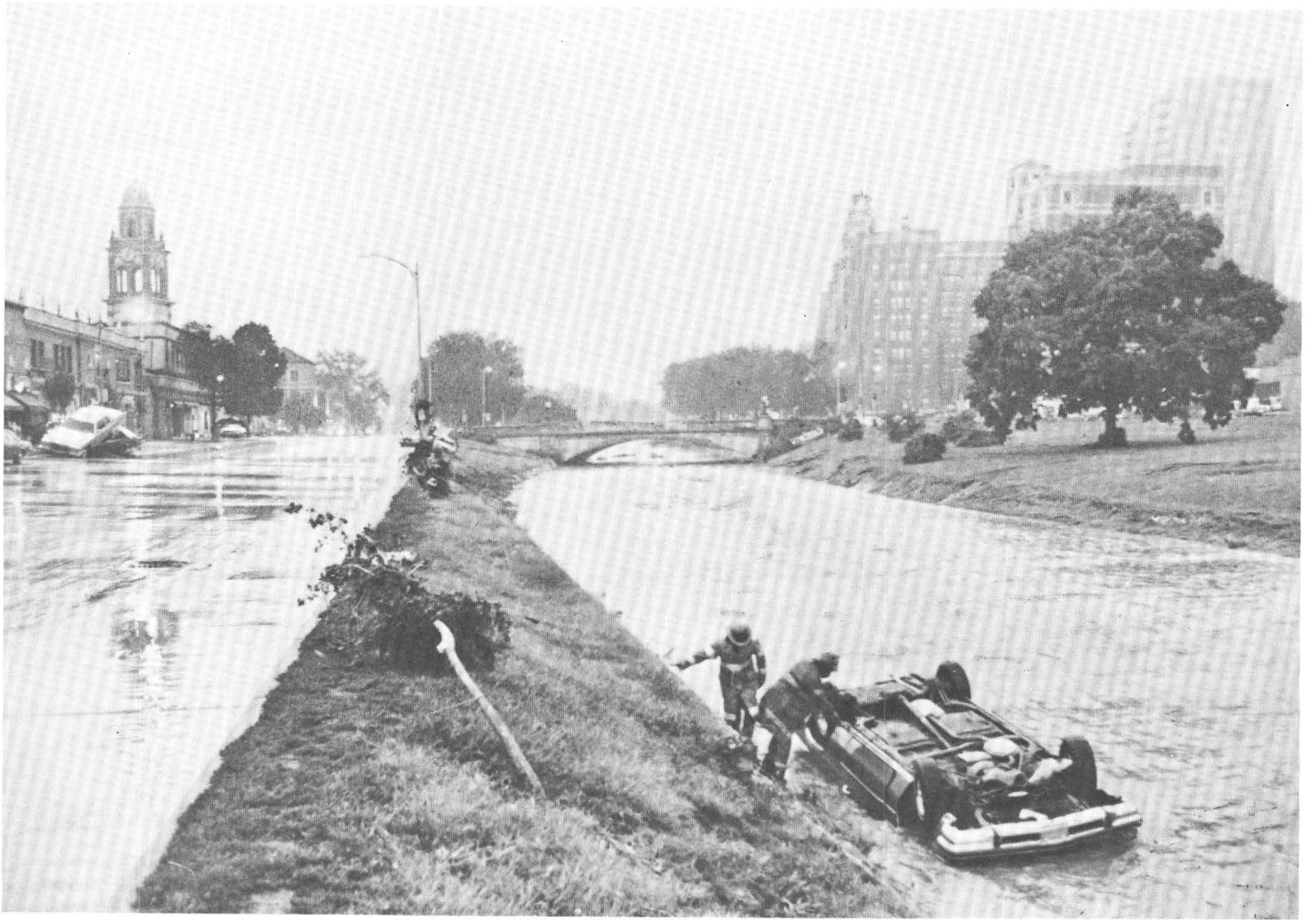


FIGURE 13.—Brush Creek, after flood crest, looking east along Ward Parkway, at Wornall Road at Country Club Plaza, Kansas City, Mo.

Mo., just upstream from the U.S. Geological Survey gaging station at Main Street, were flooded by as much as 6 ft of water, as evidenced in figures 12 to 16. Floodmarks can be seen in the window of the U.S. Post Office at Plaza Center (fig. 14).

The industrialized lower Blue River flood plain was damaged, also. Railroad tracks were undermined as much as 3 to 4 ft deep along bridge approaches. Figure 16 shows the general flooding in the industrial area in the Blue River basin between 23rd Street and Truman Road.

Residents along Rock Creek in Independence, Mo., felt the brunt of the flood when 11 houses were completely destroyed. Other houses were left in the middle of streets after ceiling-level floodwaters floated them from their foundations.

A 10-county area was affected by the floodwaters. Public damage awards made in the Kansas City area exceeded $14 million, according to Federal Disaster Assistance Administration officials in Kansas City. The Small Business Administration reports that about $31 million in Missouri and $8.5 million in Kansas has been awarded in a total of 3,000 small business loans, as a result of the flood. The U.S. Army Corps of Engineers damage survey indicates that, overall, the Rock Creek (Mo.) and Brush Creek basins, where the highest rainfall depths and intensities were recorded, sustained more than $80 million in damages.

According to Federal Insurance Administration officials in Kansas City, there were 1,539 flood insurance policies in force within the metropolitan area of Kansas City, Mo.-Kans. at the time of the flood. FIA reports that there were 2,142 flood insurance policies in force during 1978 (metropolitan Kansas City), with an increase of over $32 million in coverage.

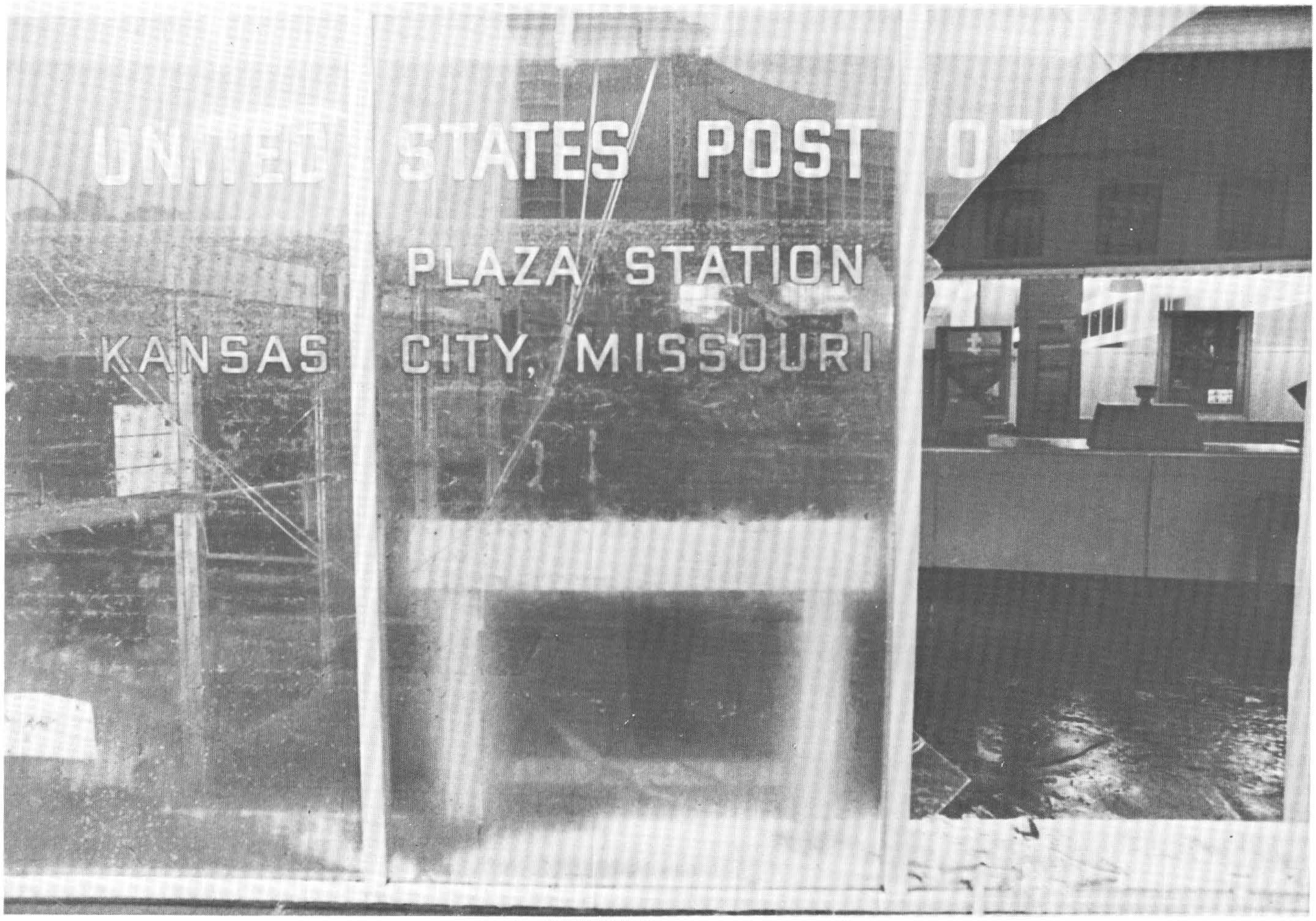


FIGURE 14.—United States Post Office, after Brush Creek flood crest, on Ward Parkway at Country Club Plaza, Kansas City, Mo.

FIGURE 15.—View of 600 block of West 48th Street, after Brush Creek flood crest, at Country Club Plaza, Kansas City, Mo.

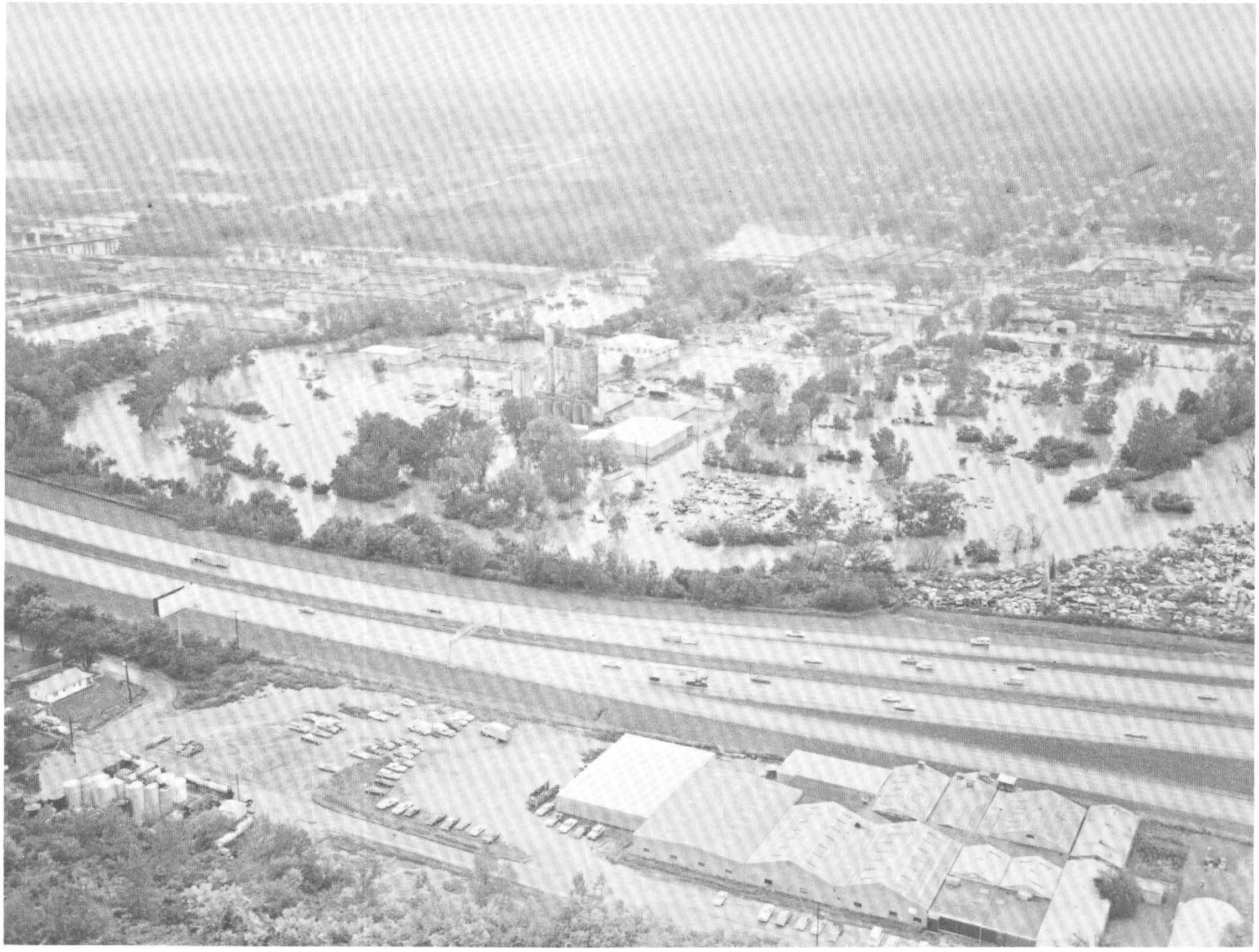


FIGURE 16.—Aerial view after flood crest, looking west along Blue River between 23rd Street and Truman Road, Kansas City, Mo.

FLOOD HYDROGRAPHS

Figures 17 to 29 are flood hydrographs for the storm period at selected U.S. Geological Survey gaging stations in the area. A rainfall mass curve is also shown for Round Grove Creek (fig. 23) where rainfall was recorded simultaneously with river stage in a dual gaging system. The gage structures on Rock Creek at Independence, Mo., and Brush Creek at Main Street at Kansas City, Mo., were damaged during the flood peak and parts of the flood hydrographs were computed on the basis of high-water marks, earlier flow records, and the stage record, prior to gage failure. Estimated hydrograph segments are shown as dashed lines.

Discharge hydrographs were developed from stage records and from the relationship between stage and stream discharge at each site (figs. 17 to 29).

Other flood hydrographs for streams outside the area of maximum precipitation depths show the variation of storm runoff over the area.

FLOOD-CREST PROFILES AND INUNDATED AREAS

Water-surface profiles of the flood on Blue River, Brush Creek, Rock Creek (Kans.), Rock Creek (Mo.), and Little Blue River are shown in figures 30 to 34. Where information is available, elevations of bridge floors are shown to indicate road overflow. The profile of the September 1961 flood on the Blue River is shown for comparison (fig. 30). The effect of inflow of Brush Creek at mile 11.3 is evident.

Commercial and residential areas along Brush Creek underwent extensive flood damage, especially at and around the Country Club Plaza shopping center. Shown in figure 35 are the flood boundaries in the Plaza area upstream from the U.S. Geological Survey stream-gaging station at Main Street. The aera of inundation within the flood lines shows that the major flooding in the Plaza area is restricted to the low left-bank flood plain. The flooded area is shown from Main Street upstream to Jefferson Street.

The Main Street roadfill was not overtopped during the flood, and the total flood discharge was confined to the bridge opening (fig. 35). Elevations of high-water marks at the bridge showed a 2.5 ft drop in water surface between the upstream and downstream sides of the bridge.

Flood boundaries of the Sept. 12–13, 1977, flood in other areas where flood-crest profiles have been determined are delineated on topographic maps (scale 1:24,000) and are available from the U.S. Geological Survey, 1400 Independence Road, Rolla, Mo. 65401.

Table 3 lists the discharge measurement sites in downstream order. A summary of location descriptions, as well as other basic data, is provided in an earlier report by Hauth and Carswell (1978).

MEASUREMENT OF FLOOD DISCHARGES

Hydrologists were in the area measuring storm runoff from the two-storm flood by noon of Sept. 13. Although floodwaters had receded from small drainage systems before daylight, useful discharge measurements were obtained from streams of greater drainage areas. At the same time, hydrologists were selecting sites and identifying floodmarks for indirect determinations of discharge.

Peak discharges were determined at 31 sites (table 3 and fig. 2). These included indirect determinations of discharge made at 13 continuous-record stations and 13 miscellaneous sites using methods described in the reports, "Techniques of Water-Resources Investigations of the U.S. Geological Survey," (Dalrymple and Benson, 1967; Matthai, 1967; Bodhaine, 1968; Haulsing, 1968). One current-meter measurement was made on Little Blue River at Lake City, Mo. Peak discharges were obtained from stage-discharge relationships developed at five sites. Figure 2 shows the location of the sites and the drainage system. Peak discharges were measured both in the fringe area (areas of low rainfall depth) and in areas of maximum rainfall.

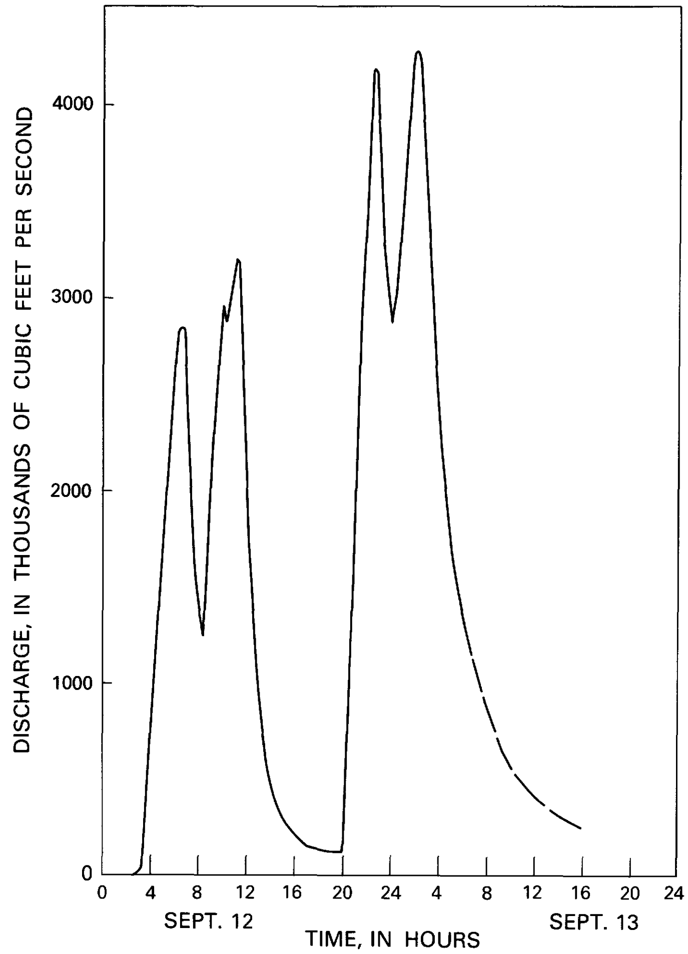


FIGURE 17.—Discharge hydrograph at U.S. Geological Survey gaging station on Line Creek at Riverside, Mo., flood of Sept. 12, 1977.

GENERAL SEDIMENT DEPOSITION

Floodwaters in the Kansas City area left very few deposits of fine sediment (silts and fine sands) on the flood plains and streets because of the high velocities experienced during the flood. Large amounts of fine sediment, however, were deposited in the basements and on the ground-floor levels of many residential and commercial buildings. Much of the fine sediment, especially in the Brush Creek basin, was transported all the way to the Blue River. Although fine-sediment deposits were sparse, deposits of large-sized sediment were numerous. Figures 36 and 37 depict sediment that was transported in Brush Creek.

The apparent source for much of the fluvial material shown in figure 36 is the Kansas part of the basin in the Mission Hills area. However, some of the material came from retaining walls and other structures that were torn out during the flood. Figure 38

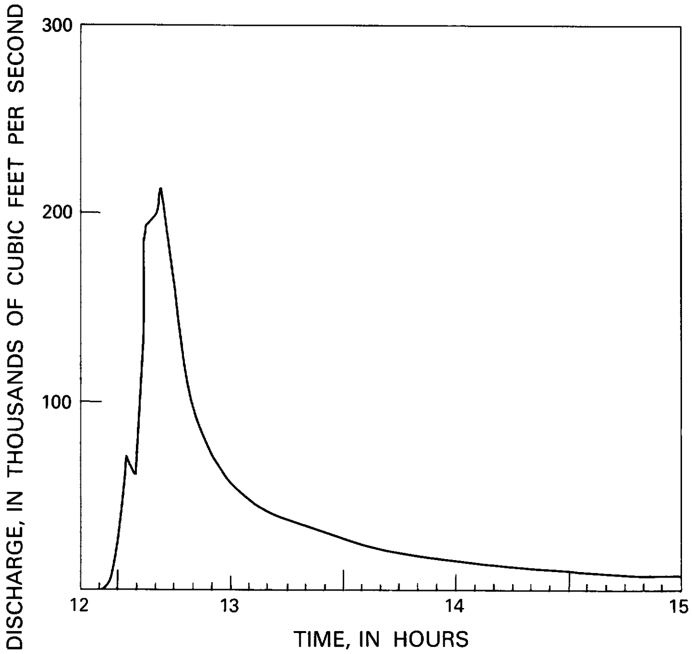


FIGURE 18.—Discharge hydrograph at U.S. Geological Survey gaging station on Blue River near Stanley, Kans., flood of Sept. 12–13, 1977.

shows the particle-size distribution of two deposits sampled near Woodland Avenue bridge. These sediment samples can be considered representative of the large-sized material transported in the Woodland Avenue reach on Brush Creek.

Flood-plain deposits in the Woodland Avenue reach were also sampled. The pebble-count method (Guy and Norman, 1970) was used to obtain a representative measure of the sediment sizes. Flood-plain deposits depicted in figure 36 had been put in a shallow pile by cleanup crews after the photograph was taken. A grid was laid out over the pile and the particles at the intersection points were measured. The intermediate dimension was recorded for each particle. The sizes measured ranged from 91.4 to 960 mm with a median size of 213 mm. Although the flood-plain deposits were not sampled in their original state, the results are considered to be a representative measurement.

Many of the very large, in-channel deposits were imbricated (fig. 37). Such large particles probably were deposited soon after the flood peak. The concrete slabs shown in figure 37 had lined Brush Creek where it was channeled through the Country Club Plaza. They measure approximately 15 ft square and are about 1.0 ft thick. These heavy slabs were dislodged from their positions in the creek bottom during the flood.

TABLE 3.—*Summary of peak stages and discharges for Kansas City area floods of Sept. 12–13, 1977*

Map No.	Permanent station No.	Stream and place of determination	Drainage area (mi²)	Period of record	Maximum previously known flood: Date	Gage height (ft)	Dis-charge (ft³/s)	Maximum flood of Sept. 12–13, 1977: Date	Gage height (ft)	Dis-charge (ft³/s)	Dis-charge [(ft³/s)/mi²]	Recurrence interval (years)
1	06821280	Line Creek at Riverside, Mo. (old U.S. Hwy. 71)	19.2	1976–	5–18–74	29.0	----	9–13–77	16.22	4,300	167	5
2	06892800	Turkey Creek at Merriam, Kans. (67th Street)	6.76	1974–	8–26–75	17.11	----	9–12–77	21.65	5,300	784	100
3	--------	Turkey Creek Trib. at Carter St. at Merriam, Kans	.82	----	-------	----	----	9–12–77	----	1,200	1,460	50
4	--------	Turkey Creek at 63rd St. at Merriam, Kans	7.84	----	-------	----	----	9–12–77	----	6,490	827	>100
5	06892940	Turkey Creek at Kansas City, Kans. (State Hwy. 10)	22.3	1974–	8–26–75	16.31	----	9–12–77	25.2	11,700	552	>100
6	06893080	Blue River near Stanley, Kans. (U.S. Hwy. 69)	46	1970–	6– 9–74	16.83	7,500	9–13–77	891.22 [b]	214	5	----
7	06893250	Indian Creek near Overland Park, Kans. (Morse Road)	14.8	1970–76	6–22–69	21.02	3,300	9–13–77	18.72	1,300	88	3
8	06893300	Indian Creek at Overland Park, Kans. (Marty Street)	26.6	1963–	7–15–76	11.62 [a]	6,540	9–13–77	872.38 [b]	8,820	332	>100
9	06893350	Tomahawk Creek near Overland Park, Kans. (119th Street)	23.9	1970–	6–25–69	19.79	----	9–13–77	855.89 [b]	4,290	179	8
10	06893500	Blue River near Kansas City, Mo. (old Bannister Road)	188	1940–	9–13–61	44.46	41,000	9–13–77	788.47 [b]	20,500	109	10
11	--------	Blue River Trib. at Bannister Road near Kansas City, Mo. (U.S. Hwy. 71)	3.38	----	-------	----	----	9–13–77	----	4,040	1,195	>100
12	--------	Brush Creek at 75th and Nall Ave. at Prairie Village, Kans	1.51	----	-------	----	----	9–12–77	----	3,000	1,990	>100
13	--------	Brush Creek at 63rd St. and Mission Hills, Kans	5.84	----	-------	----	----	9–12–77	----	14,400	2,740	>100
14	--------	Rock Creek at Woodson and Martway St. at Mission, Kans	1.15	----	-------	----	----	9–12–77	----	1,980	1,720	25
15	--------	Rock Creek at Sheridan Road at Fairway, Kans	3.04	----	-------	----	----	9–12–77	----	4,900	1,610	>100
16	06893560	Brush Creek at Main St. at Kansas City, Mo	14.8	1971–	-------	----	----	9–12–77	23.24	17,600	1,243	>100
17	06893570	Round Grove Creek at Raytown Road at Kansas City, Mo	5.87	----	-------	----	----	-------	----	13,200	2,249	>100
18	--------	Blue River at 12th St. at Kansas City, Mo	264	----	-------	----	----	9–13–77	----	34,900	132	>100
19	06893600	Rock Creek at Independence, Mo. (Northern Boulevard)	5.20	1968–	6–19–67	14.22	2,520	9–12–77	841.93 [b]	7,760	1,492	>100
20	06893670	Shoal Creek at Claycomo, Mo. (U.S. Hwy. 69)	29.8	1976–	5–18–74	33.18	----	9–12–77	753.61 [b]	9,230	310	>100
21	06893680	Mill Creek at 56th St. at Gladstone, Mo	1.24	----	-------	----	----	9–12–77	----	800	645	15
22	06893710	Cates Branch near Liberty, Mo. (Sherril Drive)	1.95	----	-------	----	----	9–12–77	765.87 [b]	2,480	1,272	>100
23	--------	Mill Creek at Courtney Road near Independence, Mo	1.95	----	-------	----	----	9–12–77	----	2,240	1,149	>100
24	06893793	Little Blue River below Longview Road Damsite at Kansas City, Mo	50.7	1967–	6–27–69	11.19	----	9–13–77	819.67 [b]	18,100	367	>100
25	--------	Cedar Creek at Lees Summit, Mo. (Chicago-Rock Island and Pacific RR)	1.84	----	-------	----	----	9–12–77	----	2,410	1,310	>100
26	--------	White Oak Creek at Raytown Road at Raytown, Mo	1.78	----	-------	----	----	9–12–77	----	2,290	1,286	>100
27	--------	Little Blue River Trib. at Noland Road at Independence, Mo	0.83	----	-------	----	----	9–12–77	----	2,330	2,807	>100
28	06893890	East Fork Little Blue River near Blue Springs, Mo. (U.S. Hwy. 40)	34.4	1970–	5–18–74	19.19	----	9–13–77	774.22 [b]	6,100	145	20
29	06894000	Little Blue River near Lake City, Mo. (Mo. Hwy. 78)	184	1949–	9–14–61	27.94	9,460	9–13–77	742.45 [b]	17,000	95.1	>100
30	06894680	Sni-A-Bar Creek near Tarsney, Mo. (Colburn Road)	29.1	1971–	9–11–77	21.93	4,300	9–13–77	811.67 [b]	15,700	540	>100
31	--------	Tucker Creek at Highway FF near Grain Valley, Mo	1.45	----	-------	----	----	9–12–77	----	1,890	1,303	>100

[a] At site 500 ft downstream.
[b] National Geodetic Vertical Datum (NGVD).

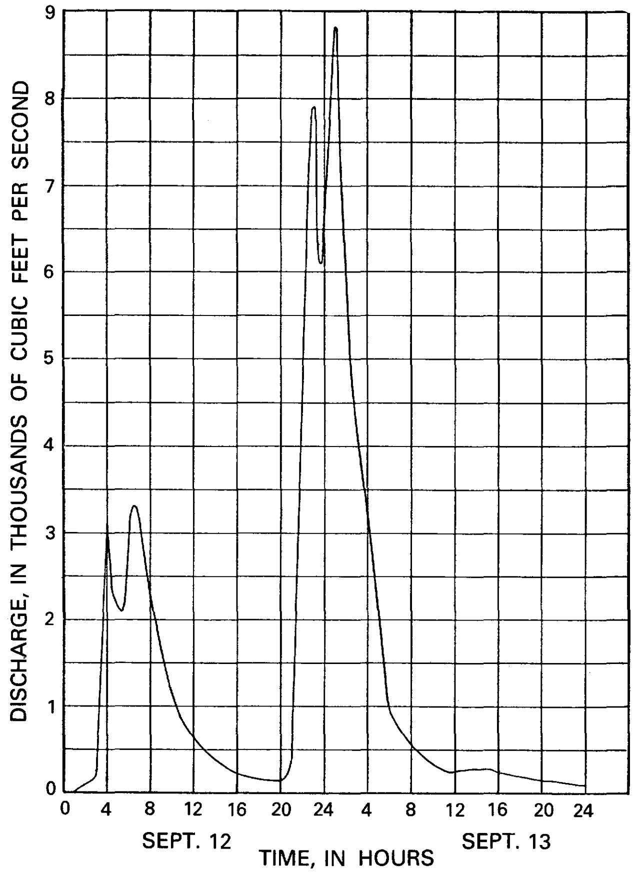


FIGURE 19.—Discharge hydrograph at U.S. Geological Survey gaging station on Indian Creek at Overland Park, Kans., flood of Sept. 12–13, 1977.

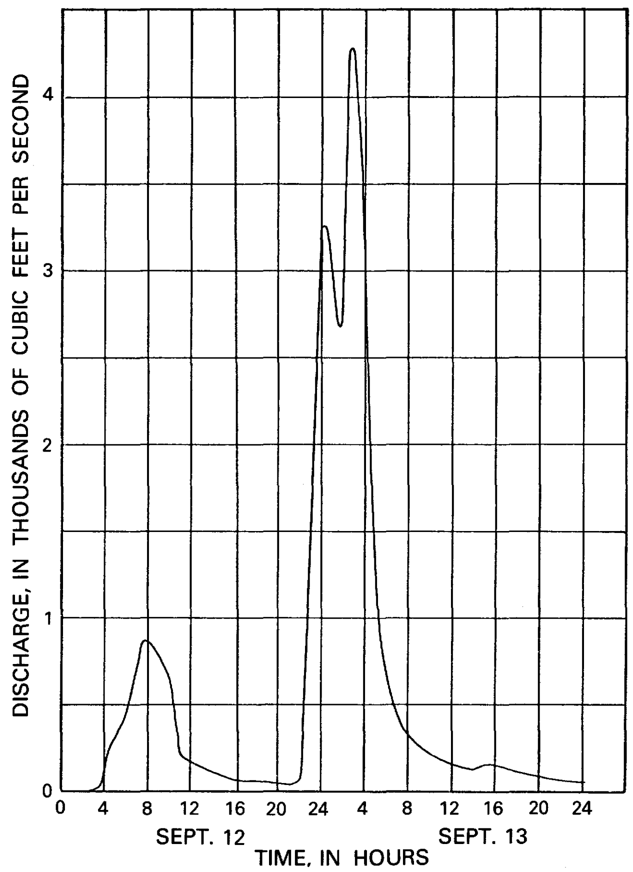


FIGURE 20.—Discharge hydrograph at U.S. Geological Survey gaging station on Tomahawk Creek at Overland Park, Kans., flood of Sept. 12–13, 1977.

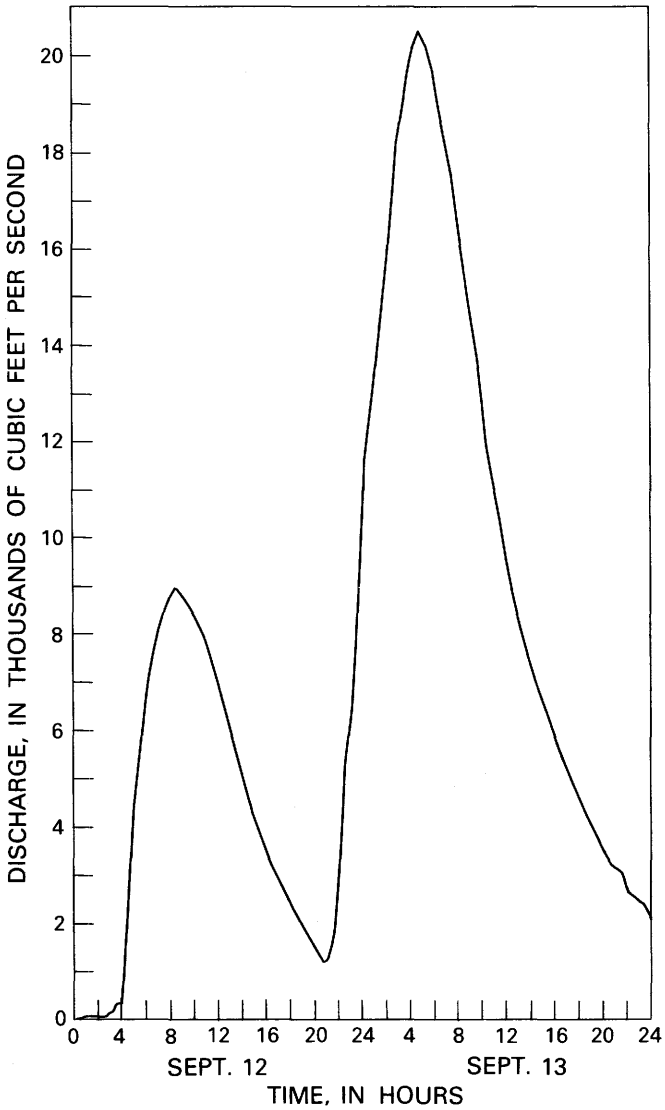


FIGURE 21.—Discharge hydrograph at U.S. Geological Survey gaging station on Blue River near Kansas City, Mo., flood of Sept. 12–13, 1977.

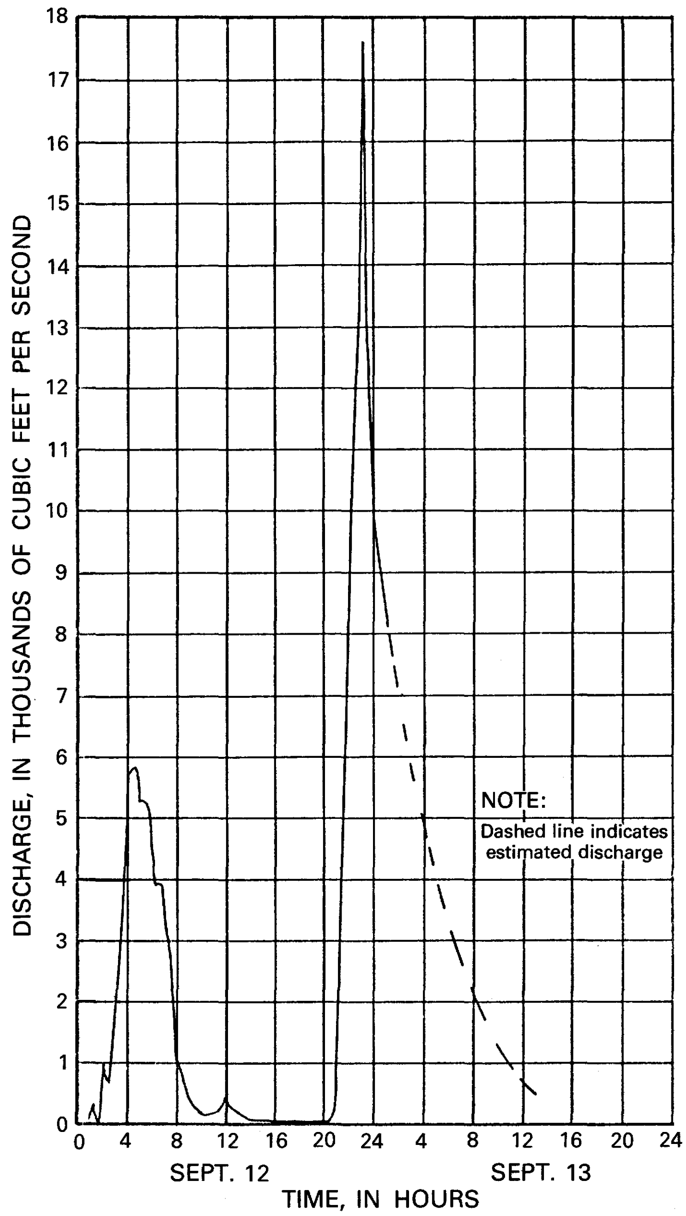


FIGURE 22.—Discharge hydrograph at U.S. Geological Survey gaging station on Brush Creek at Main Street, Kansas City, Mo., flood of Sept. 12–13, 1977.

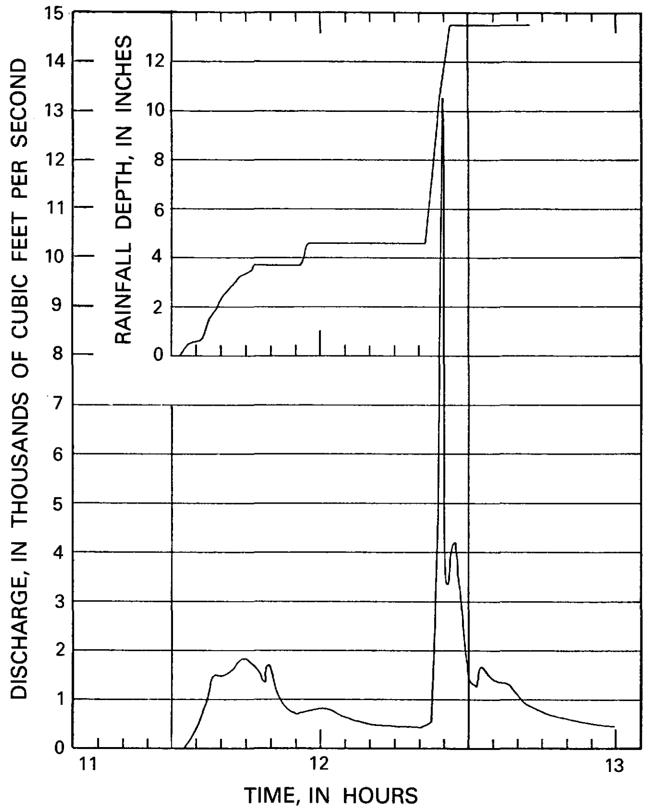


FIGURE 23.—Discharge hydrograph and mass curve of rainfall at U.S. Geological Survey gaging station on Round Grove Creek at Raytown, Mo., flood of Sept. 12–13, 1977.

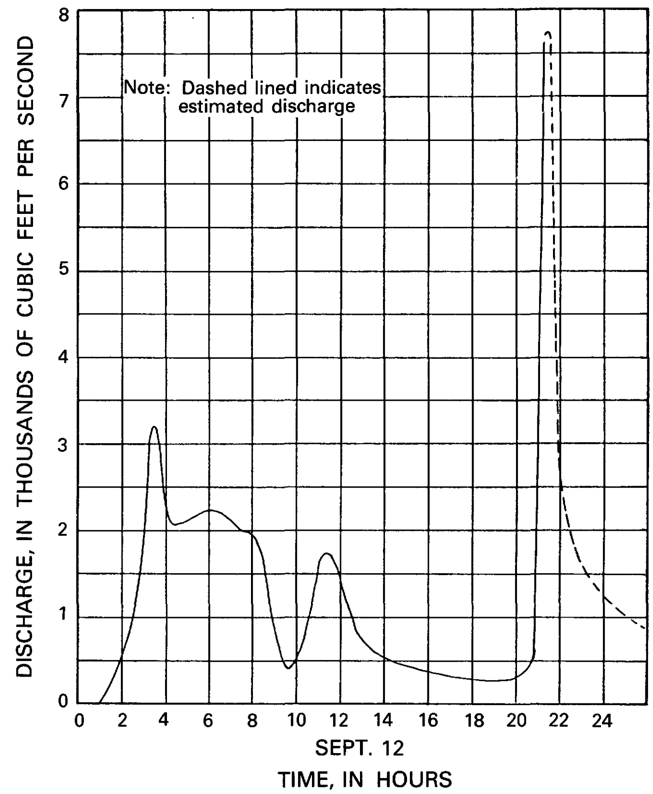


FIGURE 24.—Discharge hydrograph at U.S. Geological Survey gaging station on Rock Creek at Independence, Mo., flood of Sept. 12–13, 1977.

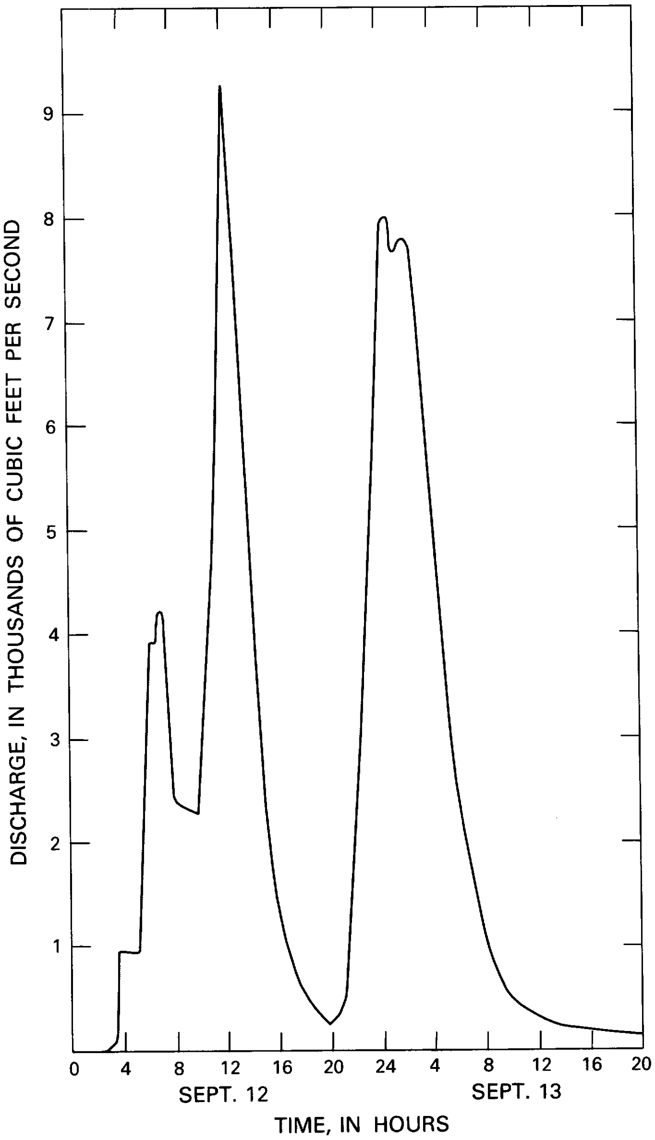


FIGURE 25.—Discharge hydrograph at U.S. Geological Survey gaging station on Shoal Creek at Claycomo, Mo., flood of Sept. 12–13, 1977.

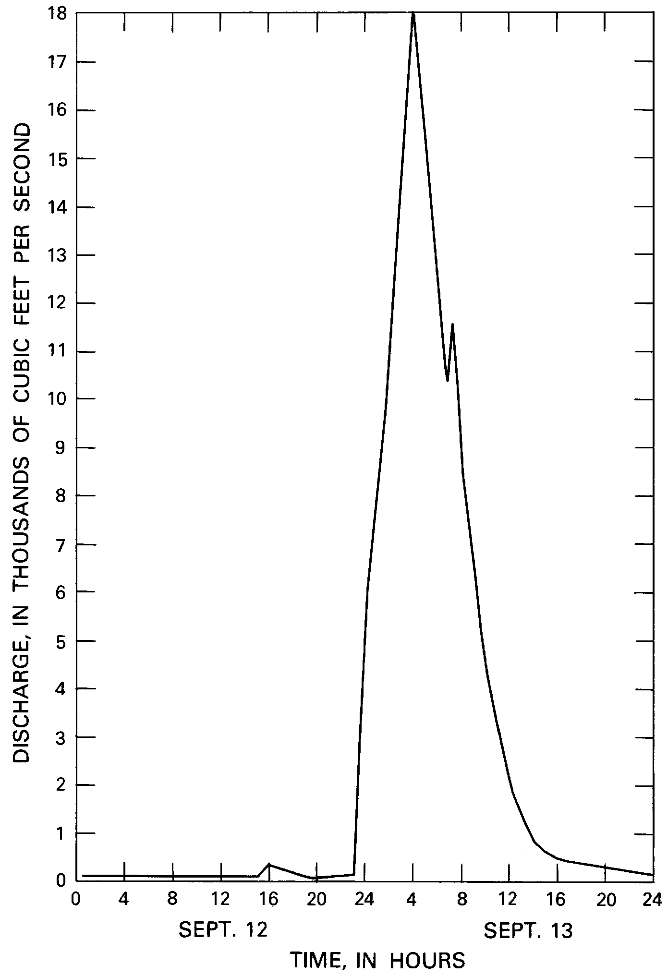


FIGURE 26.—Discharge hydrograph at U.S. Geological Survey gaging station on Little Blue River below Longview Road Damsite in Kansas City, Mo., flood of Sept. 12–13, 1977.

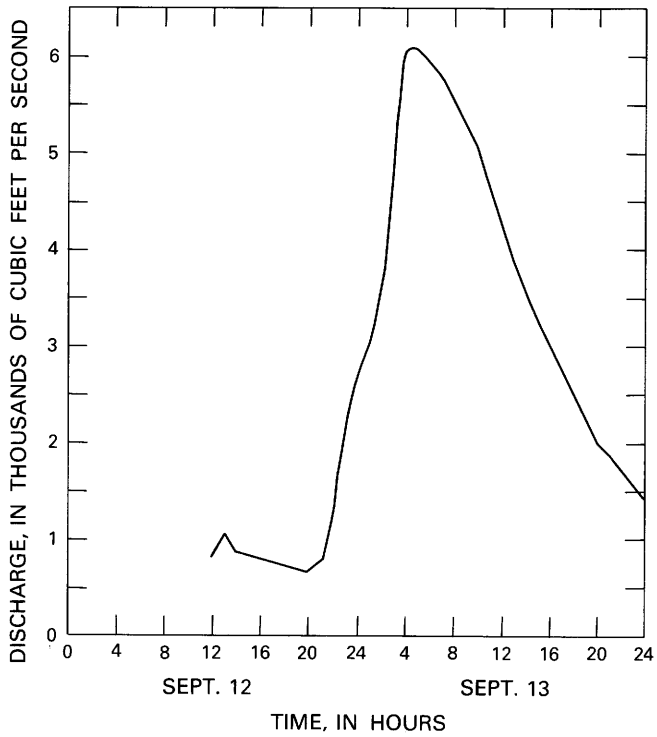


FIGURE 27.—Discharge hydrograph at U.S. Geological Survey gaging station on East Fork Little Blue River near Blue Springs, Mo., flood of Sept. 12–13, 1977.

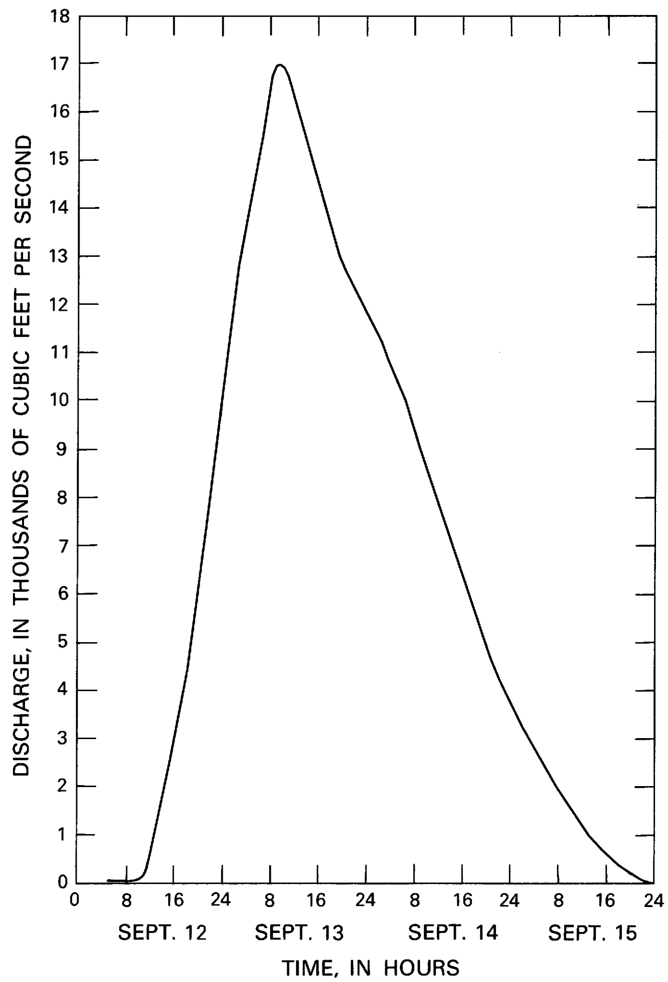


FIGURE 28.—Discharge hydrograph at U.S. Geological Survey gaging station on Little Blue River near Lake City, Mo., flood of Sept. 12–13, 1977.

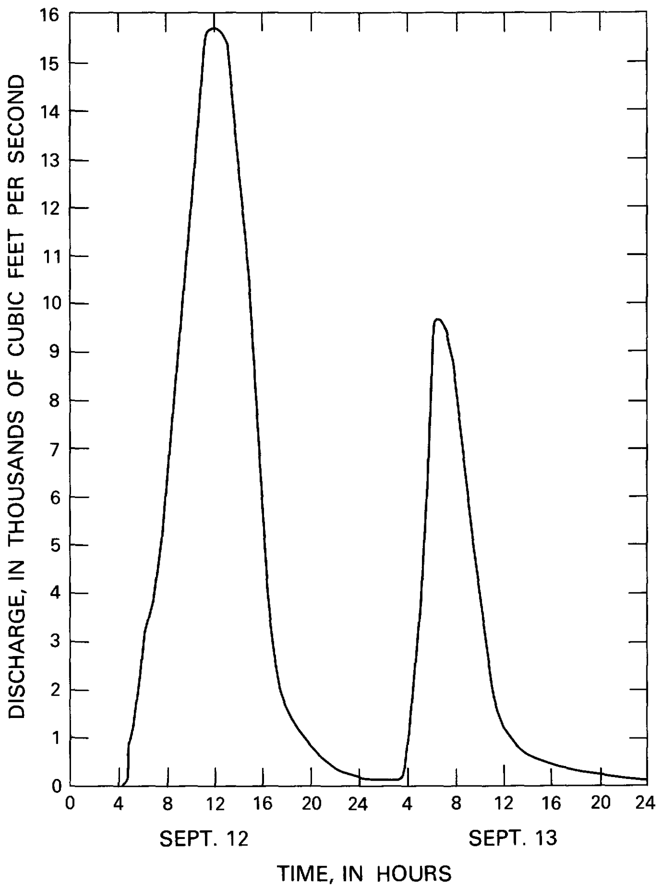


FIGURE 29.—Discharge hydrograph at U.S. Geological Survey gaging station on Sni-A-Bar Creek near Tarsney, Mo., flood of Sept. 12–13, 1977.

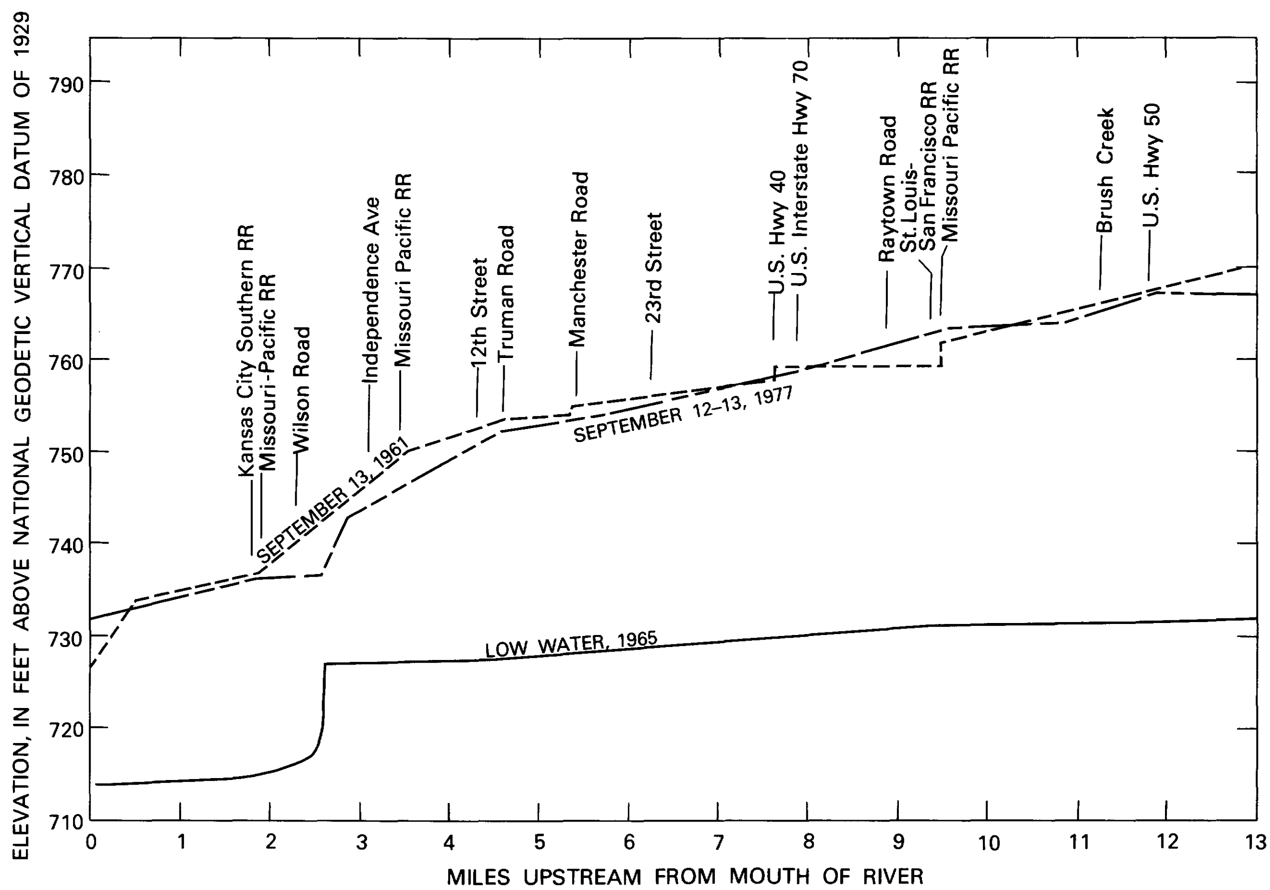
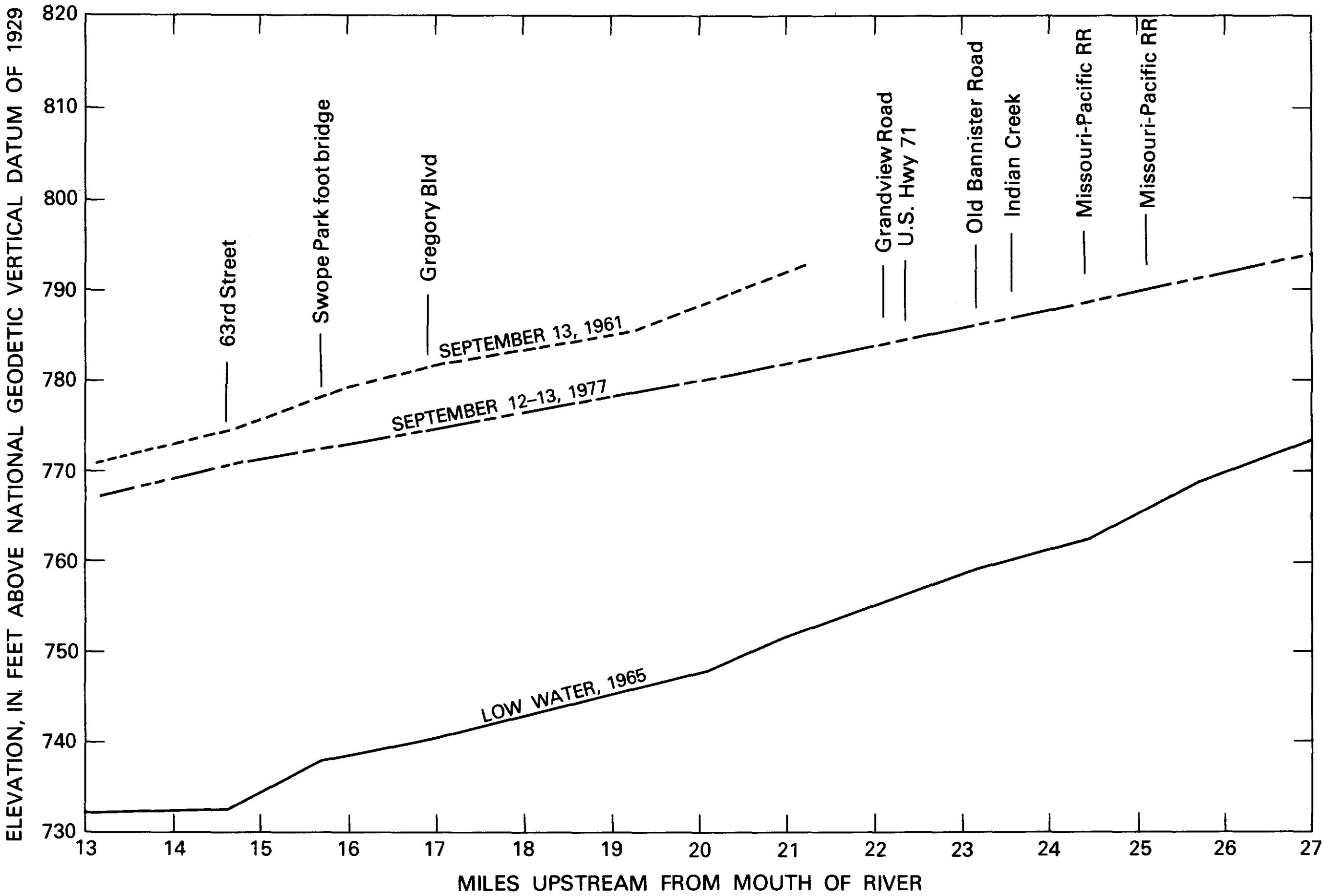


Figure 30.—Profile of water surface of Blue River



for Sept. 12–13, 1977, and Sept. 1961 floods.

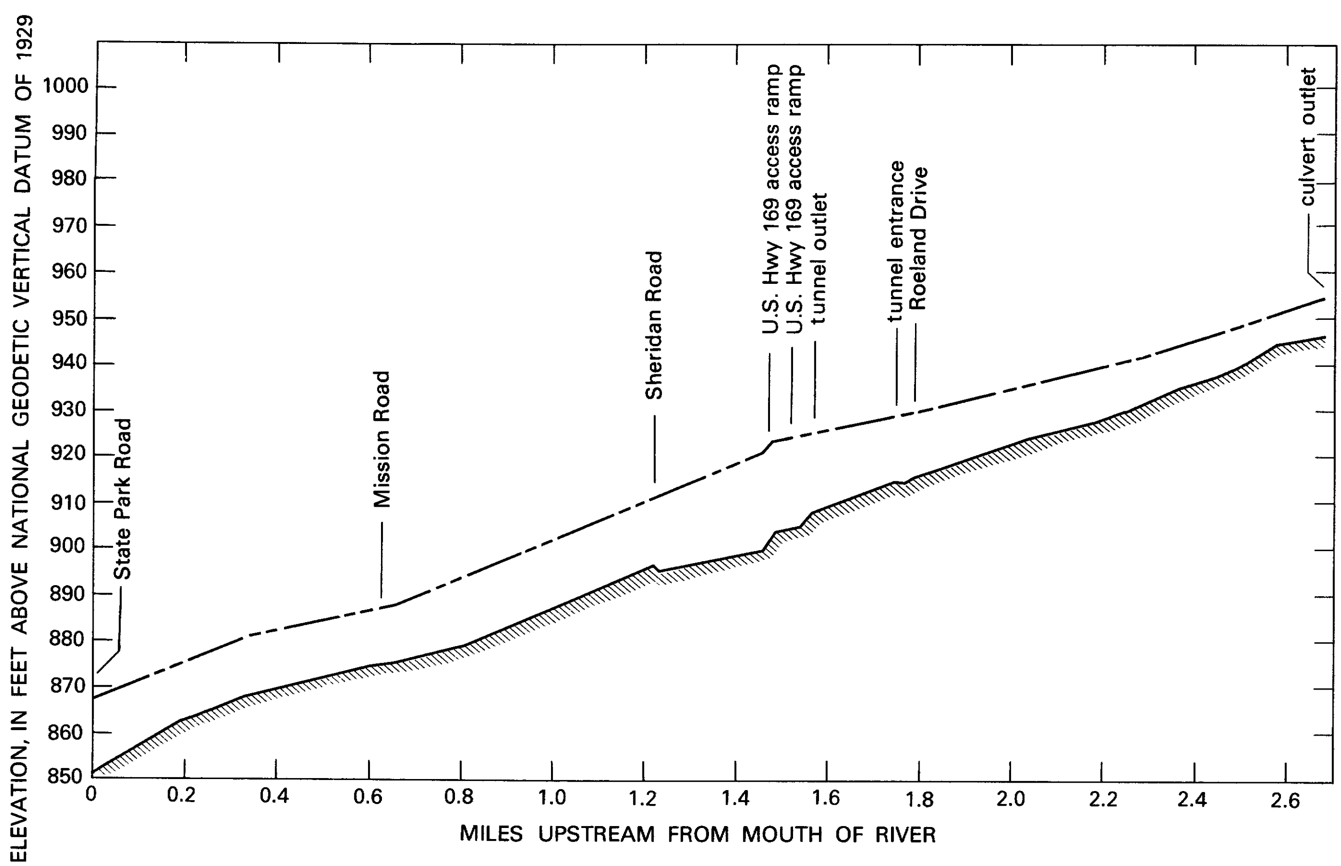


FIGURE 31. Profile of water surface of Rock Creek (Kans.), flood of Sept. 12-13, 1977.

MAGNITUDE AND FREQUENCY OF FLOODS

Knowledge of the magnitude and probable frequency of flood recurrence is useful in the design and location of many types of hydraulic structures and in the development of criteria for flood-plain management.

Techniques for deriving flood-frequency relations are those described by the U.S. Water Resources Council (1977) and by Hauth (1974).

Peak discharges of the Kansas City flood were combined with data for other floods to obtain regional flood-frequency relations. No attempt was made to adjust for the effects of urbanization. Frequencies of flood discharge are estimated for recurrence intervals of 100-years or less. For greater discharges, recurrence intervals are noted only as "greater than 100-years."

FLOOD VOLUMES

During recent years, the nationwide construction of flood-control reservoirs and the allocation of capacity in multipurpose reservoirs for flood control have increased at a higher rate than other reservoir uses. Growth in numbers and capacity of small flood-storage projects in urban areas across the nation has created a need for flood-volume data from typical urban watersheds.

Table 4 is a tabulation of flood volumes in acre-ft and in. of runoff, as computed from streamflow hydrographs available for the Kansas City area. See figures 17 to 29. Recurrence intervals of flood volumes given in table 4 are based on relationships developed by Skelton (1973) for rural areas. For a given amount of rainfall, greater flood volumes will occur in an urban area than in a rural area because of the greater area of impervious surfaces. Thus, for significantly urbanized basins, the recurrence intervals shown in table 4 may be too high because the estimates are based on rural conditions. Until more data are collected in urban areas of Missouri, there is no way to accurately adjust these frequency estimates.

COMPARATIVE MAGNITUDE OF FLOODS

Peak discharges of the Kansas City Sept. 1977 flood, the July 1951 flood in Missouri and Kansas (U.S. Geological Survey Water-Supply Paper 1139, 1952, p. 199), and miscellaneous flood discharges experienced in Missouri and Kansas are plotted against their respective drainage areas for comparison (fig. 39).

A curve developed by Crippen and Bue (1977) on the basis of maximum known floods in the United States defines their approximate upper limit through 1974 (fig. 39). The other curve also shown here was developed by Crippen and Bue using maximum floods in the Missouri-Kansas area, including metropolitan Kansas City. Peak discharges encountered in the Sept. 1977 flood do not approach the maximum flood experience in the United States. Curve values are more than double the highest peak flows of Sept. 12–13, 1977. However, the Sept. 1977 flood does approach maximum flood experience in the Missouri-Kansas area.

SUMMARY

Two record-setting rainstorms occurred in the metropolitan Kansas City area on Sept. 12–13, 1977. Storm runoff claimed the lives of 25 people and caused over $80 million in damages. The U.S. Geological Survey and the National Weather Service cooperated to document the meteorological and hydrological aspects of the flood.

Average rainfall over the metropolitan area exceeded 10 in. with a maximum of more than 16 in. Total storm rainfall of 9.39 in. at Kansas City International Airport exceeded the 100-year 2-day amount of 8.8 in. Maximum storm rainfall of 16.15 in., in approximately 36 hr, exceeded the 100-year 10-day rain of 13.0 in. The combination of meteorological factors associated with the storms are discussed. Isohyetal maps of storm rainfall are presented. Rainfall estimates, using satellite infrared imagery, are found to be consistent with the result of depth-area analysis using conventional data.

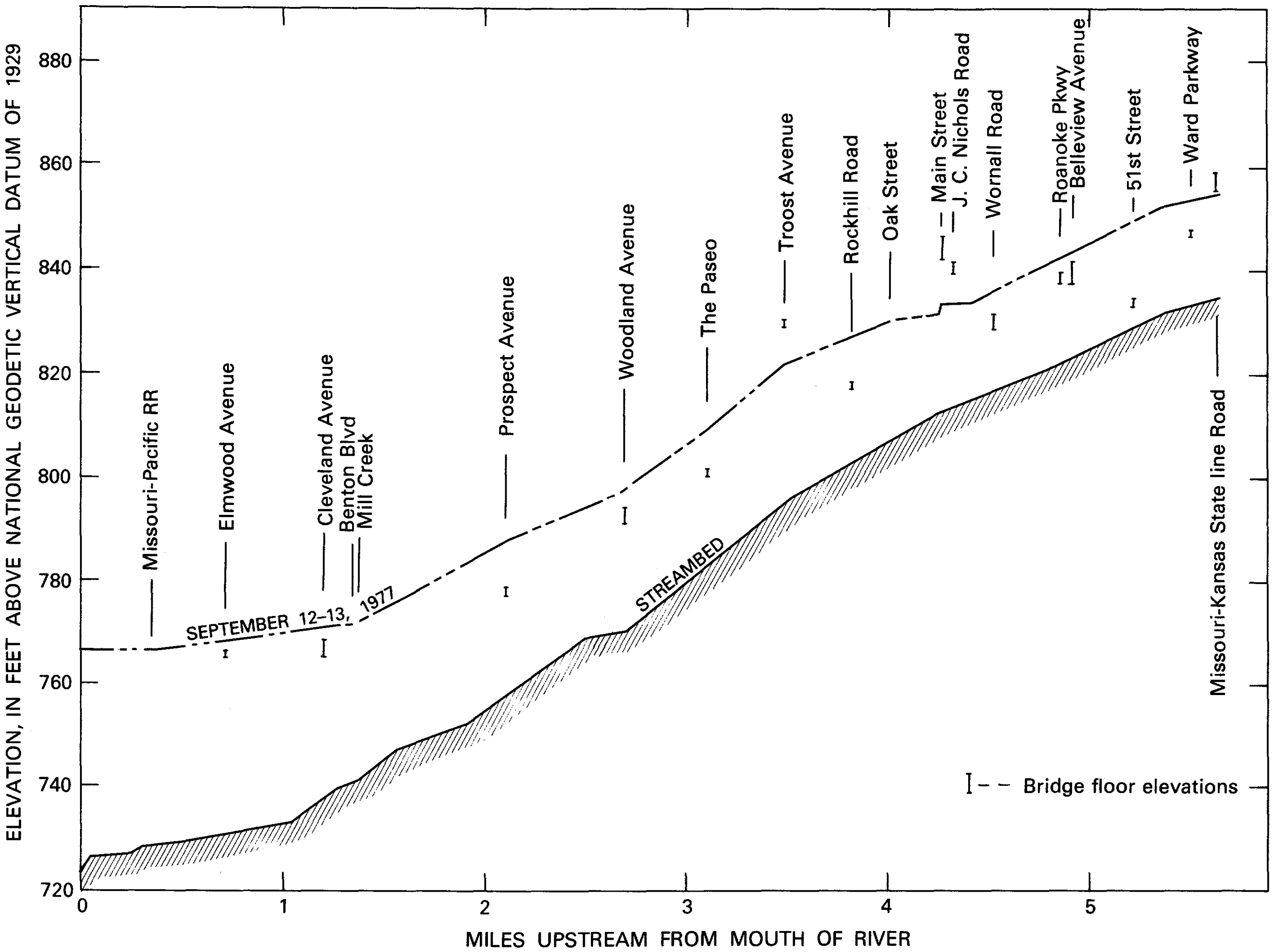
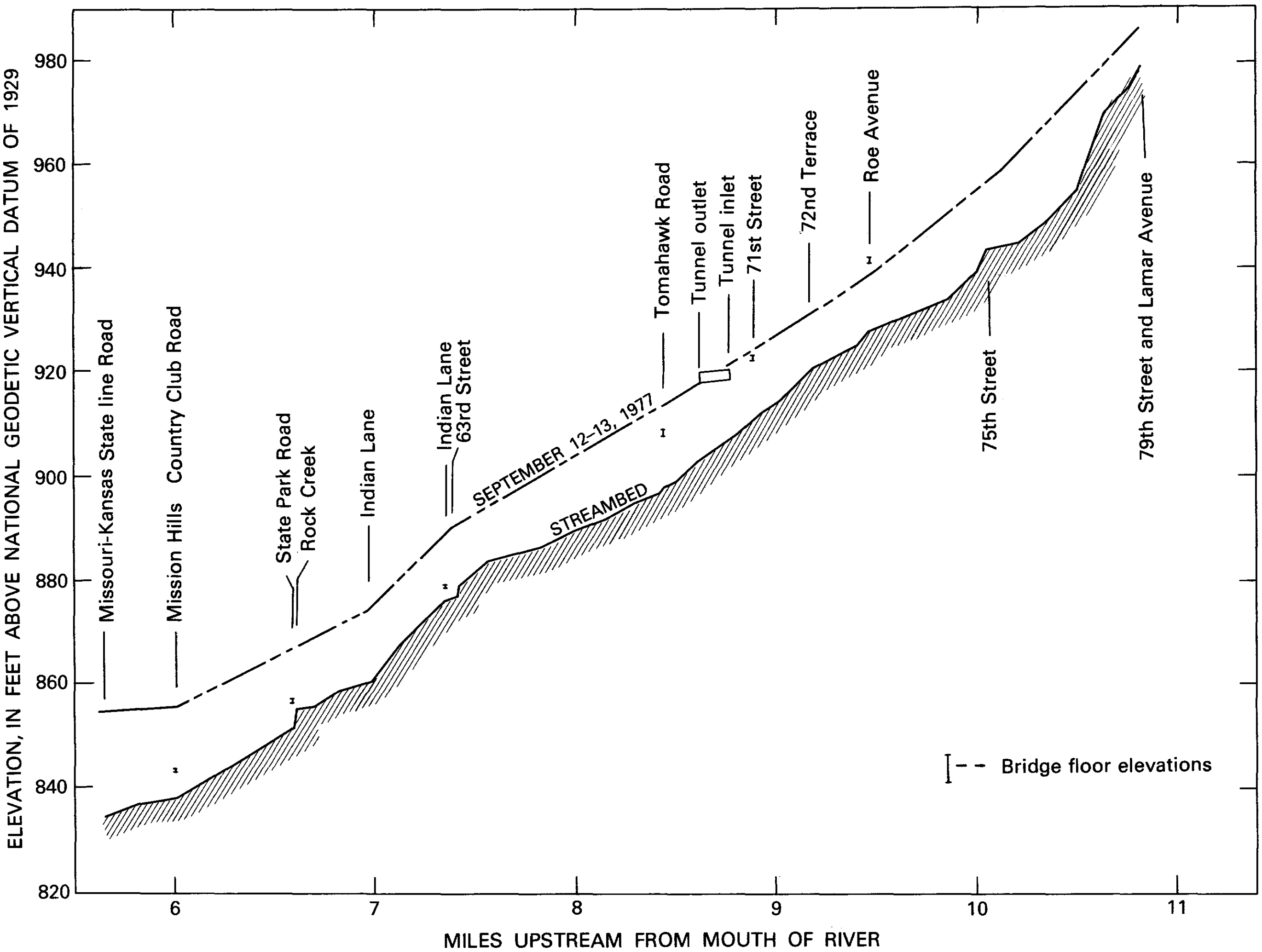


FIGURE 32.—Profiles of water surface of Brush



Creek (Kans.) flood of Sept. 12–13, 1977.

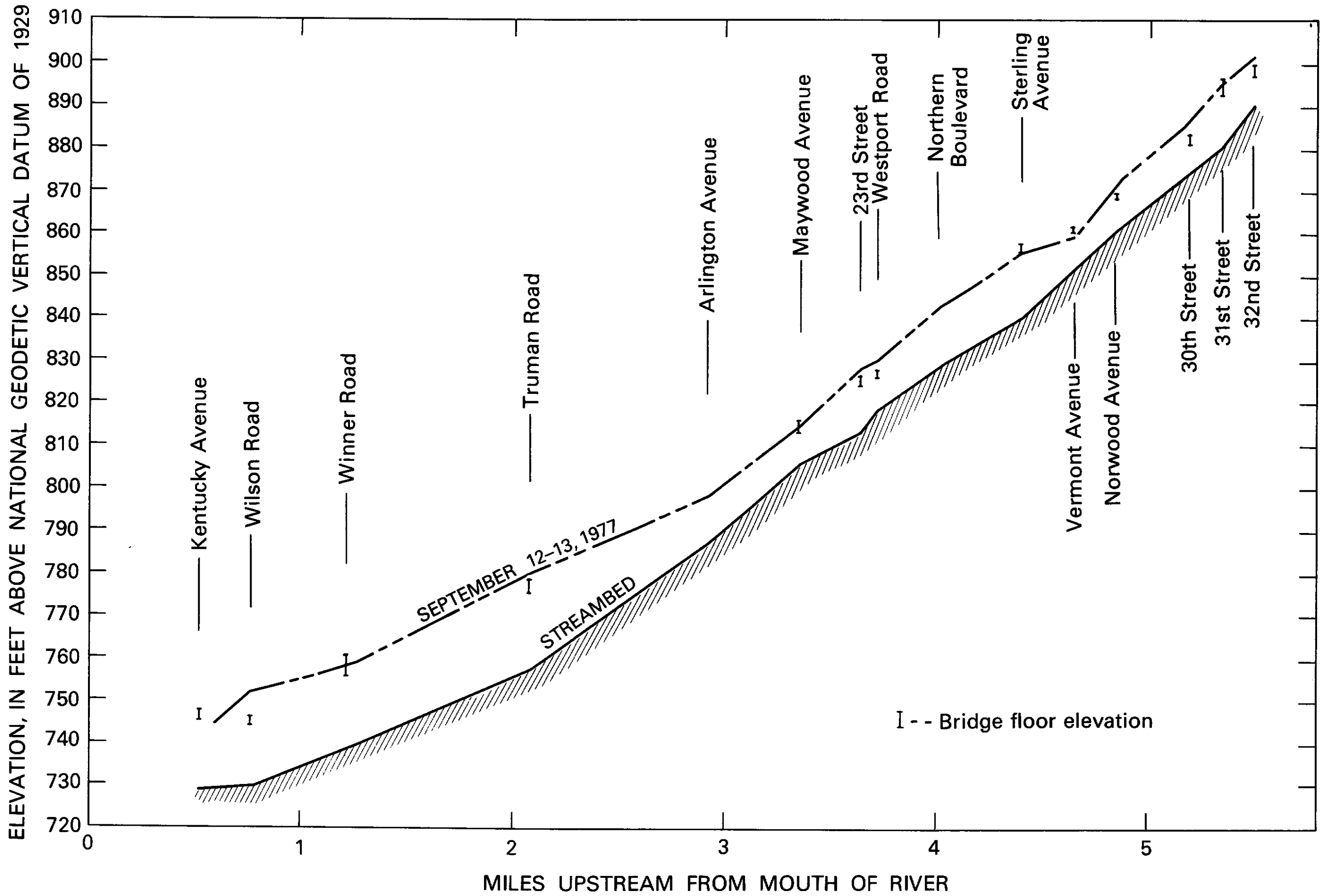


Figure 33.—Profile of water surface of Rock Creek (Mo.), flood of Sept. 12-13, 1977.

TABLE 4.—*Summary of flood volumes for Kansas City area floods, Sept. 12–13, 1977*

Map No. (see fig. 2)	Permanent station No.	Stream and place of determination	Drainage area (mi^2)	Volume of flood event: Flows in acre-ft, Sept. 12	Volume of flood event: Flows in acre-ft, Sept. 13	Volume of flood event: Total storm, Acre-ft	Volume of flood event: Total storm, In.	Recurrence interval, in years [a]: Sept. 12	Recurrence interval, in years [a]: Sept. 13
1	06821280	Line Creek at Riverside, Mo	19.2	1,770	2,973	4,743	4.60	7	13 [b]
6	06893080	Blue River near Stanley, Kans	46.0	----	----	164	.06	---	<2 [b]
8	06893300	Indian Creek at Overland Park, Kans	26.6	1,558	3,817	5,375	3.79	2	18
9	06893350	Tomahawk Creek near Overland Park, Kans	23.9	371	1,716	2,087	1.64	---	70
10	06893500	Blue River near Kansas City, Mo	188	7,423	22,049	29,472	2.94	---	7
16	06893560	Brush Creek at Main Street at Kansas City, Mo	14.8	1,910	6,254	8,164	10.34	13	>100
17	06893570	Round Grove Creek at Raytown Road at Kansas City, Mo	5.87	1,206	1,662	2,868	9.16	40	100
19	06893600	Rock Creek at Independence, Mo	5.20	1,540	968	2,508	9.04	>100	25
20	06893670	Shoal Creek at Claycomo, Mo	29.8	4,078	4,530	8,608	5.42	12	13
24	06893793	Little Blue River at Longview Road Damsite at Kansas City, Mo	50.7	----	9,940	9,940	3.68	---	19
28	06893890	East Fork Little Blue River near Blue Springs, Mo	34.4	----	----	7,398	8.06	---	20
29	06894000	Little Blue River at Lake City, Mo	184	----	----	26,514	2.70	---	10 [b]
30	06894680	Sni-A-Bar Creek at Tarsney, Mo	29.1	9,548	3,772	13,320	8.58	([c])	15

[a] Based on relationships for rural areas.
[b] Volume includes total storm period.
[c] Flood volume-frequency relationship not available for given storm duration.

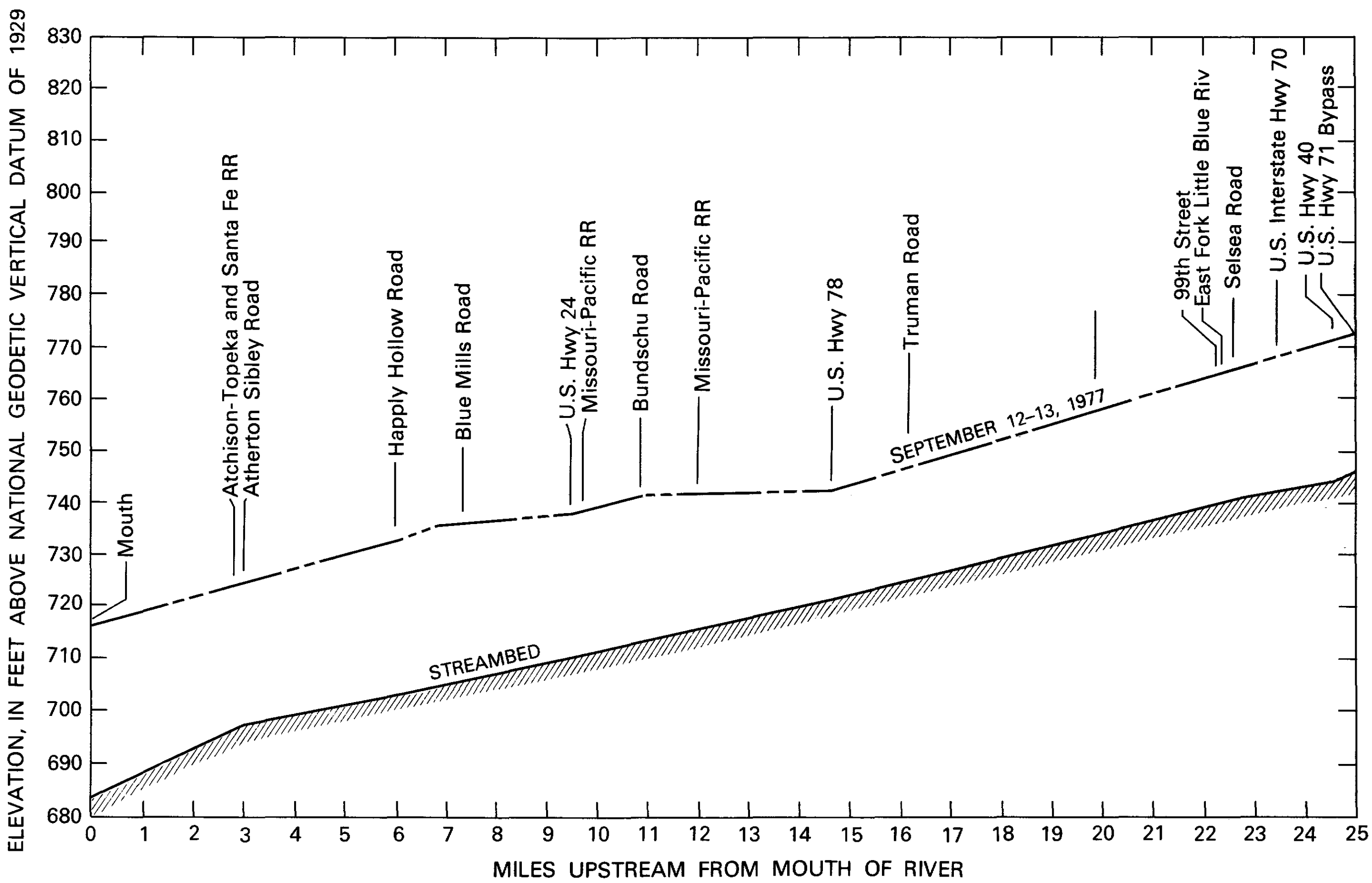
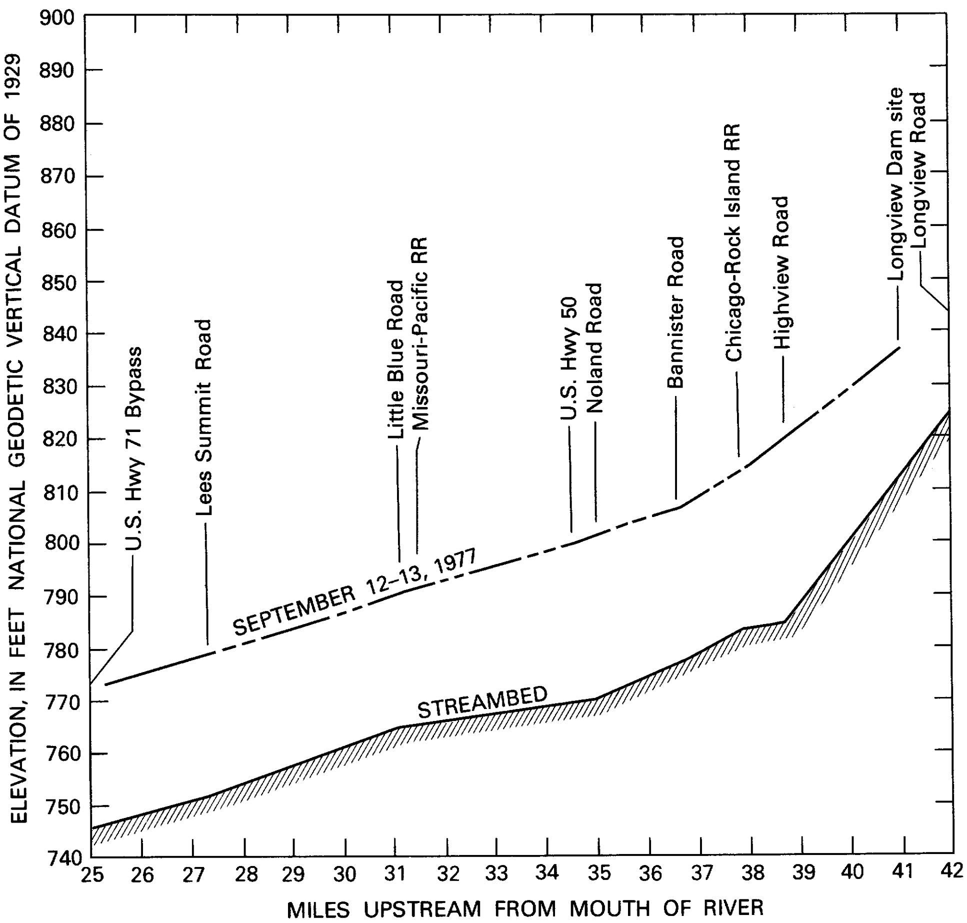


FIGURE 34.—Profiles of water surface of



Little Blue River, flood of Sept. 12–13, 1977.

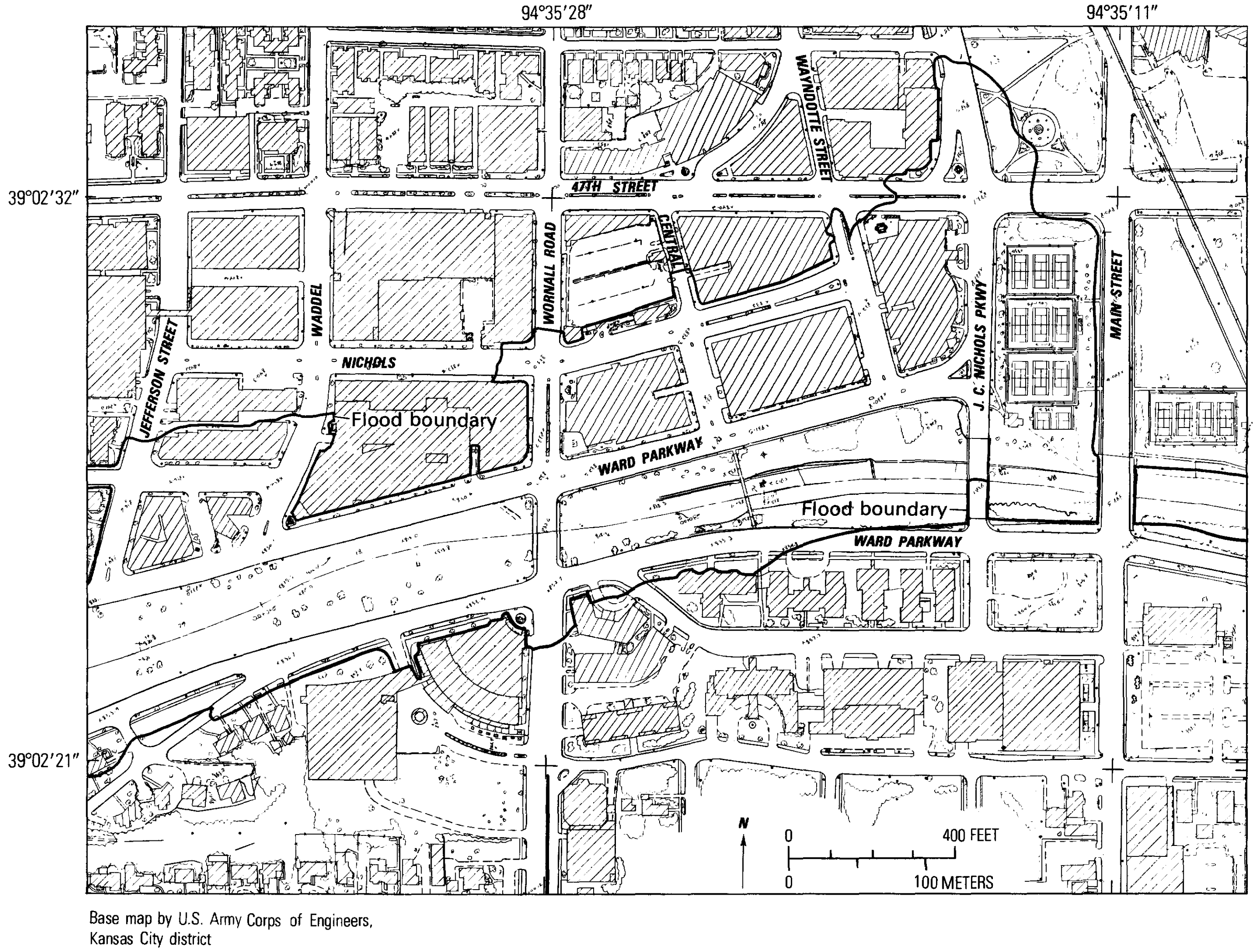


FIGURE 35.—Boundary of Sept. 12–13, 1977, flood along Brush Creek between Main Street and Jefferson Street, Kansas City, Mo.

FIGURE 36.—Recently deposited gravel and scattered coarse material on left (north) Brush Creek flood plain approximately 1,000 ft downstream from Woodland Avenue bridge, Kansas City, Mo.

FIGURE 37.—Channel-bed slabs and car in Brush Creek stream channel immediately downstream from Rockhill Road bridge, Kansas City, Mo.

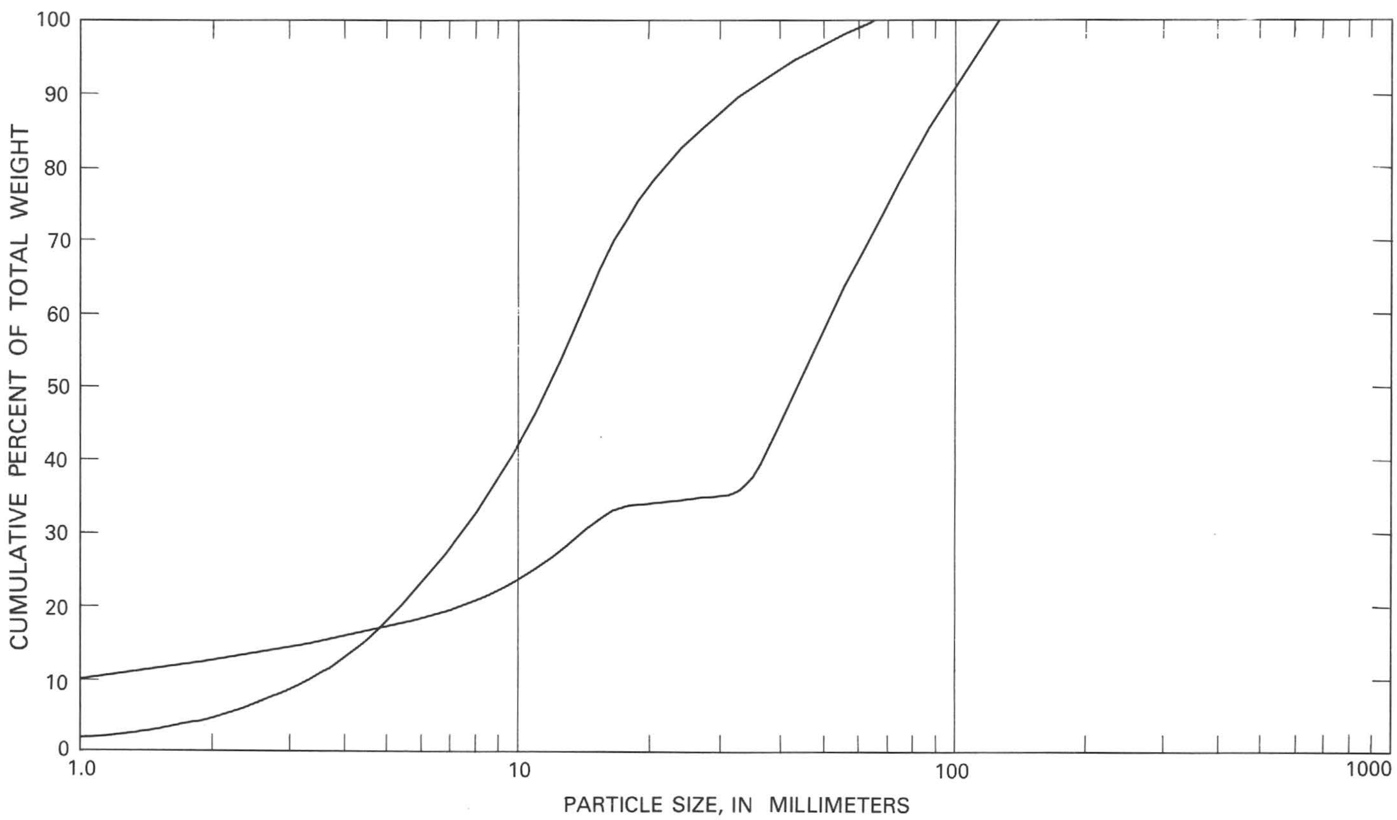


FIGURE 38.—Particle-size distribution of sediment deposits in Brush Creek in the vicinity of Woodland Avenue bridge in Kansas City, Mo.

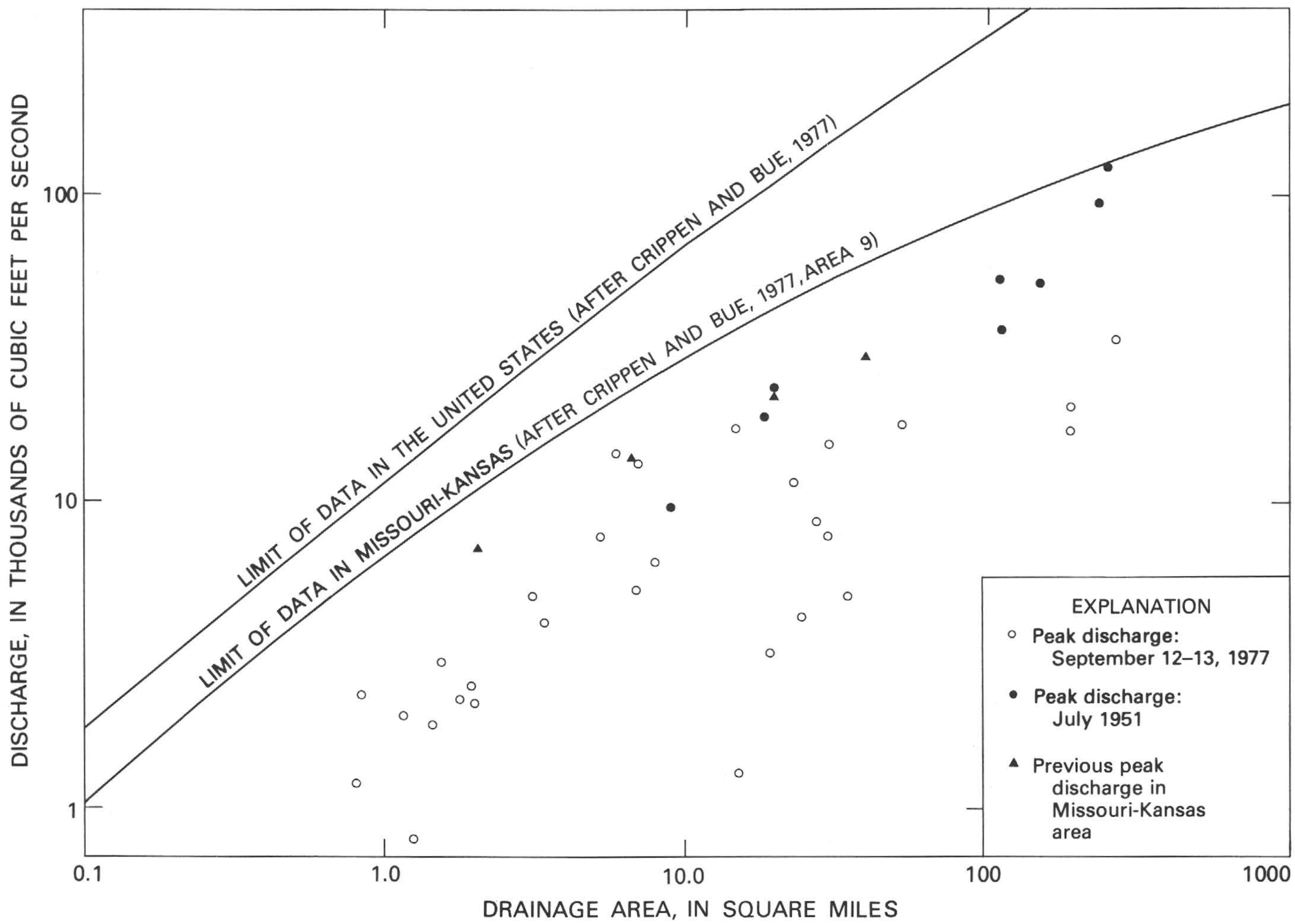


FIGURE 39.—Comparison of Sept. 12–13, 1977, peak discharges to upper limits of known floods in Missouri-Kansas area and in the United States.

Thirteen U.S. Geological Survey stream-gaging stations in operation during the flood provided information on flood volumes and peak discharges. Recurrence intervals of flood volumes experienced in areas of greatest rainfall, such as Brush Creek and Round Grove Creek, were greater than the regional 100-year estimates. In surrounding areas, the decreasing magnitude of recurrence intervals reflected the basins' distance from the center of the two storms. The second storm caused the greater flood damage because the first storm had saturated the drainage basins.

Peak discharges were determined at 31 locations in the Kansas City, Mo.-Kans. area. Recurrence intervals exceeded 100-years in many areas.

Floodflows occurring on Sept. 12–13, 1977, are considered comparable to other major floods which have been documented in Missouri and Kansas, but are not as great as those experienced in other areas of the United States.

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