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TECHNIQUES FOR ESTIMATING THE MAGNITUDE AND FREQUENCY OF FLOODS IN THE DALLAS-FORT WORTH METROPOLITAN AREA, TEXAS

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 82-18

Prepared in cooperation with the Texas Department of Water Resources; the Cities of Dallas, Fort Worth, Garland, and Mesquite; Dallas County; and the U.S. Army Corps of Engineers

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Cover photograph, Trinity River floodplain with city of Dallas skyline in the background

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METRIC CONVERSIONS

The "inch-pound" units used in this report may be converted to metric units by the following factors:

From	Multiply by	To obtain
cubic feet per second (ft^3/s)	0.02832	cubic meters per second
feet	0.3048	meters
feet per mile	1.89	meters per kilometer
inches	25.4	millimeters
miles	1.609	kilometers
square miles	2.590	square kilometers

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level."

TECHNIQUES FOR ESTIMATING THE MAGNITUDE AND FREQUENCY OF FLOODS IN THE DALLAS-FORT WORTH METROPOLITAN AREA, TEXAS

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ABSTRACT

Equations for predicting the magnitude and frequency of floods in the Dallas-Fort Worth metropolitan area were developed from recorded data of streams with drainage areas ranging in size from 1.25 to 66.4 square miles. The U.S. Geological Survey urban rainfall-runoff model was used to generate long-term flood-discharge records for gaged streams in the area. Simulated and recorded annual-peak data were subjected independently to log Pearson Type III frequency analyses. The results were weighted to determine appropriate discharges for 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. These T-year values were then used as the dependent variables in a multiple-regression analysis. The independent variables determined to be statistically significant and retained in the resulting equations were drainage area and an urbanization index that expresses the degree of urban development. Analysis of the results shows that a land-use change from rural to fully urbanized was accompanied by a 180-percent increase in discharge of a flood with a 5-year recurrence interval and about 100-percent increase in discharge of a flood with a 100-year recurrence interval.

INTRODUCTION

The U.S. Geological Survey began an urban hydrology study in the Dallas-Fort Worth area during 1961 in cooperation with the City of Dallas to develop a means of determining flood frequencies and magnitudes at ungaged stream sites in this area. The area of investigation and the intensity of the data collection gradually expanded until 1976 when the area included much of Dallas and Tarrant Counties. The cooperation also expanded to include the Cities of Dallas, Fort Worth, Garland, and Mesquite; Dallas County; the U.S. Army Corps of Engineers; and the Texas Department of Water Resources. The number of streamflow-gaging stations increased from 3 to 36 and the number of recording rain gages increased from 14 to 53. As the objectives of the investigation were fulfilled, the data-collection networks were discontinued in the Fort Worth area at the end of the 1978 water year and discontinued in the Dallas area at the end of the 1979 water year. Selected stations in the Dallas area network are presently (1981) being operated by the City of Dallas.

Purpose and Scope

The objectives of the study and the purposes of this report are to provide a technique to estimate the magnitude and frequency of flood-peak discharges at ungaged sites and to determine the effects of urbanization on these flood peaks. Regression techniques were selected to make these estimates. The scope of the study is limited to streams in the Dallas-Fort Worth area.

Previous Investigations

Two regional flood-frequency studies that included the Dallas and Fort Worth areas were previously made by the Geological Survey. The first study, considered a preliminary report on the urban hydrology of the Dallas area, was conducted by Dempster (1973). Dempster developed regional regression equations that estimated flood-peak discharges for selected frequencies from drainage area, a coefficient of imperviousness, and a value which combined the channel length and slope. A second study covering the State was conducted by Schroeder and Massey (1977) who developed regional equations for estimating the flood magnitudes at selected frequencies for natural and unregulated basins. During this second study, Texas was divided into regions with equations developed for each region; the Dallas-Fort Worth area is in region 2. The equations used the drainage area and the main-channel slope to estimate the flood-peak discharges.

HYDROLOGIC SETTING

Dallas and Fort Worth (fig. 1) are in Dallas and Tarrant Counties about 250 miles north of the Gulf of Mexico in north-central Texas. The altitude of the study area ranges from about 400 feet above the National Geodetic Vertical Datum of 1929 (NGVD) at the downstream end of South Mesquite Creek to about 800 feet above NGVD at the headwaters of Little Fossil Creek. Dallas is in the "Blackland Prairies" natural region, and Fort Worth is in the "Cross Timbers and Prairies" region (A. H. Belo Corp., 1977, p. 102). Geologically, most of the streams in the study area are in the chalk of Cretaceous age. The slopes of the main-channel streams generally range from 10 to 50 feet per mile.

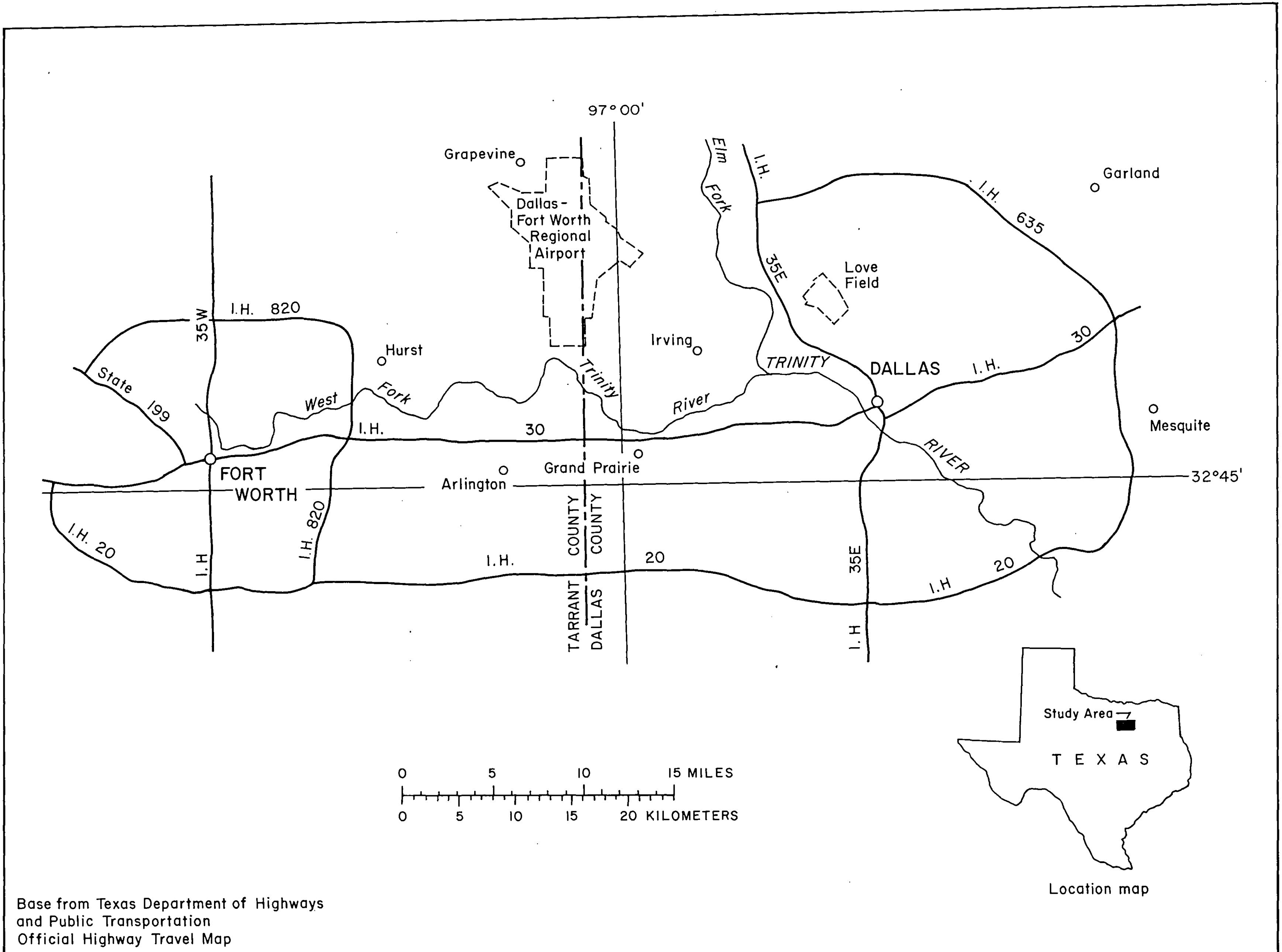


Figure 1.-Location of the Dallas-Fort Worth metropolitan area

The climate is humid and subtropical with hot summers and mild winters. The yearly mean temperature for 1941-70 was 65.5°F (U.S. Department of Commerce, 1973). Monthly mean temperatures for 1941-70 ranged from 44.8°F in January to 84.9°F in August. During the study period 1961-78, the lowest recorded temperature was 4°F and the highest was 109°F. The climate is continental, characterized by a wide range in annual-temperature extremes and an average of 249 frost-free days per year. The mean-annual class "A" pan evaporation is about 80 inches.

Precipitation averages about 32 inches per year but varies considerably from year to year, ranging from less than 20 inches to more than 50 inches. Most of the annual precipitation is produced by thunderstorms that occur at an average rate of 45 per year. These storms can occur during any month, but are most prevalent from April to October. The rainfall pattern varies areally as well as from year to year. This variable pattern was especially evident for the storm of September 20-22, 1964, when three rain gages in the upper White Rock Creek basin recorded a weighted-mean rainfall of 13.87 inches, while the National Weather Service (NWS) gage at Love Field recorded 7.51 inches. During the 1973 water year the total yearly amounts of rainfall ranged from 47.93 to 63.75 inches at the project rain gages. During this same period, the National Weather Service gage at Love Field recorded 48.08 inches. Occasionally, the remnants of a tropical storm from the Gulf of Mexico will affect the weather. The most notable storm during the study was Hurricane Carla, which produced as much as 6 inches of rain in the area on September 12, 1961.

The Dallas-Fort Worth area is in the Trinity River basin. The Trinity River, which flows near the center of the city of Dallas, has a drainage area of more than 6,200 square miles at that point. The West Fork Trinity River, which flows through the center of Fort Worth, has a drainage area of about 2,700 square miles. The river system has a considerable number of flood-protection measures in the form of reservoirs, levees, and rectified channels. Because of these improvements, the Trinity River has not experienced severe flooding since their construction. Significant flooding generally has occurred along the larger tributaries such as White Rock Creek, but also has been common along smaller streams.

METHOD OF INVESTIGATION

The approach taken to achieve the study objectives was:

1. Collect and compile a hydrologic-data base for basins representing a variety of basin characteristics, including a range in degree of urban development; describe the basin characteristics in numerical terms;
2. Calibrate a rainfall-runoff model for each stream and extend the recorded data using the calibrated model and historic climatic data;
3. Develop flood-frequency relations for each stream using recorded and simulated data and log-Pearson Type III analytical procedures;
4. Weight the discharge-frequency relations developed from recorded and simulated data to determine appropriate T-year discharges for each basin;
5. Use multiple-regression analysis with the T-year discharges as dependent variables and the basin characteristics as independent variables to develop mathematical equations for estimating flood magnitude for selected frequencies; and
6. Assess the mathematical expressions to describe relative effects of urban development on flood discharge.

DATA

Hydrologic Data

The hydrologic data necessary for the calibration of the rainfall-runoff model for a given basin consist of the storm runoff at streamflow-gaging stations, the storm rainfall and daily rainfall over the basin as recorded at one or more recording rain gages, and the daily pan evaporation in the area. Rainfall and runoff data were collected and compiled for 36 basins having various sizes and representing various degrees of urban development. Each year, several storms were analyzed for each basin by tabulating and compiling the time distribution of the rainfall at each rain gage and the discharge at the streamflow-gaging station.

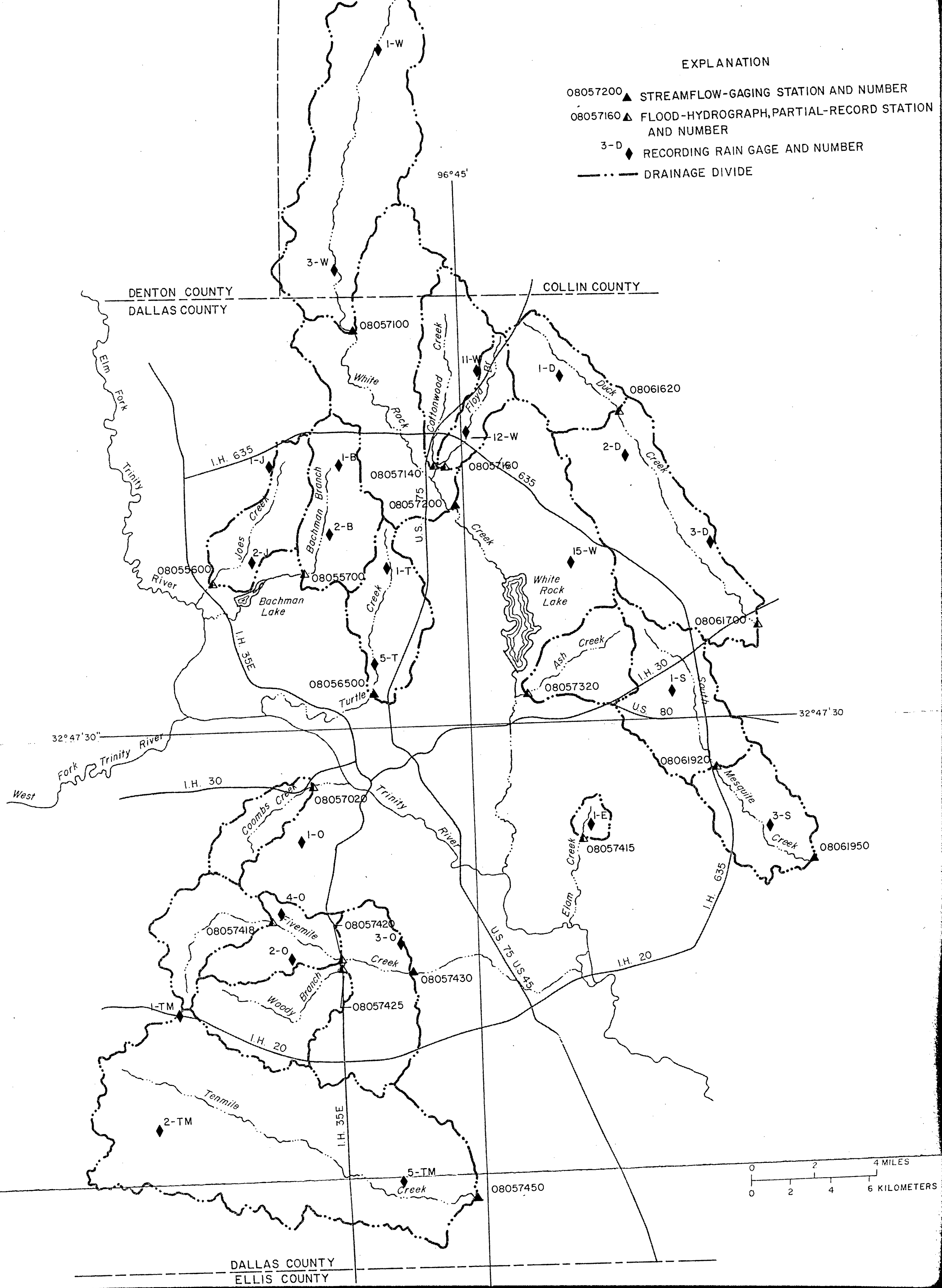
Data for about 20 storms covering a wide range of magnitudes, durations, and seasons were considered necessary for calibrating the rainfall-runoff model. Several basins did not have enough recorded storms or were undergoing major land-use or channel changes during the study. As a result, these basins were excluded from the analysis because the model could not be reasonably calibrated for them. Of the 21 basins used in the analysis, 18 are in the Dallas area and 3 are in the Fort Worth area. The number of rain gages used for calibration was decreased to 29 to facilitate the computation and data-handling tasks. The location of the selected network of basins and instrumentation is shown in figures 2 and 3. The streamflow-gaging stations, rain gages, and period of record used are listed in table 1.

The hydrologic-data requirements for long-term simulations using a calibrated rainfall-runoff model are daily and accumulated storm rainfall from one station and daily evaporation data. These data were compiled from the published record of the National Weather Service for 1914-78. The National Weather Service station at Love Field provided the rainfall record until Sept. 30, 1973, when it was discontinued. Since then, the nearby Geological Survey rain gage 1-J (325206096514834) has been used. The evaporation data were obtained from the National Weather Service Grapevine station. The locations of Grapevine and Love Field are shown in figure 1.

Each year, one to four of the largest storms were selected for generating discharge hydrographs. These storms are given in table 2.

Basin Characteristics

The selected procedure for achieving the study objective requires expressing, in numerical terms, the basin characteristics that may be significant in governing flood magnitude. The initial selection of characteristics were those that were theorized to have potential significance or have been shown in other investigations to be major factors in controlling peak discharge. These basin characteristics included drainage area, channel slope, channel length, channel conveyance, and degree of urbanization. To provide greater detail on the physical character of the basin, and to provide a means of more adequately expressing the effects of urbanization on storm runoff, the list was expanded. The degree of urbanization was expressed in several ways, in an attempt to describe the cumulative effect of such factors as curbs and gutters, storm drains, rectified channels, culverts and bridges, storage detention, terraced streets, and various forms and patterns of impervious cover. The characteristics considered in the analysis are described below.


EXPLANATION
08057200 STREAMFLOW-GAGING STATION AND NUMBER
08057160 FLOOD-HYDROGRAPH, PARTIAL-RECORD STATION AND NUMBER
3-D RECORDING RAIN GAGE AND NUMBER
DRAINAGE DIVIDE
96°45'
DENTON COUNTY
DALLAS COUNTY
COLLIN COUNTY
1-W
3-W
08057100
White
Rock
Cottonwood
Creek
11-W
Floyd
Br.
1-D
Duck
08061620
12-W
2-D
Creek
I.H. 635
1-J
1-B
08057140
08057160
635
75
U.S.
08057200
Bachman Branch
Joes
Creek
2-B
2-J
Elm
Fork
Trinity
River
08055600
08055700
1-T
Creek
Bachman
Lake
3-D
15-W
White
Rock
Lake
08061700
Ash
Creek
I.H. 30
1-S
South
I.H. 35E
5-T
08056500
Turtle
08057320
U.S. 80
32°47'30
32°47'30"
West
Fork
Trinity
River
08061920
Mesquite
I.H. 30
Coombs Creek
08057020
Trinity
River
1-E
3-S
Creek
08061950
1-0
08057415
Creek
Elam
I.H. 635
4-0
Fivemile
08057420
08057418
3-0
2-0
Creek
08057430
I.H. 20
U.S. 75 U.S. 45
Woody
Branch
08057425
1-TM
I.H. 20
Tenmile
2-TM
I.H. 35E
5-TM
Creek
08057450
0 2 4 MILES
0 2 4 6 KILOMETERS
DALLAS COUNTY
ELLIS COUNTY

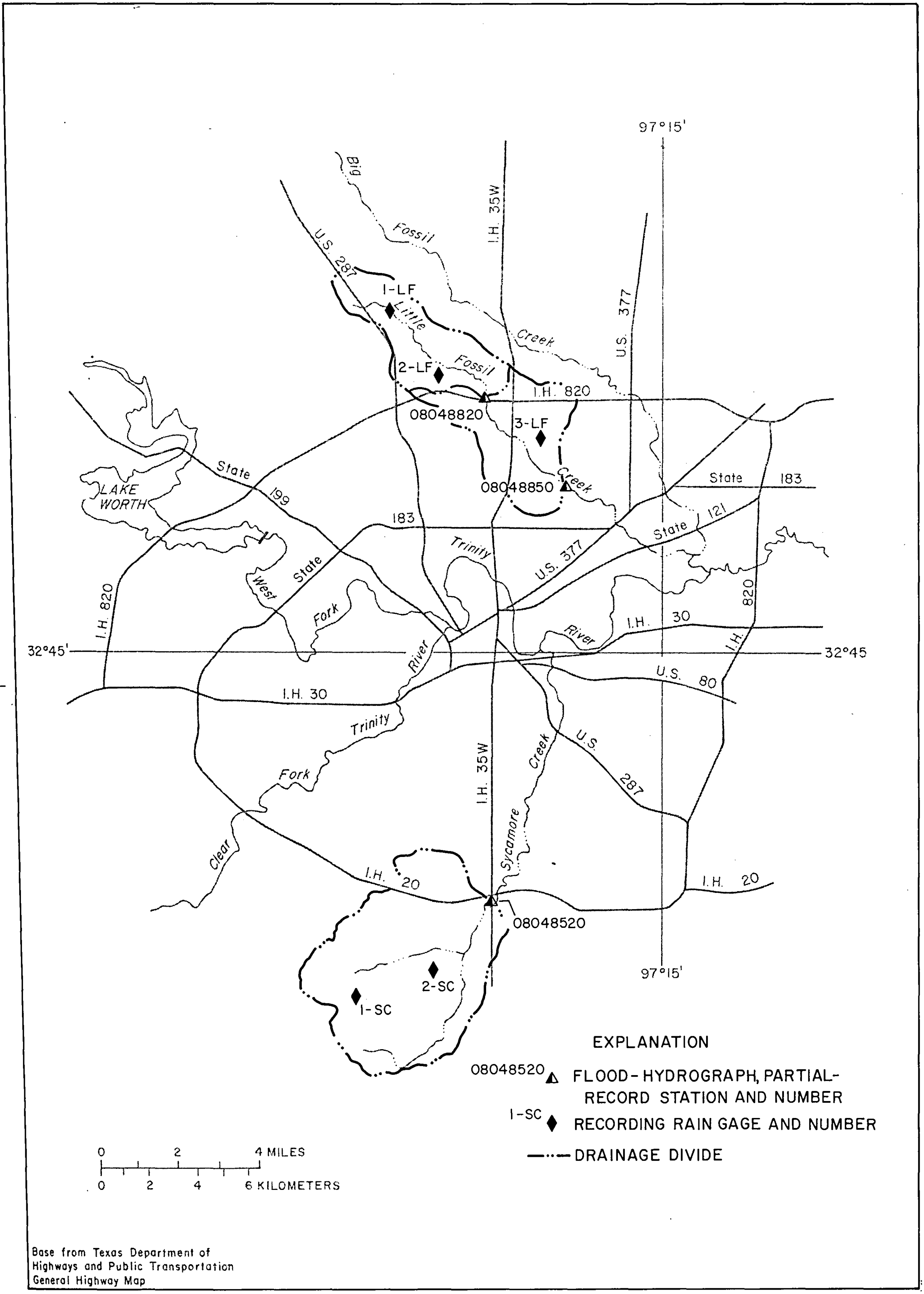


Figure 3.-Location of basins and hydrologic instrumentation in the Fort Worth area

Table 1.--List of streamflow and rainfall gages and period of record of data used

Station number and name	Period of flood hydrograph record	Rain gages (local and site 1/ identification)	
08048520 Sycamore Creek at I.H. 35-W, Fort Worth	1970-78	(1-SC)323742097255734	(2-SC)323834097211134
08048820 Little Fossil Creek at I.H. 820, Fort Worth	1969-79	(1-LF)325136097210834	(2-LF)325048097194834
08048850 Little Fossil Creek at Mesquite St. at Fort Worth	1969-77	(1-LF)325136097210834	(3-LF)324928097183834
08055600 Joes Creek at Dallas	1966-78	(1-J)325206096514834	(2-J)325436096504834
08055700 Bachman Branch at Dallas	1964-78	(1-B)325445096490134	(2-B)325248096492434
08056500 Turtle Creek at Dallas	1962-78	(1-T)325158096473234	(5-T)324903096480534
08057020 Coombs Creek at Sylvan Ave., Dallas	1965-77	(1-Ø)324431096502634	
08057100 White Rock Creek at Keller Springs Rd. at Dallas	1964-77	(1-W)330549096471634	(3-W)325956096485634
08057140 Cottonwood Creek at Forest Ln., Dallas	1970-78	(12-W)325548096445034	
08057160 Floyd Branch at Forest Ln., Dallas	1969-78	(11-W)325708096441434	(12-W)325548096445034
08057200 White Rock Creek at Greenville Ave. at Dallas	1961-78	(3-W)325956096485634	(12-W)325548096445034
08057320 Ash Creek at Highland Rd., Dallas	1972-78	(15-W)325146096415134	
08057415 Elam Creek at Seco Blvd., Dallas	1973-78	(1-E)324440096412734	
08057418 Fivemile Creek at Kiest Blvd., Dallas	1976-77	(1-TM)323943096544434	(4-Ø)324219096513234
08057420 Fivemile Creek at U.S. Hwy. 77, Dallas	1970-77	(4-Ø)324219096513234	
08057425 Woody Branch at U.S. Hwy. 77, Dallas	1970-78	(2-Ø)324104096512534	
08057430 Fivemile Creek at Lancaster Rd., Dallas	1970-77	(3-Ø)324134096473434	(4-Ø)324219096513234
08057450 Tenmile Creek at S.H. 342 at Lancaster	1970-78	(2-TM)323654096552934	(5-TM)323536096474034
08061620 Duck Creek at Buckingham Rd., Garland	1969-78	(1-D)325433096394434	
08061700 Duck Creek near Garland	1969-78	(1-D)325433096394434 (3-D)325055096415534	(2-D)325137096384634
08061950 South Mesquite Creek at Mercury Rd. near Mesquite	1969-78	(1-S)324814096383434	(3-S)324425096353534

1/ A 15-digit site identification number consists of 6-digit latitude, 7-digit longitude, and a 2-digit user selected number.

Table 2.--Major storms in the Dallas-Fort Worth area

Water year	Storm date	Total rainfall (inches)	Water year	Storm date	Total rainfall (inches)
1914	Dec. 2	2.19	1937	June 4	1.29
	May 4	2.20		16	2.19
	Aug. 25,26	2.06		Aug. 23	1.39
	Sept. 22	2.04		Sept. 6	1.24
1915	Aug. 17,18	6.91	1938	Oct. 17	2.70
	24	2.87		Jan. 21	3.00
1916	Jan. 26	2.65	1939	Apr. 5	2.33
	Aug. 5	1.99	1940	Oct. 9	1.90
1917	Oct. 13	2.79	1941	June 1,2	2.76
	May 20	1.38		27	2.36
	Aug. 18	1.65	1942	Apr. 18-20	3.38
1918	Apr. 5	3.50		May 6	2.01
	May 17	2.23		Sept. 6	2.27
	Aug. 24	2.41	1943	Oct. 15,16	4.50
1919	Oct. 26	2.66	1944	Mar. 18,19	2.89
	Sept. 21	2.00		Apr. 30,May 1	3.44
1920	Oct. 31	3.47		July 12	2.21
	Mar. 24	3.97	1945	July 5	5.34
1921	Apr. 21	1.66	1946	May 28,29	6.24
	May 1	1.41	1947	Nov. 2	4.83
1922	Apr. 3	4.63		Aug. 26,27	9.45
	25	4.88	1948	June 28	2.93
1923	June 2	3.43	1949	Jan. 24	4.88
	10	3.66		May 16,17	5.46
1924	Oct. 14	2.99	1950	Oct. 24	2.99
	May 26	2.74		May 1	1.82
1925	May 7	2.89	1951	June 2	3.22
	10	1.57		Sept. 12	2.38
	June 8	2.56	1952	May 17	2.21
1926	Apr. 10	2.37	1953	Apr. 23	1.53
	July 7	1.65		28	2.42
	Aug. 17,18	2.79	1954	Oct. 25	1.48
	Sept. 6	2.28		Apr. 11,12	2.31
1927	Mar. 7	3.06		May 10-12	4.43
	July 22	1.66	1955	May 19	1.31
1928	Oct. 1	3.04		June 4	1.51
	Apr. 5	2.02	1956	Apr. 29	2.24
1929	May 13	3.45		May 1	2.20
1930	May 3	1.54	1957	Mar. 31	2.89
	12	2.49		Apr. 26	5.09
1931	Sept. 11	2.74		May 23	3.38
1932	Sept. 3-5	5.90	1958	Mar. 29	3.05
1933	Apr. 25	3.40		Apr. 26	3.39
1934	Sept. 14	4.40	1959	July 19	1.53
1935	June 14,15	4.70		Sept. 28	1.96
1936	Sept. 26,27	6.72	1960	Oct. 1	6.30

Table 2.--Major storms in the Dallas-Fort Worth area--Continued

Water year	Storm date	Total rainfall (inches)	Water year	Storm date	Total rainfall (inches)
1960	July 13	4.13	1970	Oct. 12	4.39
1961	Sept. 12	4.02		May 30	1.96
1962	July 25-27	8.47	1971	May 27	2.57
1963	Oct. 8	4.92		Aug. 14	2.24
1964	Sept. 20-22	7.51	1972	Oct. 3	3.70
1965	May 10	2.63		Nov. 19	2.54
	Sept. 21	3.45	1973	June 3-4	3.38
1966	Apr. 28	3.61		Sept. 26	3.23
1967	Apr. 21	1.76	1974	Oct. 11-12	3.63
1968	May 12,13	1.73		June 7	2.68
	Aug. 13,14	2.48	1975	Oct. 30	2.45
1969	Oct. 9	2.44	1976	Apr. 17-19	3.58
	May 6,7	5.43	1977	Mar. 26-27	5.45
			1978	May 28	2.77

Drainage area.--This characteristic, expressed in square miles, represents the drainage area of each basin at the gaged site. Values for drainage area of basins in the Dallas-Fort Worth area ranged from 1.25 to 66.4 square miles.

Main-channel slope.--This represents the average slope in feet per mile of the main channel, between points 10 and 85 percent of stream length upstream from the gage.

Lower-channel slope.--This represents the average slope in feet per mile, of the main channel, between points 0 and 10 percent of stream length upstream from the gage.

Channel length.--Stream length, in miles, measured along the main channel from the gage to the basin divide.

Bankfull-channel conveyance.--Channel conveyance in the Manning equation is expressed as

$$\frac{1.486}{n} AR^{2/3}$$

where n = Manning's roughness coefficient,
A = cross-sectional area of the stream, in square feet, and
R = hydraulic radius, the ratio of A to the channel's wetted perimeter.
The values of conveyance were determined at a representative cross section in the vicinity of the gage.

Mean-channel elevation.--Average of channel elevation, in feet above NGVD, between points 10 to 85 percent of stream length upstream from the gage.

Percentage of impervious cover.--This characteristic expresses the proportion of the basin that is considered impervious and includes those areas that are covered by streets, buildings, parking lots, etc. The values for percentage of impervious cover were determined from estimates of various land uses in each basin.

Coefficient of imperviousness.--The use of this coefficient was described by Carter (1961) and is a variation of the percentage of impervious cover. The values for KI were determined by:

$$KI = 1.00 + 0.015\ I \qquad (1)$$

where I = percentage of impervious cover.

Urbanization index.--This type of variable was suggested by Sauer and others (1981) who described a generalized technique of estimating the magnitude and frequency of floods in urban areas. The urbanization index is an attempt to more accurately quantify the degree of urbanization by incorporating the factors of storm sewers, curbs and gutters, and channel rectifications. The index is developed by considering these alterations in the upper, middle, and lower third of the drainage basin. Values are assigned to each factor in each one-third of the basin on the basis of the percentage of the subbasin containing that factor. Each factor carries an equal weight regardless of location within the subbasin. The values of each factor vary from 1 to 4, based on the degree of development. The sum of the 9 factors can vary from 9 to 36 and is the value of the urbanization index. The factor values and corresponding percentages of the subbasin affected are listed below:

Percent	Value
0-24	1
25-49	2
50-74	3
75-100	4

The following example is given to illustrate the determination of the urbanization index.

Urbanization Index

Subarea	Factors			
	Storm sewers	Curbs and gutters	Channel rectifications	Total
Upper	4	4	2	10
Middle	3	4	1	8
Lower	3	4	1	8
Urbanization index				26

The values of each basin characteristic for each stream are given in table 3.

RAINFALL-RUNOFF MODELING

The Model

The rainfall-runoff model selected for this analysis was developed by the Geological Survey (Dawdy, Lichty, and Bergmann, 1972; Boning, 1974; and Carrigan, Dempster, and Bower, 1977). The model is based on bulk-parameter approximation to the physical laws that govern antecedent soil moisture, infiltration, and runoff. The components and parameters of the model and their function in the modeling process are given in table 4. The model was designed specifically for the simulation of flood hydrographs for small drainage areas. One of the major uses of the model has been to extend relatively short-term flood-peak discharge records in order to compute more reliable flood-frequency relationships. During the calibration phase, the hydrologic-data requirements for the model are daily rainfall, selected storm rainfall and discharge, and evaporation. During the simulation phase, the data input consists of daily rainfall and evaporation, selected storm rainfall, and the values of the parameters that were determined in the calibration phase. During nonstorm days, the model operates on a daily time step for antecedent-moisture accounting. On storm days, the model may be operated at 5-, 10-, 15-, 30-, or 60-minute time steps.

For calibration purposes, the rainfall-runoff model is available in two versions (rural and urban). Each version of the model has options to facilitate the long-term simulations. The rural model, which assumes that the impervious area is evenly distributed throughout the basin, requires data from one rain gage. The urban model represents a basin which is subdivided into as

Table 3.--Selected basin characteristics for the analyzed basins

(ft/mi - feet per mile)

Station number	Drainage area (square miles)	Main-channel slope (ft/mi)	Lower-channel slope (ft/mi)	Channel length (miles)	Bank-full channel conveyance (Manning equation)	Main-channel elevation (feet)	Impervious cover (percent)	Coefficient of imperviousness	Urbanization index
08048520	17.7	20.2	4.53	8.97	204,000	720	15	1.225	13
08048820	5.64	24.8	26.8	6.72	67,500	690	17	1.255	10
08048850	12.3	22.3	9.9	10.1	36,900	650	13	1.195	12
08055600	7.51	31.2	15.6	6.40	123,000	500	41	1.615	33
08055700	10.0	31.4	33.9	5.90	68,500	537	38	1.570	26
08056500	7.98	36.3	30.2	5.30	25,000	512	38	1.570	36
08057020	4.75	44.5	33.8	4.73	111,000	510	34	1.510	27
08057100	29.4	15.2	9.63	13.5	155,000	636	2	1.030	14
08057140	8.50	31.1	12.4	7.29	614,600	591	37	1.555	20
08057160	4.17	36.8	16.0	4.99	20,400	575	33	1.495	21
08057200	66.4	13.1	5.37	22.4	219,000	596	15	1.225	17
08057320	6.92	37.7	9.50	4.21	293,000	488	33	1.495	24
08057415	1.25	35.1	15.8	1.90	22,400	493	45	1.675	32
08057418	7.65	40.1	33.3	5.42	151,000	608	20	1.300	24
08057420	14.0	33.3	2.44	8.21	423,000	570	28	1.420	25
08057425	10.3	41.0	6.45	6.21	256,000	564	20	1.300	23
08057430	37.9	26.2	3.72	10.7	345,000	544	23	1.375	25
08057450	52.8	16.2	9.72	15.4	131,000	554	14	1.180	12
08061620	8.05	16.3	23.7	4.90	291,000	593	31	1.330	22
08061700	31.6	15.0	8.63	13.1	76,400	522	30	1.345	23
08061950	23.0	11.1	10.0	14.0	14,700	458	20	1.300	20

Table 4.--Model components and parameters

Components	Parameters	Unit	Definition and function
Antecedent-moisture accounting	EVC	--	Coefficient to convert pan evaporation to potential-evapotranspiration values.
	RR	--	Proportion of daily rainfall that infiltrates the soil.
	BMSM	Inches	Soil-moisture storage volume at field capacity.
	DRN	Inches per hour	Drainage value for redistribution of soil moisture (fraction of KSAT).
Infiltration	PSP	Inches	Product of moisture deficit and suction at the wetted front for soil moisture at field capacity.
	KSAT	Inches per hour	The minimum (saturated) hydraulic conductivity used to determine infiltration rates.
	RGF	--	Ratio of the product of moisture deficit and suction at the wetted front for soil moisture at wilting point to that at field capacity.
Routing	KSW	Hours	Time characteristic for linear reservoir routing.
	TC	Minutes	Length of the base of the triangular translation hydrograph.

many as 5 subareas, 5 land uses, and 20 distance zones. The subareas are delineated on the basis of rain-gages locations. Land-use subdivisions are determined by impervious cover, and the distance zones are delineated on the basis of flood-wave travel time along the stream. The representation of a hypothetical basin is shown in figure 4.

The model includes an optimization routine that is used in the calibration phase. This feature allows the user to set a range for the parameter values, and the model then adjusts these values within the prescribed range until the computed values of an objective function (either peak discharge or flood volume) best match the recorded values. The optimization is accomplished in three phases. The first phase involves adjusting the parameter values of the antecedent-moisture accounting and infiltration components to obtain the best fit between the recorded and simulated runoff volumes. The second phase adjusts the routing components to obtain the best hydrograph shape. The last phase readjusts the parameter values of the antecedent-moisture accounting and infiltration components to obtain the best match between the recorded and simulated peak discharge.

Model Calibration

Each basin in this study had 1 to 3 rain gages, 5 land-use classifications, and 20 distance zones. The basins were divided into subbasins using the location of rain gages and the Theissen polygon method. The land-use classifications and the estimated percentages of impervious cover are: Rural (2 percent), low-density residential (15 percent), medium-density residential (35 percent), high-density residential (50 percent), and highly developed commercial (90 percent). If a land use did not fit these categories, it was assigned to a category with approximately the same percentage of impervious cover. The distance zones are bands that are formed by drawing arcs around the basin outlet. The distance zones represent approximately equal flood-wave travel times. The accumulation of the pervious and impervious areas by distance zones are shown for individual gaging stations in figures 5-11.

Once a preliminary simulation was made, the computed and recorded discharge hydrographs were compared. Storms that obviously had large errors in either rainfall or discharge, or storms in which the recorded rainfall was not representative of the runoff, were eliminated from further use in the calibration phase. Many storms were eliminated because they were part of complex storms. Subsequent simulations involved adjusting the starting and limiting values of the various parameters so that they were reasonable and had regional continuity. Two of the parameters were found to be reasonably insensitive and were set to constant values (EVC = 0.75 and RR = 0.85). The final values for each basin are tabulated in table 5.

The success of the model was judged by comparing the recorded and simulated peak-discharge values in base 10 logarithm units. The statistical correlation coefficient ranged from 0.709 to 0.987 with a median of 0.887, while the root-mean square error ranged from 18 to 81 percent with a median of 40 percent. These statistics are given in table 5. Plots of the recorded versus simulated flood-peak discharges from the final calibration trials are shown in figures 12-18. This analysis indicates that the model was reasonably well calibrated.

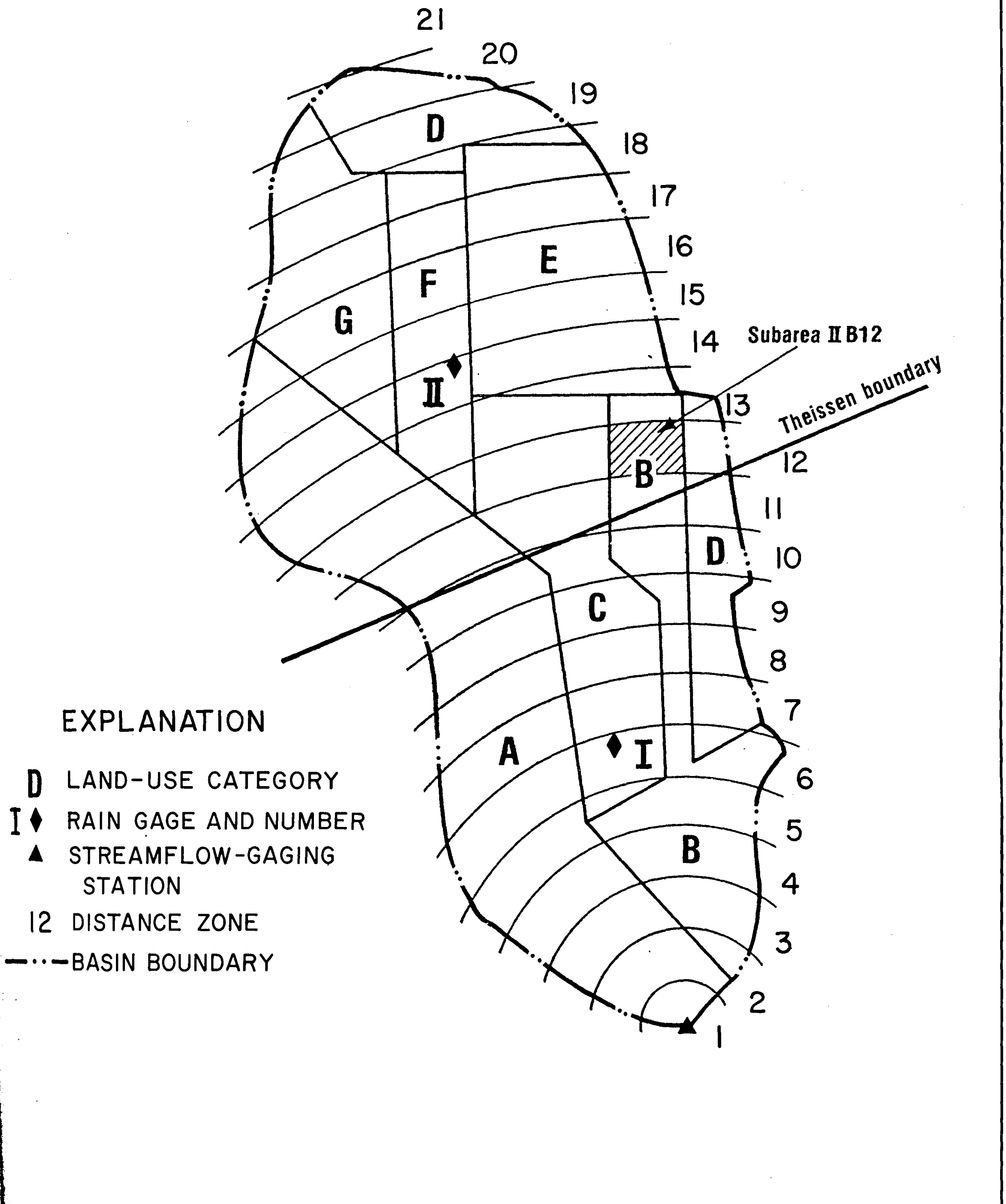


Figure 4.-Division of a hypothetical basin into subareas according to location of rain gages, land use, and time of travel

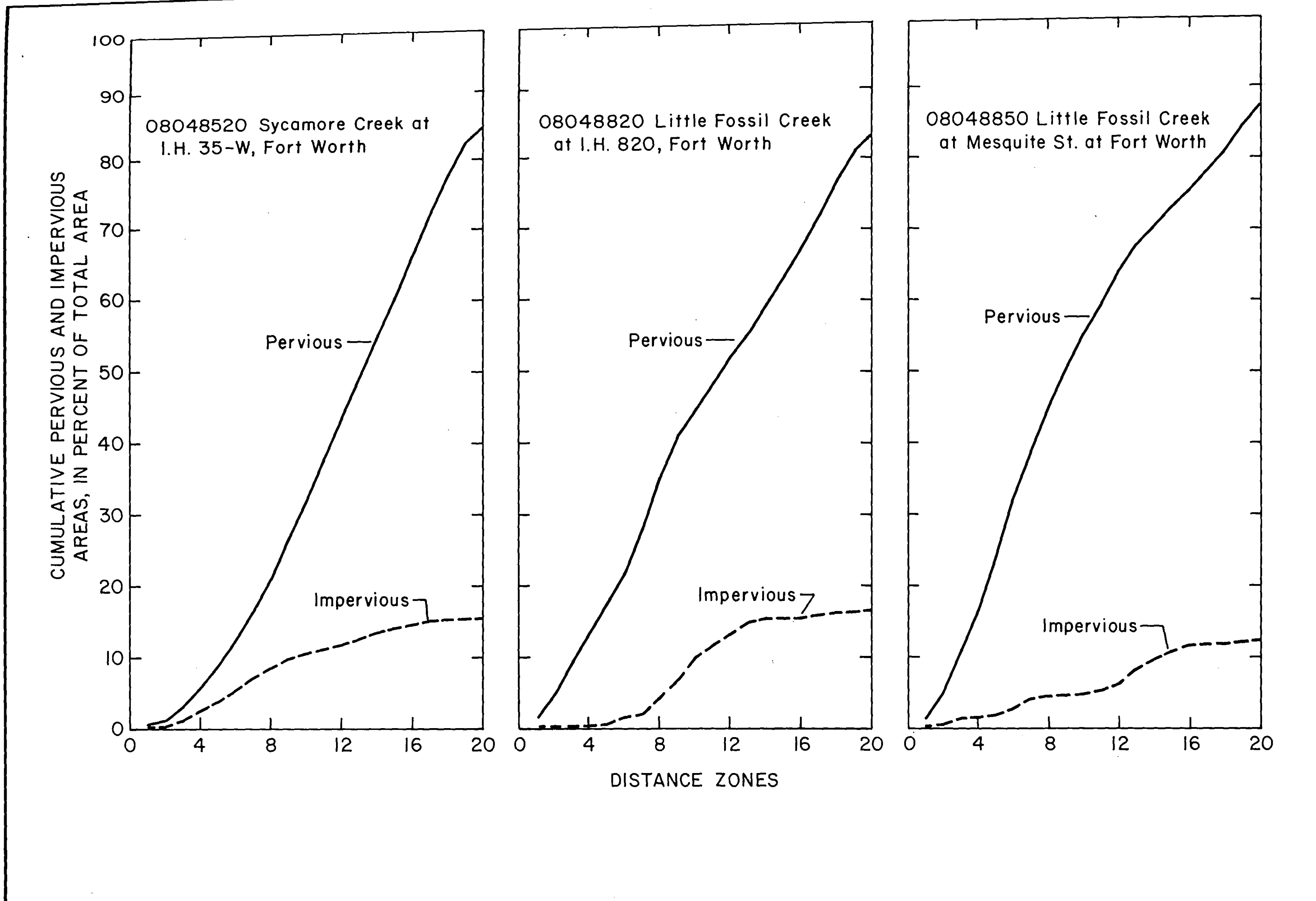


Figure 5.-Accumulation of pervious and impervious areas by distance zones, streamflow-gaging stations 08048520, 08048820, and 08048850

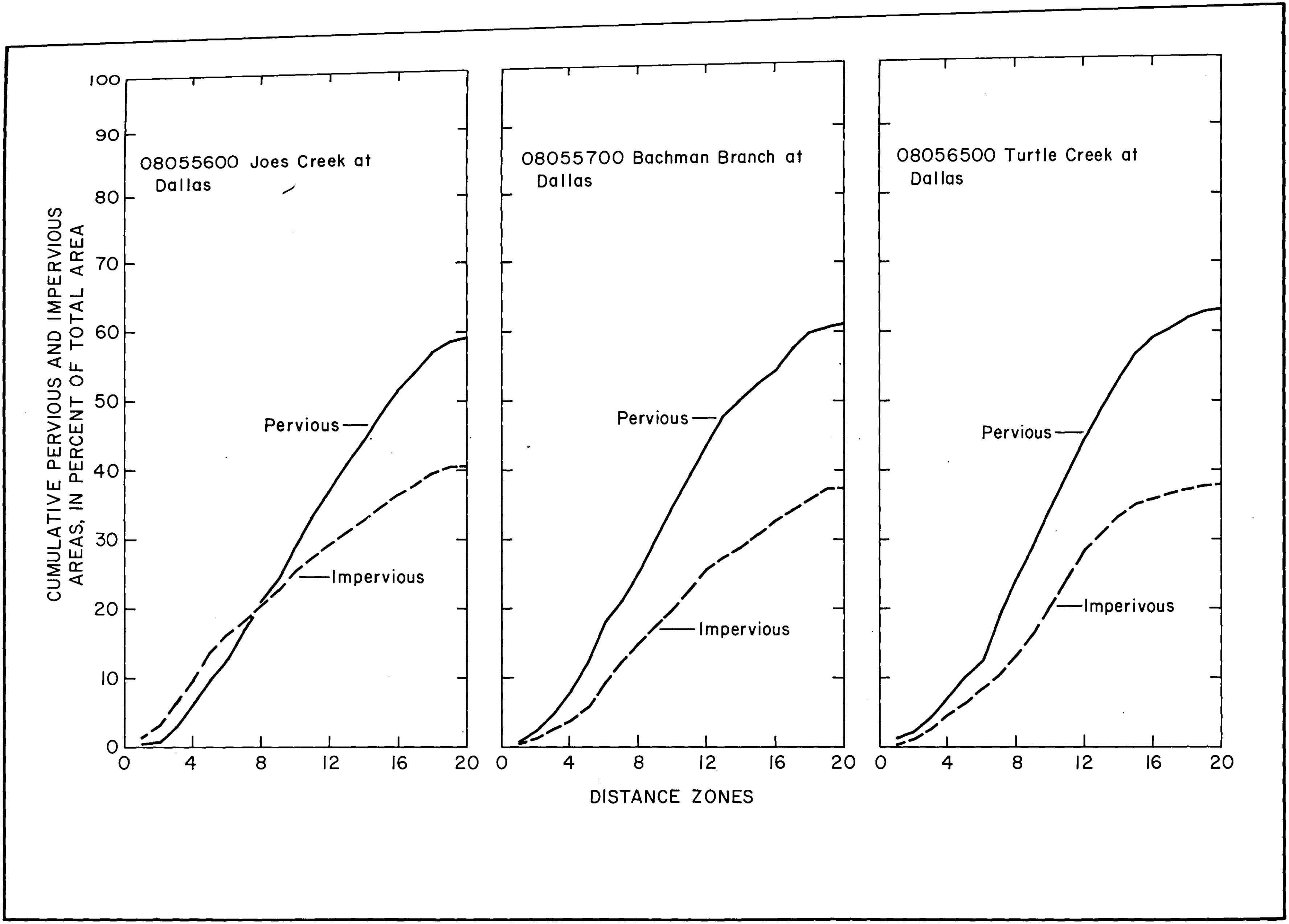


Figure 6.-Accumulation of pervious and impervious areas by distance zones, streamflow-gaging stations 08055600, 08055700, and 08056500

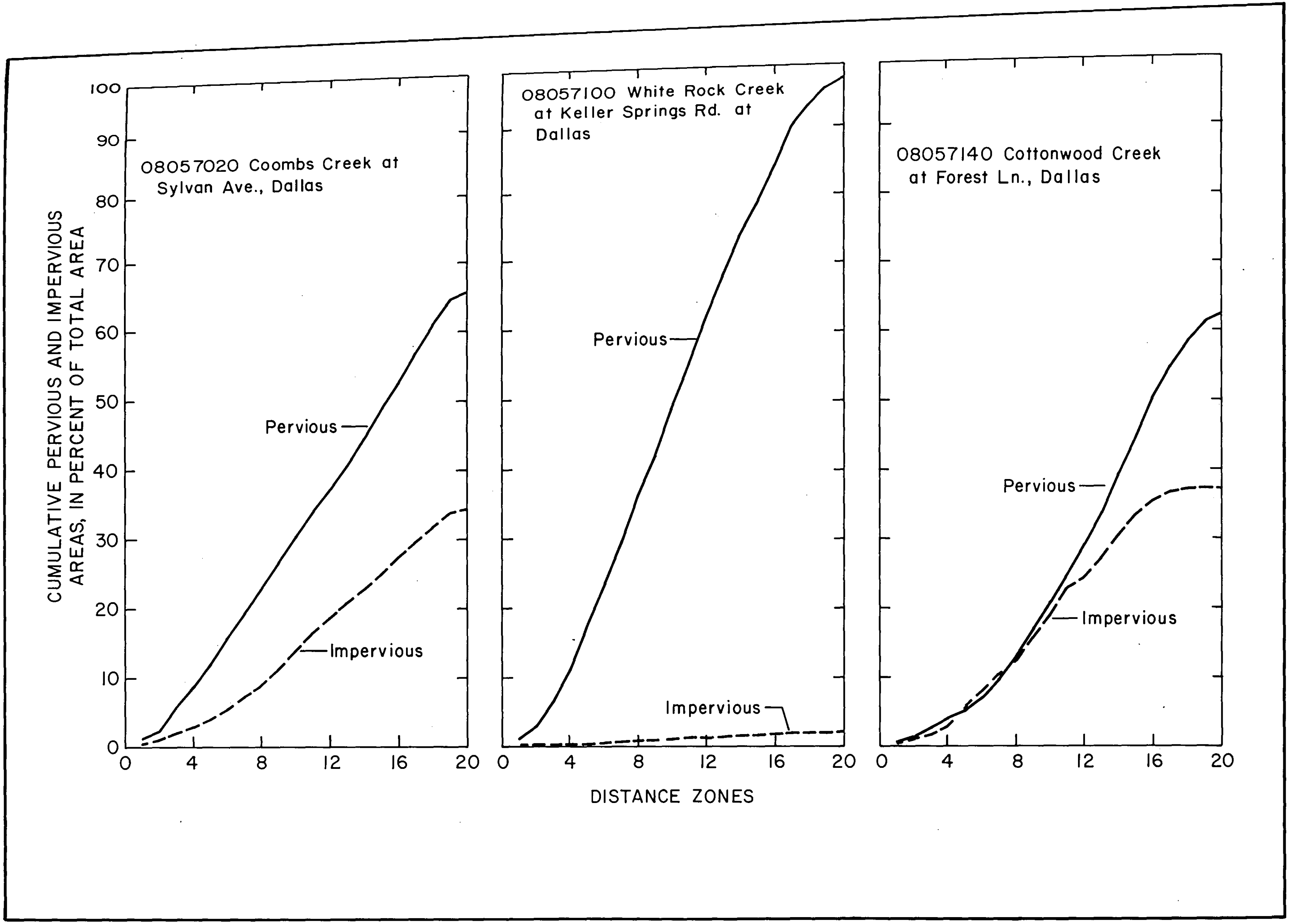


Figure 7.-Accumulation of pervious and impervious areas by distance zones, streamflow-gaging stations 08057020, 08057100, and 08057140

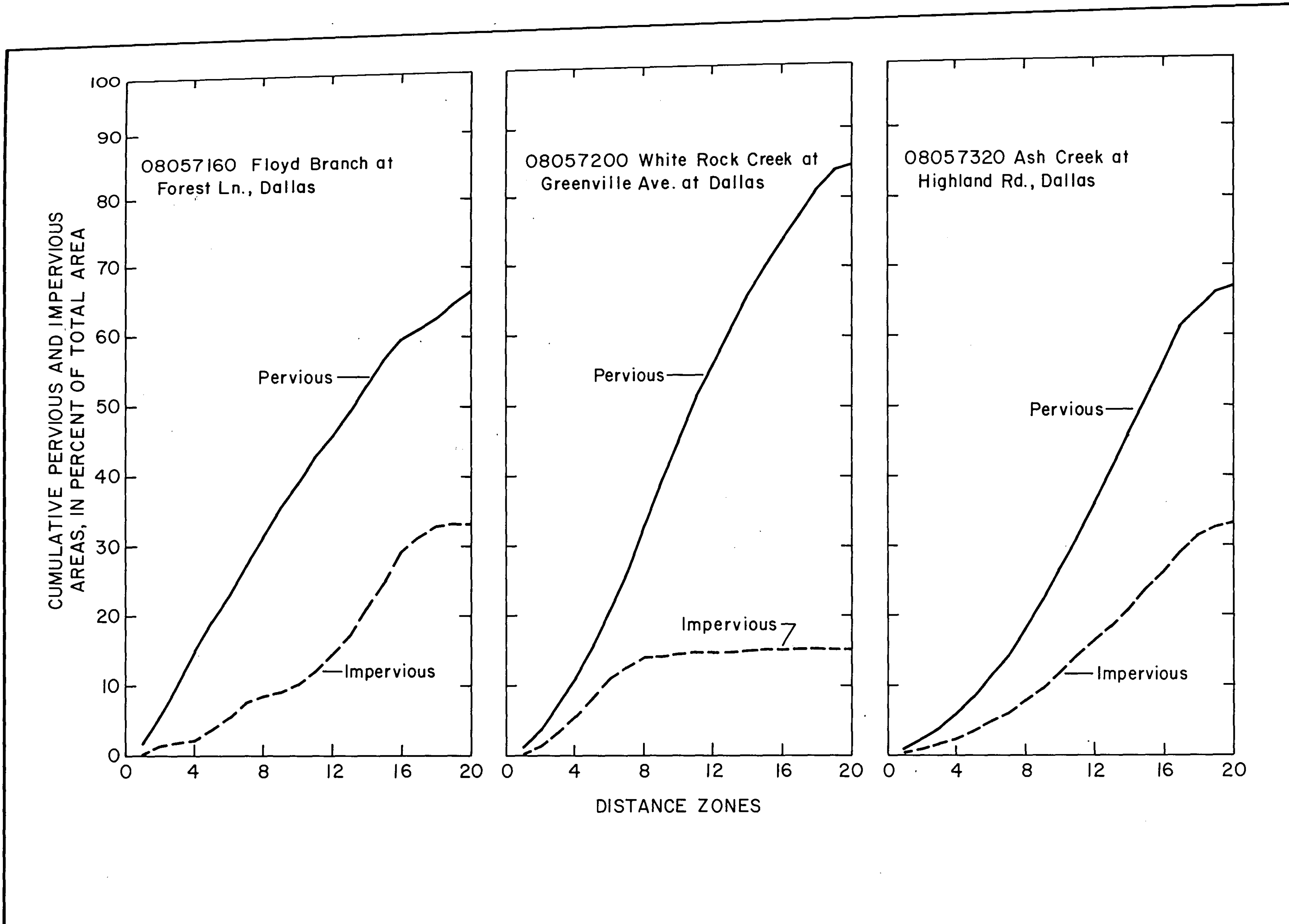


Figure 8.-Accumulation of pervious and impervious areas by distance zones, streamflow-gaging stations 08057160 08057200, and 08057320

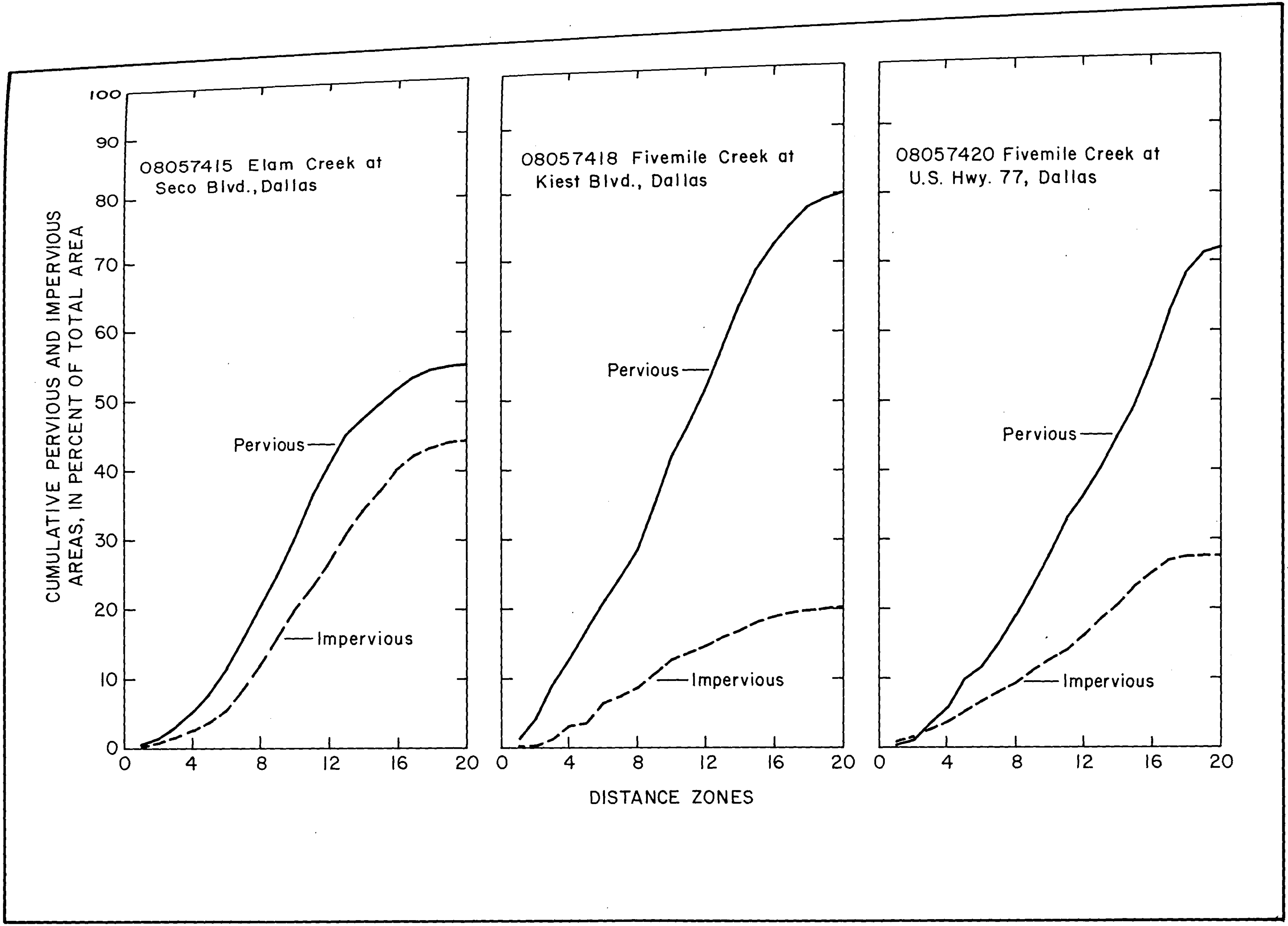


Figure 9.-Accumulation of pervious and impervious areas by distance zones, streamflow-gaging stations 08057415, 08057418, and 08057420

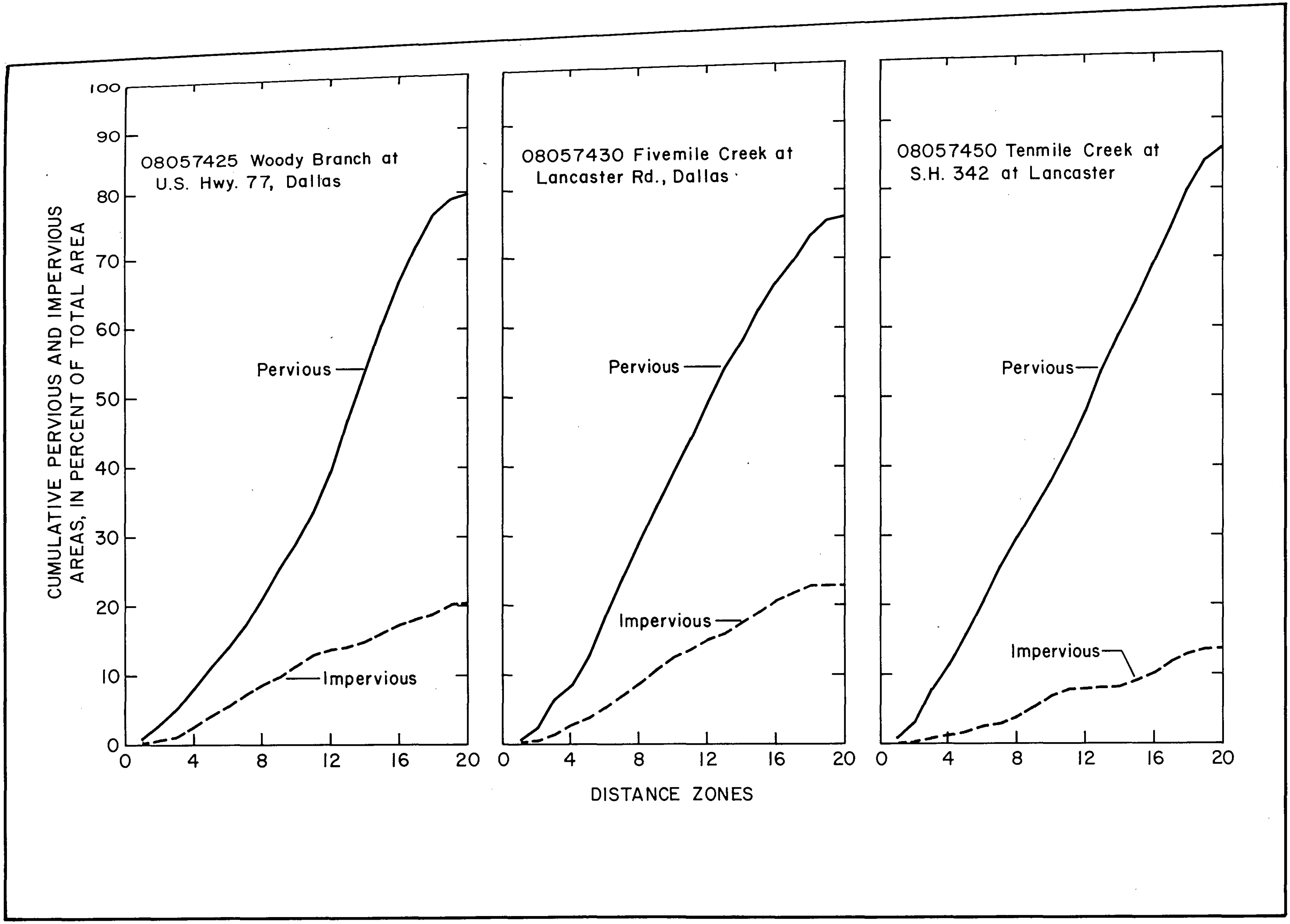


Figure 10.-Accumulation of pervious and impervious areas by distance zones, streamflow-gaging stations 08057425, 08057430, and 08057450

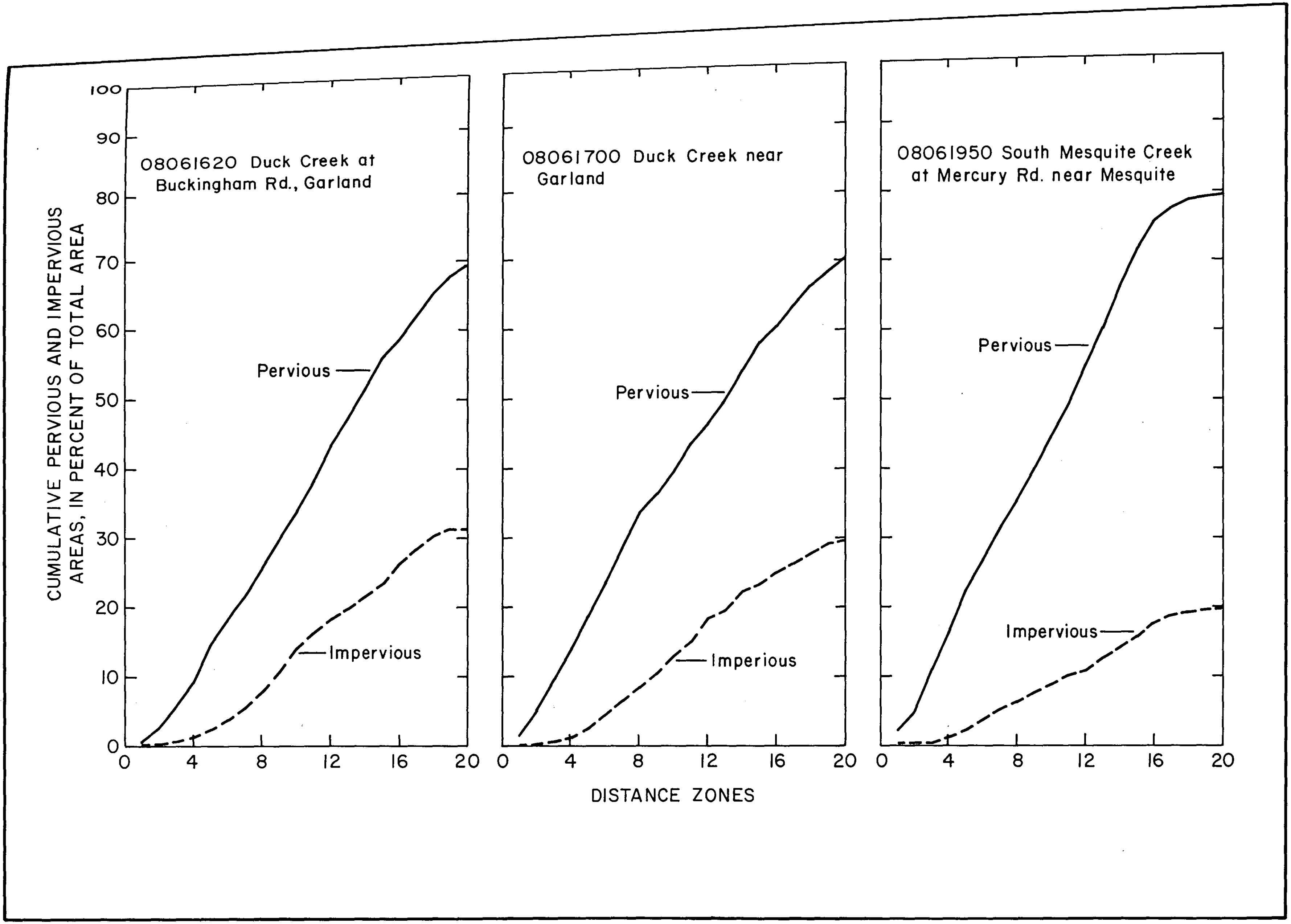


Figure 11.-Accumulation of pervious and impervious areas by distance zones, streamflow-gaging stations 08061620, 08061700, and 08061950

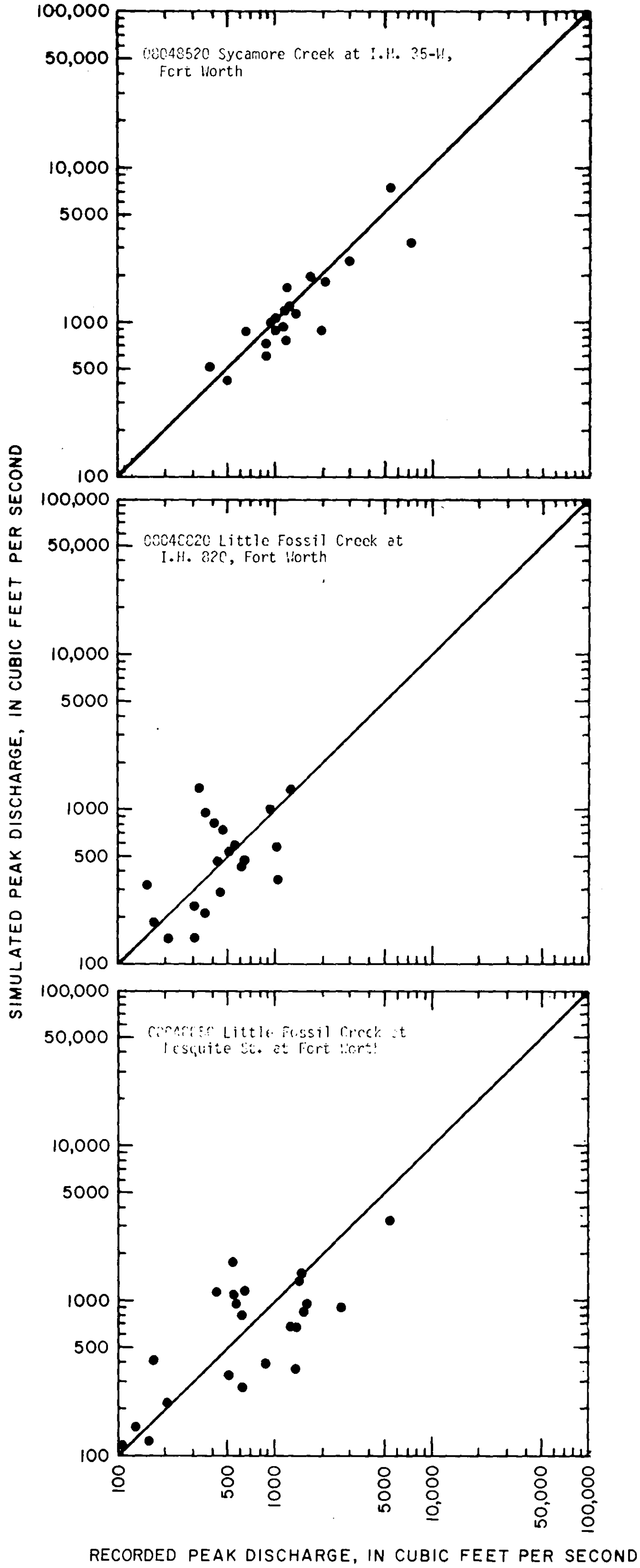


Figure 12.-Recorded and simulated flood-peak discharges from calibration phase, streamflow-gaging stations 08048520, 08048820, and 08048850

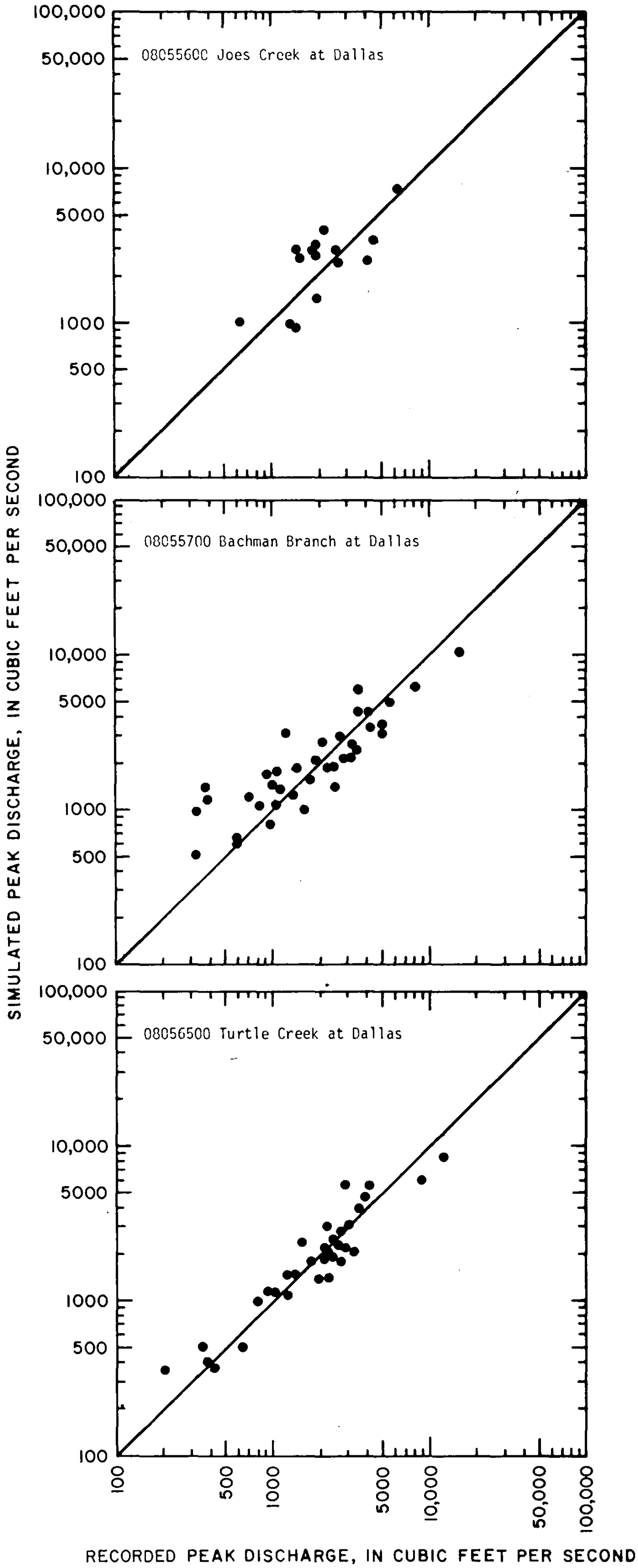


Figure 13.-Recorded and simulated flood-peak discharges from calibration phase, streamflow-gaging stations 08055600, 08055700, and 08056500

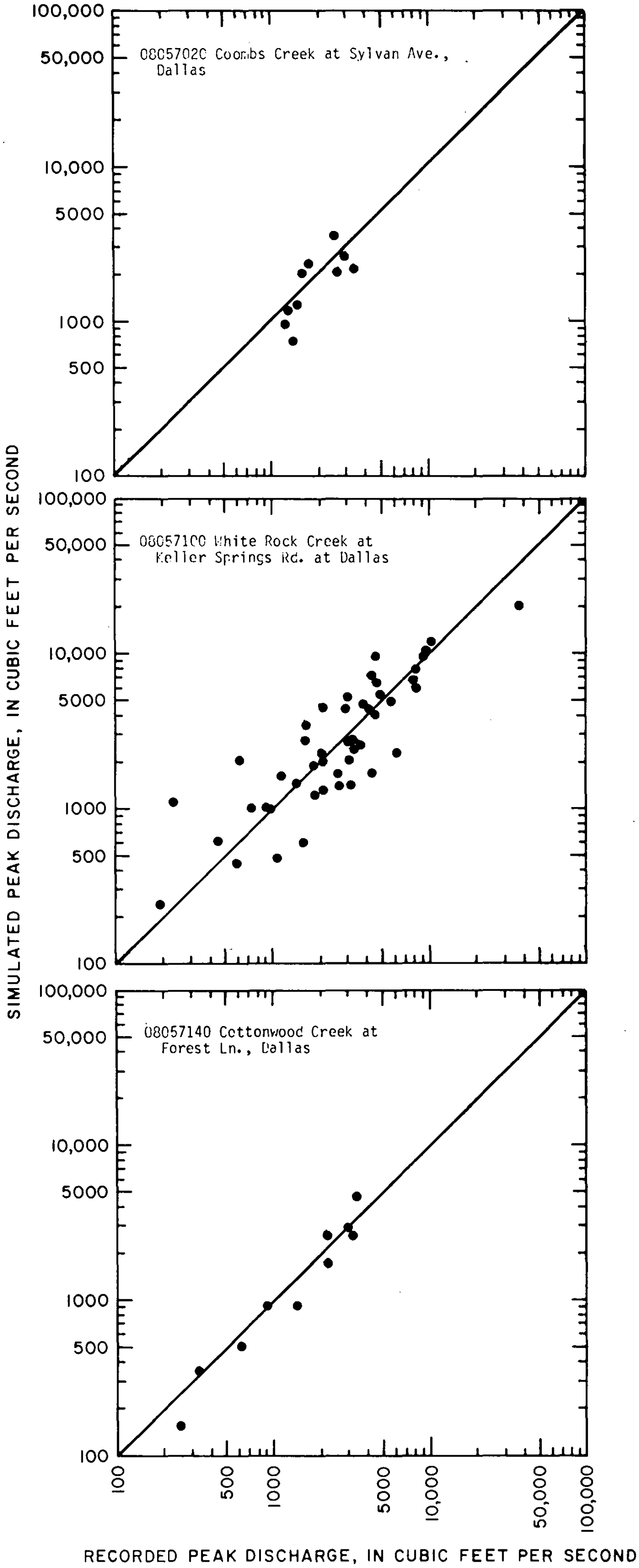


Figure 14.-Recorded and simulated flood-peak discharges from calibration phase, streamflow-gaging stations 08057020, 08057100, and 08057140

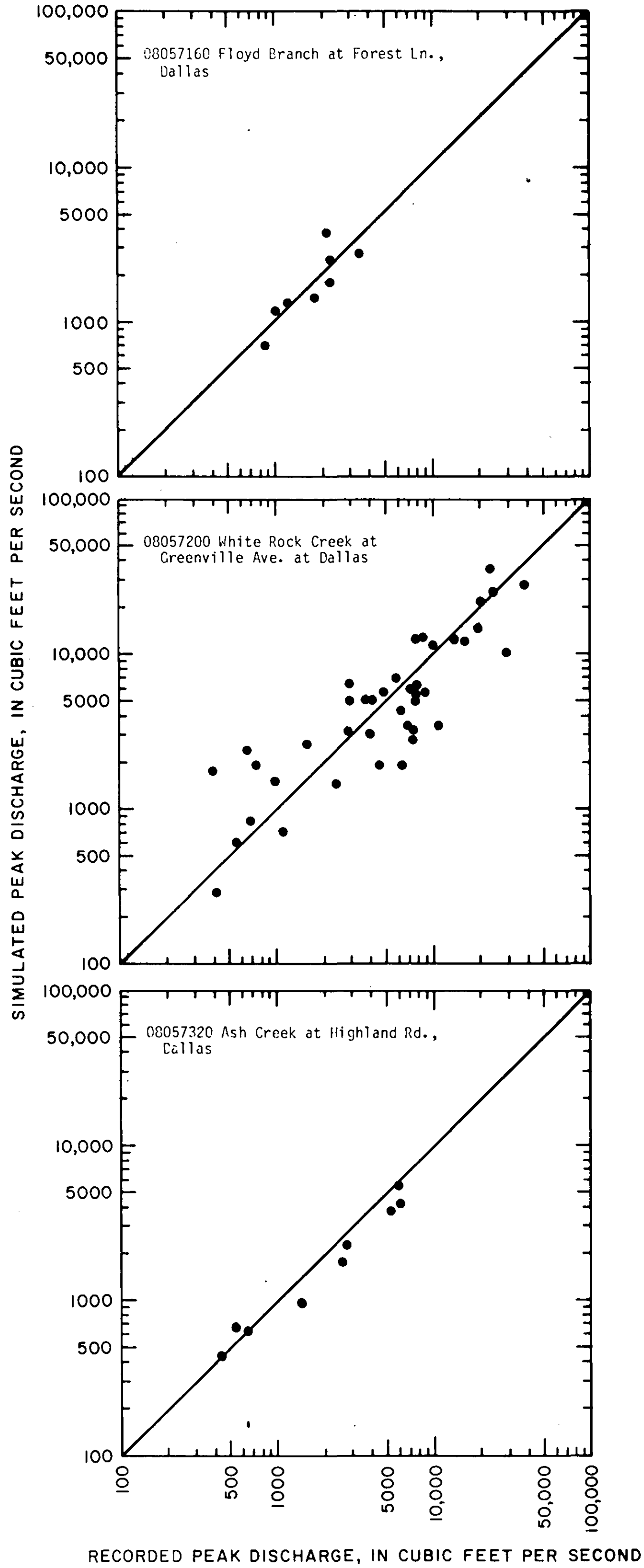


Figure 15.-Recorded and simulated flood-peak discharges from calibration phase, streamflow-gaging stations 08057160, 08057200, and 08057320

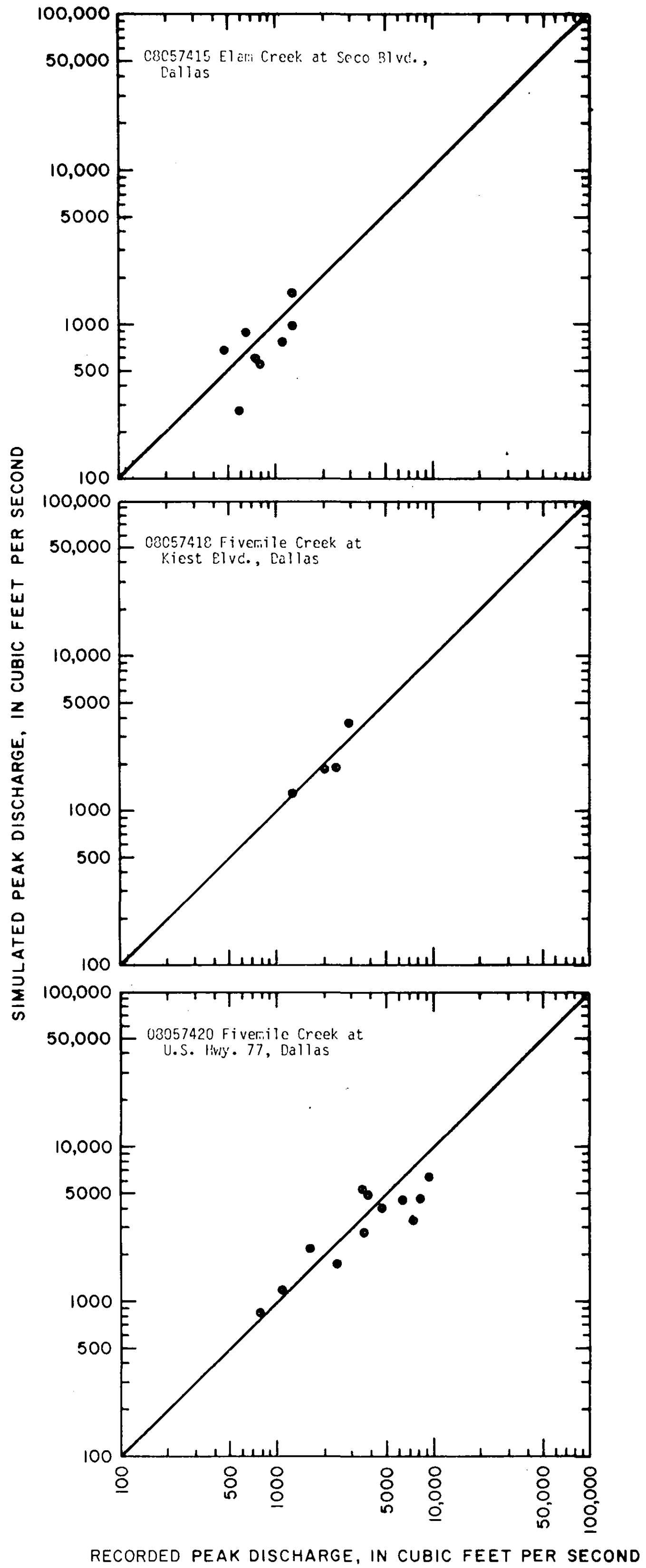


Figure 16.-Recorded and simulated flood-peak discharges from calibration phase, streamflow-gaging stations 08057415, 08057418, and 08057420

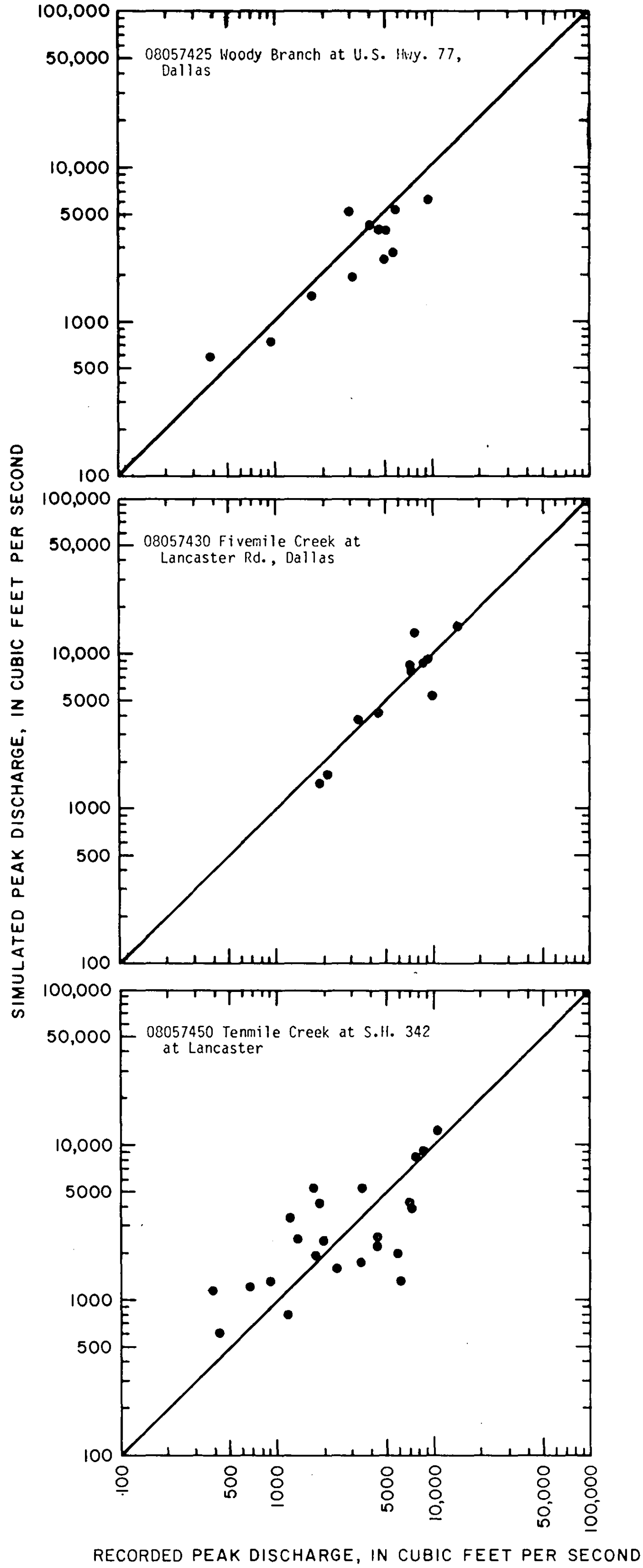


Figure 17.-Recorded and simulated flood-peak discharges from calibration phase, streamflow-gaging stations 08057425, 08057430, and 08057450

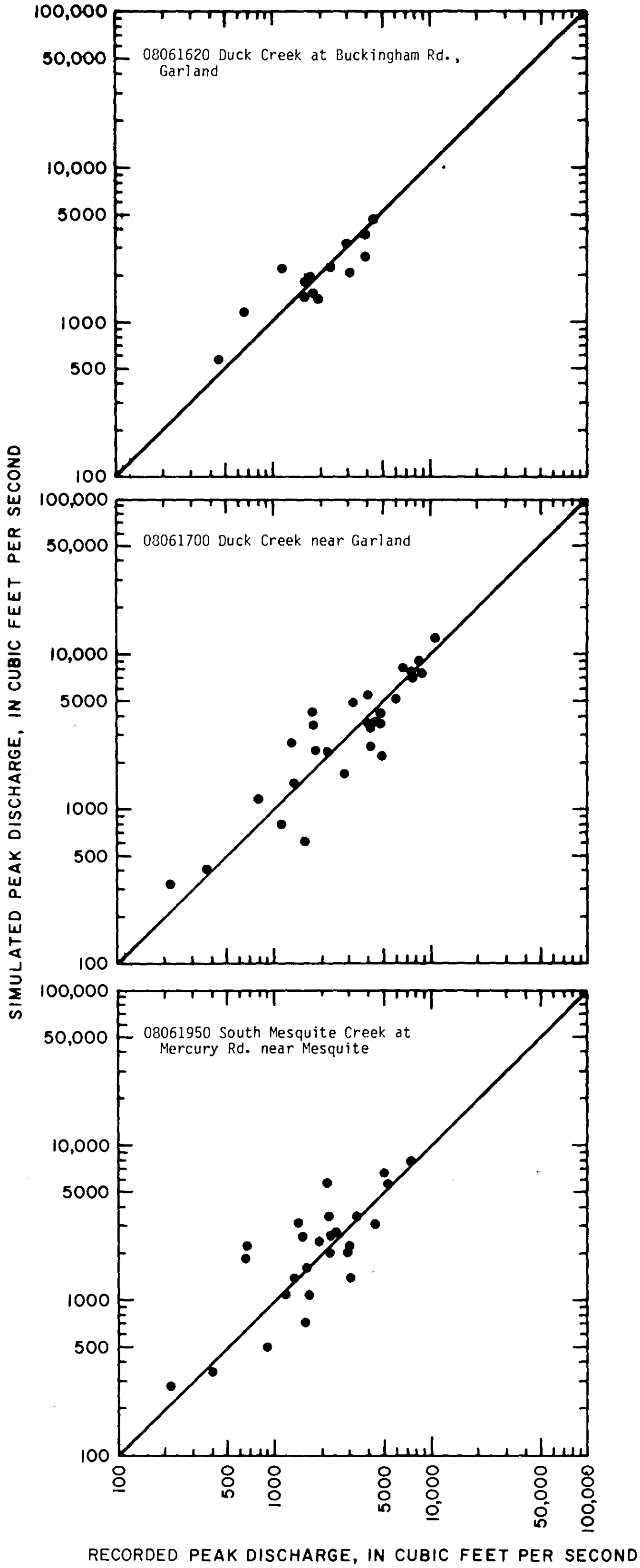


Figure 18.-Recorded and simulated flood-peak discharges from calibration phase, streamflow-gaging stations 08061620, 08061700, and 08061950

Table 5.--Model component values with correlation coefficient and root-mean square error for each basin

(RMSE - root-mean square error; ft^3/s - cubic feet per second)

Station number	PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	Correlation coefficient (R)	RMSE (percent)	Range in recorded peak discharge (ft^3/s)	Number of peaks
08048520	5.087	0.035	1.455	17.425	2.259	0.75	0.85	1.519	300.0	0.899	30.7	376-7,140	22
08048820	1.725	.032	1.015	16.400	1.625	.75	.85	5.622	312.2	.709	65.4	58-1,260	22
08048850	3.975	.049	.533	20.000	1.625	.75	.85	4.890	342.1	.732	80.9	56-5,360	26
08055600	7.000	.074	.390	19.875	3.577	.75	.85	2.708	210.0	.750	40.1	649-4,500	16
08055700	7.793	.078	.322	20.260	3.348	.75	.85	1.414	90.0	.902	50.9	71-16,000	42
08056500	2.975	.052	.320	18.250	1.680	.75	.85	1.531	93.6	.959	31.3	82-12,200	43
08057020	2.425	.043	.890	7.873	2.503	.75	.85	2.571	84.2	.779	29.4	1,220-3,320	13
08057100	2.398	.032	.493	14.788	2.148	.75	.85	4.200	354.4	.863	51.5	194-37,900	50
08057140	9.375	.196	1.430	35.000	2.438	.75	.85	1.350	89.2	.976	25.1	242-3,260	11
08057160	2.870	.038	.480	12.160	1.750	.75	.85	.990	104.3	.961	27.0	178-3,670	8
08057200	4.800	.048	.560	16.000	2.125	.75	.85	3.840	577.5	.873	59.4	382-38,100	48
08057320	2.200	.035	.480	12.100	2.800	.75	.85	1.170	65.7	.987	26.1	434-5,580	9
08057415	3.321	.046	.756	10.156	2.962	.75	.85	1.125	20.2	.948	45.8	20-1,260	9
08057418	2.187	.028	.245	6.862	.678	.75	.85	3.848	87.4	.887	18.0	1,270-2,810	4
08057420	1.647	.022	.165	4.013	1.196	.75	.85	4.860	100.0	.885	42.7	762-9,310	13
08057425	2.025	.033	.152	6.480	1.114	.75	.85	3.085	64.7	.899	40.0	395-9,350	14
08057430	2.056	.069	.787	11.090	1.191	.75	.85	4.618	104.9	.927	28.1	2,190-14,600	12
08057450	3.982	.080	.487	17.325	2.376	.75	.85	6.075	200.6	.767	79.2	87-10,700	26
08061620	3.850	.070	1.496	11.400	3.250	.75	.85	1.800	111.4	.876	31.4	458-4,400	15
08061700	3.560	.035	.526	12.800	2.080	.75	.85	5.670	315.0	.927	38.8	218-10,500	30
08061950	2.362	.021	.709	7.857	1.280	.75	.85	8.232	527.1	.807	55.1	217-7,330	27

Extension of Flood-Peak Discharge Data

The generation of simulated long-term flood-peak discharges for each basin used data from one regional rain gage and evaporation station and the calibrated rainfall-runoff model. The basin representation is similar to that of the calibration phase except that only one rain gage was used; therefore, the basin was not divided into subareas. From the flood-peak discharges simulated for the major storms, an annual flood series was developed for each basin. These simulated flood peaks and the recorded peaks are given in table 6.

FLOOD-FREQUENCY ANALYSIS

The tasks involved in the flood-frequency analysis consisted of determining flood frequencies for each basin from the annual series of simulated and recorded data (table 6) and combining these two frequency curves. The flood frequencies were determined by fitting the values in base 10 logarithm units of each of the two series of annual flood-peak discharges to a log-Pearson Type III distribution (U.S. Water Resources Council, 1977) by the equation:

$$\log Q_T = M + KS \qquad (2)$$

where Q_T = the peak discharge, in cubic feet per second, for a selected recurrence interval (T), in years;
M = the mean of the logarithms of the annual peaks;
K = a Pearson Type III coefficient, expressed as a function of selected exceedance probability and the skew coefficient (g); and
S = the standard deviation of the logarithms of the annual peaks.

Frequency curves for simulated discharges were computed using a skew coefficient that systematically fitted these data. Frequency curves for recorded discharges were first computed using systematic station records. If warrented, a station's historic record was weighted according to Water Resources Council guidelines (1977). However, at several streamflow-gaging stations the data produced unreasonable skews. This was caused by a combination of extremely high flows that occurred during 1964 and 1966 in northwest Dallas, unusually low flows for several years, and several short periods of record. When the unreasonable frequency curves were encountered, frequency curves were then hand drawn and skew coefficients were computed manually from these curves. Regional skews were not used because they have not been established for urban basins. When manual computations become necessary, variables that are needed in equation 2 are then computed from the following equations (W. O. Thomas, Jr., U.S. Geological Survey, written commun., 1978).

$$g = -2.54 + 3.12 \frac{\log (Q_{100}/Q_{10})}{\log (Q_{10}/Q_{2})} \qquad (3)$$

$$S = \frac{\log (Q_{100}/Q_{10})}{K_{100} - K_{10}} \qquad (4)$$

Table 6.--Summary of annual simulated and recorded peak-discharge data

(ft^3/s - cubic feet per second)

Water year	Sycamore Creek (08048520) Discharge (ft^3/s)		Little Fossil Creek (08048820) Discharge (ft^3/s)		Little Fossil Creek (08048850) Discharge (ft^3/s)		Joes Creek (08055600) Discharge (ft^3/s)		Bachman Branch (08055700) Discharge (ft^3/s)		Turtle Creek (08056500) Discharge (ft^3/s)	
	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded
1914	2,160	--	691	--	850	--	1,180	--	2,790	--	3,260	--
1915	1,570	--	588	--	629	--	1,060	--	1,530	--	1,390	--
1916	2,070	--	723	--	1,340	--	1,050	--	2,530	--	3,490	--
1917	2,410	--	851	--	1,050	--	1,290	--	2,890	--	3,202	--
1918	1,690	--	602	--	674	--	1,050	--	2,490	--	2,700	--
1919	2,910	--	830	--	1,270	--	1,310	--	3,160	--	3,600	--
1920	4,750	--	1,310	--	2,110	--	2,280	--	4,840	--	4,730	--
1921	913	--	326	--	310	--	673	--	1,540	--	1,610	--
1922	5,040	--	1,630	--	2,170	--	2,500	--	4,900	--	5,310	--
1923	2,370	--	871	--	995	--	1,390	--	3,070	--	3,270	--
1924	2,130	--	784	--	851	--	1,310	--	2,960	--	3,000	--
1925	2,850	--	930	--	1,270	--	1,550	--	3,780	--	4,420	--
1926	1,610	--	620	--	716	--	1,000	--	2,320	--	2,440	--
1927	2,320	--	871	--	1,074	--	1,420	--	2,590	--	2,840	--
1928	1,590	--	597	--	713	--	1,050	--	2,490	--	2,580	--
1929	4,820	--	1,470	--	2,680	--	2,300	--	5,940	--	7,120	--
1930	2,380	--	795	--	1,480	--	1,210	--	2,920	--	3,660	--
1931	2,650	--	945	--	1,100	--	1,510	--	3,650	--	4,000	--
1932	4,470	--	1,370	--	2,240	--	1,990	--	4,220	--	4,930	--
1933	3,050	--	1,030	--	1,320	--	1,700	--	4,040	--	4,410	--
1934	3,320	--	1,200	--	1,490	--	1,680	--	2,820	--	3,040	--
1935	3,760	--	1,280	--	1,700	--	1,980	--	3,750	--	4,260	--
1936	1,880	--	747	--	935	--	1,000	--	2,090	--	2,430	--
1937	969	--	406	--	433	--	675	--	1,460	--	1,460	--
1938	3,710	--	958	--	1,660	--	1,580	--	3,880	--	3,810	--
1939	1,160	--	503	--	522	--	847	--	1,490	--	1,360	--
1940	817	--	289	--	297	--	652	--	1,320	--	1,210	--
1941	2,090	--	764	--	900	--	1,300	--	2,680	--	2,890	--
1942	3,080	--	887	--	1,450	--	1,440	--	3,350	--	3,680	--
1943	1,850	--	718	--	790	--	1,160	--	2,660	--	2,740	--
1944	2,160	--	817	--	1,430	--	1,310	--	2,680	--	3,100	--
1945	6,950	--	1,880	--	3,830	--	3,050	--	7,680	--	8,760	--
1946	7,620	--	2,190	--	3,430	--	3,210	--	7,140	--	7,830	--
1947	12,420	--	3,370	--	6,250	--	5,180	--	8,970	--	9,320	3,350
1948	1,240	--	553	--	626	--	854	--	1,460	--	1,510	1,630
1949	5,450	--	1,630	--	2,780	--	2,230	--	4,730	--	5,160	2,800
1950	4,160	--	1,200	--	2,390	--	1,390	--	2,630	--	3,830	2,060
1951	2,360	--	875	--	984	--	1,330	--	3,140	--	3,380	1,700
1952	1,720	--	596	--	691	--	1,060	--	2,150	--	2,400	2,220
1953	1,380	--	499	--	853	--	740	--	1,710	--	1,800	910
1954	893	--	352	--	372	--	720	--	1,320	--	1,290	2,980
1955	978	--	367	--	350	--	720	--	1,700	--	1 740	852

Table 6.--Summary of annual simulated and recorded peak-discharge data--Continued

Water year	Sycamore Creek (08048520) Discharge (ft³/s)		Little Fossil Creek (08048820) Discharge (ft³/s)		Little Fossil Creek (08048850) Discharge (ft³/s)		Joes Creek (08055600) Discharge (ft³/s)		Bachman Branch (08055700) Discharge (ft³/s)		Turtle Creek (08056500) Discharge (ft³/s)	
	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded
1956	3,210	--	899	--	1,940	--	1,190	--	2,820	--	4,140	1,740
1957	5,740	--	1,400	--	2,900	--	2,640	--	6,130	--	5,660	3,850
1958	3,830	--	1,100	--	1,620	--	1,720	--	3,840	--	4,080	3,070
1959	1,660	--	605	--	652	--	1,060	--	2,510	--	2,760	1,460
1960	7,670	--	2,070	--	4,760	--	2,770	--	7,200	--	8,120	4,650
1961	1,020	--	475	--	496	--	693	--	1,000	--	984	1,240
1962	6,060	--	1,580	--	3,100	--	2,730	3,100	6,600	--	6,990	4,640
1963	5,380	--	1,700	--	2,490	--	2,560	7,430	4,410	9,200	4,680	4,290
1964	2,980	--	1,010	--	1,560	--	1,490	1,440	3,120	3,620	3,530	3,240
1965	2,230	--	767	--	1,010	--	1,260	1,520	3,030	5,170	3,450	4,520
1966	6,090	--	1,540	--	3,220	--	2,930	6,350	7,910	16,000	7,210	12,200
1967	1,130	--	427	--	407	--	815	930	1,790	1,450	1,780	1,790
1968	1,940	--	681	--	798	--	1,170	1,500	2,780	1,760	3,170	3,220
1969	5,570	5,800	1,690	715	3,040	1,530	2,070	2,350	4,550	8,360	5,920	8,840
1970	2,240	1,140	772	650	978	1,370	1,320	1,780	3,150	3,130	3,440	3,130
1971	1,980	2,100	725	258	751	603	1,260	1,940	2,830	3,480	2,900	2,400
1972	2,870	5,450	877	632	1,610	1,580	1,410	1,850	3,720	5,650	3,380	3,590
1973	1,340	2,960	566	586	626	1,630	882	2,870	1,650	2,750	1,820	4,160
1974	1,550	2,510	573	914	599	1,430	1,030	1,730	2,430	3,280	2,620	3,160
1975	1,180	1,990	455	1,260	534	5,360	717	1,230	1,500	2,740	1,650	2,440
1976	1,270	4,570	514	451	562	623	822	1,180	1,420	2,340	1,530	3,400
1977	3,620	7,160	1,300	1,110	1,710	2,560	1,760	2,380	3,290	5,200	3,840	4,000
1978	2,280	901	811	95	1,050	68	1,370	3,490	2,950	4,320	3,270	1,410

Table 6.--Summary of annual simulated and recorded peak-discharge data--Continued

Water year	Coombs Creek (08057020) Discharge (ft³/s)		White Rock Creek (08057100) Discharge (ft³/s)		Cottonwood Creek (08057140) Discharge (ft³/s)		Floyd Branch (08057160) Discharge (ft³/s)		White Rock Creek (08057200) Discharge (ft³/s)		Ash Creek (08057320) Discharge (ft³/s)	
	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded
1914	1,650	--	7,190	--	2,460	--	1,840	--	5,320	--	4,040	--
1915	1,090	--	2,940	--	1,140	--	881	--	4,110	--	1,840	--
1916	1,490	--	6,530	--	2,160	--	1,780	--	5,070	--	3,670	--
1917	1,660	--	5,120	--	2,490	--	1,780	--	6,030	--	4,060	--
1918	1,440	--	4,680	--	2,200	--	1,540	--	4,410	--	3,470	--
1919	1,900	--	5,420	--	2,440	--	2,100	--	6,810	--	4,290	--
1920	2,620	--	6,640	--	2,980	--	2,820	--	10,580	--	5,400	--
1921	835	--	3,150	--	1,500	--	942	--	2,460	--	2,000	--
1922	2,970	--	7,630	--	3,570	--	3,310	--	11,890	--	6,250	--
1923	1,830	--	4,890	--	2,540	--	1,910	--	6,150	--	4,030	--
1924	1,730	--	3,470	--	2,370	--	1,960	--	5,680	--	3,610	--
1925	2,200	--	7,790	--	3,170	--	2,440	--	6,880	--	5,330	--
1926	1,350	--	5,280	--	2,080	--	1,470	--	4,200	--	3,040	--
1927	1,680	--	3,600	--	2,050	--	1,670	--	5,760	--	3,420	--
1928	1,430	--	3,140	--	2,220	--	1,510	--	4,240	--	3,310	--
1929	3,260	--	9,020	--	4,410	--	3,660	--	11,320	--	7,830	--
1930	1,730	--	4,230	--	2,410	--	1,970	--	5,970	--	4,070	--
1931	2,240	--	5,440	--	3,040	--	2,440	--	6,630	--	5,080	--
1932	2,580	--	6,670	--	3,000	--	2,900	--	10,360	--	5,480	--
1933	2,420	--	4,690	--	3,210	--	2,660	--	7,720	--	5,380	--
1934	1,940	--	5,250	--	2,050	--	2,110	--	7,970	--	3,450	--
1935	2,550	--	5,830	--	2,820	--	2,760	--	8,990	--	4,940	--
1936	1,340	--	4,580	--	1,750	--	1,460	--	4,940	--	2,920	--
1937	756	--	2,220	--	1,420	--	837	--	2,570	--	1,830	--
1938	1,790	--	5,770	--	2,610	--	2,010	--	7,950	--	4,410	--
1939	892	--	2,770	--	1,290	--	860	--	3,250	--	1,660	--
1940	677	--	1,100	--	1,180	--	679	--	2,500	--	1,400	--
1941	1,620	--	5,020	--	2,170	--	1,640	--	5,040	--	3,770	--
1942	1,910	--	7,310	--	2,420	--	2,090	--	6,970	--	4,320	--
1943	1,580	--	4,200	--	2,310	--	1,640	--	5,140	--	3,510	--
1944	1,550	--	4,490	--	2,380	--	1,750	--	5,670	--	3,720	--
1945	4,120	--	9,620	--	5,220	--	4,810	--	16,020	--	9,190	--
1946	4,020	--	11,440	--	4,910	--	4,630	--	17,110	--	8,910	--
1947	5,270	--	17,550	--	5,200	--	5,400	--	27,640	--	9,360	--
1948	997	--	2,050	--	1,200	--	956	--	3,670	--	1,870	--
1949	2,520	--	8,400	--	3,210	--	2,900	--	13,020	--	5,540	--
1950	1,800	--	5,980	--	2,080	--	2,040	--	10,140	--	3,600	--
1951	1,940	--	5,080	--	2,620	--	2,150	--	6,120	--	4,290	--
1952	1,290	--	5,280	--	1,840	--	1,360	--	4,550	--	2,840	--
1953	865	--	4,940	--	1,570	--	911	--	3,480	--	2,000	--
1954	665	--	1,970	--	1,270	--	738	--	2,710	--	1,600	--
1955	928	--	3,130	--	1,590	--	1,000	--	2,610	--	2,270	--

Table 6.--Summary of annual simulated and recorded peak-discharge data--Continued

Water year	Coombs Creek (08057020) Discharge (ft^3/s)		White Rock Creek (08057100) Discharge (ft^3/s)		Cottonwood Creek (08057140) Discharge (ft^3/s)		Floyd Branch (08057160) Discharge (ft^3/s)		White Rock Creek (08057200) Discharge (ft^3/s)		Ash Creek (08057320) Discharge (ft^3/s)	
	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded
1956	1,640	--	3,770	--	3,020	--	2,120	--	7,760	--	3,714	--
1957	2,660	--	8,180	--	3,990	--	3,090	--	12,530	--	5,890	--
1958	2,200	--	9,380	--	2,830	--	2,500	--	8,930	--	4,730	--
1959	1,470	--	4,780	--	2,310	--	1,610	--	4,260	--	3,610	--
1960	3,860	--	13,080	--	5,280	--	4,340	--	18,010	--	9,240	--
1961	718	--	1,760	--	806	--	612	--	2,960	--	1,210	--
1962	3,380	--	8,200	9,410	3,990	5,090	3,890	3,200	13,980	20,000	7,530	--
1963	2,880	--	9,730	2,620	2,890	17,400	2,990	4,850	12,140	24,500	5,060	4,700
1964	2,040	--	6,010	37,900	2,320	6,200	2,220	3,500	7,000	38,100	3,980	750
1965	1,760	4,260	4,320	5,720	2,550	4,450	1,940	2,850	5,730	13,800	4,180	3,600
1966	3,280	2,780	9,860	9,020	5,550	17,600	3,670	8,590	13,440	27,000	7,630	5,180
1967	1,010	1,570	1,880	2,120	1,610	4,080	1,060	700	3,160	6,320	2,200	3,400
1968	1,630	2,900	6,420	6,220	2,470	1,380	1,810	1,100	4,780	10,800	3,990	1,540
1969	2,780	2,960	9,100	8,300	3,370	4,530	3,360	3,350	12,650	19,600	5,770	4,330
1970	1,800	2,460	5,360	4,900	2,590	3,260	1,912	3,100	5,670	7,700	4,310	1,240
1971	1,690	2,700	3,050	3,100	2,430	950	1,800	1,240	5,380	4,160	3,710	775
1972	1,550	2,560	6,270	8,250	2,350	3,180	1,700	2,460	6,520	15,800	3,530	6,200
1973	1,020	3,320	3,220	5,060	1,470	2,280	1,090	2,610	3,660	12,300	2,400	6,180
1974	1,400	2,660	4,120	4,680	2,200	2,970	1,530	2,010	3,990	8,590	3,400	5,940
1975	874	1,160	3,990	4,400	1,330	1,090	965	992	3,040	10,100	2,060	5,230
1976	1,000	1,580	2,510	1,080	1,200	1,370	1,060	1,030	3,370	2,530	1,960	4,690
1977	2,290	1,700	8,330	10,100	2,490	4,510	2,300	2,390	8,630	19,700	4,520	6,100
1978	1,780	1,060	4,950	1,900	2,380	2,370	1,870	1,190	5,650	7,860	4,040	2,790

Table 6.--Summary of annual simulated and recorded peak-discharge data--Continued

Water year	Elam Creek (08057415)		Fivemile Creek (08057418)		Fivemile Creek (08057420)		Woody Branch (08057425)		Fivemile Creek (08057430)		Tenmile Creek (08057450)	
	Discharge (ft³/s)		Discharge (ft³/s)		Discharge (ft³/s)		Discharge (ft³/s)		Discharge (ft³/s)		Discharge (ft³/s)	
	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded
1914	1,190	--	2,520	--	3,620	--	4,240	--	7,600	--	3,830	--
1915	325	--	1,600	--	2,930	--	2,450	--	4,450	--	2,780	--
1916	1,010	--	2,380	--	3,380	--	4,140	--	8,140	--	3,670	--
1917	1,050	--	2,600	--	3,810	--	4,370	--	7,640	--	4,190	--
1918	914	--	2,180	--	3,340	--	3,690	--	6,510	--	2,790	--
1919	988	--	2,590	--	3,990	--	4,420	--	8,830	--	5,510	--
1920	1,220	--	3,510	--	5,550	--	5,740	--	12,970	--	9,220	--
1921	619	--	1,280	--	2,040	--	2,150	--	3,440	--	1,420	--
1922	1,250	--	4,540	--	6,890	--	7,270	--	15,620	--	8,670	--
1923	965	--	2,900	--	4,390	--	4,530	--	8,680	--	4,120	--
1924	858	--	2,750	--	4,080	--	4,300	--	8,040	--	3,620	--
1925	1,420	--	3,330	--	4,780	--	5,590	--	10,510	--	5,000	--
1926	758	--	2,023	--	3,260	--	3,340	--	5,920	--	2,750	--
1927	769	--	2,650	--	4,130	--	4,330	--	8,500	--	3,850	--
1928	779	--	2,230	--	3,370	--	3,690	--	6,140	--	2,570	--
1929	2,110	--	5,250	--	6,740	--	8,450	--	18,860	--	9,690	--
1930	864	--	2,780	--	3,900	--	4,600	--	9,450	--	4,260	--
1931	1,070	--	3,400	--	4,920	--	5,570	--	10,390	--	4,430	--
1932	1,100	--	4,020	--	5,680	--	6,430	--	14,260	--	8,290	--
1933	1,250	--	3,710	--	5,350	--	6,060	--	11,620	--	5,260	--
1934	879	--	3,040	--	4,850	--	4,620	--	9,990	--	5,570	--
1935	1,060	--	3,970	--	5,950	--	6,220	--	13,190	--	6,460	--
1936	725	--	2,110	--	3,280	--	3,400	--	6,470	--	3,420	--
1937	507	--	1,160	--	1,900	--	1,950	--	2,970	--	1,640	--
1938	1,120	--	2,700	--	3,820	--	4,370	--	9,420	--	7,020	--
1939	463	--	1,430	--	2,410	--	2,270	--	4,080	--	1,990	--
1940	303	--	1,050	--	1,900	--	1,710	--	2,770	--	1,390	--
1941	913	--	2,520	--	3,720	--	4,170	--	7,810	--	3,370	--
1942	1,070	--	2,810	--	4,120	--	4,540	--	9,270	--	3,940	--
1943	787	--	2,540	--	3,890	--	4,180	--	7,260	--	3,220	--
1944	936	--	2,380	--	3,740	--	4,010	--	8,730	--	3,650	--
1945	1,950	--	6,400	--	8,340	--	10,190	--	23,460	--	14,050	--
1946	2,000	--	6,100	--	8,510	--	9,940	--	21,260	-	14,150	--
1947	1,900	--	8,070	--	12,140	--	12,630	--	32,640	--	24,770	--
1948	353	--	1,670	--	2,730	--	2,560	--	4,850	--	2,240	--
1949	1,510	--	4,120	--	5,840	--	6,440	--	14,640	--	11,030	--
1950	727	--	2,880	--	4,140	--	4,580	--	11,300	--	7,180	--
1951	918	--	3,080	--	4,280	--	4,890	--	9,200	--	4,040	--
1952	754	--	1,950	--	3,150	--	3,200	--	6,120	--	2,950	--
1953	621	--	1,360	--	2,240	--	2,280	--	4,750	--	2,630	--
1954	512	--	1,150	--	1,860	--	1,920	--	3,200	--	1,560	--
1955	635	--	1,420	--	2,220	--	2,410	--	3,860	--	1,540	--

Table 6.--Summary of annual simulated and recorded peak-discharge data--Continued

Water year	Elam Creek (08057415) Discharge (ft^3/s)		Fivemile Creek (08057418) Discharge (ft^3/s)		Fivemile Creek (08057420) Discharge (ft^3/s)		Woody Branch (08057425) Discharge (ft^3/s)		Fivemile Creek (08057430) Discharge (ft^3/s)		Tenmile Creek (08057450) Discharge (ft^3/s)	
	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded
1956	848	--	2,700	--	3,600	--	4,400	--	10,340	--	6900	--
1957	1,340	--	3,810	--	5,520	--	6,180	--	15,170	--	12080	--
1958	1,440	--	3,140	--	4,780	--	5,030	--	10,570	--	7120	--
1959	961	--	2,270	--	3,320	--	3,830	--	6,470	--	2720	--
1960	2,320	--	5,850	--	7,970	--	9,700	--	22,150	--	14730	--
1961	215	--	1,220	--	2,240	--	1,870	--	3,500	--	1980	--
1962	1,810	--	4,960	--	7,010	--	8,050	--	18,500	--	12440	--
1963	1,170	--	4,440	--	6,800	--	6,870	--	16,200	--	9490	--
1964	1,070	--	3,170	--	4,760	--	5,180	--	10,610	--	5470	--
1965	1,070	--	2,940	--	4,050	2,400	4,670	3,230	8,790	2,520	3880	--
1966	1,800	--	4,710	--	6,540	7,000	7,870	4,540	17,870	9,150	13200	--
1967	496	--	1,720	--	2,540	1,440	2,670	835	4,450	1,760	1820	--
1968	1,110	--	2,500	--	3,590	2,880	4,180	2,680	7,470	6,900	3190	--
1969	1,380	--	4,350	--	6,140	11,800	7,010	7,160	16,750	15,900	9970	12,900
1970	1,200	--	2,760	--	4,070	6,380	4,620	4,120	8,480	7,260	3910	7,870
1971	781	--	2,620	--	4,070	4,840	4,240	4,900	7,550	7,860	3340	3,190
1972	933	--	2,430	--	4,200	7,440	3,800	5,500	8,190	9,550	6280	11,000
1973	546	1,290	1,680	--	2,520	9,240	2,720	5,310	4,690	10,900	2370	12,900
1974	843	1,100	2,170	6,370	3,210	8,500	3,630	4,490	6,150	10,000	2500	6,830
1975	601	746	1,370	1,590	2,050	3,580	2,220	3,900	4,140	6,020	1880	6,160
1976	403	1,260	1,590	5,560	2,600	9,310	2,420	9,350	4,630	10,600	2170	10,700
1977	872	779	3,530	3,020	5,440	3,550	5,610	4,920	11,780	9,000	6290	6,130
1978	1,050	464	2,750	1,540	4,080	1,530	4,530	1,700	8,440	--	3830	1,270

Water year	Duck Creek (08061620) Discharge (ft^3/s)		Duck Creek (08061700) Discharge (ft^3/s)		South Mesquite Creek (08061950) Discharge (ft^3/s)	
	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded
1914	2,220	--	3,540	--	1,960	--
1915	1,360	--	3,400	--	2,160	--
1916	2,010	--	3,260	--	2,480	--
1917	2,220	--	4,490	--	2,680	--
1918	1,880	--	2,980	--	2,010	--
1919	2,680	--	4,440	--	2,480	--
1920	4,130	--	7,000	--	4,280	--
1921	1,060	--	1,610	--	981	--
1922	4,330	--	8,490	--	4,930	--
1923	2,360	--	4,530	--	2,980	--
1924	2,300	--	3,970	--	2,440	--
1925	3,060	--	4,510	--	2,580	--
1926	1,720	--	3,090	--	1,890	--
1927	2,140	--	4,440	--	2,690	--
1928	1,800	--	3,030	--	2,360	--
1929	4,920	--	7,050	--	3,880	--
1930	2,290	--	3,970	--	2,290	--
1931	2,910	--	4,610	--	2,740	--
1932	3,740	--	6,990	--	3,820	--
1933	3,280	--	5,360	--	3,250	--
1934	2,520	--	6,210	--	3,860	--
1935	3,420	--	6,720	--	3,950	--
1936	1,720	--	3,950	--	2,980	--
1937	951	--	2,160	--	1,660	--
1938	2,950	--	5,140	--	2,980	--
1939	1,070	--	2,630	--	1,890	--
1940	880	--	1,700	--	1,240	--
1941	2,230	--	3,750	--	2,170	--
1942	2,820	--	4,790	--	2,640	--
1943	2,010	--	3,690	--	2,600	--
1944	2,080	--	3,950	--	2,680	--
1945	6,340	--	9,850	--	5,210	--
1946	6,080	--	11,620	--	6,640	--
1947	8,440	--	18,190	--	9,900	--
1948	1,140	--	2,930	--	2,240	--
1949	3,880	--	8,720	--	5,490	--
1950	2,410	--	6,240	--	3,260	--
1951	2,510	--	4,510	--	2,950	--
1952	1,700	--	3,320	--	2,300	--
1953	1,210	--	2,710	--	1,800	--
1954	855	--	2,010	--	1,350	--
1955	1,160	--	1,760	--	1,090	--

Table 6.--Summary of annual simulated and recorded peak-discharge data--Continued

Water year	Duck Creek (08061620) Discharge (ft³/s)		Duck Creek (08061700) Discharge (ft³/s)		South Mesquite Creek (08061950) Discharge (ft³/s)	
	Simulated	Recorded	Simulated	Recorded	Simulated	Recorded
1956	2,360	--	4,350	--	2,320	--
1957	4,550	--	7,440	--	3,800	--
1958	3,260	--	5,820	7,400	3,180	--
1959	1,860	--	2,920	2,380	1,780	--
1960	5,840	--	11,090	4,820	6,960	--
1961	808	--	2,580	2,080	2,170	--
1962	5,280	--	8,460	16,000	4,750	--
1963	4,100	--	8,730	8,600	4,900	--
1964	2,460	--	5,090	6,200	3,080	--
1965	2,390	--	3,920	5,910	2,530	--
1966	5,510	--	7,970	10,400	4,060	--
1967	1,260	--	2,160	2,630	1,390	--
1968	2,150	--	3,260	4,230	1,940	--
1969	3,980	4,640	8,530	10,500	5,160	8,080
1970	2,510	2,500	4,020	6,660	2,680	2,160
1971	2,160	650	3,730	2,560	2,340	640
1972	2,370	2,800	4,580	7,550	2,970	5,920
1973	1,200	2,320	3,170	7,670	2,380	9,000
1974	1,780	3,960	2,740	8,160	1,740	3,380
1975	1,140	2,720	2,540	4,780	1,770	2,990
1976	1,110	3,100	2,730	4,680	1,740	7,330
1977	2,940	--	6,930	8,540	4,610	4,650
1978	2,410	--	4,020	2,460	2,330	1,690

$$M = \log Q_2 - K_2 S \tag{5}$$

where g = station skew,

Q_2, Q_{10}, Q_{100} = T-year discharges, and

K_2, K_{10}, K_{100} = log-Pearson Type III coefficients (U.S. Water Resources Council, 1977).

Flood-peak magnitudes and frequencies determined from simulated data are given in table 7, and flood-peak magnitudes and frequencies determined from recorded data are given in table 8.

WEIGHTED DISCHARGE-FREQUENCY RELATIONS

A comparison of the simulated and observed frequency curves for each station showed, in most instances, that the curves of the simulated discharges had flatter slopes. This has been observed in other studies in Texas and by researchers who have used this model. The trend may have occurred during this study because the long-term rainfall data from Love Field have not shown the same occurrence of storms with high rainfall and intensities as the data from the USGS network gages. The long-term rainfall station (Love Field) has recorded so few extreme storms that it might be considered to have a large sampling error.

The discrepancies between frequency curves developed from the recorded and simulated data indicated the need for a procedure for combining these relationships for each streamflow-gaging station into a single curve. Several procedures were available, including averaging, weighting on the basis of length of record, and weighting on the basis of an error analysis. The most important factor, after consideration of the Dallas-Fort Worth data set, appeared to be the length of record at a given streamflow-gaging station. As a result, a weighting curve was specially devised for this study to weight the two curves on the basis of the length of record at any given station. Using this devised weighting-curve procedure assumes that (1) a record of less than 6 years is not adequate for computing flood frequencies and gives the observed station data a weight of zero, (2) the synthetic and recorded data frequency curves for 12 years of record have equal weight, and (3) the recorded data curve at the end of 36 years has 75-percent weight. The devised weighting curve is shown in figure 19 with the weighted-frequency curve for each streamflow-gaging station shown in figures 20-24. The weighted flood-peak discharges are given in table 9.

By using the weighted-frequency curves shown in figures 20-24, the maximum floods observed at stations 08057100 White Rock Creek at Keller Springs Road, 08055600 Joes Creek, 08055700 Bachman Branch, 08056500 Turtle Creek, 08057140 Cottonwood Creek at Forest Lane, and 08057160 Floyd Branch at Forest Lane were in excess of the 100-year recurrence interval. A recorded flood at station 08057200 White Rock Creek at Greenville Avenue was in excess of the 50-year recurrence interval.

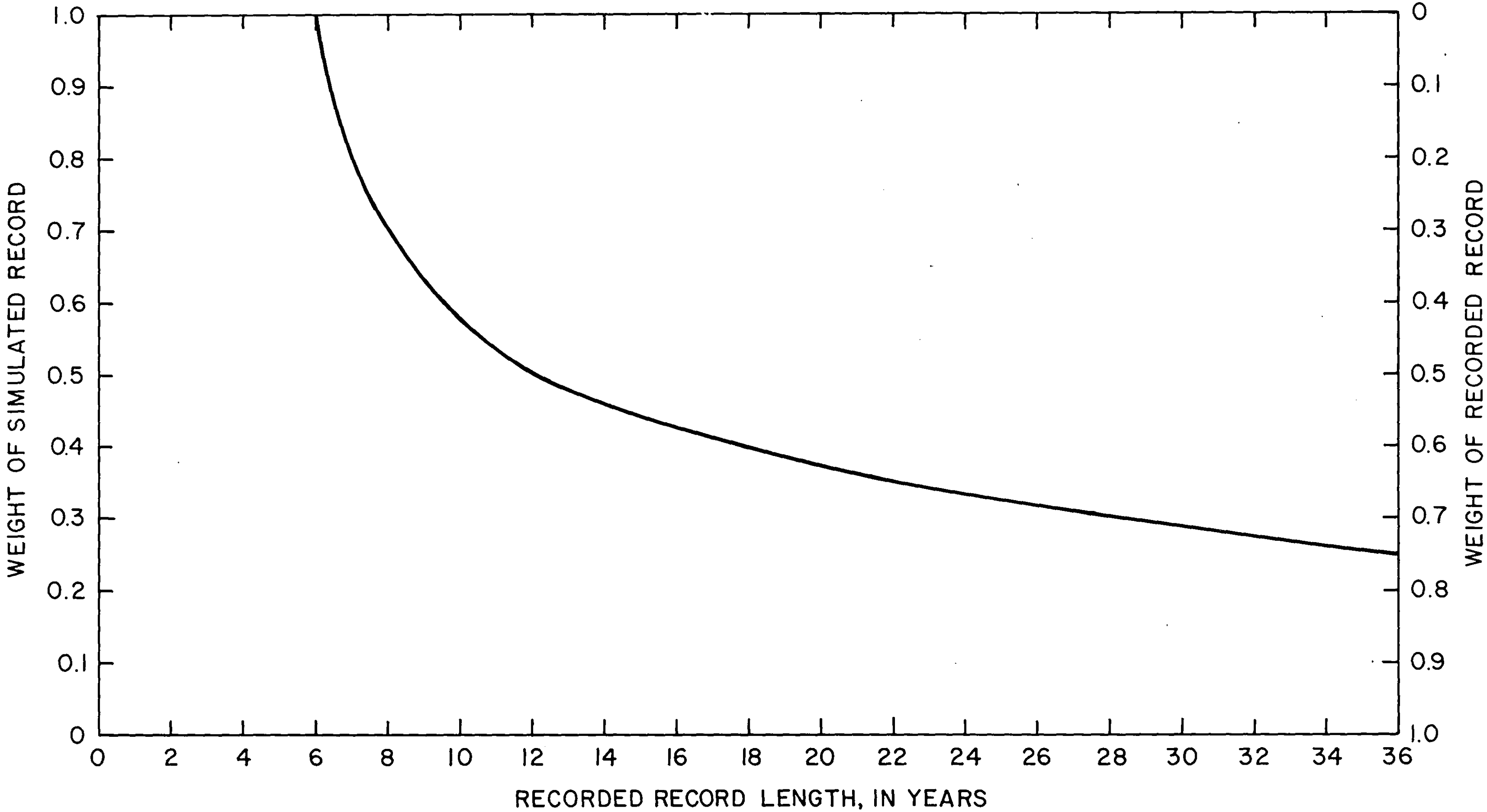


Figure 19.-Weighting of recorded and simulated T-year discharges

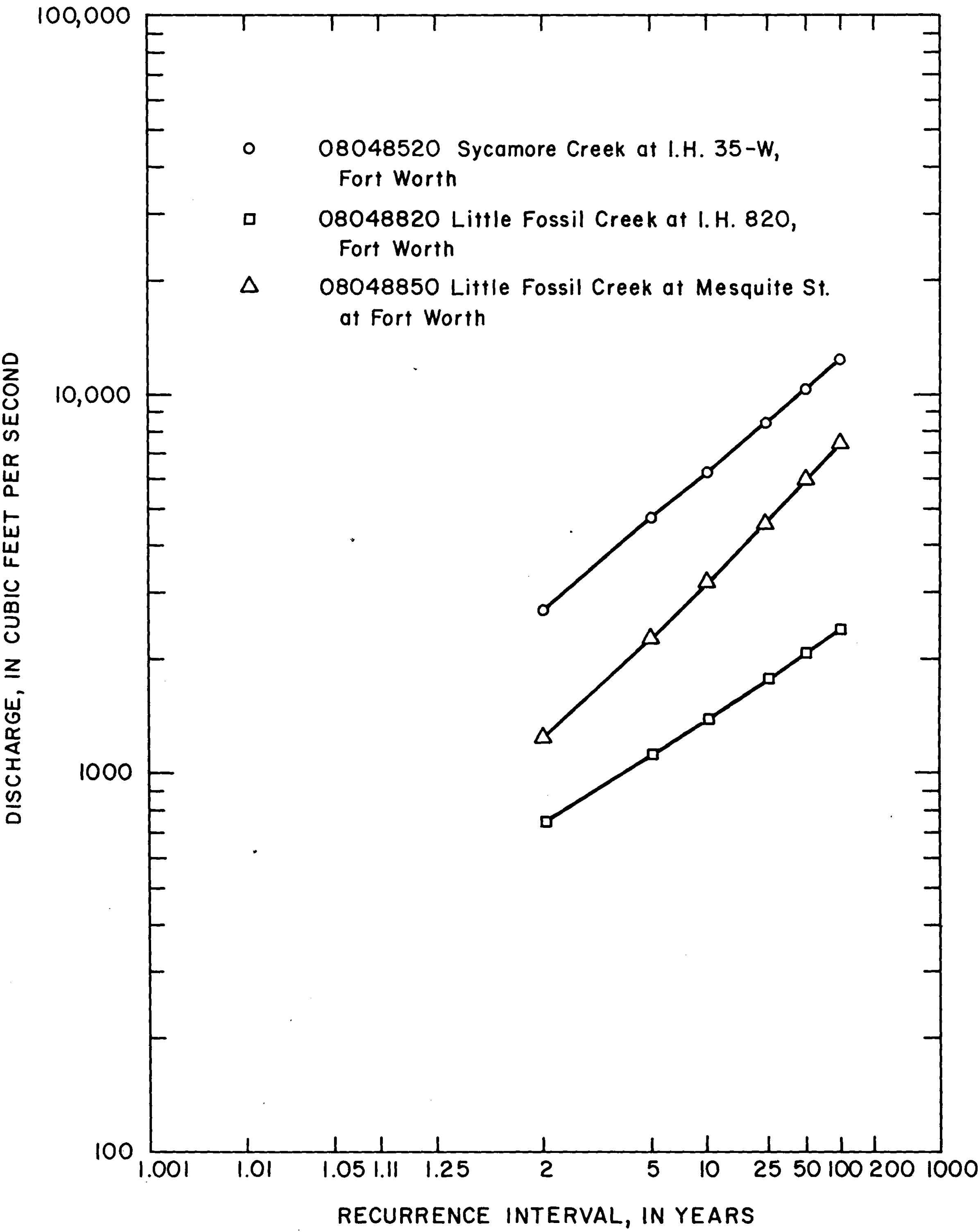


Figure 20.-Weighted flood frequencies for basins for streamflow-gaging stations 08048520, 08048820, and 08048850

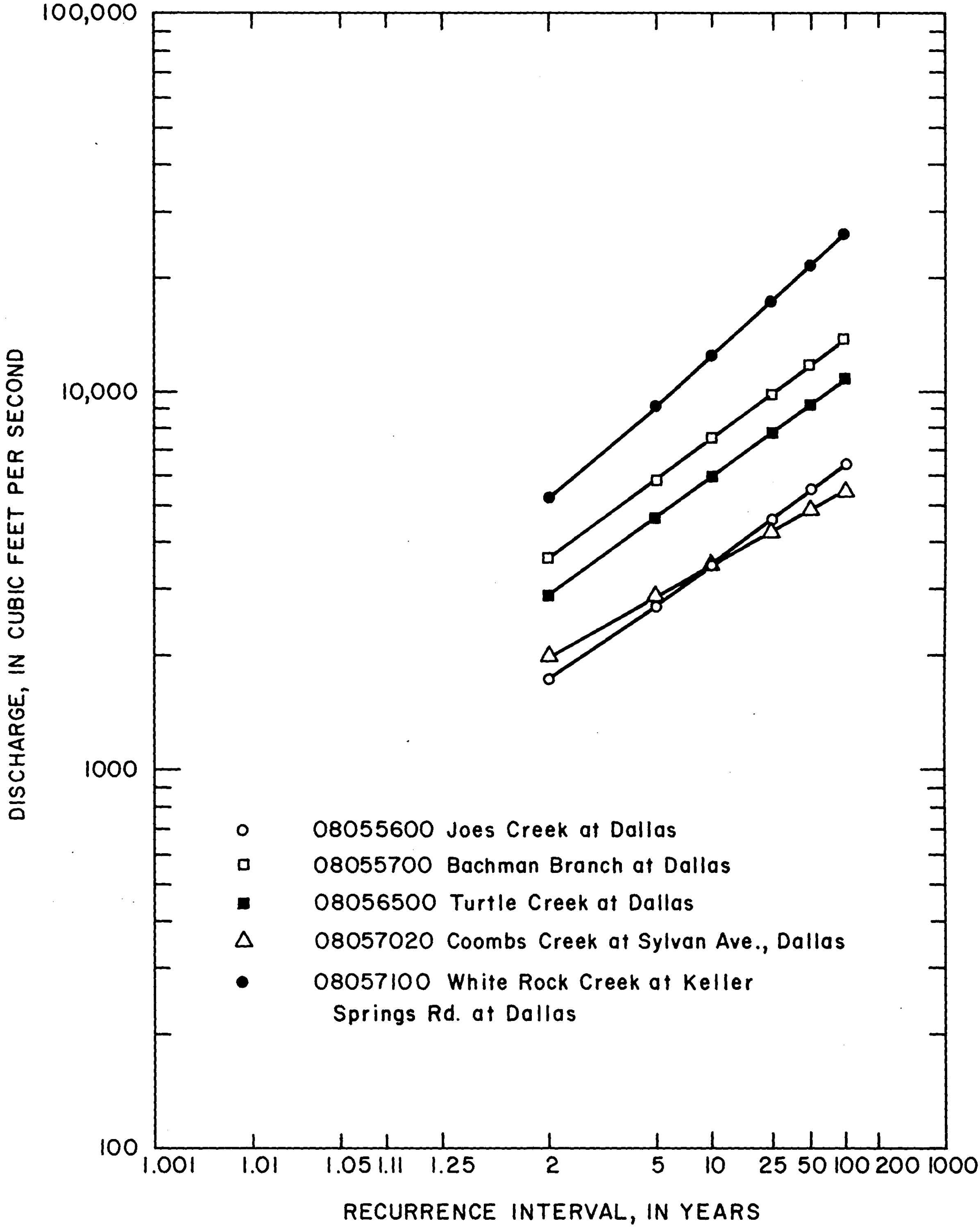


Figure 21.-Weighted flood frequencies for basins for streamflow-gaging stations 08055600, 08055700, 08056500, 08057020, and 08057100

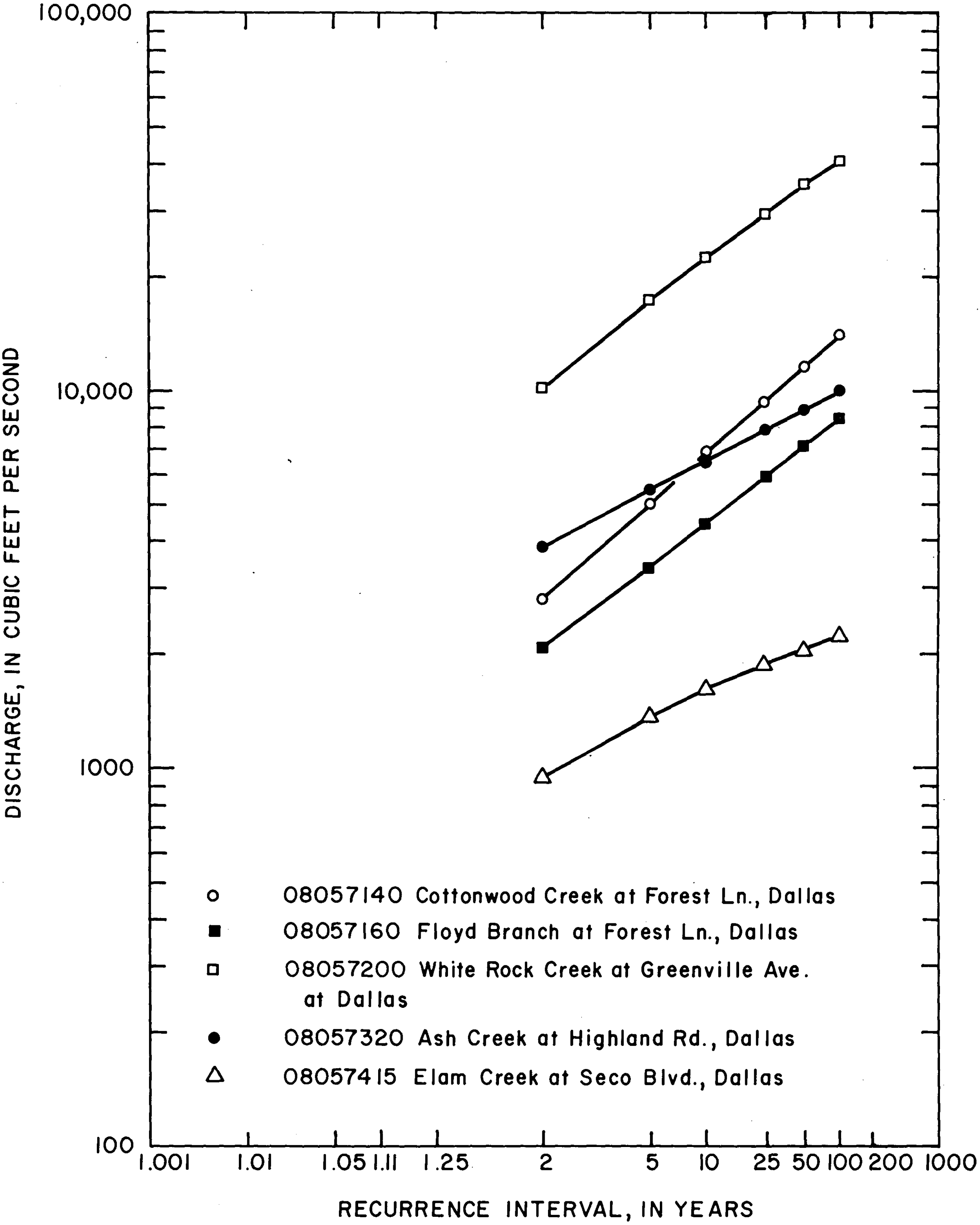


Figure 22.-Weighted flood frequencies for basins for streamflow-gaging stations 08057140, 08057160, 08057200, 08057320, and 08057415

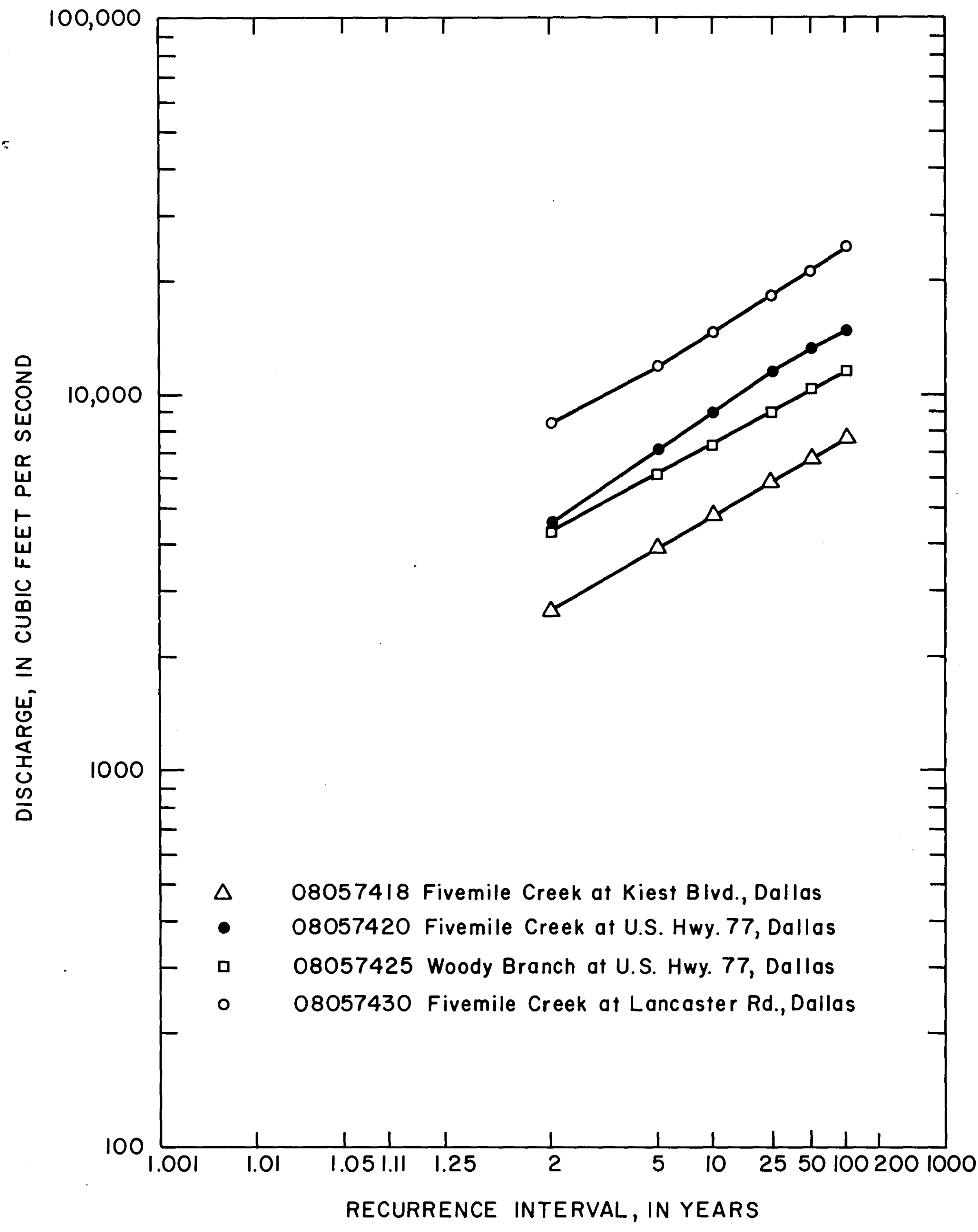


Figure 23.-Weighted flood frequencies for basins for streamflow-gaging stations 08057418, 08057420, 08057425, and 08057430

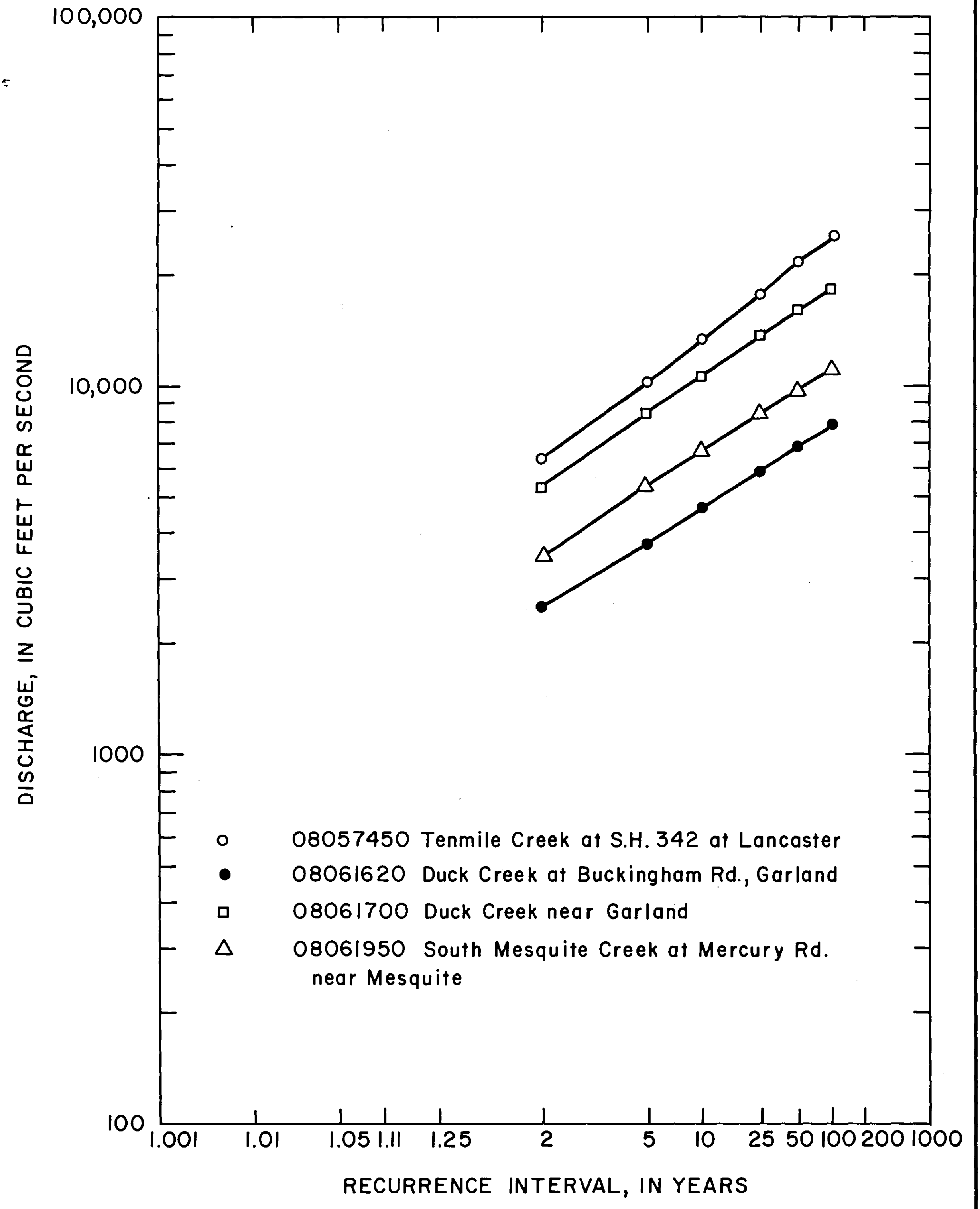


Figure 24.-Weighted flood frequencies for basins for streamflow-gaging stations 08057450, 08061620, 08061700, and 08061950

Table 7.--Flood-frequency characteristics determined from 65 years of simulated data

Station number	T-year discharges (cubic feet per second)						Statistical values		
	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Mean of logs (M)	Standard deviation (S)	Skew (g)
08048520	2,420	4,140	5,580	7,770	9,700	11,890	3.397	0.268	0.287
08048820	830	1,280	1,630	2,110	2,520	2,950	2.927	.218	.233
08048850	1,120	2,050	2,850	4,080	5,170	6,430	3.061	.302	.200
08055600	1,310	1,960	2,470	3,230	3,870	4,590	3.134	.196	.512
08055700	2,900	4,430	5,580	7,180	8,470	9,860	3.469	.214	.173
08056500	3,220	4,940	6,150	7,740	8,950	10,200	3.504	.224	-.108
08057020	1,710	2,540	3,120	3,870	4,460	5,060	3.233	.203	-.014
08057100	5,190	7,820	9,510	11,570	13,000	14,500	3.701	.225	-.382
08057140	2,370	3,330	3,960	4,750	5,340	5,920	3.372	.177	-.090
08057160	1,870	2,830	3,490	4,340	4,990	5,650	3.268	.217	-.126
08057200	6,010	9,750	12,800	17,400	21,300	25,800	3.794	.239	.368
08057320	3,830	5,620	6,800	8,260	9,340	10,400	3.575	.205	-.234
08057415	950	1,370	1,610	1,890	2,070	2,240	2.958	.208	-.590
08057418	2,650	3,880	4,740	5,880	6,760	7,660	3.424	.196	.029
08057420	3,960	5,600	6,760	8,300	9,500	10,700	3.602	.176	.154
08057425	4,310	6,290	7,650	9,440	10,800	12,200	3.634	.195	-.011
08057430	8,430	13,400	17,000	22,200	26,300	30,600	3.928	.236	.048
08057450	4,280	7,690	10,700	15,400	19,670	24,700	3.647	.290	.332
08061620	2,310	3,650	4,650	6,050	7,180	8,380	3.366	.234	.071
08061700	4,250	6,600	8,450	11,100	13,400	15,900	3.641	.218	.346
08061950	2,660	3,930	4,890	6,250	7,360	8,570	3.436	.193	.341

Table 8.--Flood-frequency characteristics determined from recorded data

Station number	Peak discharge (cubic feet per second)						Statistical values		
	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Mean of logs (M)	Standard deviation (S)	Skew (g)
08048520	2,930	5,140	6,760	8,910	10,600	12,300	3.452	0.304	a/-0.310
08048820	660	905	1,080	1,310	1,500	1,710	2.830	.153	b/.420
08048850	1,310	2,420	3,420	5,060	6,590	8,430	3.139	.300	b/.410
08055600	2,000	3,250	4,200	5,540	6,630	7,800	3.304	.248	c/.063
08055700	4,200	6,930	8,990	11,800	14,200	16,600	3.622	.260	c/-.034
08056500	2,770	4,510	5,870	7,790	9,380	11,100	3.447	.249	a/-.112
08057020	2,240	3,160	3,780	4,570	5,180	5,790	3.350	.177	d/.000
08057100	5,100	9,850	4,000	20,500	26,300	33,000	3.714	.334	c/.109
08057140	3,100	6,180	8,800	12,760	16,200	20,000	3.486	.360	c/-.085
08057160	2,270	3,850	5,150	7,100	8,790	10,700	3.366	.265	a/.242
08057200	13,000	22,500	29,200	37,900	44,300	50,400	4.092	.304	c/-.422
08057320	3,890	5,410	6,430	7,720	8,690	9,670	3.590	.170	d/.000
08057415	NC	NC	NC	NC	NC	NC	--	--	--
08057418	NC	NC	NC	NC	NC	NC	--	--	--
08057420	4,990	8,470	10,800	13,800	15,900	18,000	3.674	.297	a/-.500
08057425	4,350	5,930	7,060	8,590	9,800	11,100	3.648	.152	b/.380
08057430	8,350	10,700	12,400	14,700	16,500	18,400	3.933	.122	b/.560
08057450	8,400	12,800	16,000	20,200	23,600	27,000	3.924	.218	c/-.006
08061620	3,000	3,960	4,600	5,400	6,000	6,600	3.479	.142	c/.095
08061700	5,940	9,510	12,000	15,200	17,500	19,900	3.761	.254	a/-.287
08061950	4,240	6,800	8,520	10,700	12,200	13,700	3.610	.261	a/-.403

NC - Not computed.
a/ Determined from systematic station record.
b/ Determined by weighting historic record according to Water Resources Council guidelines (1977).
c/ Determined from hand-drawn curves.
d/ Fixed.

Table 9.--Flood-frequency characteristics determined from weighted recorded and simulated data

Station number	Peak discharge (cubic feet per second)						Statistical values		
	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Mean of logs (M)	Standard deviation (S)	Skew (g)
08048520	2,680	4,640	6,170	8,340	10,100	12,100	3.426	0.288	-0.029
08048820	750	1,110	1,370	1,750	2,050	2,380	2.886	.193	.312
08048850	1,210	2,220	3,110	4,530	5,830	7,350	3.099	.302	.304
08055600	1,720	2,720	3,490	4,590	5,500	6,480	3.242	.232	.182
08055700	3,670	5,910	7,590	9,940	11,800	13,800	3.566	.245	.029
08056500	2,880	4,630	5,940	7,780	9,270	10,900	3.463	.241	.072
08057020	2,000	2,870	3,470	4,250	4,890	5,450	3.300	.188	-.001
08057100	5,130	9,080	12,300	17,100	21,300	26,000	3.717	.288	.130
08057140	2,800	5,010	6,810	9,470	11,700	14,200	3.449	.298	.045
08057160	2,100	3,410	4,440	5,920	7,160	8,530	3.329	.245	.181
08057200	10,200	17,400	22,700	29,700	35,100	40,600	3.996	.288	-.262
08057320	3,860	5,510	6,600	8,000	8,990	10,000	3.583	.186	-.114
08057415	950	1,370	1,610	1,890	2,070	2,240	2.958	.208	-.590
08057418	2,650	3,880	4,740	5,880	6,760	7,660	3.424	.196	.029
08057420	4,520	7,150	8,960	11,300	12,960	14,600	3.642	.250	-.306
08057425	4,330	6,090	7,330	8,980	10,300	11,600	3.642	.172	.178
08057430	8,380	11,900	14,600	18,100	21,000	24,000	3.932	.177	.295
08057450	6,340	10,300	13,300	17,800	21,600	25,800	3.811	.240	.238
08061620	2,510	3,740	4,640	5,860	6,840	7,870	3.404	.203	.137
08061700	5,360	8,520	10,800	13,800	16,100	18,600	3.725	.243	-.115
08061950	3,450	5,360	6,710	8,460	9,790	11,200	3.532	.233	-.151

MULTIPLE-REGRESSION ANALYSIS

Multiple-linear regression techniques were used to define the regional relationship for predicting the T-year discharges (dependent variables given in table 9) as functions of significant basin characteristics (independent variables given in table 3). The model that was used in this analysis is of the form

$$Q_T = aB_1^{b_1} B_2^{b_2} B_3^{b_3} \ldots \tag{6}$$

where a = regression constant,

b_1, b_2, b_3 = coefficients defined by regression, and

B_1, B_2, B_3 = basin characteristics.

The dependent and independent variables were transformed to base 10 logarithms prior to performing the regression analysis. This transformation causes equation 6 to be linear.

A stepwise regression determined that the drainage area and the urbanization index have reasonable significance throughout the range of frequencies. Equation 6 resulted in:

$$Q_T = a\ DA^{b_1}\ UI^{b_2} \tag{7}$$

where DA and UI are values of the drainage area and the urbanization index. The regional equations and the error analysis are given in table 10.

DISCUSSION OF RESULTS

Use of the Analytical Result

The equations developed through the multiple-regression analysis can be used to estimate the flood-peak discharge for desired frequencies for ungaged basins in the Dallas-Fort Worth area. Users of the technique are required to determine the drainage area of the stream at the point of concern, to develop an urbanization index for the basin, and to select the equation for the desired recurrence interval. Development of the urbanization index is described in a preceding section, "Basin Characteristics."

Effects of Urbanization

The design of the drainage system as well as the different types of urbanization can significantly change the peak discharge of a given storm and therefore, the flood frequency. As a result, there does not seem to be a good index to the general term "urbanization." Many previous studies used the percentage of impervious cover or some coefficient directly linked to this percentage. In this study, the amount of curbs and gutters, storm drains, and channel rectifications used as an index of the degree of urbanization proved to be significant in the statistical analysis.

Table 10.--Flood-frequency equations

Equation for indicated T-year flood discharge (cubic feet per second)	Standard error of estimate (percent)	Correlation coefficient (R)
$Q_2 = 42.83(DA)^{0.704}(UI)^{0.836}$	30.1	0.9066
$Q_5 = 82.92(DA)^{0.724}(UI)^{0.751}$	29.4	.9142
$Q_{10} = 120.7\ (DA)^{0.735}(UI)^{0.697}$	29.6	.9157
$Q_{25} = 184.8\ (DA)^{0.745}(UI)^{0.632}$	30.2	.9153
$Q_{50} = 246.4\ (DA)^{0.752}(UI)^{0.587}$	30.9	.9137
$Q_{100} = 362.1\ (DA)^{0.752}(UI)^{0.510}$	31.8	.9112

where:

Q_T = T-year discharge, in cubic feet per second,

DA = drainage area, in square miles, and

UI = urbanization index (dimensionless).

The effect of urbanization on flood magnitude was assessed in two ways. The first was to calculate and compare the discharges for a given basin and recurrence interval for the maximum and minimum values of the urbanization index. The second was to calculate and compare the discharges from the equation at the upper limit of the urbanization index and from the regression equation that was developed for rural basins in a Statewide report (Schroeder and Massey, 1977). In the Dallas-Fort Worth area the independent parameters in the Schroeder and Massey equation were drainage area and channel slope. Several comparisons of selected typical basins are as follows:

Station	Peak discharge at 5-year recurrence interval			Peak discharge at 100-year recurrence interval		
	Maximum urbanization index (fully urbanized)	Minimum urbanization index (rural)	Schroeder and Massey (1977)	Maximum urbanization index (fully urbanized)	Minimum urbanization index (rural)	Schroeder and Massey (1977)
08048520 Sycamore Creek at I.H. 35-W, Fort Worth.	9,790	3,460	3,320	19,500	9,640	10,100
08056500 Turtle Creek at Dallas.	5,500	1,960	2,260	10,700	5,290	6,780
08057415 Elam Creek at Seco Blvd., Dallas.	1,440	508	712	2,660	1,310	1,860
08057450 Tenmile Creek at S.H. 342 at Lancaster.	21,600	7,630	6,290	44,500	21,900	20,400

When peak discharges were determined by the first method, urbanization increased the peak discharge by 181 percent for the 5-year recurrence interval and by 102 percent for the 100-year recurrence interval. For the stations listed above, calculations by the second method gave an increase ranging from 102 to 243 percent for the 5-year recurrence interval and from 43 to 118 percent for the 100-year recurrence interval. The comparisons indicate that the impact of urbanization becomes less as the recurrence interval increases.

Limitations of Equations

Use of the flood-frequency equations developed in this study have some limitations and require some judgment in their use. First, they are regional equations (for the Dallas-Fort Worth area only); second, the range of independent variables has certain limits; third, the equations are generalized and, therefore, may not be applicable to basins with unusual or special characteristics or features. The equations were developed for drainage areas ranging from 1.25 to 66.4 square miles and a range for the urbanization index of 10 to 36. The distribution of these values was poor where drainage areas were large and degrees of urbanization were fairly high. Therefore, a reliable range for drainage area is between 3 and 40 square miles and for the urbanization index the range is between 12 and 33.

Even though the development of the equations is based on standardized statistical techniques and a comprehensive, yet limited, data set, the equations are still dependent upon the use of a bulk-parameter model for extending the short-term recorded data set to a long-term simulated data set as well as the hypothesis that the data are statistically representative. Furthermore, considerable engineering judgment was used in (1) eliminating certain basins and storms, (2) accepting certain systematic frequency curves and hand drawing others, (3) devising a weighting curve for combining the recorded and simulated data frequency curves, and (4) selecting the values for urbanization variables.

SUMMARY AND CONCLUSIONS

Streamflow and rainfall data collected during the Dallas and Fort Worth urban projects from 1961-78 provided the basis for estimating the magnitude and frequency of peak discharges for ungaged basins and the effects of urbanization on these flood peaks in the Dallas-Fort Worth area. The selected procedure for making the estimates involved extending the series of annual flood-peak discharges by the use of a rainfall-runoff model. Recorded storm data for each selected basin were used to calibrate the model. The model used calibrated parameter values and long-term rainfall data from each basin to simulate a long-term series of annual flood-peak discharges. Log-Pearson Type III techniques were then used to determine the flood magnitudes for selected frequencies from the simulated data set and the recorded data set. Frequency curves for the simulated and recorded data for each basin were weighted on the basis of the length of record of the streamflow-gaging station to produce weighted frequency curves for each basin.

Multiple-linear regression techniques were used to develop generalized regional equations for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. The dependent variables were the weighted discharges for each basin and the independent variables were the characteristics of the basins. An urbanization index, which was the sum of an urbanization matrix, was included in the basin characteristics. The equations are considered to be reasonably reliable for drainage areas between 3 and 40 square miles and for a range in the urbanization index from 12 to 33. The results indicated that urbanization increases the flood-peak discharge but the increase is less for higher recurrence intervals than for lower recurrence intervals.

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