Estimating the Magnitude of Peak Discharges for Selected Flood Frequencies on Small Streams in East Texas

UNITED STATES DEPARTMENT OF THE INTERIOR
Geological Survey

Prepared by the U. S. Geological Survey in cooperation with the Texas Highway Department and the U. S. Department of Transportation, Federal Highway Administration

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ABSTRACT

Peak-discharge data from 28 stream-gaging stations with long-term records (10-33 years) and 60 stations with short-term records (less than 10 years) were used in multiple linear-regression procedures to obtain equations for estimating the peak discharge of floods with recurrence intervals of 10, 25, and 50 years on small rural streams in East Texas. The significant independent variables were drainage area, channel slope, and channel length. The relationships are presented in nomographs that can be used for estimating the peak discharges on small streams for floods of the selected recurrence intervals, provided that the magnitude of the independent variables is within the range of those used to develop the relationships.

INTRODUCTION

A program with the objective of obtaining basic hydrologic data to define the magnitude and frequency of floods for small drainage areas in Texas was begun by the U.S. Geological Survey in September 1964. This program is financed by funds made available for research by the Texas Highway Department and the U.S. Department of Transportation, Federal Highway Administration. This preliminary report, which has been prepared as part of the continuing program, presents an improved method for estimating peak discharges for floods with recurrence intervals of 10, 25, and 50 years on small rural streams in East Texas.

For the convenience of readers who may want to use metric units, the metric equivalents are given in parentheses following the English units. Data presented in the tables may be converted by using the following conversion factors:

Multiply	By	To obtain
Miles (mi)	1.609	Kilometers (km)
Feet (ft)	.3048	Meters (m)
Square miles (mi^2)	2.59	Square kilometers (km^2)
Cubic feet per second (ft^3/s)	.028317	Cubic meters per second (m^3/s)
Feet per mile	.19	Meters per kilometer

RELATED STUDIES

Two separate studies recently completed by the U.S. Geological Survey have produced flood-frequency equations that can be used in specific locations. Johnson and Sayre (1973) computed a set of equations that are applicable to the Houston metropolitan area for drainage basins that range from 0.3 to 100 square miles (0.7 to 259 square kilometers) and have impervious areas that range from 1 to 40 percent. In a study of urban hydrology of the Dallas metropolitan area, Dempster (1974) computed a set of equations that can be applied to drainage basins that range from 1 to 100 square miles (2.6 to 259 square kilometers) and have impervious areas that range from 1 to about 50 percent. Both sets of equations were developed to compute runoff from urban areas; however, they can be applied to rural areas by setting "impervious area" equal to 1 percent.

In local areas such as Houston or Dallas, the equations developed for these areas may produce more reliable estimates than the regional equations that are presented in this report.

Gilbert and Hawkinson (1971) developed a set of equations for larger rural drainage basins that related flood peaks to drainage area, slope, precipitation, and temperature. That work was done as part of a data-evaluation study, however, and the equations were not proposed for use by designers and planners.

Previous studies by Benson (1964) and Patterson (1965) also defined flood-peak estimating relations applicable to larger rural drainage areas. However, the relations defined in the study described in this report were based upon a longer period of flood records collected at sites sampling a wider range of watershed characteristics.

RANGE OF APPLICATION

The relationships presented in this report are applicable to the part of Texas generally east of longitude 98 W., an area of approximately 100,000 square miles (259,000 square kilometers). The locations of the data-collection sites are shown on figure 1. The drainage areas above these sites ranged from about 0.1 to about 120 square miles (0.26 to 310 square kilometers). Channel slopes generally ranged from 1.9 to 200 feet per mile (0.35 to 38 meters per kilometer). The relationships are applicable to all nonregulated, natural rural streams in East Texas whose drainage areas and slopes are within these ranges; the relationships should not be extrapolated.

TECHNIQUES

The final relations (equations) presented in this report were obtained by multiple linear-regression techniques. This technique has been known for many years, but it did not receive widespread use until the age of the electronic computer because of the tedious calculations necessary for solution.

Multiple linear regression is a procedure that will develop a relation for calculating a predicted value for the dependent variable (the selected T-year flood) from one or more independent variables. The independent variables that remained significant after regression were drainage area, channel slope, and channel length.

Where A is drainage area, in square miles, determined by use of a planimeter;
S is the average slope, in feet per mile, between points 10 and 85 percent of the distance from the site to the basin divide; and
L is the length, in miles, of the main channel between the site and the basin divide measured along the channel that drains the largest area.

Linearity was achieved by a logarithmic transformation of the variables.

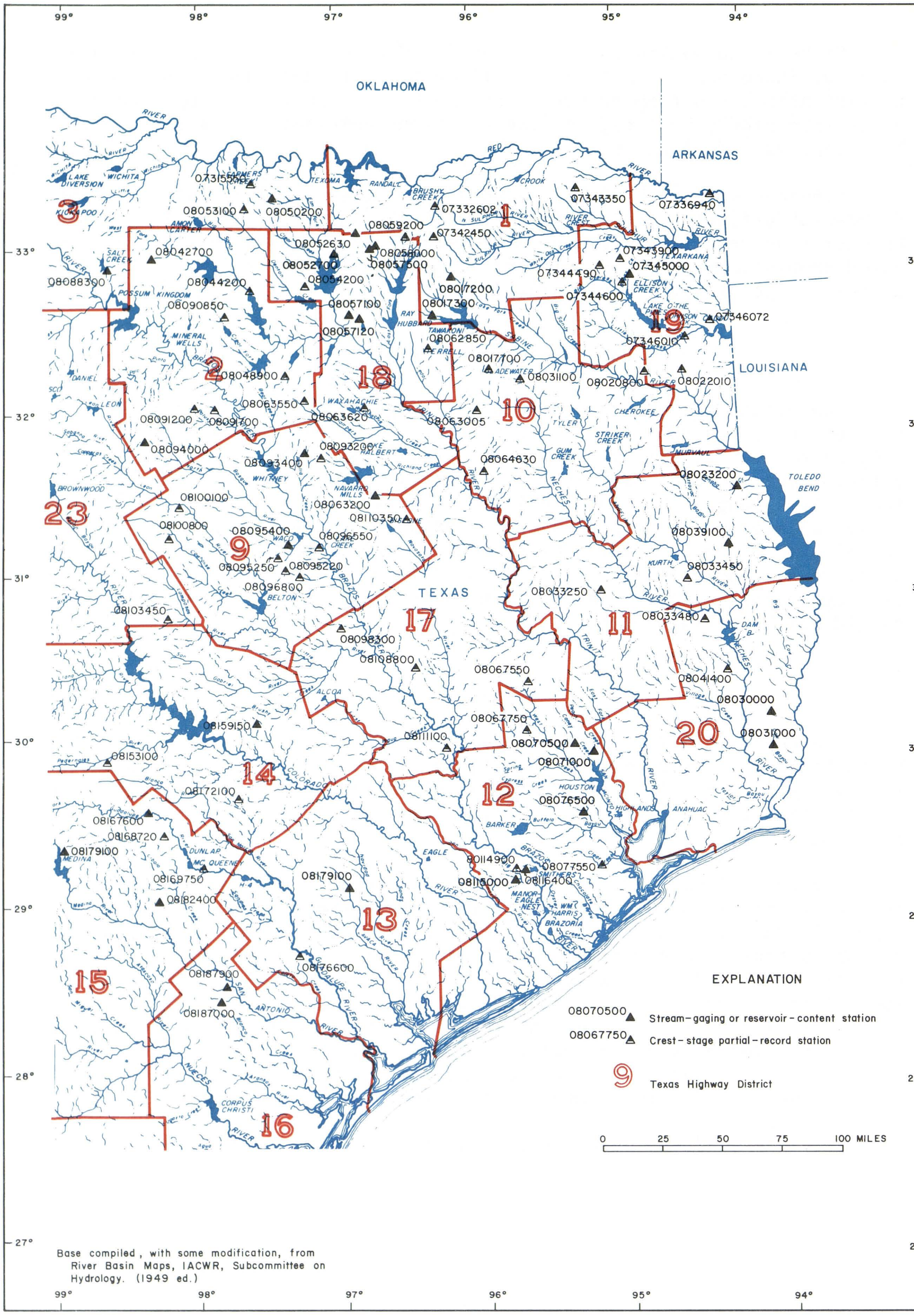

FIGURE 1. - Locations of stream-gaging stations

METHOD OF ANALYSIS

Annual peak data from 28 stations with drainage areas ranging from 1.26 to 123 square miles (3.26 to 318 square kilometers) and with periods of record ranging from 10 to 33 years were used to determine the peak discharges of floods with recurrence intervals of 10, 25, and 50 years at each station. These discharges were computed by using the log-Pearson Type III distribution. A few of the stations had unrealistic skew coefficients; therefore, frequency curves for these stations were prepared graphically by the U.S. Geological Survey on the basis of experience and engineering judgment. Discharge values were taken from the curves.

These discharges were then used as the dependent variables in a multiple-regression analysis to compute the relationships for the ratio of the 50-year discharge to the 10-year discharge and also the ratio of the 25-year discharge to the 10-year discharge. The variables used for this analysis are shown in table 1. Values of the independent variables were determined from U.S. Geological Survey topographic maps (scale 1:24,000).

The results of the analysis are as follows:

$$\frac{Q_{50}}{Q_{10}} = \frac{1.84\ A^{0.284}}{L^{0.377}} \quad \text{and} \qquad (1)$$

$$\frac{Q_{25}}{Q_{10}} = \frac{1.465\ A^{0.17}}{L^{0.229}} \qquad (2)$$

where $\frac{Q_{50}}{Q_{10}}$ = the ratio of the 50-year discharge to the 10-year discharge;

1.84 = a constant;

$\frac{Q_{25}}{Q_{10}}$ = the ratio of the 25-year discharge to the 10-year discharge;

1.465 = a constant;
A = drainage area, in square miles; and
L = main-channel length, in miles.

The standard errors of these relationships were 16 percent and 11 percent, respectively. These relationships are regional, and it is assumed that they are applicable to all small rural streams in the area, provided that the magnitude of the independent variables is within the range of those used to develop the relationships.

Table 1.--Variables used in regression equations for 28 stations with long-term (10-33 years) records

Station	Drainage area (mi^2)	Channel slope (ft per mi)	Channel length (mi)	Peak discharge at 10-year recurrence interval (ft^3/s)	Peak discharge at 25-year recurrence interval (ft^3/s)	Peak discharge at 50-year recurrence interval (ft^3/s)
07345000	72.00	6.49	19.20	11,800	19,700	27,600
08017200	77.70	7.88	21.00	17,600	--	--
08017300	78.70	8.37	12.00	23,600	--	--
08023200	97.80	7.52	19.30	10,200	16,600	22,900
08024500	123.00	7.40	22.40	14,100	23,800	--
08030000	69.20	4.79	19.00	4,860	6,290	7,390
08031000	83.30	1.91	26.60	3,740	5,380	6,860
08039100	89.00	6.14	26.00	11,500	--	--
08042700	21.60	23.90	10.70	5,230	7,350	--
08052700	75.50	8.20	24.40	9,710	13,300	--
08057100	29.40	15.20	13.50	15,350	20,100	23,630
08057120	6.77	36.60	4.88	5,030	6,420	7,410
08057500	2.14	104.80	1.40	1,580	2,170	2,620
08058000	1.26	66.20	1.50	1,320	1,700	1,950
08070500	105.00	8.14	28.80	9,990	15,800	21,300
08071000	117.00	7.58	27.40	7,250	14,150	22,000
08076500	24.70	4.41	19.00	3,340	4,080	4,640
08094000	3.34	37.00	2.80	2,900	4,950	--
08095400	78.20	16.40	34.70	18,800	--	--
08096800	5.04	64.60	3.65	3,730	5,570	--
08098300	22.80	10.80	13.30	7,980	--	15,700
08115000	42.30	2.61	15.00	6,120	8,850	11,200
08160000	1.48	69.60	1.80	1,320	1,930	2,420
08163500	108.00	9.41	24.00	26,100	40,900	54,800
08179100	56.30	36.40	13.00	21,400	35,600	--
08182400	7.01	35.40	3.70	3,430	5,540	--
08187000	3.29	52.70	2.25	3,070	4,530	--
08187900	8.43	24.20	3.70	2,580	--	--

Annual peak data from 60 short-term stations were used to determine the peak discharge for floods with a 10-year recurrence interval at each of these sites. These discharges were all determined graphically. The peak discharges for floods with a 10-year recurrence interval (dependent variable) and the independent variables--drainage area, channel slope, and channel length for each of the 60 sites are listed in table 2.

A regional 10-year frequency relationship was developed by multiple-regression analysis by using the 10-year peak discharges from the records of both the 60 short-term stations and the 28 long-term stations as the dependent variables. The standard error of this regression was 48 percent. Values of A, S, and L were obtained from U.S. Geological Survey topographic maps (scale 1:24,000). The resulting equation follows:

$$Q_{10} = \frac{260\ A^{1.304}\ S^{0.302}}{L^{0.824}} \qquad (3)$$

where Q_{10} = the 10-year discharge, in cubic feet per second;
260 = the constant;
A = the drainage area, in square miles;
L = the length, in miles, of the main channel between the site and the basin divide, measured along the channel that drains the largest area; and
S = the average slope, in feet per mile, between points 10 and 85 percent of the distance along the main channel from the site to the basin divide.

Additional Q_{10} equations developed by the regression analysis and the standard error of the regression are as follows:

$$Q_{10} = 113\ A^{0.864}\ S^{0.405} \qquad \text{(52 percent)} \qquad (4)$$

$$Q_{10} = \frac{993\ A^{1.347}}{L^{1.124}} \qquad \text{(53 percent)} \qquad (5)$$

$$Q_{10} = 551\ A^{0.684} \qquad \text{(61 percent)} \qquad (6)$$

The final step was to multiply the regional 10-year equation by each of the two ratio equations to give single equations for the 50-year and 25-year discharge as follows:

$$Q_{50} = Q_{10}\ \frac{Q_{50}}{Q_{10}} \qquad (7)$$

(all data)

$$Q_{10} = \frac{260\ A^{1.304}\ S^{0.302}}{L^{0.824}} \qquad (8)$$

(28 long-term stations)

$$\frac{Q_{50}}{Q_{10}} = \frac{1.84\ A^{0.284}}{L^{0.377}} \qquad (1)$$

Table 2.--Variables used in regression equations for 60 stations with short-term (less than 10 years) records

Station	Drainage area (mi^2)	Channel slope (ft per mi)	Channel length (mi)	Peak discharge at 10-year recurrence interval (ft^3/s)
07315550	0.82	51.20	2.85	255
07322602	6.21	23.30	4.80	3,200
07336940	3.33	.80	6.45	280
07342450	.22	66.60	.78	210
07343350	1.00	45.00	1.45	1,000
07343900	.78	87.20	1.03	700
07344490	4.27	26.90	3.60	1,650
07344600	7.11	20.30	6.80	760
07346010	.21	73.20	.75	80
07346072	.73	57.10	1.40	365
08017700	.33	21.70	.80	255
08020800	5.05	24.80	4.15	1,100
08022010	.46	108.10	1.15	360
08031100	1.09	37.76	1.90	465
08033250	1.17	25.40	2.30	480
08033450	.52	63.90	1.30	280
08033480	.15	200.00	.80	62
08041400	5.03	23.90	4.40	700
08044200	2.95	45.40	3.35	1,600
08048900	5.86	27.60	5.40	1,300
08050200	.77	60.80	1.90	720
08052630	2.04	37.30	2.52	2,500
08053100	1.70	78.50	2.35	830

Table 2.--Variables used in regression equations for 60 stations with short-term (less than 10 years) records--Continued

Station	Drainage area (mi^2)	Channel slope (ft per mi)	Channel length (mi)	Peak discharge at 10-year recurrence interval (ft^3/s)
08054200	0.50	89.40	0.88	280
08059200	.52	86.00	1.00	580
08062850	12.96	8.00	12.00	2,420
08063005	.90	40.30	1.66	640
08063180	.72	39.60	1.28	620
08063200	17.60	15.50	8.00	5,300
08063550	.84	49.50	1.42	880
08063620	.62	44.30	1.18	610
08064630	.22	93.00	.57	118
08067550	2.35	19.80	4.70	480
08067750	.13	171.40	.47	138
08077550	18.00	4.70	8.05	1,370
08088300	19.70	17.10	11.00	1,815
08090850	3.37	48.60	5.65	540
08091200	.06	382.00	.23	120
08091700	7.82	48.30	5.00	3,000
08093400	11.70	20.70	10.70	3,300
08093200	.36	70.60	.85	390
08095220	15.90	28.40	6.14	4,200
08095250	2.52	24.10	3.55	740
08096550	.40	60.00	.80	320
08100100	2.91	54.50	4.03	820
08100800	5.56	49.00	5.50	1,840

Table 2.--Variables used in regression equations for 60 stations with short-term (less than 10 years) records--Concluded

Station	Drainage area (mi^2)	Channel slope (ft per mi)	Channel length (mi)	Peak discharge at 10-year recurrence interval (ft^3/s)
08103450	1.08	74.70	2.00	620
08108800	.14	109.00	.43	128
08110350	4.42	14.80	5.25	2,480
08111100	.75	37.50	1.28	515
08114900	5.70	3.27	5.30	630
08116400	8.53	2.34	6.80	1,610
08153100	1.37	58.60	3.35	165
08159150	4.61	35.50	3.35	1,390
08167600	10.91	66.80	5.90	4,600
08168720	.48	142.60	1.25	500
08169750	5.46	13.50	4.75	870
08169850	.24	110.80	.87	190
08172100	.44	106.40	.84	400
08176600	.48	36.70	.80	278

In equation 7, replace Q_{10} and $\frac{Q_{50}}{Q_{10}}$ with equation 8 and equation 1 respectively, and

$$Q_{50} = \frac{260\ A^{1.304}\ S^{0.302}}{L^{0.824}} \frac{1.84\ A^{0.284}}{L^{0.377}}$$

combine terms and

$$Q_{50} = \frac{478.4\ A^{1.588}\ S^{0.302}}{L^{1.201}} \qquad (9)$$

similarly

$$Q_{25} = Q_{10} \frac{Q_{25}}{Q_{10}}$$

resulting in

$$Q_{25} = \frac{380.9\ A^{1.475}\ S^{0.302}}{L^{1.053}} \qquad (10)$$

The residuals for these equations were plotted and no overall bias nor areal trends were indicated.

All of the equations are presented in nomographic form on figures 2, 3, and 4. The nomographs provide a graphical method for determining discharges without having to make mathematical calculations. The standard errors (SE) for the 25-year and 50-year equations were computed as follows:

$$(SE)_{25} = \left((SE)^2_{10} + (SE)^2_{\frac{25}{10}}\right)^{\frac{1}{2}}, \text{ and}$$

$$(SE)_{50} = \left((SE)^2_{10} + (SE)^2_{\frac{50}{10}}\right)^{\frac{1}{2}}$$

where (SE) is the logarithmic value of the standard error. These values, converted to percentage, are 49 percent and 50 percent, respectively.

METRIC CONVERSIONS

Equations (3), (4), (5), (6), (9), and (10) may be converted to the International (metric) System of Units by use of the following forms:

$$Q_{10} = \frac{5.20\ A^{1.304}\ S^{0.302}}{L^{0.824}}\ (m^3/s) \qquad (3)$$

$$Q_{10} = 2.755\ A^{0.864}\ S^{0.405}\ (m^3/s) \qquad (4)$$

$$Q_{10} = \frac{13.318\ A^{1.347}}{L^{1.124}}\ (m^3/s) \qquad (5)$$

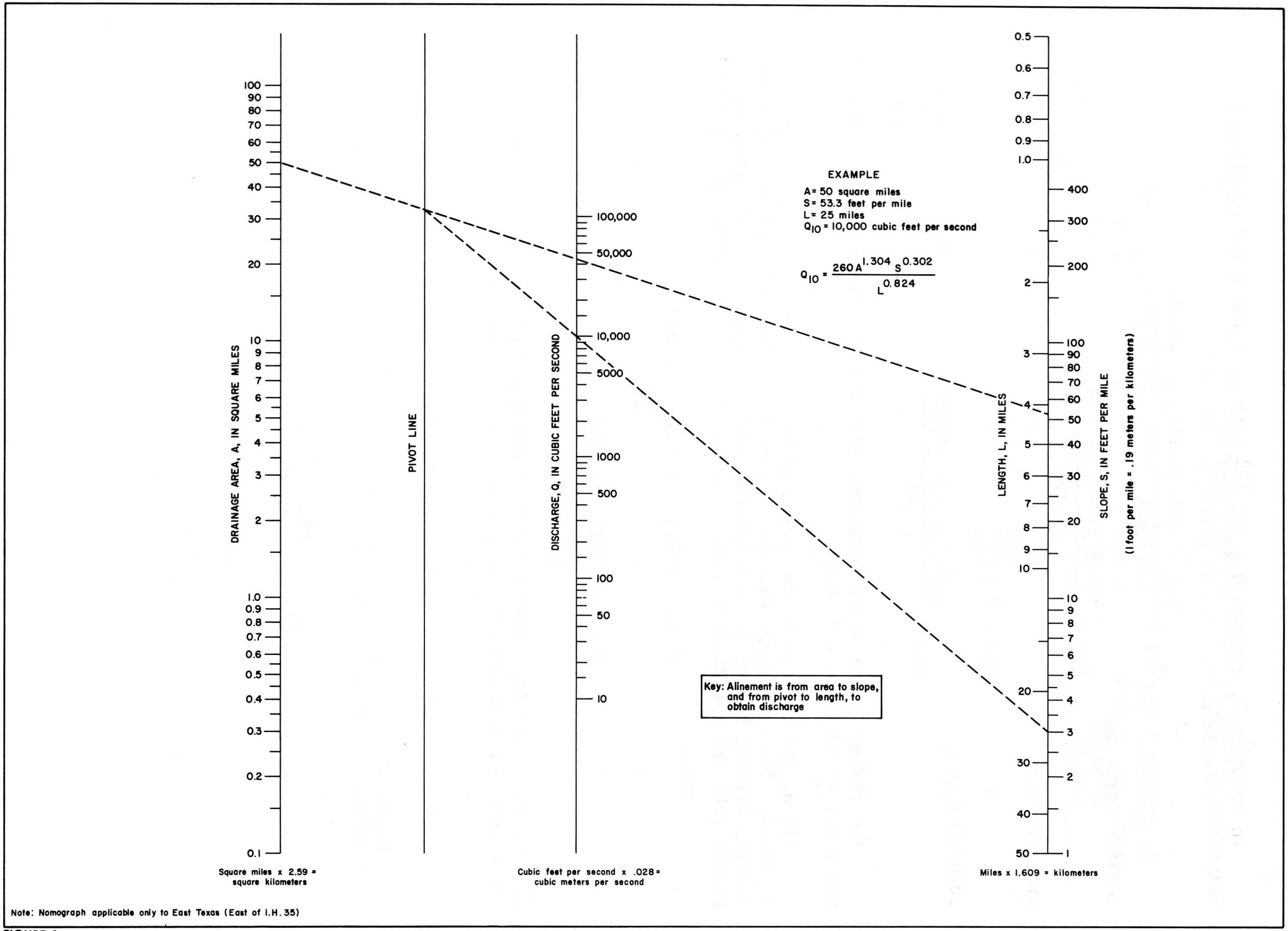

FIGURE 2. - Nomograph for determining peak discharges for floods with a 10-year recurrence interval

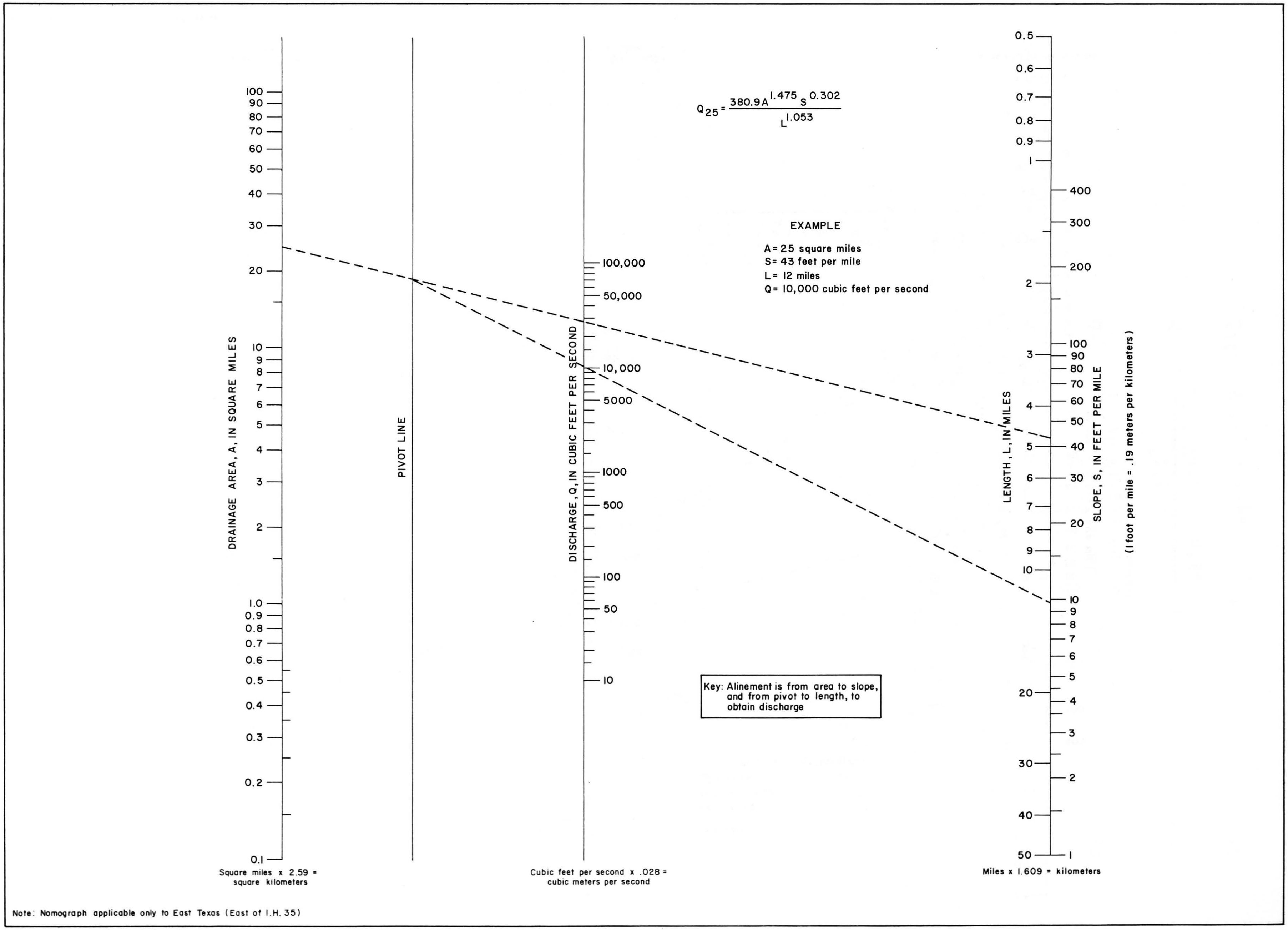

FIGURE 3. - Nomograph for determining peak discharges for floods with a 25-year recurrence interval

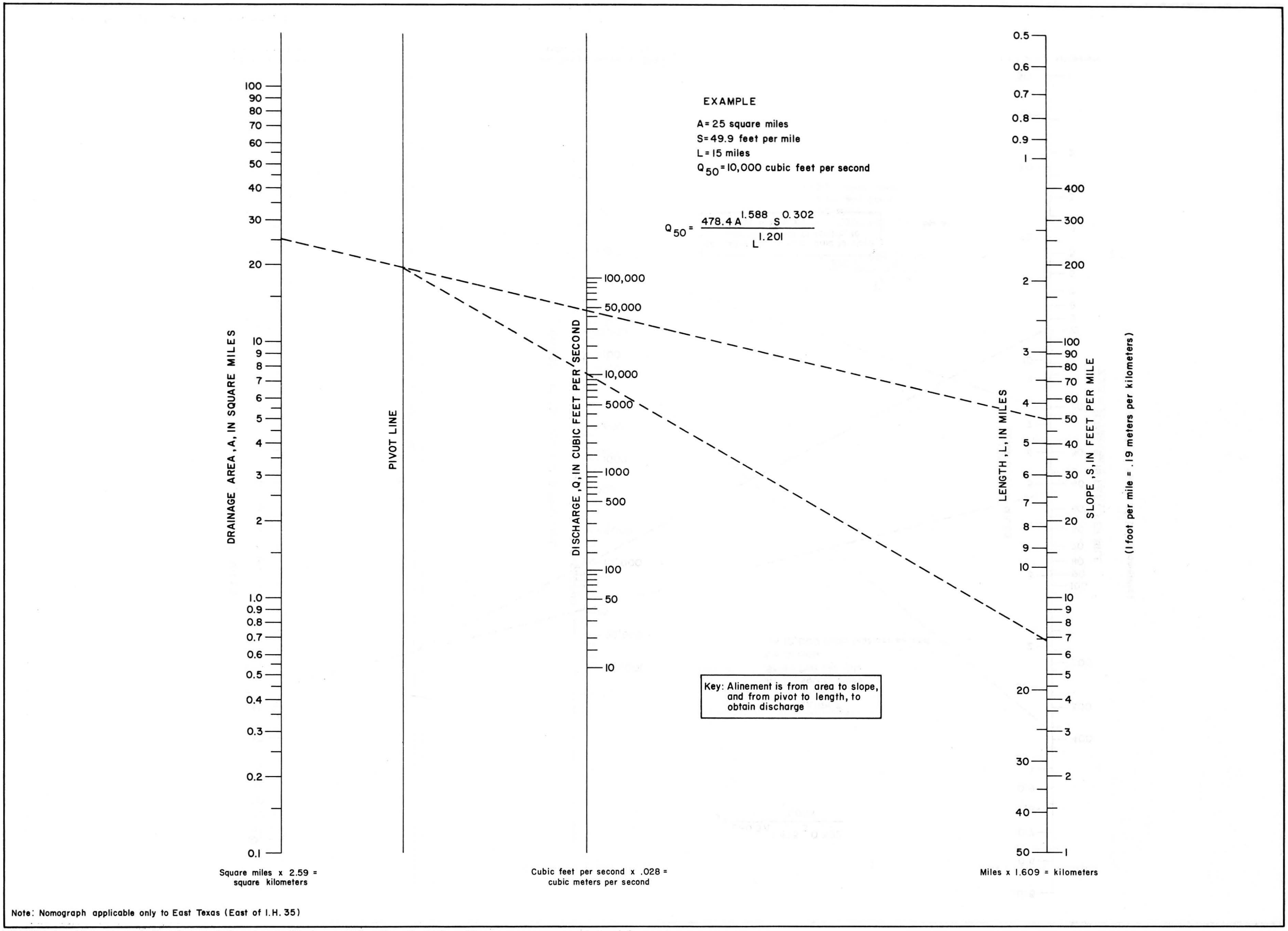

FIGURE 4. - Nomograph for determining peak discharges for floods with a 50-year recurrence interval

$$Q_{10} = 8.138\ A^{0.684}\ (m^3/s)\ . \tag{6}$$

$$Q_{25} = \frac{7.22\ A^{1.475}\ S^{0.302}}{L^{1.053}}\ (m^3/s) \tag{10}$$

$$Q_{50} = \frac{8.738\ A^{1.588}\ S^{0.302}}{L^{1.201}}\ (m^3/s) \tag{9}$$

where Q_{10} = the 10-year discharge, in cubic meters per second;
Q_{25} = the 25-year discharge, in cubic meters per second;
Q_{50} = the 50-year discharge, in cubic meters per second;
A = the drainage area, in square kilometers;
L = the length, in kilometers, of the main channel between the site and the basin divide, measured along the channel that drains the largest area; and
S = the average slope, in meters per kilometer, between points 10 and 85 percent of the distance along the main channel from the site to the basin divide.

SUMMARY

The equations presented in this report provide a method that can be used to compute quickly the discharge for floods of selected recurrence intervals on small nonregulated rural streams in a 100,000 square-mile (259,000 square-kilometer) area of East Texas. The user will be required to exercise judgment when applying the equations, which are applicable only to rural unregulated drainage areas ranging from 0.1 to 100 square miles (0.26 to 259 square kilometers) with the main-channel slope ranging from 1 to 200 feet per mile (0.19 to 38 meters per kilometer). These relations are preliminary and will be redefined after more data become available.

REFERENCES CITED

Benson, M. A., 1964, Factors affecting the occurrence of floods in the Southwest: U.S. Geol. Survey Water-Supply Paper, p. D1-D72.

Dempster, G. R., Jr., 1974, Effects of urbanization on floods in the Dallas, Texas, metropolitan area: U.S. Geol. Survey Water Resources Investigation 60-73, 55 p.

Gilbert, C. R., and Hawkinson, R. O., 1971, A proposed streamflow-data program for Texas: U.S. Geol. Survey open-file rept., 52 p.

Johnson, S. L., and Sayre, D. M., 1973, Effects of urbanization on floods in the Houston, Texas metropolitan area: U.S. Geol. Survey Water Resources Investigation 3-73, 50 p.

Patterson, J. L., 1964, Magnitude and frequency of floods in the United States--Part 7, Lower Mississippi River basin: U.S. Geol. Survey Water-Supply Paper 1681, 636 p.

______ 1965, Magnitude and frequency of floods in the United States--Part 8, Western Gulf of Mexico basins: U.S. Geol. Survey Water-Supply Paper 1682, 506 p.