INTRODUCTION

The Highland Lakes on the Colorado River are in an area periodically threatened by large storms and floods. Many storms exceeding 10 inches (in.) in depth have been documented in the area, including some with depths approaching 40 in. These storms typically produce large peak discharges that often threaten lives and property. The storms sometimes occur with little warning. Steep stream slopes and thin soils characteristic of the area often cause large peak discharges and rapid movement of floods through watersheds. A procedure to predict the discharge associated with large floods is needed for the area so that appropriate peak discharges can be used in the design of flood plains, bridges, and other structures.

The U.S. Geological Survey (USGS), in cooperation with the Lower Colorado River Authority (LCRA), studied flood peaks for streams in the vicinity of the Highland Lakes of central Texas. The Highland Lakes are a series of reservoirs constructed on the Colorado River. The chain of lakes (and year each was completed) comprises Lake Buchanan (1937), Inks Lake (1938), Lake Lyndon B. Johnson (1950), Lake Marble Falls (1951), Lake Travis (1942), and Lake Austin (1890). The study area (fig. 1), which includes all or parts of 21 counties in the vicinity of the Highland Lakes, was selected because most streams in the area have flood characteristics similar to streams entering the Highland Lakes. The entire study area is in a region subject to large storms.

The purpose of this report is to present (1) peak-flow frequency data for stations and equations to estimate peak-flow frequency for large streams with natural drainage basins in the vicinity of the Highland Lakes, and (2) a technique to estimate the extreme flood peak discharges for the large streams in the vicinity of the Highland Lakes. Peak-flow frequency in this report refers to the peak discharges for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. A large stream is defined as having a contributing drainage area of at least 0.5 square mile (mi^2); and a natural drainage basin has less than 10 percent impervious cover and less than 10 percent of its drainage area controlled by reservoirs.

The mean annual precipitation in the study area for 1951–80 ranges from about 20 in. in western Kimble County to about 34 in. at the eastern edge of Williamson County (Riggio and others, 1987, p. 23). Many large storms and catastrophic floods have occurred along or in the adjacent area west of the Balcones escarpment (fig. 1) (Dalrymple and others, 1939; Breeding and Dalrymple, 1944; Breeding and Montgomery, 1954; Schroeder and others, 1979; Caran and Baker, 1986; Slade, 1986; and Hejl and others, 1996). About a dozen storms with precipitation depths exceeding 15 in. in a few days or less have been documented in this area during the past 60 years. Some of these storms have produced world-record precipitation depths for durations less than 48 hours. The documentation for these and for other large storms indicates that they are not uniformly distributed temporally or spatially; therefore, the recurrence intervals for such storms cannot be verified (Slade, 1986, p. 17). These large storms can cause flood peaks that would exceed those that can be predicted accurately by analyses of available precipitation or flood data.

The peak-flow frequency was estimated for each of 55 qualified stations in the study area (table 1) following guidelines established by the Interagency Advisory Committee on Water Data (1982). Qualified streamflow-gaging stations for the study area are those with at least 8 years of data from natural drainage basins (sites 1–55, fig. 1). Equations to estimate peak-flow frequency for large streams with natural drainage basins in the vicinity of the Highland Lakes were developed. These equations were developed from selected stations on the basis of the relation between peak-flow frequency and basin characteristics for each station. The entire period of systematic record (through 1993) was used in the frequency analyses for each qualified station except for stations at which streamflow was regulated during part of the record. These stations are Leon River near Belton (site 1); Lampasas River near Youngsport (site 5); North Fork San Gabriel River near Georgetown (site 6); San Gabriel River at Laneport (site 12); Brady Creek at Brady (site 16); San Saba River at San Saba (site 18); Rebecca Creek near Spring Branch (site 51); and Cibolo Creek near Boerne (site 54). One or more reservoirs were completed in the basin of each of these stations during the period of systematic record. These reservoirs caused the annual peak discharges to become regulated. The annual peak discharges for 1994 and 1995 at Sandy Creek near Kingsland (site 28) were used to include data associated with extreme flooding that occurred in 1995.

The extreme flood potential in the study area was investigated using an "envelope" or "extreme flood potential" curve. This curve is based on the relation between the contributing drainage area and (1) the maximum peak discharge of record for each qualified station (table 1); (2) substantial peak discharges documented for 84 sites without stations (sites 56–139, fig. 1, table 2); and (3) 100-year peak discharges from peak-flow frequency for stations (table 1). Peak discharges estimated from this curve represent the extreme flood potential for the study area.

PEAK-FLOW FREQUENCY

Peak-Flow Frequency for Gaging Stations

Peak discharges are monitored at each of the qualified stations in the study area. These stations have various periods of systematic record, as identified in table 1. The peak discharges used in this investigation include the largest peak discharge for each year of systematic record (annual peak discharge) and all known historical peak discharges through 1993. A historical peak discharge—documented by newspaper articles, personal recollections, or other historical sources—represents the largest peak discharge since a known date preceding the beginning of the systematic record. The historical record is the number of years represented by the historical peaks. For example, 31 years of systematic record (from 1963–93) exist for the station South Fork Rocky Creek near Briggs (site 4). However, the 1976 peak discharge is the highest since 1904 or before, according to a local resident; thus that peak is the largest in at least 90 years (1904–93). Historical peak discharges can occur before or within the systematic record.

The annual and historical peak discharges for each station were used, together with the USGS computer program PEAKFQ (Slade and Asquith, 1996), to estimate peak discharges for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals (table 1). The computer program for peak-flow frequency analysis follows the guidelines established by the Interagency Advisory Committee on Water Data (IACWD) and uses the log-Pearson Type III (LPIII) frequency distribution. An example of the relation between annual peak discharge and probability of exceedance, with the LPIII frequency curve defined by the data superimposed, for Sandy Creek near Kingsland is shown in figure 2.

The skew in the distribution of annual peaks is characterized by a skew coefficient. A reliable skew coefficient is difficult to estimate for stations having short records. Therefore, the IACWD recommends using a weighted skew coefficient with the LPIII distribution. This weighted skew coefficient is computed by weighting the skew coefficient calculated for a station (station skew coefficient) with a generalized skew coefficient representative of the surrounding area. The weighted skew coefficient is based on the inverse of the respective mean square errors for the station and generalized skew coefficients. Generalized skew coefficients were determined for each station (Linda Judd, U.S. Geological Survey, written commun., 1994; Asquith and Slade, 1995b). A weighted skew coefficient then was used in the computation of the peak-flow frequency for each station except San Gabriel River at Laneport (site 12), North Llano River near Junction (site 19), Llano River near Junction (site 20), Llano River at Llano (site 27), and Rebecca Creek near Spring Branch (site 51). For these stations, only the station skew coefficient was used because it produces a better visual fit of the LPIII frequency curve to the data.

Additionally, the IACWD provides a procedure for estimating low-outlier thresholds; annual peak discharges less than this threshold—low outliers (fig. 2)—are excluded from the fitting of the LPIII frequency curve. The proper estimation of low-outlier thresholds is critical in preventing computations of erroneous peak-flow frequencies. The IACWD procedure for estimating low-outlier thresholds is not always appropriate for stations in Texas. An equation to estimate low-outlier thresholds for stations in Texas has been developed (Asquith and others, 1995). The equation was used to estimate most low-outlier thresholds for this investigation. The equation estimates low-outlier thresholds by using the mean, standard deviation, and skew of the logarithms for the systematic annual peak discharges. At five stations, low-outlier thresholds were identified by visually fitting the LPIII frequency curve to the peak-flow data rather than using the equation—South Fork Rocky Creek near Briggs (site 4); North Llano River near Junction (site 19); Llano River near Junction (site 20); Barton Creek at Loop 360 at Austin (site 38); and Rebecca Creek near Spring Branch (site 51).

Selected Basin Characteristics for Streamflow-Gaging Stations

Selected basin characteristics were aggregated for each station. Only those characteristics considered pertinent for estimation of peak-flow frequency from previous similar investigations in Texas (Schroeder and Massey, 1977; Slade and others, 1995) are included in this investigation. The characteristics are 2-year 24-hour precipitation, mean annual precipitation, contributing drainage area, stream length, shape factor, and stream slope (table 1). The 2-year 24-hour precipitation and mean annual precipitation are for the period 1951–80 and are expressed in inches. The contributing drainage area is expressed in square miles. The stream length represents the length, in miles, of the longest mapped channel from the gaging station to the drainage divide at the headwaters, based on USGS quadrangle maps (scale, 1:100,000). The shape factor is the ratio of the square of the stream length to the contributing drainage area; it represents the ratio of the longest stream length to the mean width of the basin. The stream slope, in feet per mile, is the ratio of the change in elevation of the longest mapped channel (from the gaging station upstream to the drainage divide at the headwaters) to the stream length.

Multiple-Regression Equations to Estimate Peak-Flow Frequency

A weighted-least-squares multiple-regression analysis was done to obtain equations to estimate peak discharges for selected recurrence intervals from basin characteristics. The 2-, 5-, 10-, 25-, 50-, and 100-year peak discharges obtained using the IACWD guidelines were the dependent variables, and the basin characteristics were the independent, or explanatory, variables. The dependent and independent variables, except for the 2-year 24-hour precipitation and mean annual precipitation, were transformed to their common (base 10) logarithms before the analysis. A weighted-least-squares regression was used because the peak-flow frequency analyses for stations with short record are subject to greater error than for those with long record. Empirical equations (G.D. Tasker, U.S. Geological Survey, written commun., 1994) were used to calculate a record-length weight factor for each station based on the number of years of systematic record, the number of historical peaks, and the number of years of historical record (table 1).

Various sets of stations were tested in the regression analysis to determine the set of stations that provides the best relation between peak discharge and basin characteristics—that is, the set of stations that produced regression equations that provide the most reliable estimates of peak discharge for the selected recurrence intervals. The sets of stations tested were (1) all 55 stations in the study area; (2) all stations in basins draining directly to the Highland Lakes, predominately those in the Llano and Pedernales River Basins; (3) all stations in basins that drain directly to the Highland Lakes, plus those stations in the San Saba River-Brady Creek Basins; and (4) all stations within a radius of about 45 miles (mi) from the approximate center of the Highland Lakes area (the town of Marble Falls). The set of stations that provides the best relation between peak discharge and basin characteristics, and thus is used in the analysis, is the set within about 45 mi of Marble Falls. Thirty-four stations in the study area are within about 45 mi of Marble Falls. To minimize the effects of inter-station correlation on the regression analysis, correlation between annual peak discharges for each pair of stations was computed; for those stations in which the coefficient of determination (R^2) between data from two stations was greater than or equal to 0.90, the station with the shorter period of record was excluded from the regression analysis. On that basis, three stations were excluded: North Fork San Gabriel River near Georgetown (site 6), South Fork San Gabriel River near Bertram (site 7), and Blanco River near Kyle (site 53). Therefore, 31 stations (table 1) were used to develop the regression equations.

Equations were developed using the 31 stations to estimate 2-, 5-, 10-, 25-, 50-, and 100-year peak discharges. The explanatory variable "stream length" was excluded from the regression analysis because it is highly correlated with the variable "contributing drainage area." Many equations were developed for each recurrence interval using various combinations of the five remaining independent variables (2-year 24-hour precipitation, mean annual precipitation, contributing drainage area, shape factor, and stream slope) in a forward-stepwise regression procedure. Contributing drainage area and stream slope consistently were the most significant explanatory variables. Additional basin characteristics were significant for some recurrence intervals, but they were not retained in the equations. Testing of equations showed that, if the explanatory variables are not consistent among the equations, some combinations of variable values can produce estimated peak discharges for a given recurrence interval that are less than the peak discharges computed for a smaller recurrence interval. Also, keeping only explanatory variables that are significant at all recurrence intervals has little effect on either coefficient of determination or standard error of estimation. Thus, only contributing drainage area and stream slope appear in the equations shown below.

Equation for indicated T-year peak discharge (cubic feet per second)	Coefficient of determination (R^2)	Standard error of estimation (percent)
$Q_2 = 66.7\,(CDA)^{0.693}\,(SL)^{0.255}$	0.95	33
$Q_5 = 27.0\,(CDA)^{0.804}\,(SL)^{0.652}$	.95	31
$Q_{10} = 15.5\,(CDA)^{0.868}\,(SL)^{0.874}$	.95	33
$Q_{25} = 8.08\,(CDA)^{0.940}\,(SL)^{1.12}$	.93	38
$Q_{50} = 5.13\,(CDA)^{0.989}\,(SL)^{1.29}$	.92	43
$Q_{100} = 3.34\,(CDA)^{1.04}\,(SL)^{1.44}$	.91	46

where

Q_T = discharge, for specified (T-year) recurrence interval, in cubic feet per second;

CDA = contributing drainage area, in square miles; and

SL = stream slope, in feet per mile.

The equations are based on stations in natural drainage basins within about 45 mi of Marble Falls and are applicable for estimating peak discharges for streams in that region. In the process of selecting stations used to develop the regression equations, correlations between peak discharge and basin characteristics were determined for stations as far as 90 mi from Marble Falls. Correlation generally was less for stations 45 to 90 mi from Marble Falls than for stations within 45 mi of Marble Falls. The applicability of the equations to sites farther than about 45 mi from Marble Falls probably diminishes with increasing distance from Marble Falls; but determination of a specific distance from Marble Falls beyond which the equations are not applicable is problematic.

The equations might not be applicable for stream sites in basins with contributing drainage area, shape factor, or channel slope near or outside the ranges of values of the stations used to develop the equations (table 1). In the authors' judgment, the equations can be used for sites with contributing drainage areas between about 0.5 and 3,000 mi^2; for sites with shape factors between about 1.0 and 15; and for sites with stream slopes between about 9 and 100 feet per mile.

For sites at or near the stations included in the analysis, the regression equations might yield estimates of discharge different from those computed using the LPIII frequency curve, as shown in figure 2 for Sandy Creek near Kingsland (site 28). For the subset of sites at or near the 31 stations included in the regression analysis and also in basins that drain to the Highland Lakes (basins of primary interest to the LCRA), the authors consider a weighted 100-year peak discharge preferable to the LPIII-derived and equation-derived 100-year peak. The weighted peak discharge is based on the respective mean square errors associated with the LPIII-derived 100-year peak and the 100-year regression equation; the mean square error for the 100-year regression equation is 0.036 $\log_{10}$ unit, and the mean square errors for the 100-year peak discharges for the subset of 15 stations are listed in table 1. The weighted 100-year peak discharge for a station is computed from equation (1) as shown:

$$Q_W = \frac{(0.036 \times Q_S) + (MSE_S \times Q_E)}{0.036 + MSE_S}, \qquad (1)$$

where

Q_W = the weighted 100-year peak discharge, in cubic feet per second;

0.036 = the mean square error of the 100-year regression equation;

Q_S = the 100-year discharge for the station from an LPIII frequency analysis (table 1), in cubic feet per second;

MSE_S = the mean square error of the 100-year discharge for the station (table 1); and

Q_E = the 100-year discharge from the regression equation, in cubic feet per second.

The weighted 100-year peak discharge for Sandy Creek near Kingsland (site 28) relative to the LPIII frequency curve and a frequency curve constructed from equation-derived peaks is shown in figure 2. Mean square errors for recurrence intervals other than the 100-year peak discharge are not presented in this report.

EXTREME FLOOD POTENTIAL

Knowledge of the extreme flood potential for streams in the Highland Lakes area is useful for evaluating extreme floods. To aid in extreme flood evaluation, the USGS has routinely documented substantial peak discharges at stream sites without gaging stations. Many of these substantial peak discharges are associated with catastrophic storms. These sites are identified on figure 1 (sites 56–139), and ancillary information is presented in table 2.

A common technique for investigating extreme flood potential for an area is through the use of an "envelope" or "extreme flood potential" curve (Crippen and Bue, 1977; Thomas and others, 1994; Asquith and Slade, 1995a). This curve is based on the relation between contributing drainage area and peak discharges. Recurrence intervals are not associated with peak discharges from "envelope" curves (Crippen and Bue, 1977). The extreme flood potential curve for the study area (fig. 3) envelops the maximum peak discharge of record for the stations (table 1), substantial peak discharges for stream sites without stations (table 2), and the 100-year peak discharges for stations in the study area (table 1). As more flood data are collected, peak discharges could exceed those enveloped by the curve, requiring the curve to be redrawn.

The maximum peak discharge of record exceeds the 100-year peak discharge for 17 of the 55 gaging stations; peak discharges from the extreme flood potential curve exceed the 100-year peak discharge by at least 300 percent, which indicates that the potential exists for very large floods in the study area.

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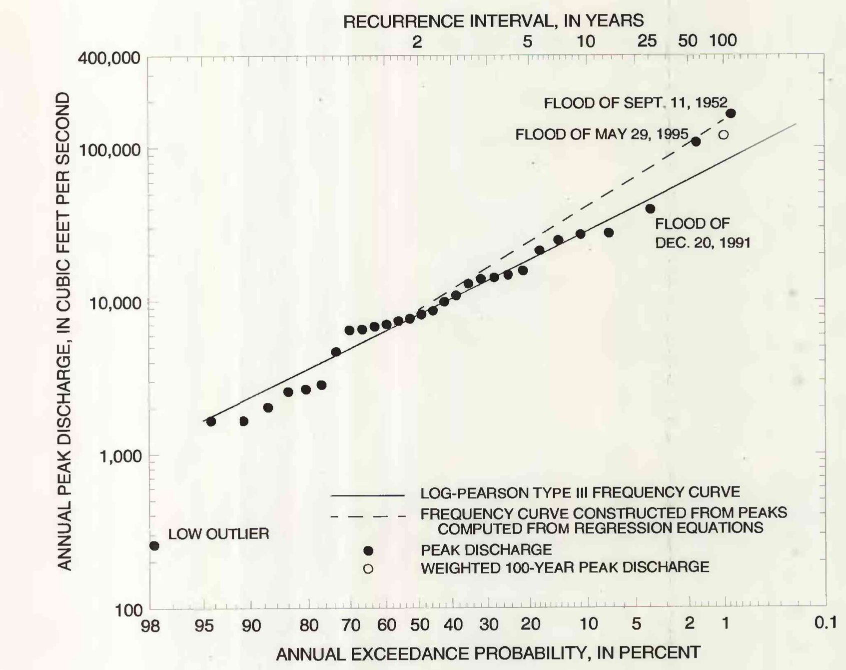

Figure 2. Relation between annual peak discharge and probability of exceedance for Sandy Creek near Kingsland, Texas.

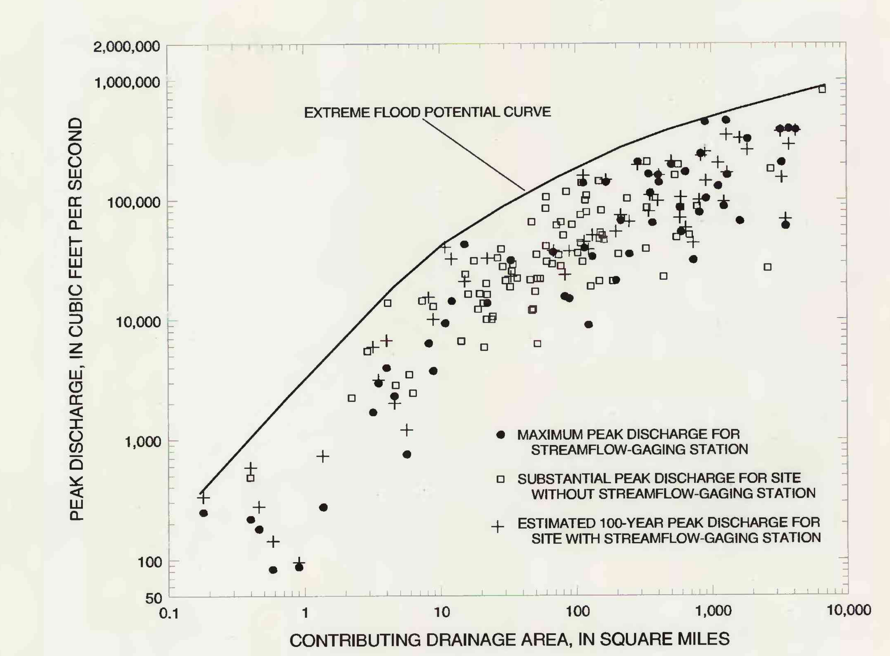

Figure 3. Extreme flood potential for the Highland Lakes, central Texas.

Table 1. Selected basin characteristics and peak-flow frequency for streamflow-gaging stations in the vicinity of the Highland Lakes, central Texas

[in., inches; mi^2, square miles; mi, mile; ft/mi, feet per mile; yr, years; ft^3/s, cubic feet per second; --, error is not presented—error is only presented for stations proximate to and in basins entering the Highland Lakes; trib., tributary; SH, State Highway; FM, Farm to Market]

Site no. (fig. 1)	Station no.	Station name	Station used in multiple regression analysis	Latitude	Longitude	Available period of systematic record[1]	2-year 24-hour precipitation (in.)	Mean annual precipitation 1951–80 (in.)	Contributing drainage area (mi^2)	Stream length (mi)	Shape factor (dimensionless)	Stream slope (ft/mi)	Available unregulated systematic record (yr)	Number of historical peaks	Historical record (yr)	Record-length weight factor (yr)	Date of maximum peak discharge of record	Maximum peak discharge of record (ft^3/s)	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	Mean square error of the 100-yr peak discharge ($\log_{10}$ units)
																			Peak discharge for indicated recurrence interval obtained from log-Pearson Type III frequency curve (ft^3/s)						
1	08102500	Leon River near Belton, Texas	No	31°04'12"	97°26'28"	[2]1924–93	3.85	28	3,542	296.12	24.76	5.09	31	2	42	36	1913	60,000	17,300	28,900	37,600	49,500	58,900	68,800	--
2	08102900	School Branch near Lampasas, Texas	No	31°13'48"	98°09'25"	1967–74	3.92	29	.90	.85	.80	61.76	8	0	0	8	05/25/1968	88	50	63	71	81	88	95	--
3	08103800	Lampasas River near Kempner, Texas	Yes	31°04'54"	98°00'59"	1963–93	3.89	28	818	65.33	5.22	13.46	31	0	0	31	12/20/1991	78,000	10,800	24,600	37,600	58,400	77,400	99,400	--
4	08103900	South Fork Rocky Creek near Briggs, Texas	Yes	30°54'41"	98°02'12"	1963–93	3.96	30	33.3	11.44	3.93	36.15	31	1	90	52	06/19/1976	31,200	3,100	6,490	9,480	14,100	18,200	22,900	--
5	08104000	Lampasas River near Youngsport, Texas	Yes	30°57'26"	97°42'30"	[3]1925–80	3.91	29	1,240	101.61	8.33	10.49	49	0	0	49	05/17/1965	87,900	16,200	31,500	44,200	63,000	78,900	96,400	--
6	[4]08104700	North Fork San Gabriel River near Georgetown, Texas	No	30°39'42"	97°42'40"	[5]1969–93	3.98	31	248	47.70	9.17	16.30	11	0	0	11	09/17/1974	35,000	7,090	15,900	24,100	37,700	50,300	65,100	--
7	[4]08104850	South Fork San Gabriel River near Bertram, Texas	No	30°43'14"	98°06'15"	1967–74	3.97	30	8.9	5.42	3.30	41.75	8	0	0	8	08/28/1974	3,720	690	1,810	2,990	5,120	7,290	9,990	--
8	08104900	South Fork San Gabriel River at Georgetown, Texas	Yes	30°37'32"	97°41'27"	1968–93	4.00	31	133	38.03	10.87	19.84	26	0	0	26	09/08/1981	33,400	7,590	15,600	22,400	32,500	41,000	50,300	--
9	08105000	San Gabriel River at Georgetown, Texas	Yes	30°39'14"	97°39'18"	1935–73	3.98	31	405	52.23	6.73	16.02	39	2	122	70	1921	160,000	13,000	26,600	38,900	58,600	76,600	97,500	--
10	08105100	Berry Creek near Georgetown, Texas	Yes	30°41'28"	97°39'21"	1968–93	4.03	32	83.1	28.01	9.44	16.04	26	0	0	26	10/31/1974	15,500	4,290	8,250	11,400	15,900	19,600	23,600	--
11	08105400	San Gabriel River near Circleville, Texas	No	30°37'43"	97°28'23"	1925–76	4.01	32	599	66.06	7.29	14.60	19	0	0	19	05/29/1929	53,400	16,800	33,600	47,600	68,400	85,900	105,000	--
12	08105700	San Gabriel River at Laneport, Texas	No	30°41'39"	97°16'43"	[6]1965–93	4.05	32	738	84.12	9.59	12.68	15	0	0	15	10/31/1974	31,200	14,100	23,100	28,700	35,200	39,500	43,500	--
13	08105900	Avery Branch near Taylor, Texas	No	30°29'11"	97°27'27"	1967–74	4.19	33	3.52	2.74	2.13	13.17	8	0	0	8	05/01/1972	2,950	691	1,190	1,580	2,150	2,620	3,140	--
14	08144500	San Saba River at Menard, Texas	No	30°55'08"	99°47'07"	1916–93	3.47	21	1,128	58.72	3.06	9.55	78	0	0	78	07/23/1938	130,000	5,950	22,100	43,200	86,900	136,000	202,000	--
15	08144600	San Saba River near Brady, Texas	No	31°00'14"	99°16'07"	1980–93	3.53	22	1,626	100.26	6.18	8.87	14	0	0	14	09/08/1980	66,000	5,960	26,600	56,800	125,000	207,000	324,000	--
16	08145000	Brady Creek at Brady, Texas	No	31°08'17"	99°20'05"	[7]1940–85	3.59	24.5	588	62.54	6.65	10.70	15	2	73	38	07/23/1938	86,000	4,940	11,800	19,400	33,900	49,500	70,200	--
17	08145100	Brady Creek trib. near Brady, Texas	No	31°05'05"	99°17'33"	1967–74	3.68	25	4.05	3.68	3.34	34.77	8	0	0	8	09/24/1974	3,970	125	486	1,030	2,340	4,060	6,720	--
18	08146000	San Saba River at San Saba, Texas	No	31°12'47"	98°43'09"	[8]1916–93	3.59	24	3,309	156.24	8.03	8.02	64	1	81	70	07/23/1938	203,000	10,600	26,800	44,300	76,500	110,000	152,000	--
19	08148500	North Llano River near Junction, Texas	No	30°31'06"	99°48'39"	1916–77	3.53	22	914	54.71	3.27	11.87	62	2	103	78	09/16/1936	102,000	10,300	35,300	58,700	92,300	118,000	143,000	--
20	08150000	Llano River near Junction, Texas	No	30°29'51"	99°43'19"	1916–93	3.55	22.5	1,851	74.29	2.98	9.98	78	1	119	92	06/14/1935	319,000	13,700	50,100	88,200	149,000	202,000	258,000	--
21	08150200	Llano River trib. near London, Texas	No	30°38'22"	99°35'52"	1966–73	3.63	23.5	.58	.16	.04	164.04	8	0	0	8	07/26/1971	84	19	39	58	87	113	143	--
22	08150700	Llano River near Mason, Texas	Yes	30°39'38"	99°06'32"	1964–93	3.60	23	3,242	128.04	5.06	8.79	26	4	119	64	06/14/1935	380,000	25,700	75,300	125,000	208,000	283,000	369,000	0.065
23	08150800	Beaver Creek near Mason, Texas	Yes	30°38'36"	99°05'44"	1964–93	3.75	26	215	33.90	5.35	25.74	30	0	0	30	08/03/1978	66,900	5,300	14,300	23,600	39,800	55,500	74,400	.053
24	08150900	Stone Creek trib. near Art, Texas	Yes	30°44'17"	99°03'29"	1966–74	3.75	25.5	.40	.95	2.26	152.63	9	0	0	9	09/22/1971	218	106	201	278	390	484	584	.074
25	08151000	Llano River near Castell, Texas	Yes	30°43'00"	98°53'00"	1925–39	3.62	23	3,742	145.06	5.62	8.12	15	1	119	51	06/14/1935	388,000	42,100	83,300	120,000	176,000	227,000	285,000	.061
26	08151300	Johnson Creek near Valley Spring, Texas	Yes	30°51'38"	98°49'52"	1967–74	3.79	26	5.66	5.44	5.23	75.95	8	0	0	8	07/09/1968	750	361	562	706	899	1,049	1,200	.043
27	08151500	Llano River at Llano, Texas	Yes	30°45'04"	98°40'10"	1940–93	3.63	23.5	4,192	159.74	6.09	8.24	54	1	119	76	06/14/1935	380,000	30,500	78,400	126,000	207,000	284,000	374,000	.027
28	08152000	Sandy Creek near Kingsland, Texas	Yes	30°33'30"	98°28'19"	[9]1967–95	3.85	28	346	48.34	6.75	24.84	29	2	115	61	09/11/1952	163,000	8,100	18,400	28,300	45,000	60,800	79,800	.045
29	08152700	Little Flatrock Creek near Marble Falls, Texas	Yes	30°30'52"	98°18'44"	1967–74	3.94	30	3.2	3.98	4.95	39.57	8	0	0	8	05/26/1970	1,690	220	749	1,400	2,690	4,080	5,900	.31
30	08152800	Spring Creek near Fredericksburg, Texas	Yes	30°18'09"	99°03'23"	1967–74	3.78	28	15.2	6.09	2.44	47.40	8	1	44	22	08/03/1978	42,500	751	2,370	4,430	8,770	13,800	20,800	.37
31	08152900	Pedernales River near Fredericksburg, Texas	Yes	30°13'13"	98°52'10"	1979–93	3.77	28	369	38.86	4.09	17.64	15	1	87	41	09/11/1952	64,000	7,170	21,700	36,600	61,200	83,300	109,000	.12
32	08153000	Pedernales River at Stonewall, Texas	Yes	30°15'00"	98°40'00"	1925–34	3.78	28.5	647	58.17	5.23	13.88	10	1	135	52	09/11/1952	170,000	9,720	18,100	25,400	36,600	46,700	58,300	.078
33	08153100	Cane Branch at Stonewall, Texas	Yes	30°14'07"	98°39'21"	1966–74	3.88	30.5	1.37	2.94	6.31	69.39	9	0	0	9	10/19/1971	275	51	138	229	389	544	734	.18
34	08153500	Pedernales River near Johnson City, Texas	Yes	30°17'30"	98°23'57"	1940–93	3.82	30	901	79.69	7.05	14.57	54	1	135	81	09/11/1952	441,000	22,300	53,200	84,000	137,000	188,000	251,000	.027
35	08154000	Pedernales River near Spicewood, Texas	Yes	30°25'15"	98°04'50"	1925–39	3.85	30	1,294	120.96	11.31	13.26	15	1	135	55	09/11/1952	452,000	17,800	48,700	84,900	157,000	236,000	345,000	.17
36	08154700	Bull Creek at Loop 360 near Austin, Texas	Yes	30°22'19"	97°47'04"	1979–93	4.09	31.5	22.3	9.40	3.96	47.82	15	0	0	15	05/13/1982	13,700	2,950	7,480	11,800	18,900	25,300	32,600	.086
37	08155200	Barton Creek at SH 71 near Oak Hill, Texas	Yes	30°17'46"	97°55'31"	1976–93	4.00	32	89.7	27.41	8.38	22.62	12	0	0	12	12/20/1991	14,900	2,760	7,460	12,200	20,400	28,100	37,200	--
38	08155300	Barton Creek at Loop 360 at Austin, Texas	Yes	30°14'40"	97°48'07"	1976–93	4.04	32	116	43.53	16.33	18.84	18	1	65	35	05/28/1929	39,400	3,790	9,820	15,700	25,400	34,200	44,400	--
39	08158700	Onion Creek near Driftwood, Texas	Yes	30°04'59"	98°00'29"	1980–93	4.01	32.5	124	31.99	8.25	15.59	14	0	0	14	06/06/1985	8,990	2,900	7,880	12,900	21,300	29,200	38,400	--
40	08158810	Bear Creek below FM Road 1826 near Driftwood, Texas	Yes	30°09'19"	97°56'23"	1979–93	4.06	33	12.2	5.49	2.47	55.55	15	1	79	38	1939	14,200	839	3,300	6,620	13,700	21,600	32,400	--
41	08158840	Slaughter Creek at FM Road 1826 near Austin, Texas	Yes	30°12'32"	97°54'11"	1978–93	4.07	32.5	8.24	4.20	2.14	52.32	16	0	0	16	12/20/1991	6,330	789	2,390	4,200	7,570	11,000	15,300	--
42	08158900	Fox Branch near Oak Hill, Texas	Yes	30°14'01"	97°52'29"	1966–74	4.08	32	.18	.40	.87	124.32	9	0	0	9	09/04/1967	249	49	99	142	208	267	332	--
43	08159150	Wilbarger Creek near Pflugerville, Texas	Yes	30°27'16"	97°36'02"	1964–80	4.15	32	4.61	2.99	1.94	38.44	17	1	87	42	1921	2,300	596	980	1,240	1,550	1,780	2,000	--
44	08165300	North Fork Guadalupe River near Hunt, Texas	No	30°03'36"	99°23'40"	1968–93	3.68	27	168	27.57	4.53	20.35	26	1	142	65	07/01/1932	140,000	7,000	24,900	44,700	78,900	111,000	147,000	--
45	08165500	Guadalupe River at Hunt, Texas	No	30°04'08"	99°19'23"	1966–93	3.70	27.5	288	33.85	3.98	19.10	28	1	142	66	07/02/1932	206,000	9,180	28,900	51,600	94,500	139,000	195,000	--
46	08166000	Johnson Creek near Ingram, Texas	No	30°06'00"	99°16'58"	[10]1942–93	3.72	27	114	19.8	3.44	25.03	50	1	142	81	07/02/1932	138,000	1,850	9,120	21,200	52,100	93,600	159,000	--
47	08166200	Guadalupe River at Kerrville, Texas	No	30°03'09"	99°09'54"	1986–93	3.69	27	510	44.31	3.85	16.73	8	2	142	57	07/02/1932	196,000	7,530	26,500	49,900	95,900	145,000	208,000	--
48	08166300	Turtle Creek trib. near Kerrville, Texas	No	29°58'11"	99°11'02"	1966–74	3.78	29	.46	1.03	2.28	224.06	9	0	0	9	08/12/1971	180	80	132	167	211	244	275	--
49	08167000	Guadalupe River at Comfort, Texas	No	29°58'10"	98°53'33"	[11]1922–93	3.75	28.5	839	68.87	5.65	15.01	64	1	146	91	08/02/1978	240,000	12,200	35,800	62,500	113,000	165,000	232,000	--
50	08167500	Guadalupe River near Spring Branch, Texas	Yes	29°51'38"	98°22'58"	1923–93	3.80	30	1,315	131.27	13.10	10.85	71	0	0	71	08/03/1978	160,000	12,700	31,400	51,100	86,800	123,000	168,000	--
51	08167600	Rebecca Creek near Spring Branch, Texas	Yes	29°55'06"	98°22'10"	[12]1960–78	3.96	33	10.9	5.57	2.84	77.79	14	0	0	14	10/18/1965	9,300	1,530	5,640	10,500	19,700	28,900	40,200	--
52	08171000	Blanco River at Wimberley, Texas	Yes	29°59'39"	98°05'19"	[13]1925–93	3.95	32.5	355	60.39	10.27	19.02	67	3	125	90	05/28/1929	113,000	7,900	21,000	34,600	58,300	81,100	109,000	--
53	[4]08171300	Blanco River near Kyle, Texas	No	29°58'45"	97°54'35"	1957–93	3.97	32.5	412	77.08	14.42	17.11	37	2	125	70	05/28/1929	139,000	11,500	32,400	53,500	89,000	122,000	160,000	--
54	08183900	Cibolo Creek near Boerne, Texas	No	29°46'26"	98°41'50"	[14]1963–93	3.88	32	68.4	17.71	4.59	35.38	15	3	86	44	09/27/1964	36,400	3,820	9,500	14,700	22,800	29,800	37,500	--
55	08184000	Cibolo Creek near Bulverde, Texas	No	29°43'33"	98°25'37"	1946–65	3.92	32.5	198	42.81	9.25	22.22	20	0	0	20	05/02/1958	21,100	2,510	9,710	17,500	30,400	41,500	53,600	--

[1] Stations with available record ending 1993 were active as of 1995.
[2] Belton Lake completed in 1955 within basin. Only peak discharges for 1924–54 used in analysis.
[3] Stillhouse Hollow Lake completed in 1974 within basin. Only peak discharges for 1925–73 used in analysis.
[4] Station excluded from multiple regression analysis because peak discharges are highly correlated with nearby station.
[5] Lake Georgetown completed in 1980 within basin. Only peak discharges for 1969–79 used in analysis.
[6] Lake Georgetown completed in 1980 within basin. Only peak discharges for 1965–79 used in analysis.
[7] Brady Creek Reservoir completed in 1955 within basin. Only peak discharges for 1940–54 used in analysis.
[8] Basin considered partly regulated beginning in 1980. Only peak discharges for 1916–79 used in analysis.
[9] Peak discharge for 1994 and 1995 included in analysis because of extreme peak discharge in 1995.
[10] Station discontinued for 2 years during 1954 and 1961.
[11] Station discontinued for 8 years during 1923–24 and 1933–38.
[12] Basin considered partly regulated beginning in 1974. Only peak discharges for 1960–73 used in analysis.
[13] Station discontinued for 2 years during 1927–28.
[14] Many small reservoirs completed in 1978 within basin. Only peak discharges for 1963–77 used in analysis.

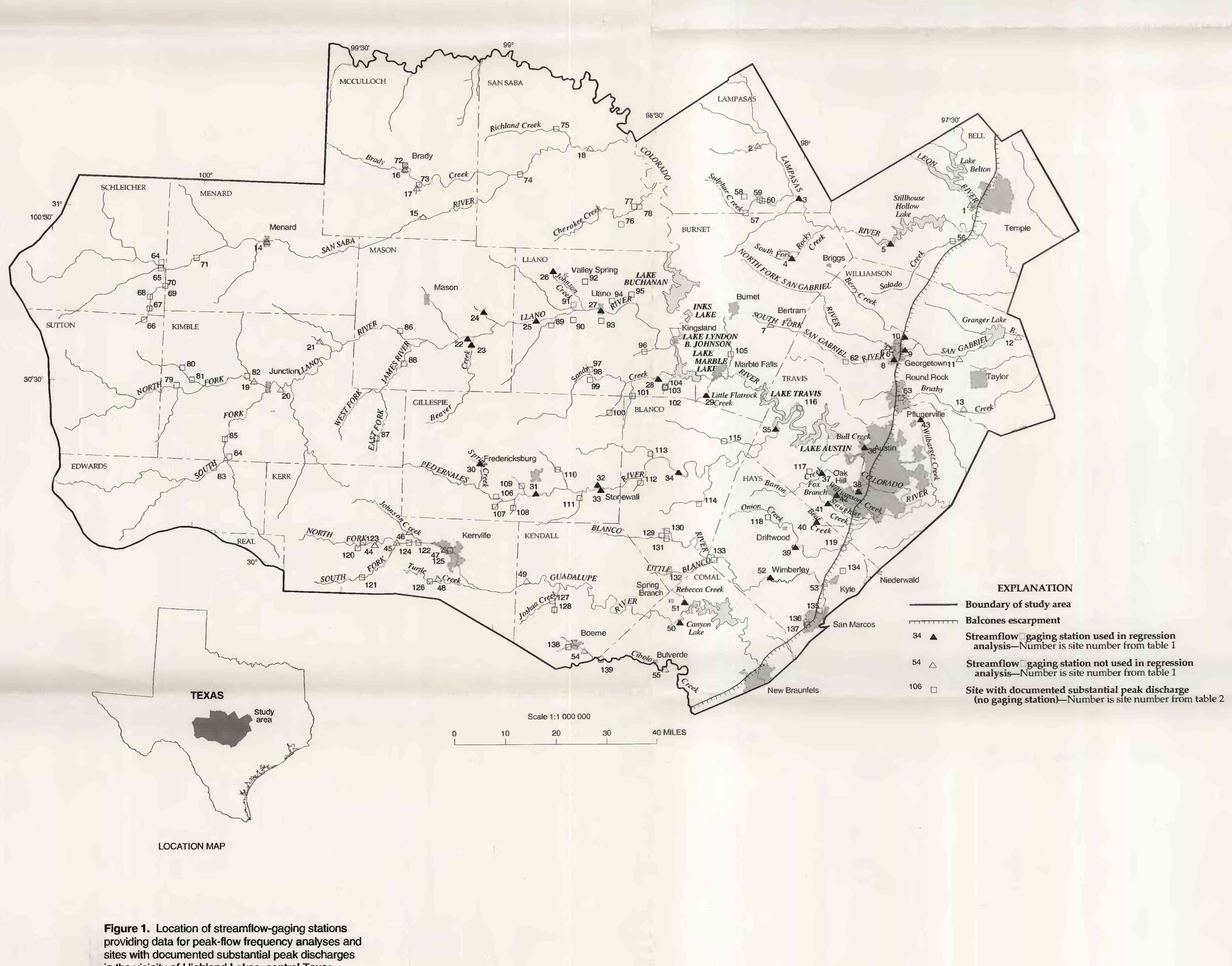

Figure 1. Location of streamflow-gaging stations providing data for peak-flow frequency analyses and sites with documented substantial peak discharges in the vicinity of Highland Lakes, central Texas.

Table 2. Substantial peak discharges for sites without streamflow-gaging stations in the vicinity of the Highland Lakes, central Texas

[mi^2, square miles; ft^3/s, cubic feet per second; trib., tributary; SH, State Highway]

Site no. (fig.1)	Stream site name and approximate location	Latitude	Longitude	Date of substantial peak discharge	Minimum historical record[1]	Contributing drainage area (mi^2)	Substantial peak discharge (ft^3/s)
56	Salado Creek below Salado, Texas[2]	30°58'00"	97°30'00"	09/10/1921	--	148	143,000
57	Sulphur Creek near Lampasas, Texas[3]	31°02'17"	98°11'36"	05/12/1957	--	78	65,300
58	Burleson Creek near Lampasas, Texas[3]	31°05'02"	98°11'56"	05/12/1957	--	7.4	14,300
59	Sulphur Creek below Lampasas, Texas[2]	31°04'35"	98°08'50"	09/27/1936	1874–1936	112	30,400
60	Sulphur Creek near mouth below Lampasas, Texas[4]	31°04'23"	98°08'20"	05/12/1957	--	108	74,600
61	North San Gabriel River near Georgetown, Texas[4]	30°39'20"	97°41'50"	04/24/1957	--	240	102,000
62	South San Gabriel River near Leander, Texas[4]	30°37'05"	97°51'05"	04/24/1957	--	120	78,800
63	Brushy Creek at Round Rock, Texas[4]	30°31'00"	97°40'00"	09/10/1921	--	74.7	34,500
64	North Valley Prong San Saba River above Fort McKavett, Texas[2]	30°51'00"	100°08'00"	09/16/1936	--	328	38,800
65	Middle Valley Prong San Saba River above Fort McKavett, Texas[2]	30°50'00"	100°08'00"	09/16/1936	1920–36	188	20,900
66	East Fork Terrett Draw near Fort McKavett, Texas[2]	30°41'00"	100°11'00"	09/16/1936	--	19	12,100
67	East Fork Terrett Draw near Fort McKavett, Texas[2]	30°43'00"	100°10'00"	09/16/1936	--	33	18,700
68	West Fork Terrett Draw near Fort McKavett, Texas[2]	30°45'00"	100°10'00"	09/16/1936	--	21	5,880
69	Colston Draw above mouth near Fort McKavett, Texas[2]	30°47'00"	100°07'00"	09/16/1936	--	24	10,000
70	Terrett Draw above Fort McKavett, Texas[2]	30°47'00"	100°07'00"	09/16/1936	1899–1936	103	35,800
71	San Saba River below Fort McKavett, Texas[2]	30°52'00"	100°01'00"	09/16/1936	1899–1936	688	50,700
72	Brady Creek at Brady, Texas[2]	31°09'00"	99°20'00"	10/06/1930	--	554	48,400
73	Brady Creek near Brady, Texas[2]	31°06'00"	99°18'00"	07/23/1938	--	595	86,000
74	San Saba River near Richland Springs, Texas[2]	31°08'00"	98°57'00"	07/22/1938	--	2,757	181,000
75	Richland Creek near Richland Springs, Texas[3]	31°16'00"	98°50'00"	07/23/1938	--	72.4	61,000
76	Bee Water Hole Branch near Cherokee, Texas[5]	30°59'55"	98°36'30"	09/10/1952	--	4.7	2,850
77	Cherokee Creek above Chapple, Texas[5]	31°03'00"	98°34'00"	07/25/1938	--	149	20,900
78	Cherokee Creek near Chapple, Texas[5]	31°03'00"	98°33'00"	09/11/1952	--	162	46,000
79	North Llano River at Roosevelt, Texas[2]	30°30'00"	100°04'00"	09/16/1936	--	443	22,600
80	West Fork Copperas Creek near Roosevelt, Texas[2]	30°33'00"	100°03'00"	09/16/1936	1879–1936	81	50,400
81	Copperas Creek near Roosevelt, Texas[2]	30°31'00"	100°01'00"	09/16/1936	--	118	98,900
82	Bear Creek near Junction, Texas[2]	30°32'00"	99°50'00"	08/03/1978	1936–78	155	81,000
83	South Llano River near Telegraph, Texas[2]	30°16'00"	99°56'00"	06/14/1935	--	540	160,000
84	Paint Creek near Telegraph, Texas[2]	30°18'00"	99°53'00"	06/14/1935	1923–36	218	69,300
85	South Llano River near Telegraph, Texas[4]	30°21'00"	99°54'00"	09/16/1936	--	785	87,600
86	Llano River near Mason, Texas[4]	30°40'40"	99°20'00"	09/10/1952	--	2,600	26,700
87	East Fork James River at Old Knoxville, Texas[3]	30°22'00"	99°24'00"	07/01/1932	1915–36	60.8	105,000
88	James River near Mason, Texas[4]	30°35'00"	99°19'00"	07/02/1932	--	336	85,900
89	Hickory Creek near Castell, Texas[4]	30°42'20"	98°50'00"	09/10/1952	--	157	50,300
90	Six Mile Creek near Llano, Texas[4]	30°43'20"	98°45'40"	09/10/1952	--	24.5	10,500
91	Johnson Creek near Llano, Texas[4]	30°46'00"	98°45'40"	09/11/1952	--	48.5	12,200
92	Pecan Creek near Llano, Texas[4]	30°50'00"	98°43'30"	09/11/1952	--	47.7	11,900
93	Oatman Creek near Llano, Texas[4]	30°43'20"	98°40'05"	09/11/1952	--	22.1	9,960
94	Wrights Creek near Llano, Texas[4]	30°46'50"	98°38'00"	09/11/1952	--	14.3	6,580
95	Little Llano River near Lone Grove, Texas[4]	30°48'00"	98°34'10"	09/10/1952	--	52	21,800
96	Honey Creek near Kingsland, Texas[4]	30°38'10"	98°31'20"	09/11/1952	--	29	27,600
97	Hog Branch near Llano, Texas[4]	30°34'50"	98°42'00"	09/10/1952	--	5.9	3,470
98	Hog Branch trib. near Llano, Texas[4]	30°34'50"	98°42'10"	09/10/1952	--	.4	482
99	Sandy Creek at SH 16 near Llano, Texas	30°33'05"	98°42'00"	05/29/1995	1952–95	149.9	47,300
100	Coal Creek near Willow City, Texas[4]	30°27'30"	98°38'00"	09/10/1952	--	15.4	23,800
101	Comanche Creek near Click, Texas[4]	30°30'30"	98°33'30"	09/10/1952	--	129	18,900
102	Walnut Creek near Round Mountain, Texas[4]	30°32'00"	98°27'00"	09/10/1952	--	19.6	16,400
103	Walnut Creek near Marble Falls, Texas[2]	30°32'06"	98°26'55"	09/15/1936	--	20.9	13,600
104	Walnut Creek at SH 71 near Kingsland, Texas	30°32'15"	98°26'50"	05/29/1995	1952–95	22.3	16,100
105	Hamilton Creek near Marble Falls, Texas[2]	30°38'00"	98°14'00"	09/15/1936	1885–1936	67	29,100
106	Pedernales River near Morris Ranch, Texas[4]	30°12'30"	99°00'00"	09/10/1952	--	206	35,200
107	Wolf Creek near Fredericksburg, Texas[4]	30°10'45"	99°00'10"	09/10/1952	--	33.8	25,200
108	Bear Creek near Fredericksburg, Texas[4]	30°10'40"	98°56'35"	09/10/1952	--	30.5	21,000
109	Live Oak Creek near Fredericksburg, Texas[4]	30°14'30"	98°55'00"	09/10/1952	--	46.2	21,300
110	Palo Alto Creek near Fredericksburg, Texas[4]	30°17'30"	98°48'00"	09/10/1952	--	36.9	22,000
111	South Grape Creek near Stonewall, Texas[4]	30°12'40"	98°43'30"	09/10/1952	--	61	30,500
112	Rocky Creek near Hye, Texas[4]	30°15'30"	98°31'30"	09/11/1952	--	28.1	38,700
113	North Grape Creek above mouth near Sandy, Texas[4]	30°20'35"	98°29'35"	09/10/1952	--	85.7	117,000
114	Miller Creek near Johnson City, Texas[4]	30°12'05"	98°19'45"	09/10/1952	--	51.3	34,700
115	Cypress Creek near Cypress Mill, Texas[4]	30°23'00"	98°15'00"	09/10/1952	--	52.1	6,210
116	Lake Travis (inflow) near Austin, Texas[6]	30°32'30"	98°00'00"	09/11/1952	--	6,650	803,000
117	Little Barton Creek near Bee Cave, Texas[4]	30°18'00"	97°58'00"	05/28/1929	1880–1936	6.3	2,450
118	Onion Creek near Dripping Springs, Texas[4]	30°10'00"	98°06'00"	05/28/1929	1881–1936	54.8	21,900
119	Onion Creek near Buda, Texas[4]	30°05'00"	97°51'00"	05/28/1929	--	151	53,200
120	North Fork Guadalupe River above Hunt, Texas[4]	30°03'00"	99°27'00"	07/01/1932	--	120	108,000
121	South Fork Guadalupe River above Hunt, Texas[4]	29°58'00"	99°26'00"	07/01/1932	1901–36	60.3	84,300
122	Guadalupe River near Ingram, Texas[4]	30°03'00"	99°15'00"	07/01/1932	--	336	206,000
123	Bear Creek near Hunt, Texas[4]	30°04'00"	99°26'00"	07/01/1932	--	50.3	17,200
124	Johnson Creek near Ingram, Texas[2]	30°03'00"	99°16'58"	07/02/1932	--	111	138,000
125	Guadalupe River at Kerrville, Texas[4]	30°03'05"	99°08'48"	07/01/1932	--	570	196,000
126	Turtle Creek near Kerrville, Texas[7]	29°57'41"	99°12'35"	08/02/1978	--	26.5	32,700
127	Big Joshua Creek near Waring, Texas[4]	29°54'50"	98°48'25"	09/10/1952	--	17.8	30,900
128	Little Joshua Creek near Welfare, Texas[4]	29°53'20"	98°47'55"	09/10/1952	--	8.94	12,800
129	Blanco River near Blanco, Texas[4]	30°06'30"	98°27'00"	09/11/1952	--	93.5	61,900
130	Hines Creek near Blanco, Texas[4]	30°07'20"	98°26'00"	09/10/1952	--	2.92	5,430
131	Blanco River at Blanco, Texas[2]	30°06'00"	98°26'00"	05/28/1929	--	108	43,500
132	Little Blanco River near Twin Sisters, Texas[4]	30°00'20"	98°25'20"	09/10/1952	--	21.9	19,900
133	Little Blanco River near Twin Sisters, Texas[4]	30°02'30"	98°16'30"	09/10/1952	--	60.3	41,000
134	Bunton Branch near Kyle, Texas[2]	30°01'00"	97°51'00"	06/30/1936	--	4.12	13,800
135	Sink Creek near San Marcos, Texas[8]	29°54'04"	97°55'26"	05/16/1970	--	47.6	65,400
136	Purgatory Creek near San Marcos, Texas[8]	29°52'06"	97°58'01"	05/16/1970	--	34.6	28,700
137	Willow Springs Creek near San Marcos, Texas[8]	29°51'41"	97°57'52"	05/16/1970	--	2.22	2,230
138	Frederick Creek at Boerne, Texas[4]	29°47'00"	98°45'00"	06/01/1937	--	16.1	16,300
139	Cibolo Creek near Boerne, Texas[4]	29°45'00"	98°38'35"	09/10/1952	--	77.6	27,900

[1] The historical record shown represents that known at the date the peak discharge was documented. In many cases, this is only a minimum historical record. The ending date may be more recent than that indicated.
[2] Data adapted from Williams and Crawford, 1940.
[3] Data adapted from Ruggles, 1966.
[4] Data adapted from Patterson, 1963.
[5] Data adapted from Texas Board of Water Engineers, 1959.
[6] Data adapted from Breeding and Montgomery, 1954.
[7] Data adapted from Schroeder and others, 1979.
[8] Data adapted from Schroeder, 1972.

PEAK-FLOW FREQUENCY AND EXTREME FLOOD POTENTIAL FOR STREAMS IN THE VICINITY OF THE HIGHLAND LAKES, CENTRAL TEXAS

By

William H. Asquith, Raymond M. Slade, Jr., and J.L. Lanning-Rush

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