Prepared in cooperation with the
OKLAHOMA DEPARTMENT OF TRANSPORTATION

Techniques for Estimating Peak-Streamflow Frequency for Unregulated Streams and Streams Regulated by Small Floodwater Retarding Structures in Oklahoma

Water-Resources Investigations Report 97–4202

U.S. Department of the Interior
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Multiply	By	To obtain
Length		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]

Sea level: In this report "sea level" refers to the 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 Sea Level Datum of 1929.

Techniques for estimating peak-streamflow frequency for unregulated streams and streams regulated by small floodwater retarding structures in Oklahoma

By Robert L. Tortorelli

Abstract

Statewide regression equations for Oklahoma were determined for estimating peak discharge and flood frequency for selected recurrence intervals from 2 to 500 years for ungaged sites on natural unregulated streams. The most significant independent variables required to estimate peak- streamflow frequency for natural unregulated streams in Oklahoma are contributing drainage area, main-channel slope, and mean-annual precipitation. The regression equations are applicable for watersheds with drainage areas less than 2,510 square miles that are not affected by regulation from manmade works.

Limitations on the use of the regression relations and the reliability of regression estimates for natural unregulated streams are discussed. Log-Pearson Type III analysis information, basin and climatic characteristics, and the peak-streamflow frequency estimates for 251 gaging stations in Oklahoma and adjacent states are listed.

Techniques are presented to make a peak-streamflow frequency estimate for gaged sites on natural unregulated streams and to use this result to estimate a nearby ungaged site on the same stream. For ungaged sites on urban streams, an adjustment of the statewide regression equations for natural unregulated streams can be used to estimate peak-streamflow frequency. For ungaged sites on streams regulated by small floodwater retarding structures, an adjustment of the statewide regression equations for natural unregulated streams can be used to estimate peak-streamflow frequency. The statewide regression equations are adjusted by substituting the drainage area below the floodwater retarding structures, or drainage area that represents the percentage of the unregulated basin, in the contributing drainage area parameter to obtain peak-streamflow frequency estimates.

Introduction

Knowledge of the magnitude and frequency of floods is required for the safe and economical design of highway bridges, culverts, dams, levees and other structures on or near streams. Flood plain management programs and flood-insurance rates also are based on flood magnitude and frequency information.

The flood peaks for many areas of Oklahoma are regulated by U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) floodwater retarding structures. Currently about 2,100 floodwater retarding structures are present in more than 120 drainage basins in Oklahoma. Eventually about 2,500 floodwater retarding structures will regulate flood peaks from about 8,500 mi^2, or about 12-percent of the state, upon completion of the present (1997) NRCS watershed protection and flood prevention program (G. W. Utley, Natural Resources Conservation Service, written commun., 1997). Floodwater retarding structures are designed to decrease main-stem flood peaks and regulate the runoff recession of single storm events (Bergman and Huntzinger, 1981). Consideration of the flood peak modification capability of floodwater retarding structures can result in more hydraulically efficient, cost-effective culvert or bridge designs along downstream segments of streams regulated by floodwater retarding structures.

The U.S. Geological Survey (USGS), in cooperation with the Oklahoma Department of Transportation conducted a study to update regression equations for estimating the peak-streamflow frequency of floods for Oklahoma streams with a drainage area less than 2,510 mi^2 (Tortorelli and Bergman, 1985).

Purpose and Scope

The purpose of this report is to present techniques for estimating the peak discharge and flood frequency (peak-streamflow frequency) for selected recurrence intervals from 2 to 500 years for ungaged sites on natural unregulated streams with drainage areas less than 2,510 mi^2 in Oklahoma. This report also provides techniques for estimating peak-streamflow frequency estimates for gaged sites on natural unregulated streams and using this result to estimate nearby ungaged sites on the same stream. Lastly, this report provides procedures to adjust estimates for ungaged urban basins and basins regulated by floodwater retarding structures.

Flood-discharge records through the 1995 water year at 251 streamflow-gaging stations located throughout Oklahoma and bordering parts of Arkansas, Kansas, Missouri, New Mexico, and Texas were used to develop the statewide peak-streamflow frequency estimation techniques. Estimates of peak-streamflow frequency from the 251 stations were related to basin and climatic characteristics using multiple-linear regression. The regression equations derived from these analyses provide simple and reliable methods to estimate the flood frequency of natural streams.

These analyses are limited to peak flows and do not consider the shape or volume of the flood hydrograph. This report provides techniques to estimate flood discharges for streams with drainage areas smaller than 2,510 mi^2. Sauer's report (1974a), and Heiman and Tortorelli's report (1988) may be used to estimate flood frequency for streams with larger drainage areas. The Oklahoma generalized skew map (Tortorelli and Bergman, 1985), an important element in the development of the peak-streamflow frequencies of the 251 stations, has not been updated for the current study; consult that report to obtain information on the map development. The analysis for peak-

streamflow frequency adjustment for urban conditions in Oklahoma is contained in Sauer's report (1974b). Nationwide urban adjustment equations are presented in Jennings and others (1994) and are not presented in this report. The analysis for the adjustment for ungaged sites on streams regulated by small floodwater retarding structures is contained in Tortorelli and Bergman (1985).

This report is intended to supersede the report by Tortorelli and Bergman (1985) to estimate flood discharges for natural Oklahoma streams with a drainage area less than 2,510 mi^2 because: (l) it includes 15 years of additional annual peak data and the records from many additional gaging-stations, thus including major peak flows recorded during water years 1981, 1983, 1987, 1990, 1993, and 1995; (2) it uses a skew map developed specifically for Oklahoma in the station flood-frequency analysis; (3) it is based on annual peak data that were edited to remove all data from sites under the influence of regulation from floodwater retarding structures; (4) the climatic parameter mean-annual precipitation is based on an updated period 1961-90; and (5) a forward stepwise weighted least-squares regression procedure was used, which is more accurate than the ordinary least-squares procedure. Weight factors used in these analyses are based on the years of record of streamflow data at sites used in this study, with an adjustment for length of historical record.

General Description and Effects of Floodwater Retarding Structures

This report includes an adjustment for the effects of small structures on peak flow. These structures are floodwater retarding structures built by the NRCS and used in their watershed protection and flood prevention program.

A typical floodwater retarding structure consists of an earthen dam, a valved drain pipe, a drop inlet principal spillway, and an open-channel earthen emergency spillway (Moore, 1969). The principal spillway is ungated and automatically limits the rate at which water can flow from the reservoir. Most of the structures built in Oklahoma have release rates of 10 to 15 $(ft^3/s)/mi^2$. The space in the reservoir between the elevation of the principal spillway crest and the emergency spillway crest is used for floodwater detention. Structures are designed so that the emergency spillway does not operate on an average of more than once in 25 years to once in 100 years.

Most floodwater retarding structures in Oklahoma are designed to draw down the floodwater-retarding pool in 10 days or less (R. C. Riley, Natural Resources Conservation Service, written commun., 1984). The 10-day drawdown requirement serves two purposes. First, most vegetation in the floodwater-retarding pool will survive up to 10 days of inundation without destroying the viability of the stand. Secondly, a 10-day drawdown period will significantly reduce the effect from repetitive storms.

These dams are small to medium size, with embankment heights ranging generally from 20 to 60 ft and their drainage areas ranging generally from 1 to 20 mi^2 (Moore, 1969). Their storage capacity is limited to 12,500 acre-ft for floodwater detention and 25,000 acre-ft total for combined uses, including recreation, municipal and industrial water, and others.

Emergency spillway design, including storage above the emergency crest and capacity of the emergency spillway, varies depending upon watershed location and size of the floodwater retarding structure. Design details may be found in the NRCS National Engineering Handbook, Section 4 (U.S. Soil Conservation Service, 1972).

The main effect of a system of upstream floodwater retarding structures on a watershed streamflow hydrograph at a point downstream from the floodwater retarding structures is that flood peak discharge is reduced and this reduction is related to the percentage of the basin that is regulated (Coskun and Moore, 1969; DeCoursey, 1975; Hartman and others, 1967; Moore, 1969; Schoof and others, 1980). The slope of the recession segment of the hydrograph will decrease as the number of floodwater retarding structures where the principal spillways are flowing increases.

Several factors significantly influence the effectiveness of the floodwater retarding structures in reducing peak flow on the main stem downstream from the floodwater retarding structures (Coskun and Moore, 1969; Hartman and others, 1967; Moore, 1969; Schoof and others, 1980). Those factors include rainfall distribution over the watershed, contents of the reservoirs before the storm, and distribution of floodwater retarding structures in the watershed. For example, rainfall occurring only on the basin area controlled by floodwater retarding structures will generally result in greater peak reduction. If the structures are empty before the storm, they are more effective in reducing the flood peak. Structures located in the upper end of an elongated basin are less effective than those in a fan shaped watershed.

Acknowledgments

William H. Asquith, USGS, provided technical advice and assistance in applying the regression analyses. Alan Rea, USGS, provided technical advice and assistance in applying the Oklahoma digital elevation model and other digital data to check and compute various streamflow-gaging station basin characteristics.

Estimation of Peak-Streamflow Frequency for Gaged Sites on Natural Unregulated Streams

This section describes the data utilized and the procedures applied in the computation of station peak- streamflow frequency relations at gaged natural unregulated sites.

The curvilinear relation between flood peak magnitude to annual exceedance probability, or recurrence interval, is commonly referred to as a peak-streamflow frequency curve. Annual exceedance probability is the probability of a given flood magnitude being equaled or exceeded in any one year. Recurrence interval is the reciprocal of the annual exceedance probability, and represents the average number of years between exceedances. For instance, a flood having an annual exceedance probability of 0.01 has a recurrence interval of 100 years. This does not imply that the 100-year flood will be equaled or exceeded each 100 years, but that it will be equaled or exceeded on the *average* of once every 100 years (Thomas and Corley, 1977). In fact, it might be exceeded in successive years, or more than once in the same year. The probability of this happening is called risk. The procedures for making risk estimates are given by the Interagency Advisory Committee on Water Data (IACWD) (1982).

The IACWD provides a standard procedure for peak-streamflow frequency estimation that involves a standard frequency distribution, the log-Pearson Type III (LPIII) distribution. The LPIII distribution uses systematically collected and historical peak-streamflow values to define its frequency distribution. The curvature in the shape of the distribution is defined by a skew coefficient that is used in the estimation procedure.

Because of variation in the climatic and physiographic characteristics in Oklahoma and the bordering areas, the LPIII distribution does not always adequately define a suitable distribution of peak-streamflow values. An inappropriate fit of the LPIII distribution to the distribution of peak-streamflow data, the distribution of the data is defined by Weibull plotting positions (Chow and others, 1988), can produce erroneous values for peak-streamflow frequency. Therefore, for the estimation of peak-streamflow frequency for the stations used in this study, historical flood information (where available), low-outlier thresholds, and skew coefficients were all considered following IACWD guidelines. Peak-streamflow frequency estimates of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year floods and the LPIII analysis information for these estimates are given for each station used in this study in table 1 (in back of report).

The following sections discuss which station data were used in the estimation of peak-streamflow frequency for natural streams and the use of historical flood information, estimation of low-outlier thresholds, and use of skew coefficients in these peak-streamflow frequency estimations for the stations in Oklahoma and the bordering areas.

Annual Peak Data

The first step in peak-streamflow frequency (or flood frequency) analysis is to collate and review all pertinent annual peak discharge data. Oklahoma stations and stations in the bordering states of Arkansas, Kansas, Missouri, New Mexico, and Texas in the Arkansas-Red River basins were reviewed. This was done to eliminate discrepancies across state lines (or the "state-line fault") and to account for data in the immediate bordering areas of a state with similar hydrology.

The station flood-frequency analysis for natural unregulated streams of less than 2,510 mi^2 drainage area presented in this report is based on annual peak flow data systematically collected at 251 gaging stations. The data were collected based on a water year, October 1 through September 30. The data were collected through September 30, 1995, for stations used in this study. The locations of these gaging stations are shown in figure 1. In this analysis, only those stations with at least 8 years of flood peak data were used in the analysis. Asquith and Slade (1997) also utilized much of this data to expand the station data analyzed. The IACWD recommends at least 10 years of data (IACWD, 1982); therefore, these data were carefully reviewed and only 9 stations with less than 10 years of data were retained. All station data are free of significant effects from regulation by major dams or floodwater retarding structures and other man-made modification of streamflow. Significant regulation by dams or floodwater retarding structures is defined as 20 percent or more of the contributing drainage basin regulated (Heimann and Tortorelli, 1988). A summary of drainage area distribution and average observed length of record per station for those stations used in the regression analysis is given in table 2.

Historical Peak Streamflows

In addition to the collection of peak-streamflow data in Oklahoma, the USGS routinely collects, through newspaper accounts and interviews with local residents, information about historical peak streamflows and historical peak stages, so historical peak elevations above mean sea level can be determined. A historical peak streamflow is the highest peak streamflow since a known date preceding the installation of the station; historical peak streamflow can occur either before or after installation of a station. Historical information is critical for evaluating peak-streamflow frequency estimates for the larger recurrence intervals. Many historical peak streamflows are associated with catastrophic storms. These large storms can cause some flood peaks to exceed those that can be estimated accurately by analyses of available precipitation or annual peak-streamflow data alone. Therefore, the next step in peak-streamflow frequency analyses is to include historical data where available.

Historical peak-streamflow data are available for about 30 percent of the 251 Oklahoma and border-state stations included in this study; historical peak-stage data also are available for many stations. The mean historical record length is 52 years, and about 6 percent of the 251 stations have historical record

Table 2. Summary of drainage area distribution and average observed length of record

Drainage area (square miles)	Number of stations							Average observed length of record (years)
		Border states						
	Oklahoma	Arkansas	Kansas	Missouri	New Mexico	Texas	Total	
0.1 to less than 1	12	4	4	1			21	22
1 to less than 5	26	1	6	1		1	35	18
5 to less than 10	19	3	6	1			29	20
10 to less than 50	28	7	11	1			47	22
50 to less than 100	6	1	1			1	9	19
100 to less than 500	33	7	10	3		5	58	30
500 to less than 1,000	19		8	1	1		29	32
1,000 to 2,510	18		3	1		1	23	38
Total	161	23	49	9	1	8	251	26

lengths equal to or exceeding 80 years. Inclusion of historical peak streamflow in frequency estimations is done by the specification of a high-outlier threshold and a historical record length. The historical record length, high-outlier threshold, and number of high outliers (historical peak discharges) for some of the 251 stations are listed in table 1.

Special consideration of historical information was done for a small number of stations as indicated by the footnotes in table 1. These considerations were necessary to produce more reliable peak-streamflow frequency analyses for these stations. For many of these stations (generally those with short periods of record), one of the systematic peak discharges is considerably larger than the other peak discharges; that peak is historically significant. Although no official documentation of the historical significance of that peak discharge is available, a historical perspective was developed through consideration of flood information from pertinent nearby stations. For the remaining stations, the footnotes document the historical adjustments used to produce a better fit of the LPIII distribution to the peak-streamflow data.

Low-Outlier Thresholds

The next step in peak-streamflow frequency analyses is to determine low outlier thresholds. The climatic and physiographic characteristics of Oklahoma occasionally produce extremely small annual peak-streamflow values (low outliers). Typically, low outliers are identified by visually fitting the LPIII distribution curve to the distribution of the peak-streamflow data. The presence of low outliers in the data can substantially affect the distribution curve; therefore, the fit of the LPIII distribution to the data should be adjusted to account for the presence of low outliers. All peak-streamflow values (including zero) below the threshold are excluded from the fitting of the LPIII distribution.

The IACWD guidelines provide a procedure for low-outlier threshold selection; however, the IACWD procedure for low-outlier threshold estimation may not produce appropriate low-outlier thresholds for stations with natural basins. Therefore, the preliminary LPIII distribution for each station was then visually inspected and some stations were assigned a low-outlier threshold based on that inspection. The low-outlier thresholds for appropriate stations are listed in table 1.

Skew Coefficients

Determining skew coefficients is the next step in peak-streamflow frequency analyses. The skew coefficient is difficult to estimate reliably for stations with short periods of record. Therefore, the IACWD recommends applying a weighted skew coefficient to the LPIII distribution. This skew coefficient is calculated by weighting the skew coefficient computed from the peak-streamflow data at the station (station skew) and 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 each of the two skew coefficients.

The IACWD guidelines recommend three types of skew coefficients be used with peak-streamflow frequency estimation. These coefficients are (1) the station skew coefficient calculated from only the systematic record with appropriate adjustments for high and low outliers, if applicable; (2) the

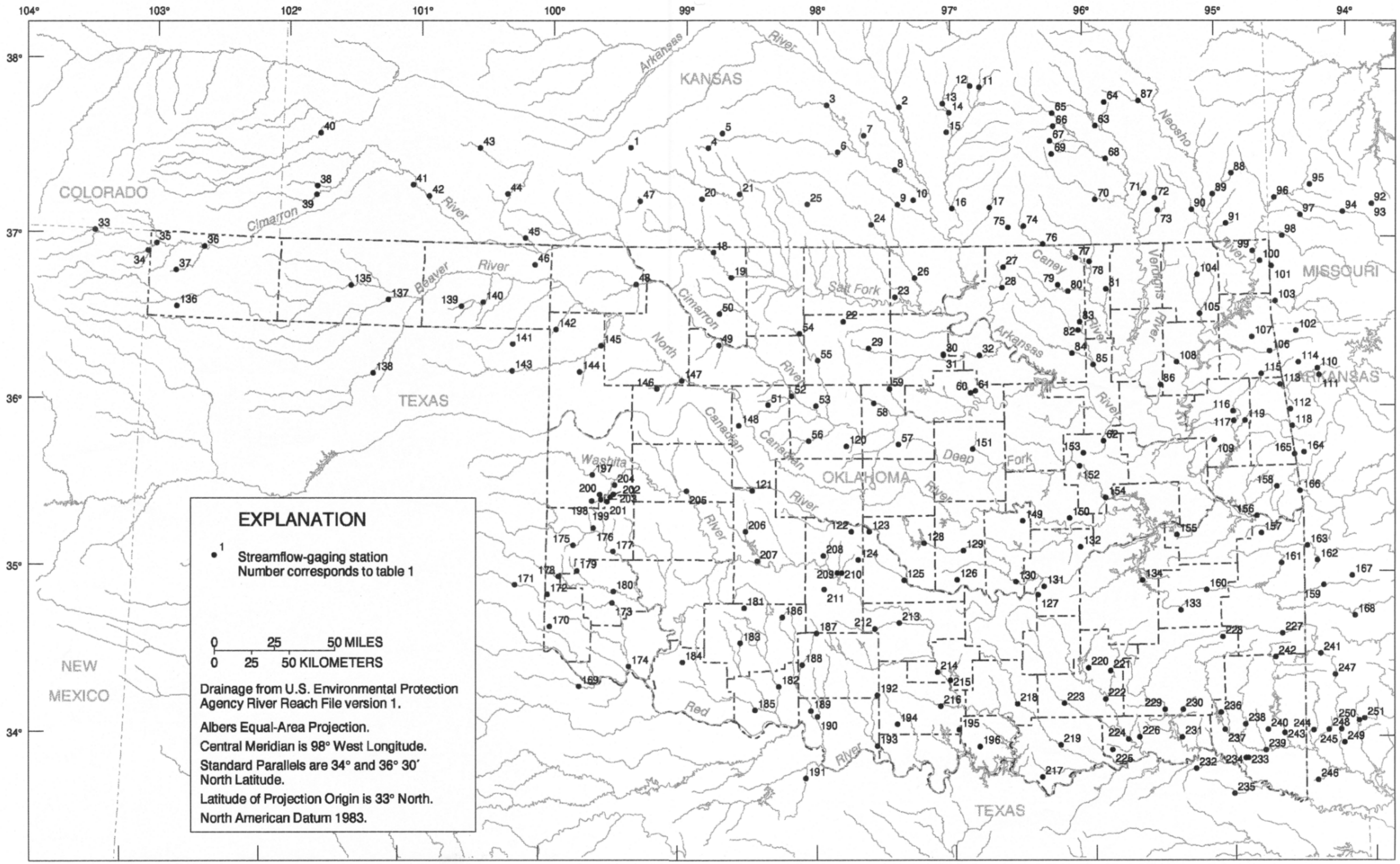


Figure 1. Location of streamflow-gaging stations with unregulated periods of record used in study.

generalized skew coefficient from the IACWD or locally developed generalized skew map (Interagency Advisory Committee on Water Data, 1982); and (3) the weighted skew coefficient, calculated using the IACWD generalized skew or locally developed generalized skew and station skew coefficients.

A study of generalized skew coefficients was done for Oklahoma (Tortorelli and Bergman, 1985) that used adjusted station skew coefficients from stations with at least 20 years of peak-streamflow data and drainage basins greater than 10 mi^2 and less than 2,510 mi^2 with streamflow data through 1980. The Tortorelli and Bergman (1985) study updates the generalized skew coefficients recommended by the IACWD (based on data through 1973). The stations used to develop the Oklahoma generalized skew map are noted in table 1 with footnote 9. Updating this generalized skew map was not part of this project; however, a check of the standard error of the generalized skew using the stations used to develop the generalized skew map and updated streamflow records through 1995, indicated the standard error value of 0.33 was still valid. That value was used to weight the station and generalized skews. The map presented herein, is slightly modified from Tortorelli and Bergman (1985) to resolve a mapping error in the northwest part of the area while retaining the same distribution of values (fig. 2). The generalized skew values for all stations were obtained by using a data set grid based on this map and rounding to the nearest 0.05.

The weighted skew coefficient generally is preferred for peak-streamflow frequency estimations. The station skew and weighted skew are listed in table 1 for each station. Weighted skew coefficients (station skews weighted with generalized skews from Tortorelli and Bergman (1985)) were used for all stations used in this study.

Regression Equations for Estimation of Peak-Streamflow Frequency for Ungaged Sites on Natural Unregulated Streams

This section describes the data utilized and the procedures applied in analyzing the peak-streamflow data. The technical details of the analyses are described including the regression analysis of the station peak-streamflow frequency at gaged sites on natural unregulated streams, and the testing of assumptions and applicability of the regression analysis. Limitations on the use of the regression equations and the reliability of regression estimates for natural unregulated streams are discussed.

Regression Analysis

Estimates of flood magnitude and frequency commonly are needed at ungaged sites. Therefore, it is necessary to transfer flood frequency data from gaged sites on natural unregulated streams to ungaged sites. This can be achieved by defining regression equations that relate peak discharges of selected frequencies to basin or climatic characteristics measured from maps or taken from readily available reports (Thomas and Corley, 1977).

Multiple-linear regression analysis was used to establish the statistical relations between one dependent and one or more independent variables. The 2-, 5-, 10-, 25-, 50-, 100- and 500-year peak discharges, respectively, were used as dependent variables, and the selected basin and climatic characteristics were used as independent variables. Logarithmic transformations of the dependent and independent variables were used to increase the linearity between the dependent and independent variables.

A forward stepwise weighted least-squares (WLS) regression procedure was used for the development of the equations to estimate peak-streamflow frequency for ungaged stream sites in natural basins. The WLS regression procedure has been shown to be more accurate than the ordinary least squares regression for predicting hydrologic statistics (Stedinger and Tasker, 1985). In WLS regression, each data point can be given a weight different from the others; these weights generally are representative of the relative accuracy of each value for the dependent variable; greater weights are assigned to values that have greater accuracy (Helsel and Hirsch, 1992).

Weights used in the analyses are based on the years of record of streamflow data at sites used in this study, with an adjustment for length of historical record. Empirical equations (G. D. Tasker, U. S. Geological Survey, written commun., 1994) based on Monte Carlo simulations (Tasker and Thomas, 1978; Stedinger and Cohn, 1986) were used to calculate a weight factor, which represents an equivalent "years of record" for each station with historical information. This weight factor is based on the length of systematic record, length of historical record, and number of high outliers; the weight factors in table 1 were used as the weights for the WLS regression procedure.

In forward stepwise regression, the independent variable having the highest mathematical correlation to the dependent variable is entered into the equation, and successively, the remaining independent variables are tested for their statistical significance to the dependent variable. Each independent variable that tests as statistically significant (F ratio > 1.5) is entered into the equation. Thus, each independent variable (a basin or climatic characteristic) in the final equation is considered statistically significant, and its inclusion contributes to the explanation of the variance in the dependent variable (the peak discharge).

Selected Basin and Climatic Characteristics

A variety of parameters were investigated in the multiple regression analysis to find the most suitable relations to estimate flood peak discharges. The parameters investigated as possible predictors of flood discharge are shown in table 3 and are available in a USGS basin and streamflow characteristics computer file (U.S. Geological Survey, 1983). Most of the parameters were readily available for gaging stations. Excep-

Table 3. Parameters investigated as possible predictors of flood discharge for natural unregulated streams

Parameter Code Name	Description of parameter
A	Contributing drainage area of the study site, in square miles; does not include noncontributing areas.
LENGTH	Main-channel length, in miles, measured along channel from the study site to the basin divide.
SHAPE	Shape factor, dimensionless, computed by $\mathbf{LENGTH}^2$/A
S	Main-channel slope, in feet per mile, measured between points that are 10 percent and 85 percent of the main-channel length upstream from the study site.
P	Point mean-annual precipitation for the period 1961-90, in inches, at the study site (Daly and others, 1994).
AWP	Area-weighted mean-annual precipitation for the period 1961-90, in inches, over the contributing drainage area (Daly and others, 1994).
I24,2	Rainfall, in inches, for the 24-hour, 2-year recurrence interval, determined from Hershfield, 1961.
LAT GAGE	Latitude of study site, in decimal degrees.
LNG GAGE	Longitude of study site, in decimal degrees.

tions are the updated point and area-weighted values for mean-annual precipitation, which are explained below. The shape factor is a dimensionless parameter computed as $(\mathbf{LENGTH})^2/\mathbf{A}$ (table 3). The values for the basin and climatic characteristics of the sites used in this study are listed in table 1.

The climatic parameter of mean-annual precipitation proved to be very significant as a predictor parameter in past analyses (Sauer, 1974a; Thomas and Corley, 1977; Tortorelli and Bergman, 1985); therefore, an updated data set was utilized. A nationwide data set grid based on the period 1961-90 was obtained from Oregon State University (Daly and others, 1994). The cell size is 2.5 minutes of latitude and longitude (about 3X3 mi in Oklahoma). A map of mean-annual precipitation drawn from these data is presented in figure 3. These data enabled the testing of both a point (at the gage site) and an area-weighted value for mean-annual precipitation.

A geographic information system (GIS) was used in conjunction with a Digital Elevation Model of Oklahoma (DEM) (Cederstrand and Rea, 1995) to define drainage basin areas in Oklahoma and parts of Arkansas, Kansas, and Texas. In the bordering areas of Arkansas, Kansas, Missouri, and Texas not covered by the DEM, the drainage areas were manually delineated on the GIS using the stream network. These drainage areas were used in conjunction with the mean-annual precipitation data grid to compute area-weighted mean-annual precipitation. Sites with drainage areas less than 0.1 mi^2 were not used because they exerted a disproportionate amount of leverage on the regression analysis.

Models Investigated

It was decided to investigate 100-year statewide two-parameter and three-parameter models and three- parameter models with divided data sets. The 100-year equation was used as the comparison because it is the frequency of most interest. The increase in accuracy achieved beyond three parameters was found to be so small that this was the limit set on number of predictor parameters.

The two-parameter statewide models used contributing drainage area and another parameter (table 3) in order of decreasing accuracy (percent error):

1. **A** and **AWP**
2. **A** and **P**
3. **A** and **LNG GAGE**

These two-parameter models had very similar accuracy. The area-weighted mean-annual precipitation had the best accuracy by less than 1 percent compared to point mean-annual precipitation and by less than 1.5 percent compared to longitude.

Longitude was used instead of a climatic characteristic to test the theory proposed by Asquith and Slade (1997). They proposed that the inclusion of climatic characteristics into an equation often causes other basin characteristics to be excluded. Their inclusion might produce more statistically "robust" equations (any significant variables are present in the equation), but the equation consequently can produce less reliable peak-streamflow frequency estimates (the robust equation does not produce intuitively appropriate peak discharges) (Asquith and Slade, 1997).

For example, two nearby watersheds, having similar contributing drainage areas, will have similar climatic characteristics because of the proximity of the watersheds. Therefore, equations including the drainage area (drainage area generally is the most predictive basin characteristic of flood peaks) and one of the climatic characteristics will indicate similar peak discharges for each station. However, if the basin shape factor and stream slope are different, the flood characteristics of the two

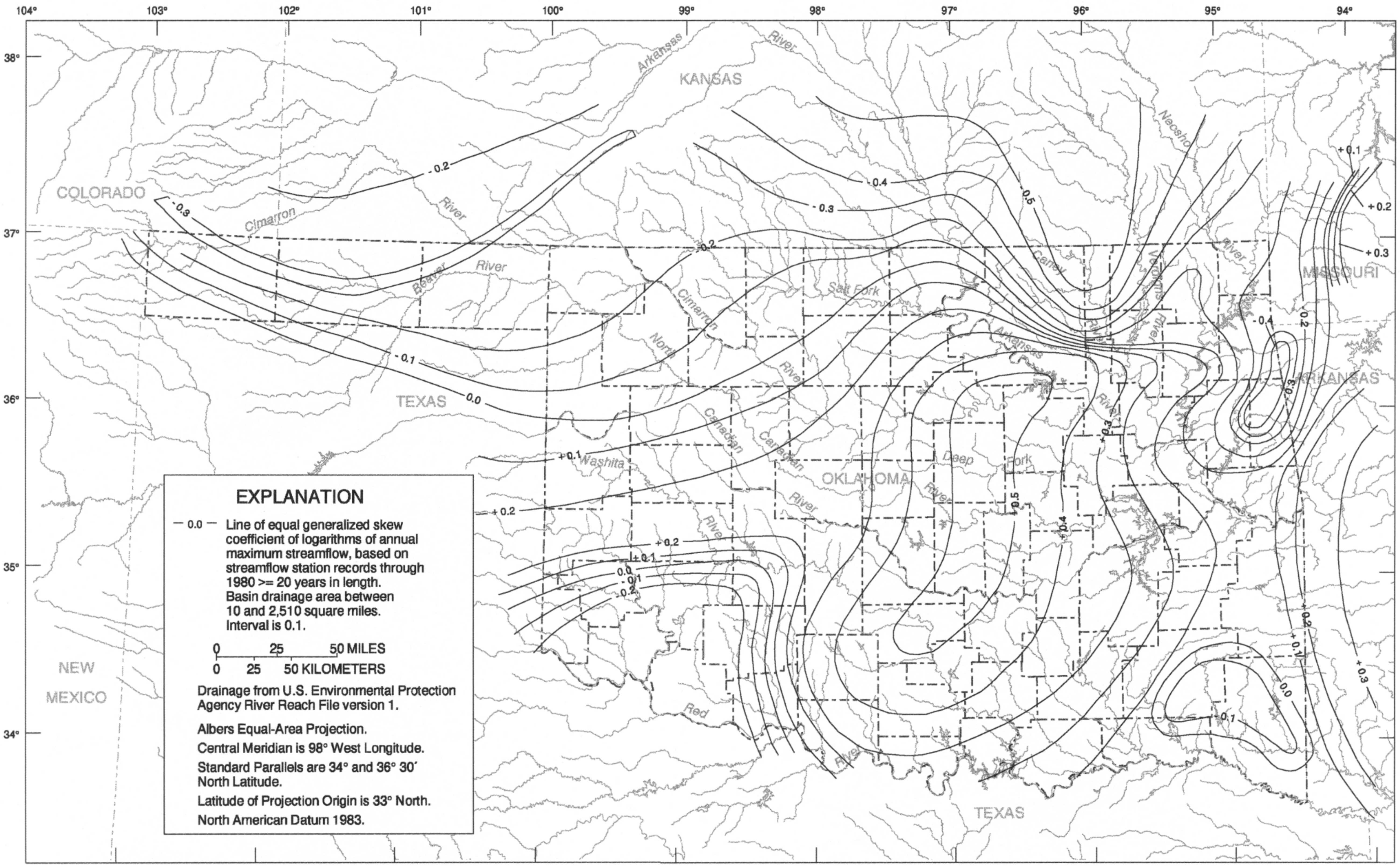


Figure 2. Generalized skew coefficients of logarithms of annual maximum streamflow for Oklahoma streams less than or equal to 2, 510 square miles in drainage area (adapted from Tortorelli and Bergman, 1985).

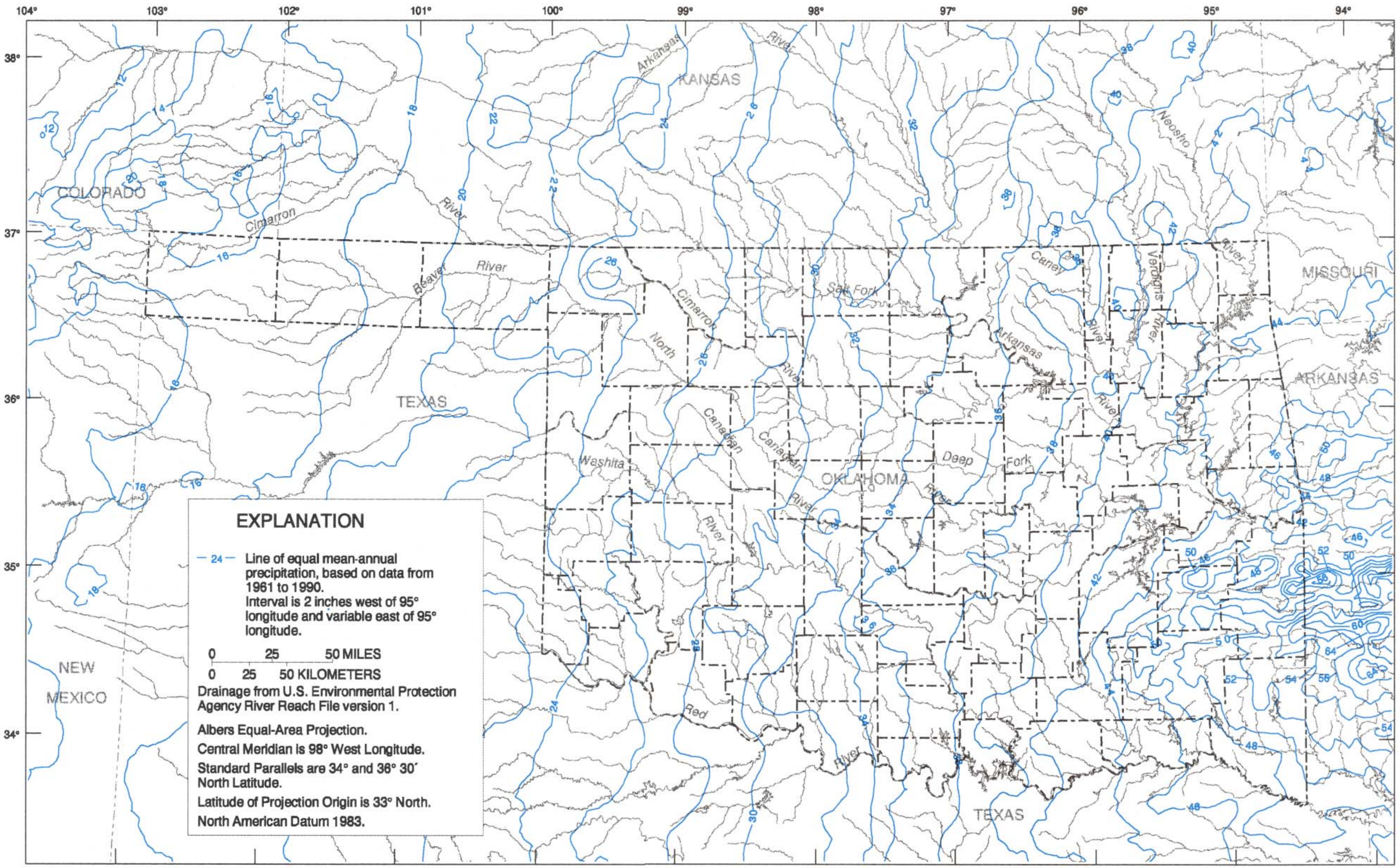


Figure 3. Mean-annual precipitation for the period 1961-90 (adapted from Daly and others, 1994).

stations could be expected to be dissimilar (Asquith and Slade, 1997).

However, any basin characteristic that uses channel length, such as shape factor and main-channel slope, must be used with caution. Measurement of sinuous stream channel lengths on topographic maps can be problematic because the length measured is highly dependent on the scale and amount of generalization of the maps used. For example, the length of a particular reach of stream channel (expressed in ground distance) measured on a 1:250,000-scale map would be shorter than that measured on a 1:100,000-scale map, which would be shorter than that measured on a 1:24,000-scale map. This is because the maps show progressively more detail and sinuosity in the stream channel (A.H. Rea, U.S. Geological Survey, written commun.,1997).

Fletcher and others (1977) and McDermott and Pilgrim (1982) found that these differences in stream length due to map scale were significant in design flood estimation. Both studies found it necessary to include a conversion factor to account for scale dependencies in stream length. USGS topographic maps for large areas (such as Oklahoma) are likely to have been produced over a long time period, under different mapping standards. This can result in considerable variability in density and detail in the streams represented, even on maps of the same scale (A.H. Rea, U.S. Geological Survey, written commun., 1997).

Mandelbrot (1983) hypothesized that area measurements (such as contributing drainage area, the main predictor parameter) do not exhibit such scale dependency. The increasing detail in delineating the boundary tends to both include and exclude areas. The included areas tend to balance with the excluded areas, leaving the total area approximately the same. Hjelmfelt (1988) measured basin areas on maps of three scales for eight basins in Missouri, and concluded that basin area was not influenced by map scale (A.H. Rea, U.S. Geological Survey, written commun., 1997).

The three-parameter statewide models used contributing drainage area, main-channel slope, and another parameter (table 3) in order of decreasing accuracy (percent error):

1. **A**, **S**, and **AWP**
2. **A**, **S**, and **P**
3. **A**, **S**, and **LNG GAGE**

These three-parameter models had very similar accuracy. The area-weighted mean-annual precipitation had the best accuracy by less than 1 percent compared to point mean-annual precipitation and by less than 1.5 percent compared to longitude. Shape factor was added to evaluate a four-parameter step-wise regression in each model, but it was the fourth parameter added and did not improve the accuracy.

One of the three-parameter statewide models investigated in greater detail used contributing drainage area, main-channel slope, and point mean-annual precipitation and divided data sets. This model was tested by dividing the data set as follows:

1. Oklahoma gages only.
2. Dividing the data set into Arkansas and Red River basins.
3. Dividing the data set into drainage areas equal to or less than 32 mi^2 and greater than 32 mi^2.

The first two models had accuracy very similar to the three-parameter model with all the data. The third model indicates some improvement on the greater-than-32-mi^2 subset and poorer accuracy on the equal-to-or-less-than-32-mi^2 subset.

After discussing the comparisons of the models investigated with the cooperator, it was decided to use the three-parameter statewide models using contributing drainage area, main-channel slope, and point mean-annual precipitation. The use of the three-parameter model with area-weighted mean-annual precipitation, or any model with the split of the data set, models 2 and 3 above, (thus doubling the number of required equations) complicates the use of the equations for little or no gain in accuracy. The use of the three-parameter statewide model with Oklahoma data only was not used as it is desirable to include the bordering areas to enhance the prediction capability of the model and preclude discrepancies across state lines.

Tortorelli and Bergman (1985) performed a correlation analysis of possible predictor parameters and provided some insight as to why the two parameters, contributing drainage area and point mean-annual precipitation, are good predictor parameters. The drainage area is highly correlated with stream length in Oklahoma. The mean-annual precipitation is highly correlated with mean basin elevation, forested area, longitude of stream-gaging station and precipitation intensity.

Regression Equations

Multiple-linear regression techniques were used to relate station peak-discharge estimates of the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year floods (table 1) to basin and climatic parameters. Drainage area, main-channel slope, and mean-annual precipitation were the most significant parameters for estimating flood peaks for ungaged natural sites. The three parameters used in the regression equations are listed in table 1 for each station used in the analysis and are (table 3):

1. Drainage area, (**A**) - the contributing drainage area of the basin, in mi^2.
2. Main-channel slope, (**S**) - the main-channel slope, measured at the points that are 10 percent and 85 percent of the main-channel length between the study site and the drainage divide, in ft/mi.
3. Mean-annual precipitation, (**P**) - the point mean-annual precipitation at the study site, from the period 1961-90, in in. (fig. 3).

The model used in the regression analysis has the following form:

$$\log \mathbf{Q}_{\mathbf{x(r)}} = \log a + b \log \mathbf{A} + c \log \mathbf{S} + d \log \mathbf{P} \qquad (1)$$

where $\mathbf{Q_{x(r)}}$ = regression estimate of peak discharge for ungaged sites on natural unregulated streams, for recurrence interval **x**, in ft^3/s,

a = regression constant,

b, **c**, and **d** = regression coefficients,

and **A**, **S**, and **P** = basin and climatic parameters as defined above.

The following equations were computed for natural unregulated streams from the results of the WLS regression analysis:

$$\mathbf{Q_{2(r)}} = 0.075\ \mathbf{A}^{0.615}\ \mathbf{S}^{0.159}\ \mathbf{P}^{2.103} \quad (2)$$

$$\mathbf{Q_{5(r)}} = 0.799\ \mathbf{A}^{0.616}\ \mathbf{S}^{0.173}\ \mathbf{P}^{1.637} \quad (3)$$

$$\mathbf{Q_{10(r)}} = 2.62\ \mathbf{A}^{0.615}\ \mathbf{S}^{0.181}\ \mathbf{P}^{1.404} \quad (4)$$

$$\mathbf{Q_{25(r)}} = 8.80\ \mathbf{A}^{0.614}\ \mathbf{S}^{0.190}\ \mathbf{P}^{1.171} \quad (5)$$

$$\mathbf{Q_{50(r)}} = 18.6\ \mathbf{A}^{0.614}\ \mathbf{S}^{0.197}\ \mathbf{P}^{1.029} \quad (6)$$

$$\mathbf{Q_{100(r)}} = 35.6\ \mathbf{A}^{0.614}\ \mathbf{S}^{0.202}\ \mathbf{P}^{0.907} \quad (7)$$

$$\mathbf{Q_{500(r)}} = 126\ \mathbf{A}^{0.612}\ \mathbf{S}^{0.213}\ \mathbf{P}^{0.674} \quad (8)$$

The above equations are based on inch-pound units of measurements. Substitution of metric values for **A**, **S**, and **P** will **not** provide correct answers. To convert the final answers of discharge from ft^3/s to the metric equivalent of m^3/s, multiply by 0.02832.

To estimate peak discharges for ungaged sites on natural unregulated streams, the first step is to determine the drainage area and main-channel slope from the best available maps, field survey, or digital data (Cederstrand and Rea, 1995). The next step is to determine the point mean-annual precipitation at the study site from figure 3 or digital data (Daly and others, 1994). Then the data are entered in the regression equations 2-8 to obtain the regression estimate of the peak discharge, $\mathbf{Q_{x(r)}}$. Application of equations 2-8 is illustrated in the section “Application of Techniques.”

Assumptions and Applicability of Regression Equations

Plots of the log-residuals, the differences between the log-observed and log-predicted values of the dependent value in the regression, were used to check the linearity of the regression equations (Thomas and Corley, 1977). The log-residual is the base-10 logarithm (log) of the station peak discharge value, for recurrence interval **x**, from table 1 ($\mathbf{Q_{x(s)}}$) minus the log of the regression equation peak discharge value, for recurrence interval **x** ($\mathbf{Q_{x(r)}}$). Log-residuals of the flood peak discharge for the 100-year frequency were plotted against log-contributing drainage areas, log-main-channel slopes, log-point mean-annual precipitations, log-longitudes and log-latitudes. These plots indicated no apparent trend for the log-residuals throughout the range of variables used in the analysis. Therefore, the hypothesis of linearity of the regression equations was accepted.

The regression equations were checked for a possible regionalization effect, or that a positive or negative bias in the log-residuals exists according to geographic regions. The log-residuals of the flood peak discharge for the 100-year frequency were plotted against log-latitudes after dividing the log-residual data set into four quadrants as follows:

Northeast Region	north of 35.5° latitude	east of 97.5° longitude
Southeast Region	south of 35.5° latitude	east of 97.5° longitude
Northwest Region	north of 35.5° latitude	west of 97.5° longitude
Southwest Region	south of 35.5° latitude	west of 97.5° longitude

These plots also did not indicate any apparent regional trends or differences. Therefore, equations 2-8 are considered applicable statewide for Oklahoma within the limitations given in the following section.

Accuracy and Limitations

Two measures of the accuracy of a regression peak-discharge estimate are the adjusted coefficient of determination ($\mathbf{R}^2$) and the weighted standard error of estimate (weighted standard error). $\mathbf{R}^2$ is the proportion of the variability in the dependent variable (station peak discharge, $\mathbf{Q_{x(s)}}$) that is accounted for by the independent variables (the basin and climatic variables **A**, **S**, and **P**)–the larger the $\mathbf{R}^2$ the better the fit of the model-with a value of 1.00 indicating that 100 percent of the variability in the dependent variable is accounted for by the independent variables. The $\mathbf{R}^2$ of the regression equations for each recurrence interval are listed in table 4.

The weighted standard error is a measure of the portion of the variability in the dependent variable that is not accounted for by the independent variables-the smaller the weighted standard error the better the fit of the model-with a value of 0.0 indicating that all the variability in the dependent variable is accounted for by the independent variables. The difference between the regression estimate ($\mathbf{Q_{x(r)}}$) and station peak discharge ($\mathbf{Q_{x(s)}}$) for two-thirds of the estimates will be within plus or minus one weighted standard error expressed in $\log_{10}$ units. The weighted standard errors of the regression equations 2-8 in $\log_{10}$ units are listed in table 4. The weighted standard errors of the regression equations 2-8 in $\log_{10}$ units can then be expressed in two ways-percent or equivalent years of record.

The accuracy in percent is the standard error of the estimate converted to a percent and is the accuracy to be expected,

Table 4. Accuracy of regression equations for unregulated streams

Recurrence interval in years	Adjusted R-squared	Weighted standard error of estimate ($\log_{10}$ units)	Weighted standard error of estimate (percent)	Equivalent years of record
2	0.8780	0.2373	59	3
5	0.9099	0.1937	47	5
10	0.9141	0.1846	45	8
25	0.9108	0.1864	45	11
50	0.9035	0.1929	47	13
100	0.8933	0.2026	49	14
500	0.8605	0.2331	58	14

on average, two-thirds of the time (Hardison, 1971; G.D. Tasker, U.S. Geological Survey, written commun., 1978). The accuracy of the regression equations 2-8 for natural unregulated streams, expressed as percent, is summarized in table 4.

Hardison (1969) and W.O. Thomas, Jr. (U.S. Geological Survey, written commun., 1980) related the standard error and streamflow variability to equivalent years of record. When converted to equivalent years of record, the standard error reflects the number of years of streamflow record that is needed at an ungaged site to provide an estimate equal in accuracy to the standard error of the regression equation. The accuracy of the regression equations 2-8 for natural unregulated streams, expressed as equivalent years, is summarized in table 4.

The statewide regression equations for natural unregulated streams are applicable for watersheds with drainage areas less than 2,510 mi^2 that are not significantly affected by regulation from manmade works. The equations are intended for use on natural streams in Oklahoma and should not be used outside the range of the predictor parameters used in the analysis:

A	equal to or greater than 0.144 mi^2	less than or equal to 2,510 mi^2
S	equal to or greater than 1.89 ft/mi	less than or equal to 288 ft/mi
P	equal to or greater than 15.0 in.	less than or equal to 55.2 in.

Due to the small data set with drainage areas less than 1.0 mi^2 (table 2), caution should be exercised when predicting peak-streamflow frequency estimates for very small drainage areas.

Estimates from equations 2-8 can be adjusted to account for the effect of regulation from small floodwater retarding structures. The same cautions are applicable as with natural unregulated drainage basin peak-discharge estimates. The adjusted equations can be used when the percent of regulated drainage area is not greater than 86 percent of the basin, which is the upper limit of the range of regulated data used to check the validity of the adjustment (Tortorelli and Bergman, 1985). The adjusted equations should be used only for those portions of a watershed regulated by NRCS-built floodwater retarding structures and are not applicable to any other type of floodwater retarding structures. The description of floodwater retarding structures is explained earlier in the report in the section "General description and effects of floodwater retarding structures." The adjusted equations are not meant to replace site-specific information when only one pond is present on the watershed immediately upstream of the point of interest. When the percent of regulated drainage area is greater than 86 percent of the basin, it is suggested that flow routing techniques, such as outlined in Chow and others (1988), be used.

Application of Techniques

This section briefly outlines the techniques to use the regression equations presented in this report for making a weighted peak-streamflow frequency estimate for gaged sites on natural unregulated streams with a drainage area of less than 2,510 mi^2 in Oklahoma, and using this result to make an estimate for a nearby ungaged site on the same stream. For ungaged sites on urban streams, an adjustment of the statewide regression equations for natural unregulated streams can be used to estimate peak-streamflow frequency. For ungaged sites on streams regulated by floodwater retarding structures, an adjustment of the statewide regression equations for natural unregulated streams can be used to estimate peak-streamflow frequency. The statewide regression equations are adjusted by substituting the drainage area below the floodwater retarding structures, or drainage area that represents the percentage of the unregulated basin, in the contributing drainage area parameter to obtain peak-streamflow frequency estimates.

Weighted Peak-Streamflow Frequency Estimates for Gaged Sites on Natural Unregulated Streams

It is suggested that peak-streamflow frequency estimates for gaged sites on natural unregulated streams are combinations of station data and regression estimates. The estimates weighted by years of record are considered more reliable than either the regression or station data when making estimates of flood frequency relations at gaged sites (Sauer, 1974a; Thomas and Corley, 1977). The equivalent years of record concept is used to combine station estimates with regression estimates to obtain weighted estimates of peak flow at a gaged site.

The location of the gaging stations with unregulated periods of record used in the study are shown in fig. 1. Use figure 1 to obtain the site number of the station of interest. For this site number, obtain the appropriate station peak-discharge value, flood discharge or $\mathbf{Q_{x(s)}}$, for recurrence interval **x**, from table 1. The stations that have unregulated periods of record, but are now regulated, are noted with footnote 10 in table 1. If the station of interest is still unregulated, then this peak discharge value is used with the regression estimate $\mathbf{Q_{x(r)}}$ in a weighting procedure that is illustrated later in the report in the section "Examples of techniques."

This method was described by Sauer (1974a) and Thomas and Corley (1977) and is expressed in the following equation:

$$\mathbf{Q_{x(w)} = [Q_{x(s)}\,(N) + Q_{x(r)}\,(E)] / (N + E)} \qquad (9)$$

where $\mathbf{Q_{x(w)}}$ = the weighted estimate of peak discharge, for recurrence interval **x**, in ft^3/s,
$\mathbf{Q_{x(s)}}$ = the station estimate of peak discharge, for recurrence interval **x** (table 1), in ft^3/s,
$\mathbf{Q_{x(r)}}$ = the regression estimate of peak discharge, for recurrence interval **x** (equations 2-8), in ft^3/s,
N = number of actual years record at the gaged site (table 1),
E = equivalent years of record for recurrence interval **x** (table 4).

Peak-Streamflow Frequency Estimates for Ungaged Sites Near Gaged Sites on Natural Unregulated Streams

The combined use of the regression equations and the station data can estimate the magnitude and frequency of floods for ungaged sites near gaging stations and on the same stream. The following procedure is suggested for use if the ungaged site has a drainage area within 50 percent of the drainage area of the gaging station. The ratio, $\mathbf{R_w}$, represents the correction needed to adjust the regression estimate, $\mathbf{Q_{x(r)}}$, to the weighted estimate, $\mathbf{Q_{x(w)}}$, at the gaged site:

$$R_w = \frac{Q_{x(w)}}{Q_{w(r)}} \qquad (10)$$

where $\mathbf{Q_{x(w)}}$ is the weighted estimate of peak discharge at the gaged site, for recurrence interval **x** (equation 9), in ft^3/s,
and $\mathbf{Q_{x(r)}}$ is the regression estimate of peak discharge at the gaged site, for recurrence interval **x** (equations 2-8), in ft^3/s.

$\mathbf{R_w}$ is then used to determine the correction factor $\mathbf{R_c}$ for the ungaged site. The following equation derived by Sauer (1974a) gives the correction factor $\mathbf{R_c}$, for an ungaged site that is near a gaged site on the same stream,

$$R_c = R_w - \frac{\Delta A}{0.5 A_g}(R_w - 1.00) \qquad (11)$$

where $\Delta\mathbf{A}$ is the difference between the drainage areas of the gaged and ungaged sites,
and $\mathbf{A_g}$ is the drainage area of the gaged site.

The regression estimate, $\mathbf{Q_{x(r)}}$, for the ungaged site is multiplied by the correction factor $\mathbf{R_c}$ to improve the estimate by using nearby station data. An example of this technique is presented in "Examples of techniques." If the drainage area of the ungaged site is 50 percent more than or less than that of the gaged site (that is, $\Delta\mathbf{A}/\mathbf{A_g}$ is greater than 0.5) equation 9 should not be used and the regression equations 2-8 should be used without adjustment.

If the drainage area of the ungaged site is within 50 percent of two gaged sites, the frequency calculations for the ungaged site can be made by interpolation of the weighted station values ($\mathbf{Q_{x(w)}}$) for each gaged site. Interpolation should be on the basis of drainage area.

If the flood discharges for the ungaged site are affected by urbanization, they should be modified by techniques given in the following section "Adjustment for ungaged sites on urban streams."

Adjustment for Ungaged Sites on Urban Streams

For estimating flood magnitude and frequency for ungaged sites on urban streams, the percentage of the basin impervious and the percentage of the basin served by storm sewers is required in addition to the variables needed for ungaged sites on natural unregulated streams. The percentage of the basin that is impervious can be determined from aerial photographs, recent USGS topographic maps, or field surveys. The percentage of the basin served by storm sewers should be determined from the best available storm sewer and drainage map.

After determining the percentages of the basin impervious and served by storm sewers, obtain $\mathbf{R_L}$, the urban adjustment factor, from figure 4 (Leopold, 1968). The urban adjustment factor, $\mathbf{R_L}$, is the ratio of the mean annual flood under urban conditions to that under rural conditions. The following equations computed by Sauer (1974b) can be used to adjust estimates from equations 2-8 to urban conditions:

$$Q_{2(u)} = R_L\, Q_{2(r)} \quad (12)$$

$$Q_{5(u)} = 1.60\,(R_L\text{-}1)\, Q_{2(r)} + 0.167\,(7\text{-}R_L)\, Q_{5(r)} \quad (13)$$

$$Q_{10(u)} = 1.87\,(R_L\text{-}1)\, Q_{2(r)} + 0.167\,(7\text{-}R_L)\, Q_{10(r)} \quad (14)$$

$$Q_{25(u)} = 2.21\,(R_L\text{-}1)\, Q_{2(r)} + 0.167\,(7\text{-}R_L)\, Q_{25(r)} \quad (15)$$

$$Q_{50(u)} = 2.46\,(R_L\text{-}1)\, Q_{2(r)} + 0.167\,(7\text{-}R_L)\, Q_{50(r)} \quad (16)$$

$$Q_{100(u)} = 2.72\,(R_L\text{-}1)\, Q_{2(r)} + 0.167\,(7\text{-}R_L)\, Q_{100(r)} \quad (17)$$

$$Q_{500(u)} = 3.30\,(R_L\text{-}1)\, Q_{2(r)} + 0.167\,(7\text{-}R_L)\, Q_{500(r)} \quad (18)$$

where $\mathbf{Q_{x(u)}}$ = the adjusted regression estimate of peak discharge for ungaged sites on urban streams, for recurrence interval **x**, in ft^3/s,
$\mathbf{R_L}$ = urban adjustment factor (fig. 4), and
$\mathbf{Q_{x(r)}}$ = the regression estimate of peak discharge for ungaged sites on natural unregulated streams, for recurrence interval **x** (equations 2-8), in ft^3/s.

A nationwide seven-parameter urban adjustment equation set is presented in Jennings and others (1994). These may be compared to or used instead of the above Oklahoma equations.

Adjustment for Ungaged Sites on Streams Regulated by Floodwater Retarding Structures

When estimating flood magnitude and frequency in basins regulated by floodwater retarding structures, an adjustment should be made. The regression estimate of peak discharge for ungaged sites on regulated streams, or $\mathbf{F_{x(r)}}$, for recurrence interval **x**, can be computed from equations 2-8 by substituting the drainage area of the unregulated portion of the basin or drainage area below the floodwater retarding structures, $\mathbf{A_u}$, for **A**. A complete discussion of the analysis can be seen in Tortorelli and Bergman (1985). Slope was not considered in the Tortorelli and Bergman (1985) analysis. It is suggested that the main-

channel slope for the entire basin be used for a conservative answer (this will give a larger value than using main-channel slope below floodwater retarding structures only).

If there are floodwater retarding structures regulating less than 86 percent of the basin, use the following equations to adjust the regression estimate of peak discharge of ungaged sites on natural unregulated streams:

$$\mathbf{F_{2(r)}} = 0.075\, \mathbf{Au}^{0.615}\, \mathbf{S}^{0.159}\, \mathbf{P}^{2.103} \quad (19)$$

$$\mathbf{F_{5(r)}} = 0.799\, \mathbf{Au}^{0.616}\, \mathbf{S}^{0.173}\, \mathbf{P}^{1.637} \quad (20)$$

$$\mathbf{F_{10(r)}} = 2.62\, \mathbf{Au}^{0.615}\, \mathbf{S}^{0.181}\, \mathbf{P}^{1.404} \quad (21)$$

$$\mathbf{F_{25(r)}} = 8.80\, \mathbf{Au}^{0.614}\, \mathbf{S}^{0.190}\, \mathbf{P}^{1.171} \quad (22)$$

$$\mathbf{F_{50(r)}} = 18.6\, \mathbf{Au}^{0.614}\, \mathbf{S}^{0.197}\, \mathbf{P}^{1.029} \quad (23)$$

$$\mathbf{F_{100(r)}} = 35.6\, \mathbf{Au}^{0.614}\, \mathbf{S}^{0.202}\, \mathbf{P}^{0.907} \quad (24)$$

$$\mathbf{F5_{00(r)}} = 126\, \mathbf{Au}^{0.612}\, \mathbf{S}^{0.213}\, \mathbf{P}^{0.674} \quad (25)$$

where $\mathbf{F_{x(r)}}$ = the regression peak discharge estimate adjusted for floodwater retarding structures, for recurrence interval **x**, in ft^3/s,
$\mathbf{A_u}$ = the contributing drainage area of the unregulated portion of the basin or drainage area below the floodwater retarding structures, in mi^2,
S = the main-channel slope, measured at the points that are 10 percent and 85 percent of the main-channel length between the study site and the drainage divide, in ft/mi, and
P = the point mean-annual precipitation at the study site, for the period 1961-90, in in. (fig. 3).

The adjusted equations can be used when the percent of regulated drainage area is not greater than 86 percent of the basin, which is the upper limit of the range of regulated data used to check the validity of the adjustment (Tortorelli and Bergman, 1985). When the percent of regulated drainage area is greater than 86 percent of the basin, it is suggested that flow routing techniques, such as outlined in Chow and others (1988), be used.

Examples of techniques

The following sections contain specific examples of the application techniques previously described. The concept of the main-channel slope, defined at the 10 and 85 percent points between the site of interest and the drainage divide in ft/mi, may be new to some readers. Because main-channel slope is used in all the regression equations, an example calculation of main-channel slope on a hypothetical drainage basin is presented in figure 5.

Weighted Peak-Streamflow Frequency Estimates for Gaged Sites on Natural Unregulated Streams

The following example illustrates how a weighted estimate is calculated for a gaged site on a natural unregulated stream and how to apply equations 2-8. The example computation is for Turkey Creek near Drummond, Okla., (07159000) and the results are presented in table 5.

The columns $\mathbf{Q_{x(s)}}$ and **N** indicate the computed peak-streamflow frequency relations derived from the 27 years of record at station 07159000 (site 55, table 1). The values in the column labeled $\mathbf{Q_{x(r)}}$ were estimated using equations 2-8 and the following basin and climatic characteristics (table 1):

A = 248 mi^2
S = 5.70 ft/mi
P = 30.8 in.

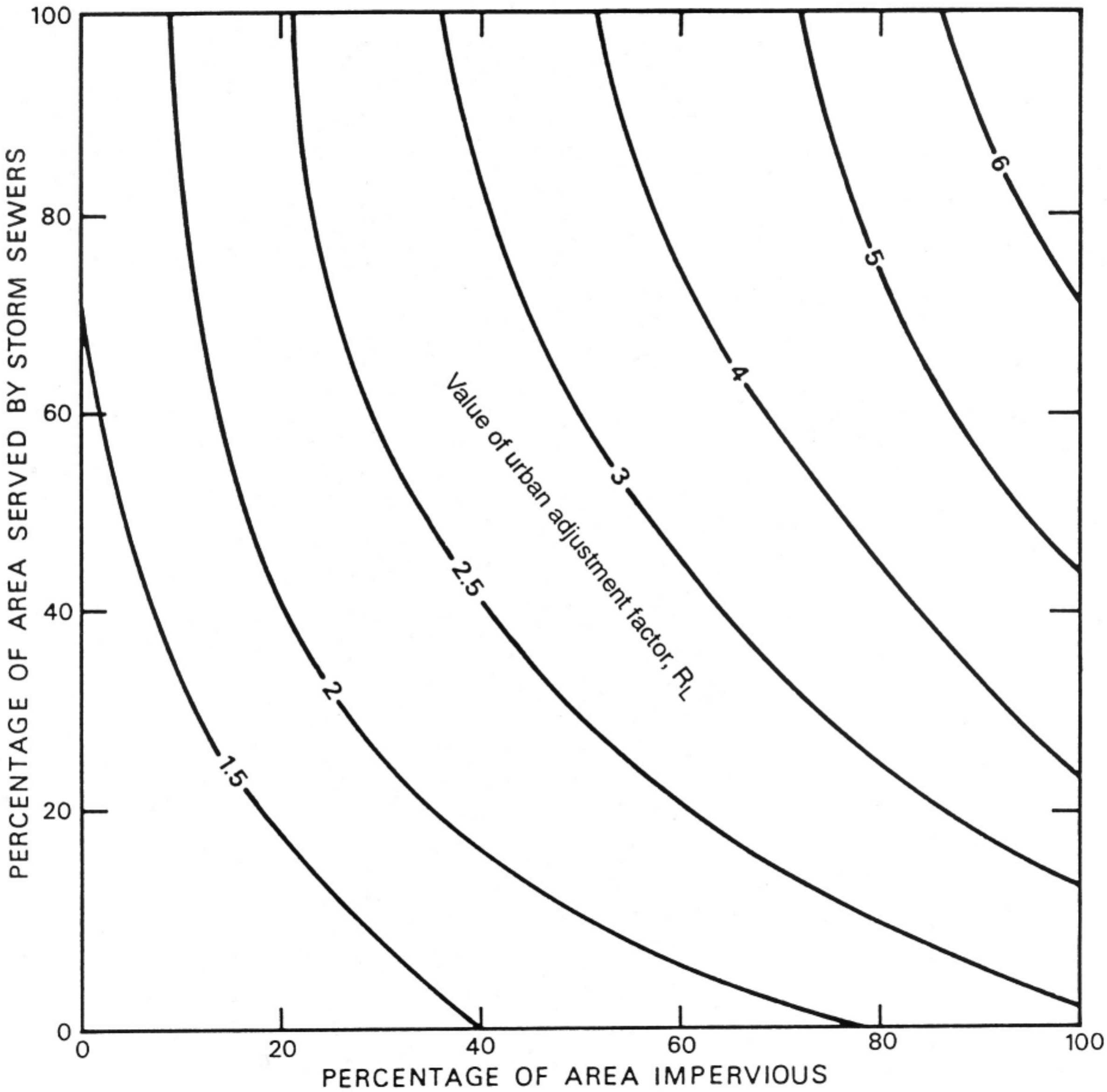
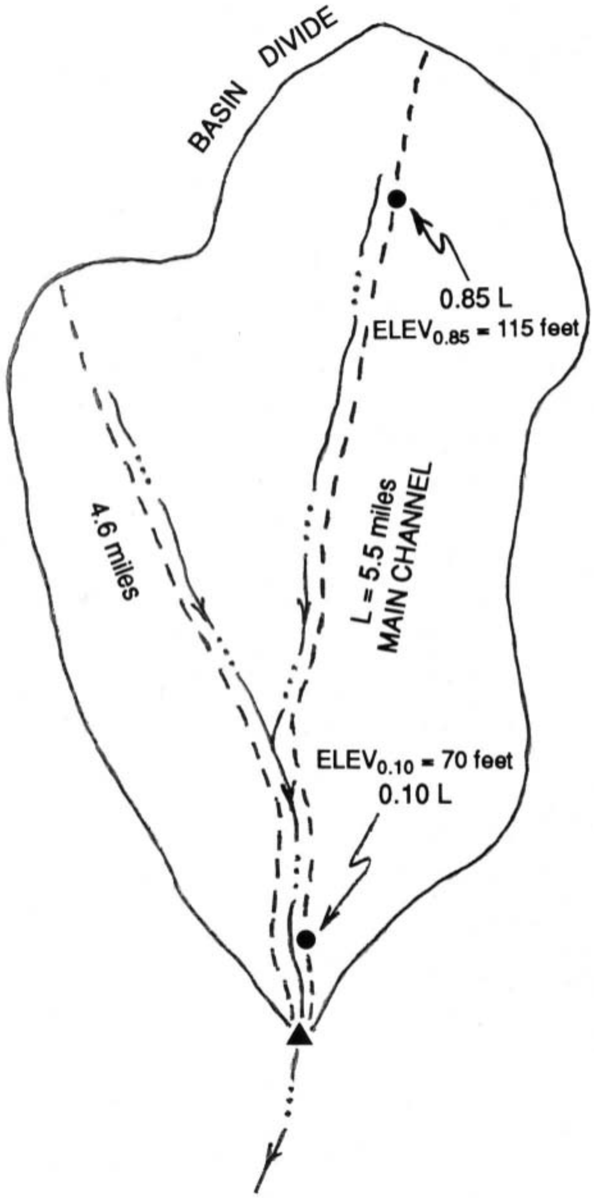


Figure 4. Relationship to urban adjustment factor, R_L, to the percentage of the area impervious, and served by storm sewer (adapted from Leopold, 1968).



EXPLANATION

———	Drainage basin divide
—•••➤—	Stream with flow direction
— — — —	Trace of the stream-channel length from study site to the basin divide
▲	Study site
●	Stream points at 10 percent and 85 percent of main-channel length upstream from study site
L	Main-channel length, or longest stream-channel length, from study site to basin divide, in miles
S	Main-channel slope, in feet per mile
$ELEV_{0.10}$	Streambed elevation at 10 percent of main-channnel length upstream from study site
$ELEV_{0.85}$	Streambed elevation at 85 percent of main-channnel length upstream from study site

EXAMPLE CALCULATION

$$S = \frac{ELEV_{0.85} - ELEV_{0.10}}{0.85\,L - 0.10\,L}$$

$$S = \frac{115 - 70}{4.68 - 0.55}\ \frac{\text{feet}}{\text{mile}}$$

$$S = \frac{45}{4.13} = 10.9 \text{ feet/mile}$$

Figure 5. Example calculation of main-channel slope on a hypothetical drainage basin.

Table 5. Weighted peak-streamflow frequency estimates for Turkey Creek near Drummond, Oklahoma (07159000)

[ft^3/s, cubic feet per second]

Recurrence interval, x (years)	$Q_{x(s)}$ [1] (ft^3/s)	N [2] (years)	$Q_{x(r)}$ [3] (ft^3/s)	E [4] (years)	$Q_{x(w)}$ [5] (ft^3/s)
2	2,630	27	3,970	3	2,760
5	7,200	27	8,810	5	7,450
10	12,200	27	13,100	8	12,400
25	21,500	27	20,000	11	21,100
50	31,100	27	26,300	13	29,500
100	43,300	27	33,500	14	40,000
500	85,000	27	53,700	14	74,300

[1]Station estimate of peak discharge, unregulated basin, for recurrence interval x, table 1.

[2]Number of actual years of streamflow record at gaged site, table 1.

[3]Regression estimate of peak discharge, unregulated basin, for recurrence interval x, equations 2-8.

[4]Equivalent years of unregulated streamflow record for recurrence interval x, table 4.

[5]Weighted estimate of peak discharge, unregulated basin, for recurrence interval x, equation 9.

The $\mathbf{Q_{x(r)}}$ values computed from equations 2-8 are presented in table 5. The weighted estimates, $\mathbf{Q_{x(w)}}$ were computed from equation 9 using the appropriate values of **E** from table 4.

Peak-Streamflow Frequency Estimates for Ungaged Sites Near Gaged Sites on Natural Unregulated Streams

The second example illustrates how to adjust a weighted estimate calculated for a gaged site on a natural unregulated stream for an ungaged site on the same stream. Assume an estimate of the 100-year flood is needed at an ungaged site upstream from station 07159000 on Turkey Creek (table 5). Assume the following hypothetical basin and climatic characteristics:

$\mathbf{A} = 150\ mi^2$
$\mathbf{S} = 10.00$ ft/mi
$\mathbf{P} = 30.0$ in.

The following data and calculations are needed to estimate $\mathbf{Q_{100}}$ at the ungaged site.

1. Gaged site, 07159000, Turkey Creek near Drummond

$\mathbf{A_g} = 248\ mi^2$
$\mathbf{Q_{100(r)}} = 33{,}500\ ft^3/s$, from equation 7, table 5
$\mathbf{Q_{100(w)}} = 40{,}000\ ft^3/s$, from equation 9, table 5
$\mathbf{R_w} = \mathbf{Q_{100(w)}}/\mathbf{Q_{100(r)}} = 1.19$

2. Ungaged site on Turkey Creek

$\mathbf{A} = 150\ mi^2$
$\mathbf{Q_{100(r)}} = 26{,}900\ ft^3/s$, from equation 7
$\Delta\mathbf{A} = 98\ mi^2$

$\frac{\Delta A}{A_g} = 0.40$ (This is less than 0.5, therefore, $\mathbf{R_c}$ should be computed from equation 11 and used to adjust $\mathbf{Q_{100(r)}}$)

$$\mathbf{R_c} = 1.19 - \frac{98}{0.5(248)}(1.19 - 1.00) = 1.04$$

$$\mathbf{Q_{100}} = \mathbf{Q_{100(r)}}\ (\mathbf{R_c}) = 26{,}900\ (1.04) = 28{,}000\ ft^3/s$$

Therefore, the estimate of the 100-year flood at the ungaged site on Turkey Creek is 28,000 ft^3/s after the regression estimate is adjusted for the station data at station 07159000.

Adjustment for Ungaged Sites on urban Streams

For the third example, assume there is an ungaged site on a hypothetical urban stream and an estimate of $\mathbf{Q_{100}}$ is needed under urban conditions. Assume the basin is 60 percent impervious and that 75 percent of the basin is served by storm sewers. The following data and calculations are needed to estimate $\mathbf{Q_{100(u)}}$ for this hypothetical urban site:

$\mathbf{A} = 22.5\ mi^2$
$\mathbf{S} = 15.00$ ft/mi
$\mathbf{P} = 30.0$ in.
$\mathbf{Q_{100(r)}} = 9{,}100\ ft^3/s$, from equation 7 (rural conditions)

$\mathbf{Q_{2(r)}}$ = 1,000 ft^3/s, from equation 2 (rural conditions)
$\mathbf{R_L}$ = 4.0, from figure 4
$\mathbf{Q_{100(u)}}$ = 12,700 ft^3/s, from equation 17 (urban conditions)

Therefore, the estimate of the 100-year flood under urban conditions for this ungaged watershed is 12,700 ft^3/s. This is an increase of 40 percent over the 100-year flood for rural conditions.

Adjustment for Ungaged Sites on Streams Regulated by Floodwater Retarding Structures

The fourth example illustrates how a peak-streamflow estimate is calculated for an ungaged site on a stream regulated by floodwater retarding structures. Assume an estimate of the $\mathbf{Q_{100}}$ is needed for an ungaged site on Uncle John Creek in Kingfisher County regulated by floodwater retarding structures.

To obtain the regression flood-frequency estimate for an ungaged site on a stream regulated by floodwater retarding structures, $\mathbf{F_{100(r)}}$, equation 24 is used. Equation 24 uses $\mathbf{A_u}$, the area of the drainage basin unregulated by floodwater retarding structures, instead of **A**. The following data and calculations are needed to estimate $\mathbf{Q_{100}}$ for the ungaged site on a stream regulated by floodwater retarding structures:

A = 155 mi^2
$\mathbf{A_u}$ = 65.1 mi^2
S = 12.0 ft/mi
P = 31.0 in.

The following step is required to obtain the needed peak discharge estimate:

$\mathbf{F_{100(r)}}$ = 17,200 ft^3/s from equation 24

Therefore, the estimate of the 100-year flood with 58 percent of the basin regulated by floodwater retarding structures is 17,200 ft^3/s.

Summary

Statewide regression equations for Oklahoma were determined to estimate peak discharge and frequency of floods for selected recurrence intervals from 2 to 500 years. The most significant independent variables required to estimate peak-streamflow frequency for natural streams in Oklahoma are contributing drainage area, main-channel slope, and mean-annual precipitation. The regression equations are applicable for watersheds with drainage areas less than 2,510 square miles that are not significantly affected by regulation from manmade works.

Limitations on the use of the regression relations and the reliability of regression estimates for natural unregulated streams are given. Log-Pearson Type III analysis information, basin and climatic characteristics, and the peak-streamflow frequency estimates for 251 gaging stations in Oklahoma and adjacent states are listed.

Mean-annual precipitation proved to be very significant as a predictor parameter in past analyses. Therefore, an updated data set was used because the values in the USGS basin characteristics file are based on the period 1931-60. A nationwide data set grid based on the period 1961-90 was obtained. The cell size is 2.5 minutes of latitude and longitude (about 3X3 mi in Oklahoma). A map of mean-annual precipitation was drawn from these data. These data enabled the testing of both a point (at the gage site) and an area-weighted value for mean-annual precipitation. The area-weighted data did not increase the accuracy of the regression equations significantly.

Techniques are presented to make a peak-streamflow frequency estimate for gaged sites on natural unregulated streams and to use this result to estimate a nearby ungaged site on the same stream. For ungaged sites on urban streams, an adjustment of the statewide regression equations for natural unregulated streams can be used to estimate peak-streamflow frequency. For ungaged sites on streams regulated by small floodwater retarding structures, an adjustment of the statewide regression equations for natural unregulated streams can be used to estimate peak-streamflow frequency. The statewide regression equations are adjusted by substituting the drainage area below the floodwater retarding structures, or drainage area that represents the percentage of the unregulated basin, in the contributing drainage area parameter to obtain peak-streamflow frequency estimates.

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TABLE 1

Table 1. Analyses information, basin and climatic characteristics, and peak-streamflow frequency estimates for selected stations

[yrs, years; ft^3/s, cubic feet per second; LPIII, Log-Pearson Type III; mi^2, square miles; mi, miles; ft/mi, feet per mile; in., inches; wt, weighted; yr, year;

			Analysis information							
Site number (fig. 1)	Station number	Station name	Available systematic record[1] (yrs)	Historical record length[2] (yrs)	Weight factor[3] (yrs)	Number of high outliers	High-outlier threshold[4] (ft^3/s)	Low-outlier threshold[5] (ft^3/s)	Skew coefficient for LP III distribution[6] Station	Weighted
1	07142100	Rattlesnake Creek Trib. near Mullinville, Kans.[9]	33		33			10	-1.127	-0.297
2	07144200	Little Arkansas River at Valley Center, Kans.	78	80	79	1	32,000		-0.683	-0.592
3	07144780	North Fork Ninnescah River above Cheney Res., Kans.	30		30				0.228	-0.231
4	07144850	South Fork South Fork Ninnescah River near Pratt, Kans.	19		19			28	-0.746	-0.222
5	07144900	South Fork Ninnescah River Trib. near Pratt, Kans.	33		33			25	-1.258	-0.323
6	07145200	South Fork Ninnescah River near Murdock, Kans.[9]	45		45			1,300	-0.526	-0.284
7	07145300	Clear Creek near Garden Plain, Kans.	33		33			100	-0.710	-0.549
8	07145500	Ninnescah River near Peck, Kans.[9, 10]	26	41	32	1	70,000		-0.060	-0.094
9	07145700	Slate Creek at Wellington, Kans.[9]	36		36			500	-0.636	-0.376
10	07145800	Antelope Creek Trib. near Dalton, Kans.	34		34				0.000	-0.175
11	07146570	Cole Creek near DeGraff, Kans.	19		19				0.253	-0.289
12	07146700	West Br Walnut River Trib. near DeGraff, Kans.[9]	21		21				0.087	-0.317
13	07147020	Whitewater River Trib. near Towanda, Kans.	32		32			7	-0.694	-0.461
14	07147070	Whitewater River at Towanda, Kans.[9]	33		33				-0.352	-0.444
15	07147200	Dry Creek Trib. near Augusta, Kans.	21		21				0.253	-0.275
16	07147800	Walnut River at Winfield, Kans.[9, 10]	44	89	62	3	35,000	1,250	-1.085	-0.164
17	07148100	Grouse Creek near Dexter, Kans.[9]	30	90	51	1	51,000		0.173	-0.060
18	07148350	Salt Fork Arkansas River near Winchester, Okla.[9]	34	37	35	1	80,000		-0.390	-0.156
19	07148400	Salt Fork Arkansas River near Alva, Okla.	32		32				-0.842	-0.362
20	07148700	Dog Creek near Deerhead, Kans.	21		21				-0.145	-0.218
21	07148800	Medicine Lodge River Trib. near Medicine Lodge, Kans.	21		21			5	-0.730	-0.344
22	07150580	Sand Creek Trib. near Kremlin, Okla.	12	46	25	1	12,000	10	-0.591	0.368
23	07150870	Salt Fork Arkansas River Trib. near Eddy, Okla.	22		22				0.208	0.134
24	07151500	Chikaskia River near Corbin, Kans.[9]	36	73	49	1	35,000	1,000	-0.559	-0.132
25	07151600	Rush Creek near Harper, Kans.	33		33			77	-1.311	-0.296
26	07152000	Chikaskia River near Blackwell, Okla.[9]	60	73	65	1	100,000	2,000	-0.373	0.065
27	07152360	Elm Creek near Foraker, Okla.	12		12			200	-0.648	-0.045
28	07152410	Rock Creek near Shidler, Okla.	8		8				-0.014	-0.044
29	07152520	Black Bear Creek Trib. near Garber, Okla.	12		12			10	-0.106	0.177
30	07152842	Subwatershed W-4 near Morrison, Okla.	22		22			14	-1.240	0.223
31	07152846	Subwatershed W-3 near Morrison, Okla.	25		25			1	-1.184	0.183
32	07153000	Black Bear Creek at Pawnee, Okla.[9, 10]	20	55	33	1	30,200		0.411	0.364
33	07153500	Dry Cimarron River near Guy, N. Mex.[9]	33	34	33	1	46,100		0.461	0.167
34	07154400	Carrizozo Creek near Kenton, Okla.[9]	42		42				-0.197	-0.199
35	07154500	Cimarron River near Kenton, Okla.[9]	45		45			500	-0.458	0.022
36	07155000	Cimarron River above Ute Creek near Boise City, Okla.	13	49	27	1	80,000		0.392	-0.206
37	07155100	Cold Springs Creek near Wheeless, Okla.	18		18				0.096	-0.045
38	07156000	North Fork Cimarron River Trib. near Richfield, Kans.[9]	21		21			12	-0.681	-0.193
39	07156010	North Fork Cimarron River near Richfield, Kans.	15		15				0.364	-0.068
40	07156220	Bear Creek near Johnson, Kans.	29		29				-0.627	-0.303

with at least 8 years of annual peak-streamflow data from natural basins within and near Oklahoma

hr, hour; Trib., Tributary; Res., Reservoir; L., Little; blw, below; SWS, subwatershed]

Basin and climatic characteristics								Peak-streamflow frequency estimates — Peak discharge for indicated recurrence interval (ft^3/s)						
Site number (fig. 1)	Contributing drainage area (mi^2)	Stream length (mi)	Stream shape factor (dimensionless)	Stream slope (ft/mi)	Point mean annual precipitation[7] (in.)	Area-wt mean annual precipitation[8] (in.)	2-yr 24-hr precipitation (in.)	2 yr	5yr	10 yr	25 yr	50 yr	100 yr	500 yr
1	10.3	8.65	7.26	13.10	24.0	24.4	2.80	408	1,100	1,780	2,920	3,960	5,160	8,600
2	1,250.	124.00	12.30	2.30	31.7	30.3	3.30	6,580	14,100	19,900	27,700	33,600	39,500	52,900
3	550.	72.20	9.48	5.85	29.5	27.4	3.00	4,450	13,400	23,300	40,900	58,200	79,300	145,000
4	21.	13.40	8.55	10.60	25.7	25.4	3.00	656	1,580	2,450	3,850	5,100	6,540	10,600
5	1.48	2.70	4.93	18.80	25.6	25.6	3.00	354	699	972	1,360	1,670	1,990	2,810
6	543.	94.70	16.52	7.13	28.9	27.1	3.10	6,510	12,500	17,100	23,700	28,900	34,500	48,400
7	5.03	5.48	5.97	15.30	30.4	30.4	3.40	623	1,070	1,360	1,730	1,990	2,240	2,780
8	1,785.	128.00	9.18	4.80	31.2	28.2	3.20	11,800	20,300	26,800	36,000	43,300	51,100	71,200
9	154.	43.20	12.12	6.08	31.8	30.8	3.50	3,800	7,620	10,600	14,900	18,200	21,700	30,400
10	0.41	1.44	5.06	56.50	31.9	31.9	3.60	131	246	339	471	580	696	1,000
11	30.0	17.70	10.44	7.36	34.0	33.5	3.62	2,140	5,020	7,620	11,600	15,100	19,000	29,700
12	11.0	9.60	8.38	13.15	33.9	33.4	3.60	1,330	2,460	3,310	4,480	5,390	6,330	8,640
13	0.17	0.95	5.31	66.20	33.4	33.4	3.60	84	164	226	309	372	437	589
14	426.	49.20	5.68	4.15	34.2	33.0	3.50	7,720	16,900	24,400	35,100	43,700	52,700	74,800
15	0.90	1.15	1.47	42.90	35.4	35.4	3.60	226	374	478	615	719	824	1,070
16	1,872.	128.00	8.75	2.50	33.7	34.0	3.60	18,100	34,000	46,700	65,100	80,200	96,500	139,000
17	170.	40.20	9.51	8.16	34.5	35.2	3.70	8,370	16,700	23,900	34,800	44,400	55,100	84,900
18	856.	52.50	3.22	15.10	24.9	24.5	3.00	6,690	16,100	25,100	39,800	53,300	69,100	115,000
19	1,009.	70.00	4.86	14.80	26.3	24.6	3.00	7,420	16,100	23,300	33,900	42,600	51,900	75,700
20	5.31	3.45	2.24	30.92	25.3	25.3	3.00	261	932	1,760	3,370	5,070	7,260	14,700
21	2.04	3.02	4.47	27.37	26.5	26.5	3.20	149	485	857	1,520	2,160	2,930	5,260
22	7.21	6.90	6.60	19.30	31.7	31.6	3.60	384	731	1,050	1,580	2,070	2,670	4,560
23	2.35	2.70	3.10	19.80	32.9	32.9	3.60	254	524	774	1,180	1,560	2,020	3,400
24	794.	90.90	10.41	7.79	31.2	28.9	3.30	8,190	16,300	23,200	33,400	42,100	51,800	78,000
25	12.0	10.50	9.19	21.46	28.7	28.6	3.30	1,180	2,290	3,160	4,380	5,370	6,400	9,000
26	1,859.	136.00	9.95	7.25	33.1	30.0	3.40	17,800	36,700	54,000	81,800	107,000	137,000	226,000
27	18.20	9.40	4.85	17.50	35.7	36.1	3.80	2,180	4,640	6,860	10,400	13,600	17,100	27,600
28	9.13	5.40	3.19	35.80	35.9	35.9	3.80	1,630	2,090	2,380	2,730	2,990	3,230	3,780
29	0.97	1.20	1.48	42.30	32.6	32.6	3.50	90	290	547	1,100	1,740	2,640	6,290
30	0.32	0.84	2.21	74.90	33.5	33.5	3.65	130	238	330	474	603	751	1,190
31	0.14	0.66	3.03	104.00	33.5	33.4	3.65	67	182	311	561	829	1,180	2,480
32	576.	71.00	8.75	4.05	35.8	33.7	3.70	6,710	11,700	16,000	22,700	28,800	35,900	57,000
33	545.	54.00	5.35	50.00	16.2	17.1	2.40	2,860	6,760	10,800	17,900	25,100	34,100	64,300
34	111.	34.20	10.54	38.00	16.7	16.8	2.40	1,710	4,620	7,580	12,600	17,400	23,200	40,400
35	1,038.	104.00	10.42	26.20	16.6	17.0	2.40	4,920	11,500	17,900	28,800	39,300	51,900	91,200
36	1,879.	138.00	10.14	21.00	15.0	17.1	2.20	8,600	16,000	21,800	30,100	36,800	43,900	62,000
37	11.0	8.10	5.96	29.10	16.3	16.3	2.40	89	419	938	2,200	3,800	6,200	16,600
38	58.9	23.38	9.28	13.77	16.4	16.4	2.40	746	2,410	4,340	7,970	11,700	16,400	31,700
39	463.	85.40	15.75	16.50	16.5	16.1	2.37	806	3,590	7,760	17,500	29,400	46,800	119,000
40	835.	122.00	17.83	13.90	16.0	15.9	2.35	737	3,210	6,580	13,600	21,400	31,600	67,300

Table 1. Analyses information, basin and climatic characteristics, and peak-streamflow frequency estimates for selected stations

Site number (fig. 1)	Station number	Station name	Analysis information: Available systematic record[1] (yrs)	Historical record length[2] (yrs)	Weight factor[3] (yrs)	Number of high outliers	High-outlier threshold[4] (ft³/s)	Low-outlier threshold[5] (ft³/s)	Skew coefficient for LP III distribution[6]: Station	Weighted
41	07156600	Cimarron River Trib. near Moscow, Kans.	33		33			12	-1.041	-0.405
42	07156700	Cimarron River Trib. near Satanta, Kans.	38		38			16	-0.507	-0.206
43	07157100	Crooked Creek near Copeland, Kans.[9]	33		33			15	-1.211	-0.235
44	07157400	Crooked Creek Trib. at Meade, Kans.	33		33			100	-0.444	-0.364
45	07157500	Crooked Creek near Nye, Kans.	53		53				-0.560	-0.415
46	07157550	West Fork Creek near Knowles, Okla.	22		22			25	-0.273	-0.154
47	07157900	Cavalry Creek at Coldwater, Kans.[9]	32		32				-0.107	-0.197
48	07157960	Buffalo Creek near Lovedale, Okla.	28		28				-0.515	-0.303
49	07158020	Cimarron River Trib. near Lone Wolf, Okla.	12		12				-0.478	-0.135
50	07158080	Sand Creek Trib. near Waynoka, Okla.	12		12				-0.281	-0.137
51	07158180	Salt Creek Trib. near Okeene, Okla.	12	19	15	1	4,500		-0.038	0.072
52	07158400	Salt Creek near Okeene, Okla.	12	23	17	1	12,700		0.433	0.201
53	07158500	Preacher Creek near Dover, Okla.	27	67	42	1	6,420		0.806	0.257
54	07158550	Turkey Creek Trib. near Goltry, Okla.	19		19				0.149	0.043
55	07159000	Turkey Creek near Drummond, Okla.[9]	27	43	34	2	30,000		0.080	0.031
56	07159200	Kingfisher Creek near Kingfisher, Okla.	16		16				0.020	0.152
57	07159810	Watershed W-IV near Guthrie, Okla.	14		14				-0.097	0.244
58	07160500	Skeleton Creek near Lovell, Okla.[9]	46	82	59	1	75,200		0.150	0.166
59	07160550	West Beaver Creek near Orlando, Okla.	22		22				-0.397	0.094
60	07163000	Council Creek near Stillwater, Okla.[9]	60	82	68	1	25,000		0.312	0.356
61	07163020	Corral Creek near Yale, Okla.	12		12				-0.327	0.331
62	07165550	Snake Creek near Bixby, Okla.	15		15			381	-1.370	0.233
63	07166000	Verdigris River near Coyville, Kans.[9, 10]	20		20				-0.039	-0.359
64	07166200	Sandy Creek near Yates, Kans.	38		38				-0.413	-0.465
65	07167000	Fall River near Eureka, Kans.	30	54	40	2	58,000		-1.588	-0.386
66	07167500	Otter Creek at Climax, Kans.	48	92	64	1	107,000	500	-0.998	-0.512
67	07169200	Salt Creek near Severy, Kans.	21		21				-0.736	-0.562
68	07169500	Fall River at Fredonia, Kans.	13	46	27	2	36,000		-0.589	-0.429
69	07169700	Snake Creek near Howard, Kans.	21		21				0.191	-0.290
70	07170000	Elk River near Elk City, Kans.[9]	31	43	36	2	52,000		-0.540	-0.527
71	07170600	Cherry Creek near Cherryvale, Kans.	21		21				0.578	-0.169
72	07170700	Big Hill Creek near Cherryvale, Kans.	23		23				1.307	-0.109
73	07170800	Mud Creek near Mound Valley, Kans.	34		34			175	-0.366	-0.082
74	07171700	Spring Branch near Cedar Vale, Kans.	38		38			17	-1.779	-0.625
75	07171800	Cedar Creek Trib. near Hooser, Kans.	34		34				-0.852	-0.513
76	07172000	Caney River near Elgin, Kans.[9, 10]	26	81	46	1	62,000		-0.933	-0.705
77	07173000	Caney River near Hulah, Okla.[10]	14	25	19	1	51,000		-0.402	-0.490
78	07174200	L. Caney River blw Cotton Creek near Copan, Okla.[9, 10, 11]	20		20			5,000	-0.642	-0.207
79	07174570	Dry Hollow near Pawhuska, Okla.	8		8				-0.381	-0.439
80	07174600	Sand Creek at Okesa, Okla.[9]	34		34				-0.821	-0.571
81	07174720	Hogshooter Creek Trib. near Bartlesville, Okla.	21		21			83	-0.895	-0.482
82	07176500	Bird Creek at Avant, Okla.[9, 10]	32	34	33	1	32,400	3,000	-1.216	-0.292
83	07176800	Candy Creek near Wolco, Okla.	12		12				-0.482	-0.336
84	07177000	Hominy Creek near Skiatook, Okla.[9, 10]	38		38			1,500	-0.835	0.473
85	07177500	Bird Creek near Sperry, Okla.[9, 10]	46		46			2,190	0.216	0.559

with at least 8 years of annual peak-streamflow data from natural basins within and near Oklahoma—Continued

Basin and climatic characteristics								Peak-streamflow frequency estimates						
								Peak discharge for indicated recurrence interval (ft³/s)						
Site number (fig. 1)	Contributing drainage area (mi²)	Stream length (mi)	Stream shape factor (dimensionless)	Stream slope (ft/mi)	Point mean annual precipitation[7] (in.)	Area-wt mean annual precipitation[8] (in.)	2-yr 24-hr precipitation (in.)	2 yr	5yr	10 yr	25 yr	50 yr	100 yr	500 yr
41	8.00	5.75	4.13	29.22	18.6	18.4	2.50	446	1,410	2,450	4,230	5,890	7,830	13,400
42	2.41	3.30	4.52	41.62	18.9	18.9	2.50	245	590	915	1,440	1,910	2,450	4,010
43	44.0	16.20	5.96	11.44	20.4	20.4	2.50	506	1,520	2,630	4,620	6,560	8,920	16,300
44	6.57	5.60	4.77	33.10	21.6	21.6	2.70	338	1,350	2,640	5,160	7,780	11,100	21,700
45	813.	127.00	19.84	4.23	21.6	21.2	2.60	1,040	3,790	7,020	12,900	18,700	25,700	46,900
46	4.22	3.90	3.60	59.20	21.7	21.7	2.70	106	271	435	713	974	1,280	2,220
47	39.0	17.50	7.85	8.61	24.5	24.5	2.90	481	1,280	2,090	3,470	4,770	6,310	10,900
48	408.	38.70	3.67	12.76	25.0	25.2	2.90	1,050	4,110	7,980	15,700	23,800	34,200	68,800
49	4.26	5.30	6.59	37.10	26.4	26.3	3.30	534	771	929	1,130	1,280	1,420	1,770
50	1.61	2.20	3.01	62.40	25.9	25.9	3.20	139	319	487	756	1,000	1,280	2,090
51	8.23	8.00	7.78	30.00	29.2	29.1	3.40	660	1,960	3,500	6,540	9,810	14,200	30,100
52	196.	27.40	3.83	20.15	29.5	28.8	3.50	4,590	7,130	9,060	11,800	14,000	16,500	22,900
53	14.5	9.30	5.96	14.80	30.6	30.7	3.50	200	521	897	1,640	2,440	3,520	7,600
54	5.08	5.30	5.53	19.50	29.0	28.7	3.50	342	999	1,760	3,230	4,790	6,840	14,100
55	248.	39.00	6.13	5.70	30.8	29.6	3.50	2,630	7,200	12,200	21,500	31,100	43,300	85,000
56	157.	23.70	3.58	12.00	29.9	29.0	3.65	2,190	7,270	13,900	28,100	44,700	68,200	163,000
57	0.15	0.68	3.14	116.20	33.2	33.2	3.70	30	80	137	250	371	534	1,140
58	410.	43.40	4.59	8.40	31.5	31.3	3.60	5,090	12,900	21,400	37,100	53,300	74,300	147,000
59	13.9	6.40	2.95	23.80	32.4	32.7	3.70	972	2,190	3,380	5,400	7,330	9,680	17,100
60	31.0	9.00	2.61	17.30	35.3	35.2	3.80	2,150	4,660	7,190	11,700	16,200	21,900	41,500
61	2.89	2.40	1.99	53.90	35.4	35.4	3.80	582	908	1,160	1,530	1,850	2,190	3,150
62	50.0	11.50	2.65	24.30	39.8	40.0	4.00	3,280	5,800	7,930	11,200	14,100	17,400	26,900
63	747.	91.60	11.23	4.98	37.1	36.7	3.70	19,300	43,800	65,000	96,600	123,000	152,000	227,000
64	6.80	6.15	5.56	19.29	38.6	39.4	3.70	1,270	2,050	2,560	3,190	3,640	4,080	5,030
65	307.	38.90	4.93	9.95	37.2	35.5	3.60	12,000	29,000	44,300	67,500	87,300	109,000	166,000
66	129.	27.80	5.99	13.20	36.6	37.0	3.70	8,120	17,800	25,600	36,500	45,100	53,900	74,800
67	7.59	4.30	2.44	21.92	36.9	36.9	3.80	2,730	5,300	7,180	9,620	11,400	13,200	17,200
68	827.	75.80	6.95	5.46	38.3	36.4	3.70	15,600	27,500	35,900	46,700	54,800	62,800	81,200
69	1.84	2.40	3.13	38.44	37.0	37.0	3.80	502	978	1,360	1,890	2,320	2,780	3,920
70	575.	74.60	9.68	5.25	37.9	37.4	3.80	13,900	32,100	47,100	68,400	85,300	103,000	145,000
71	15.0	6.27	2.62	16.52	41.1	41.1	3.90	2,480	4,660	6,410	8,920	11,000	13,200	19,000
72	37.0	24.20	15.83	9.10	41.9	41.0	3.90	3,740	7,020	9,680	13,600	16,800	20,400	29,800
73	4.22	3.48	2.87	25.67	42.6	42.6	3.90	1,270	2,180	2,880	3,850	4,640	5,480	7,650
74	3.10	3.25	3.41	50.05	35.0	35.0	3.80	840	2,160	3,310	4,960	6,280	7,630	10,800
75	0.56	1.53	4.18	165.00	35.4	35.4	3.70	148	334	488	706	880	1,060	1,490
76	445.	60.60	8.25	7.39	38.0	35.9	3.80	13,900	28,400	38,800	52,100	61,600	70,600	89,800
77	736.	72.70	7.18	6.73	35.6	36.4	3.75	14,900	25,600	32,900	42,100	48,800	55,300	69,700
78	502.	50.10	5.00	8.80	36.6	37.7	3.80	13,100	21,100	26,800	34,400	40,200	46,100	60,300
79	1.67	1.80	1.94	83.00	37.6	37.6	3.80	320	607	822	1,110	1,330	1,550	2,070
80	139.	37.00	9.85	13.50	37.7	37.6	3.80	8,260	13,300	16,600	20,400	23,100	25,600	30,900
81	0.94	1.10	1.29	58.20	38.4	38.4	3.90	353	517	618	737	818	895	1,060
82	364.	55.80	8.55	6.22	38.3	38.1	3.80	12,500	19,300	23,900	29,700	34,000	38,200	47,900
83	30.6	10.98	3.94	17.60	38.5	38.9	3.90	5,190	7,910	9,700	11,900	13,500	15,100	18,600
84	340.	46.30	6.30	7.20	38.0	37.2	3.80	8,300	12,800	16,500	21,900	26,600	31,900	46,900
85	905.	85.00	7.98	4.14	38.9	37.8	3.80	14,200	25,600	35,900	52,900	69,000	88,600	152,000

Table 1. Analyses information, basin and climatic characteristics, and peak-streamflow frequency estimates for selected stations

Site number (fig. 1)	Station number	Station name	Analysis information							
			Available systematic record[1] (yrs)	Historical record length[2] (yrs)	Weight factor[3] (yrs)	Number of high outliers	High-outlier threshold[4] (ft^3/s)	Low-outlier threshold[5] (ft^3/s)	Skew coefficient for LP III distribution[6]	
									Station	Weighted
86	07178640	Bull Creek near Inola, Okla.	11		11			400	-1.052	0.001
87	07183100	Owl Creek near Piqua, Kans.	11		11				0.206	-0.362
88	07183800	Limestone Creek near Beulah, Kans.[9]	33		33				-0.513	-0.344
89	07184000	Lightning Creek near McCune, Kans.[9]	45		45				0.588	0.090
90	07184500	Labette Creek near Oswego, Kans.[9]	37	56	45	2	21,000	1,340	-1.189	-0.271
91	07184600	Fly Creek near Faulkner, Kans.[9]	21		21				-0.145	-0.148
92	07185500	Stahl Creek near Miller, Mo.	26		26			138	-0.687	0.083
93	07185600	South Fork Stahl Creek near Miller, Mo.	27		27				0.290	0.297
94	07185700	Spring River at LaRussell, Mo.[9]	23		23				0.356	0.317
95	07185900	O'Possum Creek at Jasper, Mo.	23		23				-0.332	-0.275
96	07186000	Spring River near Waco, Mo.[9, 12]	73	101	84	2	103,000		0.083	-0.061
97	07186400	Center Creek near Carterville, Mo.	28		28				0.452	-0.016
98	07187000	Shoal Creek above Joplin, Mo.[9]	72		72				-0.016	-0.090
99	07188000	Spring River near Quapaw, Okla.[9]	57	101	72	1	180,000		0.050	-0.121
100	07188140	Flint Branch near Peoria, Okla.	22		22				0.483	-0.003
101	07188500	Lost Creek at Seneca, Mo.[9]	29	31	30	1	20,000		0.264	-0.061
102	07188900	Butler Creek Trib. near Gravette, Ark.	21		21			2	-0.956	-0.379
103	07189000	Elk River near Tiff City, Mo.[9]	56		56				-0.469	-0.326
104	07190600	Big Cabin Creek near Pyramid Corners, Okla.	15		15			456	-1.380	-0.093
105	07191000	Big Cabin Creek near Big Cabin, Okla.[9]	55	61	57	1	63,000		-0.123	-0.124
106	07191220	Spavinaw Creek near Sycamore, Okla.[9]	36	116	64	1	39,800		-0.328	-0.418
107	07191260	Brushy Creek near Jay, Okla.	8	10	9	1	4,640		1.093	-0.048
108	07192000	Pryor Creek near Pryor, Okla.[9]	21		21				0.193	0.163
109	07194515	Mill Creek near Park Hill, Okla.	20		20			100	-1.584	-0.086
110	07195000	Osage Creek near Elm Springs, Ark.[9]	30		30			500	-0.429	-0.106
111	07195200	Brush Creek Trib. near Tontitown, Ark.	21		21				-0.332	-0.097
112	07195450	Ballard Creek at Summers, Ark.	24		24				-1.052	-0.403
113	07195500	Illinois River near Watts, Okla.[9]	40		40				-0.477	-0.431
114	07195800	Flint Creek at Springtown, Ark.[9]	35		35				0.198	-0.098
115	07196000	Flint Creek near Kansas, Okla.[9]	36	68	48	1	43,600		-0.205	-0.302
116	07196380	Steely Hollow near Tahlequah, Okla.	11		11				-0.292	-0.218
117	07196500	Illinois River near Tahlequah, Okla.[9]	61	80	68	2	60,000		-0.124	-0.175
118	07196900	Baron Fork at Dutch Mills, Ark.[9]	38		38			389	-1.486	-0.372
119	07197000	Baron Fork at Eldon, Okla.[9]	49	51	50	1	55,500	1,500	-1.435	-0.267
120	07228290	Rough Creek near Thomas, Okla.	22		22			100	-0.512	0.025
121	07228450	Deer Creek Trib. near Hydro, Okla.	12		12				0.518	0.303
122	07228930	Worley Creek near Tuttle, Okla.	15		15			87	-2.470	0.060
123	07228960	Canadian River Trib. near Newcastle, Okla.	11		11				-0.244	0.194
124	07229220	Walnut Creek near Blanchard, Okla.	9		9				-0.501	0.211
125	07229300	Walnut Creek near Purcell, Okla.	28		28			1,500	0.014	0.410
126	07229420	Julian Creek Trib. near Asher, Okla.	21		21			54	-0.434	0.506
127	07229430	Arbeca Creek near Allen, Okla.	11		11			150	-0.584	0.394
128	07230000	Little River blw Lk Thunderbird near Norman, Okla.[10, 13]	12	33	20	1	34,600		1.396	0.620
129	07230500	Little River near Tecumseh, Okla.[9, 10]	21	33	26	1	60,000		1.204	0.680
130	07231000	Little River near Sasakwa, Okla.[10, 13]	19	23	21	1	33,000	3,000	-0.610	0.202

with at least 8 years of annual peak-streamflow data from natural basins within and near Oklahoma—Continued

Basin and climatic characteristics								Peak-streamflow frequency estimates						
								Peak discharge for indicated recurrence interval (ft^3/s)						
Site number (fig. 1)	Contributing drainage area (mi^2)	Stream length (mi)	Stream shape factor (dimensionless)	Stream slope (ft/mi)	Point mean annual precipitation[7] (in.)	Area-wt mean annual precipitation[8] (in.)	2-yr 24-hr precipitation (in.)	2 yr	5yr	10 yr	25 yr	50 yr	100 yr	500 yr
86	10.7	5.80	3.14	12.20	40.9	40.8	4.00	901	1,410	1,780	2,280	2,670	3,090	4,140
87	177.	28.40	4.56	5.87	39.7	39.7	3.80	7,250	14,500	20,200	28,300	34,700	41,400	58,000
88	12.0	6.18	3.18	16.18	42.2	42.7	3.90	3,190	6,550	9,290	13,200	16,400	19,700	28,200
89	197.	45.80	10.65	3.43	41.3	42.3	3.90	7,360	17,300	27,200	44,500	61,300	82,000	149,000
90	211.	34.20	5.54	4.74	41.5	40.8	3.90	8,310	12,900	16,100	20,100	23,100	26,000	32,900
91	27.0	10.60	4.16	7.80	42.0	41.9	4.00	4,170	11,000	18,000	30,000	41,500	55,300	97,500
92	3.86	3.00	2.33	4.13	43.6	43.6	3.90	663	1,070	1,370	1,810	2,160	2,540	3,530
93	0.94	1.40	2.09	66.70	43.6	43.6	3.90	200	396	579	883	1,170	1,520	2,620
94	306.00	32.90	3.54	9.84	43.2	43.5	3.90	5,420	10,800	15,900	24,500	32,700	42,700	74,700
95	9.67	5.50	3.13	16.00	42.9	43.0	3.90	1,190	1,870	2,330	2,930	3,370	3,810	4,840
96	1,164.	72.80	4.55	6.08	42.2	43.3	3.90	18,600	34,300	47,100	65,700	81,400	98,600	145,000
97	232.	48.40	10.10	8.90	42.9	43.1	3.90	5,620	11,500	16,700	24,900	32,200	40,500	64,500
98	410.	57.90	8.18	8.34	42.9	43.2	4.00	7,420	15,400	22,300	33,000	42,300	52,900	82,600
99	2,510.	101.00	4.06	5.93	43.4	43.1	3.90	35,800	64,200	86,300	118,000	143,000	171,000	242,000
100	4.90	3.60	2.64	59.50	43.5	43.5	4.00	786	1,480	2,060	2,940	3,690	4,530	6,860
101	42.0	14.00	4.67	25.20	42.9	43.2	4.00	890	3,140	6,010	11,900	18,500	27,500	60,400
102	0.96	2.00	4.17	109.00	45.1	45.1	4.10	101	296	495	828	1,130	1,490	2,480
103	872.	59.70	4.09	8.05	42.3	43.8	4.00	21,000	42,100	59,100	83,100	103,000	123,000	175,000
104	71.10	15.00	3.16	8.00	42.1	41.9	4.00	4,710	8,470	11,400	15,700	19,200	23,000	32,900
105	450.	43.50	4.21	5.52	42.7	42.5	4.00	16,400	29,000	38,700	52,400	63,600	75,400	106,000
106	133.	22.00	3.64	20.00	44.3	45.2	4.10	3,410	8,530	13,200	20,300	26,400	33,000	50,400
107	16.0	8.60	4.62	31.20	44.0	44.4	4.10	843	2,160	3,530	5,910	8,230	11,100	20,100
108	229.	37.50	6.14	5.52	40.9	41.6	4.00	5,180	11,600	18,100	29,100	40,000	53,300	96,700
109	2.57	2.90	3.27	107.00	44.2	44.6	4.10	433	864	1,230	1,790	2,270	2,810	4,300
110	130.	18.20	2.55	16.90	45.0	45.2	4.00	4,980	10,200	14,800	21,800	27,900	34,700	53,800
111	0.37	1.00	2.70	107.00	44.9	44.9	4.10	63	164	268	449	624	837	1,500
112	14.6	7.20	3.55	41.00	46.4	46.8	4.10	1,700	4,010	6,040	9,090	11,600	14,400	21,600
113	635.	44.50	3.12	8.50	45.4	45.4	4.10	18,500	33,500	44,400	58,700	69,400	80,200	105,000
114	14.20	6.20	2.71	22.70	45.5	45.5	4.10	740	2,000	3,320	5,670	7,960	10,800	19,800
115	110.	23.40	4.98	19.40	45.1	45.4	4.10	3,920	9,930	15,600	24,800	33,000	42,200	68,000
116	3.59	2.60	1.88	110.00	45.2	45.2	4.10	536	1,760	3,190	5,880	8,630	12,100	23,300
117	959.	96.20	9.65	5.33	44.9	45.4	4.10	19,600	39,600	56,300	81,100	102,000	125,000	187,000
118	46.0	11.60	2.93	40.20	46.9	47.6	4.20	6,560	13,100	18,300	25,600	31,400	37,400	52,300
119	307.	38.20	4.75	13.40	44.9	46.2	4.20	14,400	25,400	33,700	44,900	53,600	62,700	84,800
120	10.4	6.30	3.82	41.00	27.8	27.6	3.30	794	2,170	3,690	6,500	9,390	13,100	25,600
121	2.31	1.70	1.25	59.00	29.0	29.0	3.60	304	539	741	1,060	1,340	1,670	2,640
122	11.2	6.30	3.54	19.20	33.7	33.7	3.70	1,260	2,130	2,800	3,770	4,570	5,450	7,780
123	3.32	3.80	4.35	49.10	33.8	33.8	3.70	710	1,180	1,550	2,090	2,550	3,060	4,470
124	1.26	1.30	1.34	70.80	33.8	33.8	3.70	378	666	906	1,270	1,590	1,960	3,000
125	202.	7.20	0.26	7.72	36.9	34.6	3.75	8,750	16,900	24,500	37,400	49,700	64,800	114,000
126	2.28	2.40	2.53	35.00	37.6	37.6	3.80	400	746	1,070	1,610	2,140	2,780	4,870
127	2.26	2.20	2.14	26.60	39.6	39.6	3.90	660	1,210	1,690	2,490	3,220	4,100	6,830
128	257.	24.00	2.24	5.50	36.2	35.1	3.75	5,300	8,500	11,200	15,500	19,400	23,900	37,700
129	456.	42.80	4.02	4.30	37.8	35.9	3.80	9,200	16,800	24,000	36,500	48,800	64,100	116,000
130	865.	95.90	10.63	3.66	38.4	36.9	3.80	15,200	26,900	36,700	51,500	64,500	79,300	122,000

Table 1. Analyses information, basin and climatic characteristics, and peak-streamflow frequency estimates for selected stations

Site number (fig. 1)	Station number	Station name	Analysis information							
			Available systematic record[1] (yrs)	Historical record length[2] (yrs)	Weight factor[3] (yrs)	Number of high outliers	High-outlier threshold[4] (ft^3/s)	Low-outlier threshold[5] (ft^3/s)	Skew coefficient for LP III distribution[6]: Station	Skew coefficient for LP III distribution[6]: Weighted
131	07231320	Leader Creek Trib. near Atwood, Okla.	22		22				0.259	0.357
132	07231560	Middle Creek near Carson, Okla.	11		11			300	-0.978	0.304
133	07231950	Pine Creek near Higgins, Okla.	22		22			575	-0.374	0.092
134	07232000	Gaines Creek near Krebs, Okla.[9]	21	52	33	1	70,000		0.609	0.428
135	07232500	Beaver River near Guymon, Okla.[9]	57		57			500	-0.999	-0.389
136	07232650	Aqua Frio Creek near Felt, Okla.	12		12				-0.389	-0.038
137	07233000	Coldwater Creek near Hardesty, Okla.[9, 14]	38		38			100	-0.230	-0.222
138	07233500	Palo Duro Creek near Spearman, Tex.[9]	35	44	39	2	26,100		0.047	0.145
139	07234050	North Fork Clear Creek near Balko, Okla.	22		22			10	-0.524	-0.265
140	07234100	Clear Creek near Elmwood, Okla.	28		28			100	-0.779	-0.185
141	07234150	White Woman Creek Trib. near Darrouzett, Tex.	9		9				0.072	-0.153
142	07234290	Clear Creek Trib. near Catesby, Okla.	20		20				-0.480	-0.276
143	07235000	Wolf Creek at Lipscomb, Tex.[9]	39		39			100	-0.647	-0.251
144	07235700	Little Wolf Creek near Gage, Okla.	11		11				0.244	-0.073
145	07236000	Wolf Creek near Fargo, Okla.	34	64	45	1	81,600		-0.018	-0.196
146	07237750	Cottonwood Creek near Vici, Okla.	21		21				-0.977	-0.200
147	07237800	Bent Creek near Seiling, Okla.	20		20			935	-0.262	-0.111
148	07239050	North Canadian River Trib. near Eagle City, Okla.	12		12				-0.141	0.089
149	07241880	Sand Creek near Cromwell, Okla.	22		22			220	-2.165	0.336
150	07242160	Alabama Creek near Weleetka, Okla.	19		19			1,000	-1.242	0.216
151	07243000	Dry Creek near Kendrick, Okla.	39		39				0.141	0.343
152	07243500	Deep Fork near Beggs, Okla.[9, 10]	29		29				0.322	0.340
153	07243550	Adams Creek near Beggs, Okla.	20		20			64	-2.030	0.117
154	07244000	Deep Fork near Dewar, Okla.	18	47	30	2	29,000		-0.050	0.203
155	07244790	Brooken Creek near Enterprise, Okla.	11		11				-0.418	0.083
156	07245500	Sallisaw Creek near Sallisaw, Okla.[9, 10]	22		22				0.111	0.104
157	07246610	Pecan Creek near Spiro, Okla.	12		12				-0.095	0.058
158	07246630	Big Black Fox Creek near Long, Okla.	21		21			250	-0.961	-0.067
159	07247000	Poteau River at Cauthron, Ark.[9, 10]	35		35				-0.319	0.031
160	07247500	Fourche Maline near Red Oak, Okla.[9, 10]	26		26				0.089	0.096
161	07249000	Poteau River at Poteau, Okla.	12	23	17	3	21,000		-0.749	0.106
162	07249300	James Fork near Midland, Ark.[14]	20	38	27	1	25,400		0.038	0.145
163	07249400	James Fork near Hackett, Ark.[9]	38		38				0.079	0.175
164	07249500	Cove Creek near Lee Creek, Ark.[9]	46		46				0.196	0.171
165	07249650	Mountain Fork near Evansville, Ark.	20		20				-0.408	-0.041
166	07250000	Lee Creek near Van Buren, Ark.[9]	50	63	55	1	112,000	4,000	-0.350	0.077
167	07258200	Pack Saddle Creek Trib. near Waldron, Ark.	34		34				0.339	0.314
168	07261300	Tan-a-Hill Creek near Boles, Ark.	22		22				0.342	0.313
169	07299670	Groesbeck Creek at S.H. 6 near Quannah, Tex.[9]	34		34			44	-0.779	-0.029
170	07299705	Bitter Creek near Hollis, Okla.	9		9				-0.573	-0.218
171	07300000	Salt Fork Red River near Wellington, Tex.	15	58	31	1	146,000	911	-0.457	0.164
172	07300150	Bear Creek near Vinson, Okla.	22		22			100	-0.725	-0.071
173	07300500	Salt Fork Red River at Magnum, Okla.[9]	58		58			1,020	-0.293	-0.107
174	07301110	Salt Fork Red River near Elmer, Okla.	16		16				0.338	-0.068
175	07301455	Turkey Creek near Erick, Okla.	18		18			200	-1.277	0.031

with at least 8 years of annual peak-streamflow data from natural basins within and near Oklahoma—Continued

Basin and climatic characteristics								Peak-streamflow frequency estimates						
								Peak discharge for indicated recurrence interval (ft^3/s)						
Site number (fig. 1)	Contributing drainage area (mi^2)	Stream length (mi)	Stream shape factor (dimensionless)	Stream slope (ft/mi)	Point mean annual precipitation[7] (in.)	Area-wt mean annual precipitation[8] (in.)	2-yr 24-hr precipitation (in.)	2 yr	5yr	10 yr	25 yr	50 yr	100 yr	500 yr
131	0.72	1.15	1.84	75.20	39.9	39.9	3.90	300	590	868	1,330	1,780	2,330	4,110
132	7.40	4.60	2.86	21.70	40.6	40.6	4.00	1,650	3,030	4,260	6,200	7,980	10,100	16,400
133	9.99	5.10	2.60	62.40	48.1	48.1	4.10	4,150	7,940	11,200	16,300	20,800	26,000	40,900
134	588.	45.40	3.51	4.98	43.6	45.4	4.00	11,600	20,500	28,300	40,900	52,500	66,300	108,000
135	1175.	203.00	35.07	14.80	17.5	16.6	2.40	3,960	13,500	24,200	43,500	62,100	84,400	151,000
136	31.0	15.40	7.65	23.00	16.0	15.6	2.40	131	706	1,690	4,270	7,750	13,200	38,600
137	767.	156.00	31.73	11.40	18.5	17.1	2.60	1,680	5,390	9,630	17,500	25,400	35,200	66,900
138	440.	74.00	12.45	9.83	18.8	17.6	2.70	2,400	6,510	11,200	20,100	29,500	42,000	86,700
139	4.22	4.06	3.91	29.10	20.4	20.4	2.70	59	306	691	1,590	2,660	4,180	10,100
140	170.	26.42	4.11	15.24	21.2	20.6	2.70	1,290	4,710	9,040	17,700	27,100	39,400	82,400
141	4.03	2.16	1.16	7.59	22.6	22.6	2.85	78	210	346	584	813	1,090	1,950
142	8.57	4.10	1.96	34.70	22.3	22.3	2.90	113	462	920	1,860	2,870	4,210	8,800
143	475.	50.00	5.26	10.30	21.2	20.9	2.80	1,277	4,870	9,450	18,600	28,400	41,100	84,500
144	17.8	8.00	3.60	23.00	21.7	22.0	3.00	495	1,400	2,380	4,170	5,980	8,250	15,700
145	1,386.	89.30	5.75	8.96	22.8	21.7	2.80	3,390	8,460	13,400	21,500	28,900	37,600	62,900
146	11.8	7.20	4.39	38.30	25.4	25.6	3.20	436	1,010	1,540	2,380	3,130	3,980	6,380
147	139.	20.00	2.88	16.50	25.6	25.4	3.20	2,280	4,370	6,080	8,610	10,700	13,100	19,300
148	0.52	0.92	1.63	112.00	27.9	27.9	3.40	89	228	378	649	924	1,270	2,460
149	9.48	5.80	3.55	30.60	38.2	38.2	3.90	1,400	2,160	2,760	3,610	4,340	5,130	7,310
150	16.5	7.80	3.69	26.80	39.6	39.4	3.90	2,180	3,350	4,220	5,460	6,470	7,560	10,500
151	69.0	9.00	1.17	11.90	35.3	35.5	3.80	3,870	6,940	9,640	13,900	17,800	22,400	36,200
152	2,018.	145.00	10.42	2.60	39.5	36.4	3.80	9,440	22,600	36,900	63,800	92,100	130,000	265,000
153	5.90	4.40	3.28	32.20	39.6	39.5	3.95	1,090	2,100	2,980	4,360	5,590	7,010	11,200
154	2,307.	186.00	15.00	1.89	40.3	36.8	3.82	11,100	23,600	35,600	56,000	75,400	99,200	175,000
155	5.66	5.00	4.42	40.50	43.7	44.4	4.10	1,840	3,390	4,690	6,660	8,380	10,300	15,800
156	182.	35.00	6.73	15.20	44.3	45.1	4.20	12,700	28,500	43,900	70,100	95,200	126,000	223,000
157	0.90	2.00	4.44	42.00	44.5	44.3	4.20	265	407	511	654	767	886	1,190
158	5.32	3.30	2.05	68.50	45.7	45.8	4.20	865	1,410	1,810	2,370	2,800	3,260	4,430
159	203.	33.60	5.56	9.79	51.7	51.7	4.00	11,000	19,800	26,900	37,400	46,300	56,100	83,000
160	122.	31.80	8.29	3.91	48.0	48.4	4.10	6,560	14,100	21,200	32,900	43,800	56,900	97,300
161	1,240.	100.00	8.06	3.60	45.5	49.2	4.20	22,400	46,000	67,600	103,000	135,000	172,000	286,000
162	44.0	13.00	3.84	46.50	46.1	49.3	4.20	4,890	10,200	15,200	23,400	31,100	40,200	68,600
163	147.	26.90	4.92	14.20	44.4	46.6	4.00	6,350	10,900	14,700	20,300	25,100	30,500	45,600
164	35.30	13.40	5.09	37.00	48.3	48.8	4.00	4,740	9,740	14,400	22,100	29,300	37,900	64,500
165	8.15	5.30	3.45	72.80	47.9	48.9	4.10	1,240	2,450	3,470	5,040	6,390	7,920	12,200
166	426.	53.20	6.64	17.40	45.2	47.6	4.00	23,900	42,000	56,700	78,200	96,600	117,000	173,000
167	0.92	2.10	4.79	58.60	48.6	48.6	4.20	167	299	413	592	754	942	1,510
168	2.33	3.20	4.39	288.00	55.2	55.2	4.20	392	980	1,630	2,880	4,220	6,000	12,600
169	303.	44.20	6.45	7.54	24.6	23.2	3.40	1,870	5,020	8,380	14,500	20,500	28,100	53,000
170	11.1	6.60	3.92	40.80	23.3	23.2	3.20	129	389	674	1,190	1,690	2,310	4,250
171	1,013.	84.00	6.97	16.50	22.1	22.1	3.00	16,500	38,500	60,800	100,000	139,000	188,000	349,000
172	7.24	5.00	3.45	41.90	23.1	23.1	3.20	661	1,620	2,570	4,180	5,700	7,530	13,100
173	1,357.	132.00	12.84	13.80	25.9	22.3	3.00	12,400	24,600	34,900	50,200	63,400	78,000	118,000
174	1,669.	164.00	16.12	13.00	25.7	23.1	3.50	8,920	20,600	31,600	49,700	66,500	86,200	145,000
175	19.8	7.00	2.47	17.70	24.6	24.7	3.10	1,020	1,940	2,720	3,910	4,940	6,110	9,410

Table 1. Analyses information, basin and climatic characteristics, and peak-streamflow frequency estimates for selected stations

Site number (fig. 1)	Station number	Station name	Analysis information							
			Available systematic record[1] (yrs)	Historical record length[2] (yrs)	Weight factor[3] (yrs)	Number of high outliers	High-outlier threshold[4] (ft^3/s)	Low-outlier threshold[5] (ft^3/s)	Skew coefficient for LP III distribution[6]	
									Station	Weighted
176	07301480	Short Creek near Sayre, Okla.	20		20				0.262	0.254
177	07301500	North Fork Red River near Carter, Okla.[9, 16]	66	72	68	1	28,000		-0.580	-0.216
178	07303400	Elm Fork of North Fork Red River near Carl, Okla.[9]	21	36	27	1	62,300	462	-0.438	0.265
179	07303450	Deer Creek near Plainview, Okla.	12		12			250	-0.669	-0.008
180	07303500	Elm Fork of North Fork Red River near Magnum, Okla.[9]	29	72	45	1	30,600	1,000	-0.548	-0.317
181	07309480	Canyon Creek near Medicine Park, Okla.	11		11			30	-1.697	-0.350
182	07311000	East Cache Creek near Walters, Okla.[10]	24	56	36	1	28,200	1,000	-1.015	0.021
183	07311200	Blue Beaver Creek near Cache, Okla.	31	89	52	1	13,600	114	-0.383	-0.087
184	07311420	Deadman Creek Trib. at Manitou, Okla.	8	11	9	1	900		-0.238	-0.218
185	07311500	Deep Red Creek near Randlett, Okla.[9]	44	88	60	1	72,300	1,200	0.028	-0.065
186	07312850	Nine Mile Beaver Creek near Elgin, Okla.	22		22			100	-0.606	0.003
187	07312950	Little Beaver Creek near Marlow, Okla.	12		12				0.238	0.327
188	07313000	Little Beaver Creek near Duncan, Okla.[17]	15	89	41	1	47,500	4,000	-0.422	-0.178
189	07313500	Beaver Creek near Waurika, Okla.[9, 10]	24	26	25	1	65,300		0.433	0.358
190	07313600	Cow Creek near Waurika, Okla.[10]	12	23	17	1	29,500		-0.902	0.137
191	07315200	East Fork Little Wichita River near Henrietta, Tex.	32	76	50	3	15,500		0.445	0.217
192	07315680	Cottonwood Creek Trib. near Loco, Okla.	21		21				-0.419	0.166
193	07315700	Mud Creek near Courtney, Okla.[9]	35	39	37	1	30,000		0.228	0.250
194	07315880	Demijohn Creek near Wilson, Okla.	10		10				-0.949	0.145
195	07316130	Wilson Creek Trib. near McMillan, Okla.	11		11				-0.327	0.220
196	07316140	Brier Creek near Powell, Okla.	21		21				0.263	0.289
197	07316500	Washita River near Cheyenne, Okla.[9, 10]	23	27	25	1	52,000		0.108	0.142
198	07317500	Sandstone Creek SWS 16A near Cheyenne, Okla.[18]	21		21				0.337	0.240
199	07318500	Sandstone Creek SWS 14 near Cheyenne, Okla.[18]	12	20	15	1	1,160		-0.220	0.071
200	07319000	Sandstone Creek SWS 17 near Cheyenne, Okla.[18]	20		20			49	-0.858	-0.003
201	07320000	Sandstone Creek SWS 10A near Elk City, Okla.[18]	20		20			200	-1.300	-0.005
202	07321500	Sandstone Creek SWS 3 near Elk City, Okla.[18]	14	19	16	1	1,780	25	-1.159	0.134
203	07322000	Sandstone Creek SWS 9 near Elk City, Okla.[18]	19		19			88	-1.016	0.073
204	07324000	Sandstone Creek SWS 1 near Cheyenne, Okla.[18]	18		18				-0.267	0.074
205	07325000	Washita River near Clinton, Okla.[9, 10]	26	28	27	1	90,000		0.440	0.347
206	07325850	Lake Creek near Eakly, Okla.	9		9				1.008	0.316
207	07326000	Cobb Creek near Fort Cobb, Okla.[10]	19	22	20	1	51,000		0.851	0.272
208	07327150	Salt Creek near Chickasha, Okla.	11		11				0.089	0.218
209	07327420	West Bitter Creek near Tabler, Okla.	15		15			206	-1.523	0.048
210	07327440	East Bitter Creek near Tabler, Okla.[10]	10		10				-0.582	0.147
211	07327490	Little Washita River near Ninnekah, Okla.[9, 10]	22	27	24	1	36,000		0.413	0.411
212	07329000	Rush Creek at Purdy, Okla.[10]	15		15				0.244	0.400
213	07329500	Rush Creek near Maysville, Okla.[10]	11		11				0.003	0.399
214	07329810	Honey Creek near Davis, Okla.	21		21			500	-2.175	0.288
215	07329900	Rock Creek near Dougherty, Okla.[10]	11		11			272	-1.027	0.386
216	07330500	Caddo Creek near Ardmore, Okla.	14		14			926	-1.260	0.178
217	07332070	Rock Creek near Achille, Okla.	10		10				0.587	0.226
218	07332400	Blue River at Milburn, Okla.	22	61	37	1	35,100		-0.426	-0.062
219	07332500	Blue Creek near Blue, Okla.[9]	59		59			1,090	0.022	0.313
220	07333500	Chickasaw Creek near Stringtown, Okla.	19		19			2,000	-1.104	0.177

Table 2. Analyses information, basin and climatic characteristics, and peak-streamflow frequency estimates for selected stations

Site number (fig. 1)	Station number	Station name	Analysis information						Skew coefficient for LP III distribution[6]	
			Available systematic record[1] (yrs)	Historical record length[2] (yrs)	Weight factor[3] (yrs)	Number of high outliers	High-outlier threshold[4] (ft^3/s)	Low-outlier threshold[5] (ft^3/s)	Station	Weighted
221	07333800	McGee Creek near Stringtown, Okla.	20		20			2,180	-1.761	-0.073
222	07334000	Muddy Boggy Creek near Farris, Okla.[9, 10]	22		22			5,350	-0.262	0.250
223	07335000	Clear Boggy Creek near Caney, Okla.[9, 10]	20	24	22	1	54,600		0.050	0.177
224	07335300	Muddy Boggy Creek near Unger, Okla.	13		13				0.124	0.105
225	07335310	Rock Creek near Boswell, Okla.	21		21				-0.685	-0.108
226	07335320	Bokchito Creek near Soper, Okla.	11		11			670	-1.270	-0.107
227	07335700	Kiamichi River near Big Cedar, Okla.	30	81	48	1	21,500		-0.342	-0.195
228	07335760	Kiamichi River Trib. near Albion, Okla.	8		8				0.530	0.080
229	07336500	Kiamichi River near Belzoni, Okla.[9]	47	57	51	1	72,000		-0.147	-0.116
230	07336520	Frazier Creek near Oleta, Okla.	22		22				-0.184	-0.126
231	07336710	Rock Creek near Sawyer, Okla.	11		11				0.156	0.031
232	07336750	Little Pine Creek near Kanawha, Tex.	12	33	20	1	30,200	1,200	-0.142	0.233
233	07336780	Perry Creek near Idabel, Okla.	10		10			714	-0.955	0.189
234	07336785	Bokchito Creek near Garvin, Okla.	12		12			240	-1.071	-0.104
235	07336800	Pecan Bayou near Clarksville, Tex.	17	21	19	1	21,300	1,000	-0.422	0.154
236	07337220	Big Branch near Ringold, Okla.	11		11				0.385	-0.008
237	07337500	Little River near Wright City, Okla.[9, 10]	26		26				-0.042	-0.047
238	07337900	Glover River near Glover, Okla.[9]	35		35				0.340	0.071
239	07338500	Little River blw Lukfata Creek near Idabel, Okla.[9, 10]	39		39				-0.055	-0.052
240	07338520	Yanubbee Creek near Broken Bow, Okla.	22		22				-0.394	-0.187
241	07338700	Twomile Creek near Hatfield, Ark.	21		21				0.394	0.256
242	07338780	Mountain Fork Trib. near Smithville, Okla.	20		20				0.505	0.173
243	07339000	Mountain Fork near Eagletown, Okla.[9, 10]	40	54	45	1	92,000	10,000	-0.469	-0.214
244	07339500	Rolling Fork near DeQueen, Ark.[9, 10]	25	27	26	1	110,000		0.139	0.180
245	07339800	Pepper Creek near DeQueen, Ark.	26		26				-0.503	-0.056
246	07340200	West Flat Creek near Foreman, Ark.	21		21				-0.607	-0.128
247	07340300	Cossatot River near Vandervoort, Ark.	28	35	31	1	48,000		-0.808	-0.078
248	07340500	Cossatot River near DeQueen, Ark.[9, 10]	37		37				0.225	0.210
249	07340530	Mill Slough Trib. near Locksburg, Ark.	24		24			45	-0.351	0.103
250	07341000	Saline River near Dierks, Ark.[9, 10]	34	53	41	1	42,000	1,500	0.113	0.350
251	07341100	Rock Creek near Dierks, Ark.	23		23			350	-0.552	0.135

[1] Available systematic record reflects number of annual peak discharges from natural basins. Many stations became regulated during the period of operation. Regulated annual peak discharges not included in peak-streamflow frequency analysis.

[2] Historical record length reflects that known as of 1995 water year.

[3] Weight factor calculated from empirical equations (G.D. Tasker, 1994 and W.H. Asquith, 1997, U.S. Geological Survey, written commun.)

[4] High-outlier threshold based on available historical streamflow data.

[5] Low-outlier threshold used in frequency analysis; provided by Interagency Advisory Committee on Water Data (1982) or visual by author.

[6] Reflects weighting adjusted station skew with skew value from Oklahoma generalized skew map (fig.2; Tortorelli and Bergman, 1985).

[7] Values at station location derived from gridded mean-annual precipitation based on 1961-90 data (Daly and others, 1994).

[8] Values based on drainage basin area-weighted derived from gridded mean-annual precipitation based on 1961-90 data (Daly and others, 1994).

[9] Station used in construction of Oklahoma generalized skew map (fig. 2; Tortorelli and Bergman, 1985).

[10] Station has an unregulated period of record used in the analysis, but now is regulated.

[11] Frequency analysis includes streamflow record from nearby station 07174000.

[12] Historical record length assumed equal to that for nearby station 07188000.

[13] Historical record length assumed equal to that for nearby station 07230500.

[14] Frequency analysis includes streamflow record from nearby station 07232900.

[15] Historical record length assumed equal to that for nearby station 07249400.

[16] Frequency analysis includes streamflow record from and historical record length assumed equal to that for nearby station 07302000.

[17] Historical record length assumed equal to that for nearby station 07313500.

[18] Streamflow data computed from inflow to floodwater retarding structure.

Table 3. with at least 8 years of annual peak-streamflow data from natural basins within and near Oklahoma—Continued

Basin and climatic characteristics								Peak-streamflow frequency estimates						
								Peak discharge for indicated recurrence interval (ft³/s)						
Site number (fig. 1)	Contributing drainage area (mi²)	Stream length (mi)	Stream shape factor (dimensionless)	Stream slope (ft/mi)	Point mean annual precipitation[7] (in.)	Area-wt mean annual precipitation[8] (in.)	2-yr 24-hr precipitation (in.)	2 yr	5yr	10 yr	25 yr	50 yr	100 yr	500 yr
221	86.6	22.30	5.74	8.33	44.9	46.1	4.00	6,660	8,870	10,300	12,000	13,300	14,500	17,300
222	1,087.	97.70	8.78	3.73	43.1	42.2	4.00	21,400	33,000	41,800	54,500	64,900	76,300	107,000
223	720.	63.90	5.67	6.26	42.2	40.1	3.90	1,400	28,600	42,200	64,600	85,500	111,000	188,000
224	2,273.	136.80	8.23	2.29	43.9	41.7	4.05	21,900	35,900	46,800	62,200	75,000	88,900	126,000
225	0.94	1.30	1.80	22.60	43.8	43.8	4.05	250	428	562	749	899	1,060	1,460
226	16.6	16.60	16.60	4.60	44.9	45.4	4.10	3,230	5,100	6,440	8,240	9,630	11,100	14,600
227	40.1	11.90	3.53	58.90	53.9	56.2	4.25	9,050	14,000	17,400	21,700	25,000	28,400	36,200
228	1.43	2.50	4.37	246.00	49.5	49.6	4.15	222	538	862	1,430	2,000	2,700	5,000
229	1,423.	121.00	10.29	3.08	45.8	48.8	4.00	34,500	49,400	59,400	72,000	81,400	90,800	113,000
230	19.4	7.40	2.82	57.60	47.2	49.1	4.10	2,500	4,570	6,220	8,570	10,500	12,600	18,000
231	3.39	2.60	1.99	34.40	45.9	45.8	4.10	790	1,170	1,440	1,790	2,060	2,350	3,050
232	75.4	20.83	5.75	5.82	46.4	46.3	4.20	5,890	10,100	13,500	18,600	23,000	28,100	42,300
233	7.53	3.20	1.36	31.60	47.6	47.6	4.20	2,220	3,020	3,580	4,310	4,870	5,440	6,860
234	2.96	3.60	4.38	26.30	47.6	47.6	4.25	726	1,020	1,210	1,450	1,630	1,810	2,220
235	100.	20.90	4.37	4.58	46.2	46.9	4.30	4,280	7,210	9,560	13,000	15,900	19,200	28,100
236	1.99	2.20	2.43	84.80	49.0	49.0	4.20	450	857	1,200	1,720	2,160	2,660	4,050
237	645.	76.40	9.05	7.50	47.6	50.3	4.15	30,500	49,700	64,100	83,800	99,500	116,000	158,000
238	315.	42.50	5.73	14.30	49.9	51.6	4.20	28,400	45,800	59,000	77,500	92,600	109,000	151,000
239	1,226.	114.00	10.60	5.13	47.3	50.5	4.20	27,500	46,100	60,100	79,500	95,200	112,000	155,000
240	9.10	4.90	2.64	66.00	50.0	50.9	4.20	1,780	3,110	4,110	5,500	6,600	7,750	10,600
241	16.1	9.50	5.61	48.90	54.2	54.9	4.30	1,960	3,530	4,870	6,950	8,810	11,000	17,300
242	0.68	2.20	7.12	91.40	53.8	53.8	4.20	199	356	488	689	865	1,070	1,640
243	787.	87.50	9.73	6.63	50.0	53.7	4.20	39,400	64,400	82,300	106,000	124,000	143,000	187,000
244	182.	35.10	6.77	18.60	52.0	53.4	4.00	15,700	31,200	45,300	68,100	89,100	114,000	190,000
245	6.41	6.40	6.39	47.70	52.7	52.7	4.40	961	2,400	3,840	6,330	8,720	11,600	20,600
246	10.6	6.78	4.34	12.00	50.0	50.1	4.40	1,540	2,650	3,490	4,660	5,590	6,580	9,100
247	89.6	18.40	3.78	29.90	55.2	58.4	4.30	15,000	26,700	35,800	48,800	59,500	71,000	101,000
248	360.	53.70	8.01	15.50	52.6	56.0	4.00	27,800	46,600	61,800	84,300	104,000	125,000	185,000
249	0.64	1.97	6.06	60.50	51.7	51.7	4.40	189	337	460	643	801	977	1,470
250	121.	35.90	10.65	21.50	53.3	56.9	4.00	9,640	17,900	25,400	37,500	48,800	62,200	104,000
251	9.48	6.40	4.32	50.00	53.7	54.8	4.30	2,160	4,280	6,180	9,220	12,000	15,200	24,900