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Methods for Estimating the Magnitude and Frequency of Peak Streamflows for Unregulated Streams in Oklahoma

Scientific Investigations Report 2010–5137

U.S. Department of the Interior
U.S. Geological Survey

On Cover: Photograph of the Cimarron River near Guthrie (U.S. Geological Survey station number 07160000) taken by Martin Schneider, U.S. Geological staff.

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
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]
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Water year is the 12-month period October 1 through September 30, designated by the calendar year in which the water year ends.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Methods for Estimating the Magnitude and Frequency of Peak Streamflows for Unregulated Streams in Oklahoma

By Jason M. Lewis

Abstract

Peak-streamflow regression equations were determined for estimating flows with exceedance probabilities from 50 to 0.2 percent for the state of Oklahoma. These regression equations incorporate basin characteristics to estimate peak-streamflow magnitude and frequency throughout the state by use of a generalized least squares regression analysis. The most statistically significant independent variables required to estimate peak-streamflow magnitude and frequency for unregulated streams in Oklahoma are contributing drainage area, mean-annual precipitation, and main-channel slope. The regression equations are applicable for watershed basins with drainage areas less than 2,510 square miles that are not affected by regulation. The resulting regression equations had a standard model error ranging from 31 to 46 percent.

Annual-maximum peak flows observed at 231 streamflow-gaging stations through water year 2008 were used for the regression analysis. Gage peak-streamflow estimates were used from previous work unless 2008 gaging-station data were available, in which new peak-streamflow estimates were calculated. The U.S. Geological Survey StreamStats web application was used to obtain the independent variables required for the peak-streamflow regression equations. Limitations on the use of the regression equations and the reliability of regression estimates for natural unregulated streams are described. Log-Person Type III analysis information, basin and climate characteristics, and the peak-streamflow frequency estimates for the 231 gaging stations in and near Oklahoma are listed.

Methodologies are presented to estimate peak streamflows at ungaged sites by using estimates from gaging stations on unregulated streams. For ungaged sites on urban streams and 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 magnitude and frequency.

Introduction

Estimates 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. Estimates of the magnitude and frequency of flooding events, or peak streamflows, are commonly needed at ungaged sites with no streamflow data available. Regional regression equations can be used to estimate peak streamflows at ungaged sites.

The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) has constructed several floodwater retarding structures throughout Oklahoma that regulate flood peaks. Currently (2010), about 2,105 floodwater retarding structures are in more than 120 watershed basins in Oklahoma. On completion of the NRCS watershed protection and flood prevention program (G.W. Utley, Natural Resources Conservation Service, written commun., 1997) about 2,500 floodwater retarding structures will regulate flood peaks for about 8,500 square miles (mi^2) (about 12 percent) of the state. By design, floodwater retarding structures decrease the magnitude of main-stem flood peaks and decrease the rate of runoff recession of single storms (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 (Tortorelli, 1997).

The U.S. Geological Survey (USGS), in cooperation with the Oklahoma Department of Transportation, updated the regression equations for estimating peak-streamflow frequencies for Oklahoma streams with a drainage area less than 2,510 mi^2, as suggested by Tortorelli (1997). The methods used in this report should provide more accurate estimates of peak flows for Oklahoma than previous reports (Tortorelli, 1997; Tortorelli and Bergman, 1985) because of the use of additional data and more rigorous statistical procedures. The generalized least squares (GLS) regression method was used in this report, as opposed to the weighted least squares method used in Tortorelli (1997) to better handle cross-correlation of peak streamflow between gaging stations and differing historic record lengths.

Purpose and Scope

This report presents methods for estimating the magnitude and frequency of peak streamflows for the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent chance exceedance floods for ungaged sites on unregulated streams with drainage areas of less than 2,510 mi^2 in Oklahoma. This report provides methods that can be used to estimate peak-streamflow frequencies for gaging stations on unregulated streams and by using this result to, in turn, estimate nearby ungaged sites on the same stream. Methods used to adjust estimates for ungaged urban streams and streams regulated by floodwater retarding structures also are presented. This report also provides peak streamflow frequency analyses and basin characteristics for all streamflow-gaging stations used in the regression analysis.

Flood-discharge records through the 2008 water year at 231 streamflow-gaging stations throughout Oklahoma and in bordering parts of Arkansas, Kansas, Missouri, and Texas were used to develop statewide peak-streamflow frequency estimate equations. Estimates of peak-streamflow frequency from the 231 gaging stations were related to climatic and physiographic attributes, referred to as basin characteristics, by using multiple-linear regression. The regression equations derived from these analyses provide methods to estimate flood frequencies of unregulated streams.

This report provides methods to estimate peak streamflows for streams with drainage areas less than 2,510 mi^2. Peak-streamflow frequency for streams with greater than or equal to 2,510 mi^2 drainage areas can be estimated by using methods described in Sauer (1974a) and Lewis and Esralew (2009). The Oklahoma generalized skew map (Lewis and Esralew, 2009), a necessary element in the development of the peak-streamflow frequencies for the 231 gaging stations, was updated in 2008. In this report, methods are presented to estimate peak-streamflow frequencies at sites on urban streams (based on Sauer, 1974b) and streams regulated by floodwater retarding structures (based on Tortorelli and Bergman, 1985).

This report supercedes the report by Tortorelli (1997) to estimate peak-streamflow frequencies for unregulated Oklahoma streams with a drainage area less than 2,510 mi^2. The current report incorporates (1) an additional 13 years of annual peak-streamflow data, with major peak-streamflows recorded during water years 1999, 2000, 2004, 2007, and 2008; (2) additional streamflow-gaging stations that now have adequate numbers of years for frequency analysis; (3) removal of gaging stations included in Tortorelli (1997) that were later determined to be influenced by regulation or were outside of the modified study area; (4) basin characteristics determined at each gaging station location by using a geographic information system (GIS); (5) mean-annual precipitation based on an updated period 1971–2000 and an area-weighted average of precipitation for the contributing drainage area, from which a point estimate of mean-annual precipitation was determined; and (6) a GLS regression method shown to be a better method at handling cross-correlation and differing record lengths of peak-streamflow at gaging stations (Tasker and Stedinger, 1989).

General Description and Effects of Floodwater Retarding Structures

This report includes an adjustment for the effects of floodwater retarding structures on peak streamflow because many areas of Oklahoma are regulated by these structures. Floodwater retarding structures built by the NRCS are used in watershed basin protection and flood-prevention programs.

Floodwater retarding structures generally consist 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 a reservoir. Most of the structures built in Oklahoma have release rates of 10 to 15 cubic feet per seconf per square mile ((ft^3/s)/mi^2). The space in a reservoir between the elevation of the principal spillway crest and the emergency spillway crest is used for floodwater detention.

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 as much as 10 days of inundation without destroying the viability of the stand. Second, a 10-day drawdown period will substantially reduce the effect from repetitive storms (Tortorelli, 1997).

Floodwater retarding structures have embankment heights ranging generally from 20 to 60 feet (ft) and drainage areas ranging generally from 1 to 20 mi^2 (Moore, 1969). 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 (Tortorelli, 1997).

The emergency spillway design, including storage above the emergency crest, and capacity of an emergency spillway is influenced by the size of the floodwater retarding structure and the location of the structure in the basin. Design details may be found in the NRCS National Engineering Handbook, Section 4 (U.S. Soil Conservation Service, 1972).

The primary effect of a system of upstream floodwater retarding structures on a basin streamflow hydrograph at a point downstream from the floodwater retarding structures is that flood peak discharge is reduced. This reduction is related to the percentage of the overall basin that is regulated by the floodwater retarding structures (Hartman and others, 1967; Moore, 1969; Moore and Coskun, 1970; DeCoursey, 1975; 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 substantially influence the effectiveness of the floodwater retarding structures in reducing peak flow on the main stem downstream from the floodwater retarding structures (Hartman and others, 1967; Moore, 1969; Moore and Coskun, 1970; Schoof and others, 1980). Those factors include rainfall distribution over the basin, contents of the reservoirs before the storm, and distribution of floodwater retarding structures in the basin. For example, rainfall that is only on the basin area controlled by floodwater retarding structures will generally result in greater peak reduction. The structures are more effective in reducing the flood peak if the structures are empty before the storm. Structures in the upper end of an elongated basin are less effective than structures in a fan-shaped basin (Tortorelli, 1997).

Data Development

Annual Peak Data

The first step in peak-streamflow frequency analysis is the compilation and review of all streamflow-gaging stations with peak-streamflow data. Streamflow-gaging stations selected for analysis (fig. 1) were in 8-digit hydrologic unit boundaries (based on the 8-digit hydrologic unit codes, or HUCs) that were in or were adjacent to the Oklahoma state boundary (*http://www.ncgc.nrcs.usda.gov/products/datasets/watershed/*, accessed June 2009). Review was done to eliminate discrepancies in peak-streamflow data for gages across state lines. Peak-streamflow data from streamflow-gaging stations in the immediate bordering areas of Oklahoma with similar hydrologic characteristics also were selected for regression analysis.

The streamflow-gaging station flood-frequency analysis for natural unregulated streams of less than 2,510 mi^2 drainage area provided in this report is based on annual peak-streamflow data systematically collected at 231 gaging stations (table 1, back of report).

The data were collected on the basis of a water year, from October 1 to September 30. Available data collected through September 30, 2008, were used from streamflow-gaging stations for this report. Only data from those streamflow-gaging stations with at least 8 years of flood peak data were used in the analysis. The Interagency Advisory Committee on Water Data (IACWD) recommends at least 10 years of data (Interagency Advisory Committee on Water Data, 1982). Asquith and Slade (1997) and Tortorelli (1997) used 8 years to utilize more streamflow-gaging stations to improve coverage in certain areas. Data from 8 streamflow-gaging stations with less than 10 years of peak-streamflow record were retained and carefully reviewed. All streamflow-gaging stations selected are on streams that are not substantially regulated by dams and floodwater retarding structures. Substantial regulation is defined as a contributing drainage basin where 20 percent or more of the basin is upstream of dams and floodwater retarding structures (Heimann and Tortorelli, 1988).

Basin Characteristics

Several basin characteristics were investigated for use as potential independent variables in the regression analyses. In this report, the basin characteristics (table 2) are the independent variables and the resulting peak-streamflow frequency values are the dependant variables.

Basin characteristics were calculated for each streamflow-gaging station by using geographic information system (GIS) techniques and the USGS StreamStats application (Ries and others, 2004; Ries and others, 2008, Smith and Esralew, 2010) to ensure consistency and reproducibility. Regression equations and flow statistics at gaging stations are integrated into the USGS StreamStats Web-based tool available at *http://water.usgs.gov/osw/streamstats/index.html*. StreamStats allows users to obtain flow statistics, basin characteristics, and other information for user-selected stream locations. The user can ‘point and click’ on a stream location or a GIS-based interactive map of Oklahoma and StreamStats will delineate the drainage-basin upstream from the selected location, compute basin characteristics, and compute flow statistics at the ungaged stream locations by using regression estimates (Smith and Esralew, 2010).

Selection of the final characteristics were based on several factors including ease of measurement of the characteristic, coefficient of determination (R^2), Mallow’s Cp statistic, multicollinearity, and statistical significance (p-value <0.05) of the independent variables. Multicollinearity among the independent variables was assessed by the variance inflation factor (VIF) that describes correlation among independent variables. Of the possible basin characteristics used in the regression analysis, contributing drainage-basin area (CONTDA), mean annual precipitation (PRECIP), and main channel 10-85 slope (CSL10_85fm) were selected as the most appropriate independent variables for the regression analyses. CONTDA, PRECIP, and CSL10_85fm short names were selected to be consistent with StreamStats terminology.

The contributing drainage-basin area can be defined by a point on a stream to which all areas in the basin contribute runoff. The StreamStats application takes a user-defined outlet on a stream and delineates the drainage basin of the stream at that location. The basin outlet and delineated basin are used as the templates for estimating basin characteristics. The contributing drainage areas calculated by using StreamStats were compared to previously published drainage areas for those streams with gaging stations. The drainage areas were within 2 percent of each other in 95 percent of cases.

Mean-annual precipitation proved to be an influential independent variable in past analyses (Sauer, 1974a; Thomas and Corley, 1977; Tortorelli and Bergman, 1985; Tortorelli, 1997). Mean-annual precipitation data over the drainage basin for the period 1971 to 2000 (PRISM Climate Group, 2008), computed by using an area-weighted method, were used to define a point estimate of mean-annual precipitation for a streamflow gage.

The Oklahoma StreamStats application was used to compute 10–85 channel slope, which is defined as the difference in elevation between points at 10 and 85 percent of the stream length starting from the outlet and along the longest flow path (also referred to as main-channel length). StreamStats computes the longest flow path from the USGS National Hydrography Dataset (NHD) and the corresponding elevations by using a Digital Elevation Model (DEM) from the USGS National Elevation Dataset (NED, U.S. Geological Survey, 2006). The automated slope computation procedures used in StreamStats are similar to the manual computation procedures used by Tortorelli (1997), but generally are more precise because the automated slope computations are performed exclusively on 1:24,000-scale data (Smith and Esralew, U.S. Geological Survey, written commun., 2010) but previous methods used slope computations at different scales. The computed slope is reported in units of feet per mile (ft/mi).

Estimate of Magnitude and Frequency of Peak Streamflows at Streamflow-Gaging Stations on Unregulated Streams

This section describes the procedures applied to estimate peak streamflow at specific frequencies for gaging stations on unregulated streams.

Flood magnitude and frequency can be estimated for a specific gaging station by analysis of peak annual streamflow at that gaging station. These estimates, in the past, have been reported in terms of a T-year flood (for example, 100-year flood) based on the recurrence interval for that flood. The terminology associated with flood-frequency estimates has shifted away from the T-year recurrence interval flood to the P-percent chance exceedance flood. T-year recurrence intervals with corresponding annual exceedance probabilities and P-percent chance exceedances are shown in table 3. Throughout the remaining sections of this report the P-percent chance exceedance terminology will be used to describe peak-streamflow frequency estimates.

Peak Streamflow Frequency

The IACWD provides a standard procedure for peak-streamflow frequency estimate, U.S. Geological Survey Bulletin 17B, that involves a standard frequency distribution, the log-Pearson Type III (LPIII) (Interagency Advisory Committee on Water Data, 1982). Systematically collected and historic peak streamflows are fit to the LPIII distribution. The asymmetry in the shape of the distribution is defined by a skew coefficient that is used in the estimate procedure. Estimates of the P-percent chance exceedance flows can be computed by the following equation:

$$\log Q_x = X + KS, \qquad (1)$$

where

Q_x is the P-percent chance exceedance flow, in cubic feet per second;

X is the mean of the logarithms of the annual peak flows;

K is a factor based on the skew coefficient and the given percent chance exceedance, which can be obtained from appendix 3 in U.S. Geological Survey Bulletin 17B; and

S is the standard deviation of the logarithms (base 10) of the annual peak-streamflows that is a measure of the degree of variation of the annual log of peak-streamflow about the mean log peak-streamflow.

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 (Tortorelli, 1997). To reduce errors in peak-streamflow frequency resulting from a poor LPIII fit, estimates of peak-streamflow frequency for the streamflow-gaging stations evaluated in this report were adjusted based on historic flood information (where available), low-outlier thresholds, and skew coefficients, and IACWD guidelines.

The USGS computer program PEAKFQWin version 5.2.0 was used to compute flood-frequency estimates for the 231 streamflow-gaging stations on unregulated streams evaluated in this report. PEAKFQWin automates many of the analytical procedures recommended in U.S. Geological Survey Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). The PEAKFQWin program and associated documentation can be downloaded from the Web at *http://water.usgs.gov/software/PeakFQ/*. Peak-streamflow frequency estimates of the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent chance exceedances are given in table 1 for each streamflow-gaging station used in this report.

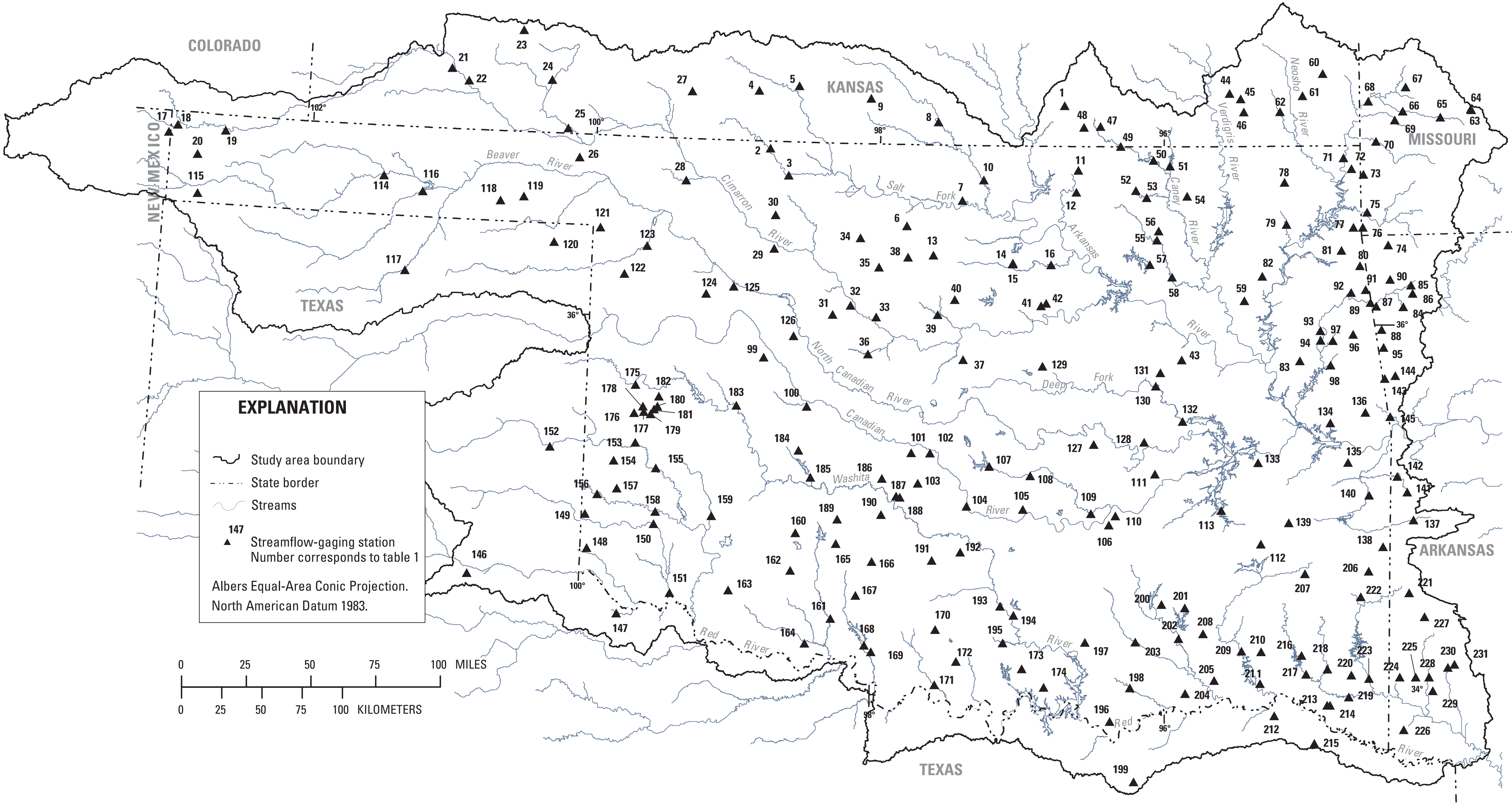


Figure 1. Location of streamflow-gaging stations with unregulated periods of record used in report.

Table 2. Basin characteristics investigated as possible independent variables for regressions used to estimate peak-streamflows for unregulated streams.

(NED, National Elevation Dataset; NHD, National Hydrography Dataset; WBD, Watershed Boundary Dataset; PRISM, Parameter-elevation Regressions on Independent Slopes Model; FWRS, Floodwater Retarding Structures)

Characteristic Name	Units	Method	Source data
Contributing Drainage Area (CONTDA)	Square miles	ArcHydro method	NED 10-meter resolution elevation data (*http://seamless.usgs.gov/index.php*), high resolution NHD (*http://nhdgeo.usgs.gov/viewer/htm*, accessed July 2006) and WBD (source: *http://www.ncgc.nrcs.usda.gov/products/datasets/*watershed/, accessed July 2006)
Mean annual precipitation 1971–2000 (PRECIP)	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008
Main-channel slope (CSL10_85_fm)	Feet per mile	ArcHydro method of computing stream slope from points 10 and 85 percent of the distance from the site to the basin divide, along the main channel	NED 10-meter resolution elevation data (*http://seamless.usgs.gov/index.php*), and high resolution NHD (*http://nhdgeo.usgs.gov/viewer.htm*, accessed July 2006)
Drainage area behind FWRS	Square miles	ArcHydro method	NED 10-meter resolution elevation data (*http://seamless.usgs.gov/index.php*), high resolution NHD (*http://nhdgeo.usgs.gov/viewer/htm*, accessed July 2006) and WBD (source: http://www.ncgc.nrcs.usda.gov/products/datasets/watershed/, accessed July 2006)
Forest canopy	Percent	Area-weighted average	National Land-Cover Dataset 2001, 30-meter resolution data layer from the Multi-Resolution Land Characterisitics Consortium, accessed August 2001
Impervious cover	Percent	Area-weighted average	National Land-Cover Dataset 2001, 30-meter resolution data layer from the Multi-Resolution Land Characterisitics Consortium, accessed August 2001
Mean annual precipitation at basin outlet	Inches	Point extract	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Elevation at basin outlet	Feet	Point extract	NED 10-meter resolution elevation data (*http://seamless.usgs.gov/index.php*), and high resolution NHD (*http://nhdgeo.usgs.gov/viewer.htm*, accessed July 2006)
Soil permeability	Inches per hour	Area-weighted average	State Soil Geographic (STATSGO) Data (http://www.ncgc.nrcs.udsa.gov/products/datasets/statsgo/, accessed July 2008)

Table 2. Basin characteristics investigated as possible independent variables for regressions used to estimate peak-streamflows for unregulated streams.

(NED, National Elevation Dataset; NHD, National Hydrography Dataset; WBD, Watershed Boundary Dataset; PRISM, Parameter-elevation Regressions on Independent Slopes Model; FWRS, Floodwater Retarding Structures)

Characteristic Name	Units	Method	Source data
Mean precipitation June-October	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Mean precipitation November-May	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Mean annual precipitation 1961-1990	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Mean June precipitation	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Mean May precipitation	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Mean February precipitation	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Mean March precipitation	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Mean April precipitation	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Mean December precipitation	Inches	Area-weighted average	PRISM (*http://www.prism.oregonstate.edu/*, accessed July 2008)
Mean basin elevation	Feet	Area-weighted average	NED 10-meter resolution elevation data (*http://seamless.usgs.gov/index.php*)
Mean basin slope	Feet per mile	Area-weighted average	Local slope derived from NED 10-meter resolution elevation data (*http://seamless.usgs.gov/index.php*)

Table 3. T-year recurrence intervals with corresponding annual exceedance probabilities and P-percent chance exceedances for peak-streamflow frequency estimates.

T-year recurrence interval	Annual exceed-ance probability	P-percent chance exceedance
2	0.5	50
5	0.2	20
10	0.1	10
25	0.04	4
50	0.02	2
100	0.01	1
500	0.002	0.2

Low-Outlier Thresholds

Determining low-outlier thresholds are necessary in peak-streamflow frequency analyses because of the fact that these low outliers have a strong influence on the skew coefficient. Past flood frequency analyses for Oklahoma have shown that extremely small annual peak-streamflow discharges (low outliers) occasionally happen. The effects of low outliers can been seen visually by fitting the LPIII distribution, but the U.S. Geological Survey Bulletin 17B method specifies a mathematical low-outlier threshold based on skew and standard deviation of the peak-streamflow time series. The fit of the LPIII distribution to the data needs to adjusted to account for low outliers because these outliers can substantially affect the distribution curve. All peak-streamflow discharges (including zero) below the threshold are excluded from the fitting of the LPIII distribution. The computer program PEAKFQWin was used to identify these low outliers.

PEAKFQWin, which incorporates the IACWD guidelines, provides a procedure for low-outlier threshold selection based on a 90-percent confidence interval for a standard distribution. However, the IACWD procedure may not always produce appropriate low-outlier thresholds for streamflow-gaging stations. Therefore, the preliminary LPIII distribution for each streamflow-gaging station was then visually inspected and some streamflow-gaging stations were assigned a low-outlier threshold based on that inspection. The low-outlier thresholds for appropriate streamflow-gaging stations are listed in table 1.

Weighted Skew

Determining skew coefficients is the next step in peak-streamflow frequency analyses. The skew coefficient measures the asymmetry of the probability distribution of a set of annual peaks and is difficult to estimate reliably for streamflow-gaging 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 gaging station (station skew) and a generalized skew coefficient representative of the surrounding area (fig. 2). The weighted skew coefficient is based on the inverse of the respective mean square errors for each of the two skew coefficients (Interagency Advisory Committee on Water Data, 1982).

The weighted skew coefficient generally is preferred for peak-streamflow frequency estimates. The station skew and weighted skew are listed in table 1 (back of report) for each gaging station. Weighted skew coefficients (station skews weighted with generalized skews from Lewis and Esralew, (2009)) were used for all streamflow-gaging stations in this report.

Generalized-Skew Analysis

A nationwide generalized-skew map is provided in U.S. Geological Survey Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). However, a more accurate generalized skew map was needed for Oklahoma instead of a map prepared at a national scale. Previously, a report of generalized skew coefficients was done for Oklahoma (Lewis and Esralew, 2009) that used adjusted station skew coefficients from streamflow-gaging 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 2007.

The generalized skew map for Oklahoma was created in GIS by using a point interpolation (pointintrp) method and contour smoothing functions (Lewis and Esralew, 2009). The streamflow-gaging stations used to develop the Oklahoma generalized skew map are noted in table 1 with footnote 7. The generalized skew values for all streamflow-gaging stations were obtained by using GIS.

Estimate of Magnitude and Frequency of Peak Streamflows at Ungaged Sites on Unregulated Streams

Estimates of magnitude and frequency of peak streamflows commonly are needed at ungaged sites. These estimates can be achieved by defining regression equations that relate peak discharges of selected frequencies at streamflow-gaging stations to basin characteristics. Multiple-linear regression analysis was used to establish the statistical relations between one dependent variable (peak streamflow) and one or more independent variables (basin characteristics). The 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent chance exceedance flows, respectively, were used as dependent variables, and the selected basin 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. The general steps followed in this report to develop regression equations are:

1. Basin characteristics were screened to identify possible explanatory variables used in the regression equations.
2. Peak-streamflow percent chance exceedance flows and basin characteristics were log transformed to obtain better linear relations between the dependent variables and the independent variables.
3. Stepwise regression analysis was used to assess the most appropriate basin characteristics.
4. Preliminary multiple linear regression models were formed by using ordinary least squares (OLS).
5. Residual plots were examined, and leverage and influence statistics were computed and plotted to identify data observations that may substantially influence regression results. Outliers were removed based on this procedure.
6. Iterations of steps 2–5 were completed, for OLS regression models, in an attempt to reduce the number of independent variables.
7. Weighting procedures were developed.
8. Significance of coefficients in the weighted least squares (WLS) regression model was checked along with residuals, and streamflow-gaging stations with large leverage and influence were identified.
9. From the same dataset, a generalized least squares (GLS) regression model was formed by using the USGS computer program weighted-multiple-linear regression WREG v.1 (Eng and others, 2009).

OLS regression analysis was performed on streamflow data from the 231 streamflow-gaging stations to determine if regression equations for separate hydrologic regions in the state was warranted. A similar check was performed on the GLS models. No geographic patterns were evident after the residuals (differences between estimated peak streamflow and measured peak streamflow) were examined (fig. 3).

Regression Analysis

Previous regression analysis of peak-streamflow frequency for Oklahoma (Tortorelli, 1997) used WLS procedures. In this report OLS, WLS, and GLS regression procedures were used. WLS regression was used to test the statistical significance ($p<0.05$) of possible independent variables (Ries and Dillow, 2006). The GLS method was then used to determine the final regression equations. Stedinger and Tasker (1985) showed that the GLS method can be used to assign weights to the streamflow-gaging station data used in the regression analysis to adjust not only for differences in record length, as in WLS, but also for cross-correlation of the annual time series on which the peak-flow statistics for the gaging station data are based, and for spatial correlation among the gaging station data. Annual peak flows of basins are cross-correlated because a single storm can cause the annual peak in several basins. One advantage of using GLS is that cross-correlation among basins is taken into account.

GLS regression entails weighting each basin in accordance with the variance (time-sampling error) and spatial-correlation structure of the streamflow characteristic (annual peak-discharge among streamflow-gaging stations) (Lumia and others, 2006). The residual mean square error for ungaged sites is portioned into regression model error (error in assuming an incomplete regression form) and sampling error (time- and spatial-sampling errors). When using GLS, the variance of prediction (and the square root, the standard error of prediction) is the sum of the model error variance and an additional term. This additional term has been called a sampling error variance (of the coefficients), but is different from the time-sampling and spatial-sampling error.

The GLS regression analysis used in this report incorporated logarithmic (base 10) transformations of the streamflow (annual peak discharges) and basin characteristics to obtain a constant variance of the residuals about the regression line, and to make the relation between the dependent variable (peak-discharge) and independent variables (basin characteristics) acceptable for linear least-squares regression procedures. The multiple-regression equations based on logarithmic transformation of the variables has the following form:

$$\mathrm{Log}_{10} Y = b_0 + b_1 \log_{10} X_1 + b_2 \log_{10} X_2 + \ldots\ldots + b_n \log_{10} X_n, \quad (2)$$

and the following form after taking antilogs,

$$Y = 10^{b0} (X_1^{b1}) (X_2^{b2}) \ldots\ldots (X_n^{bn}) \quad (3)$$

where

Y = dependent variable (peak-discharge for selected exceedance),

b_o to b_n = regression model coefficient estimate by using GLS procedures, and

X_1 to X_n = independent variables (basin characteristics).

The USGS computer program WREG applying OLS, WLS, and GLS approaches was used to estimate the regression parameters (Eng and others, 2009). WREG allows for selection between the three approaches and also for transformations on the dependent and independent variables. The multiple performance metrics from the WREG program were used to identify possible problem sites used in the regression. The residuals metric is used to show differences between estimated and measured flow at various flow magnitudes. Residuals randomly distributed around zero are preferred. The leverage metric is used to measure how distant the values of

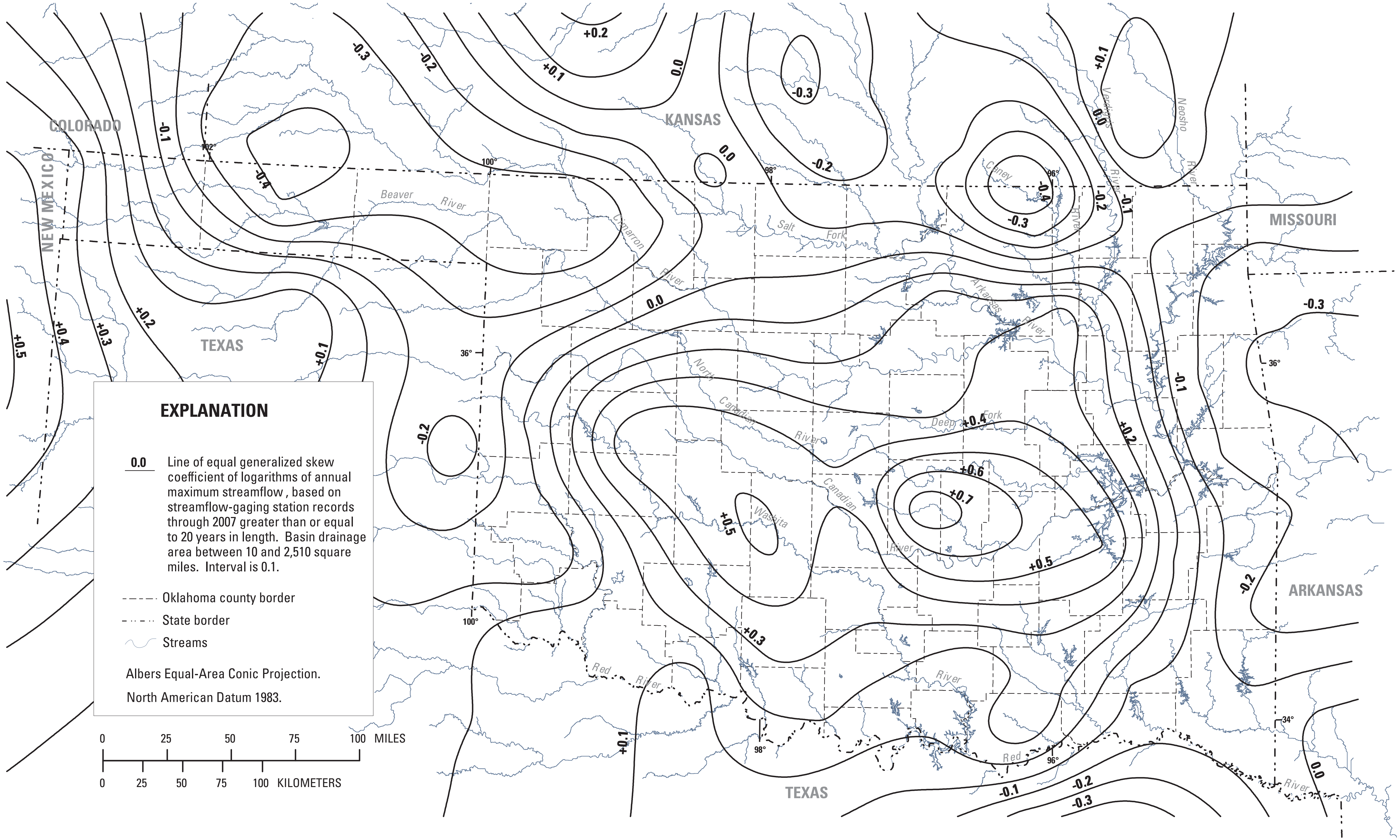


Figure 2. Generalized skew coefficients of logarithms of annual maximum streamflow for Oklahoma streams with drainage area less than than or equal to 2,510 square miles.

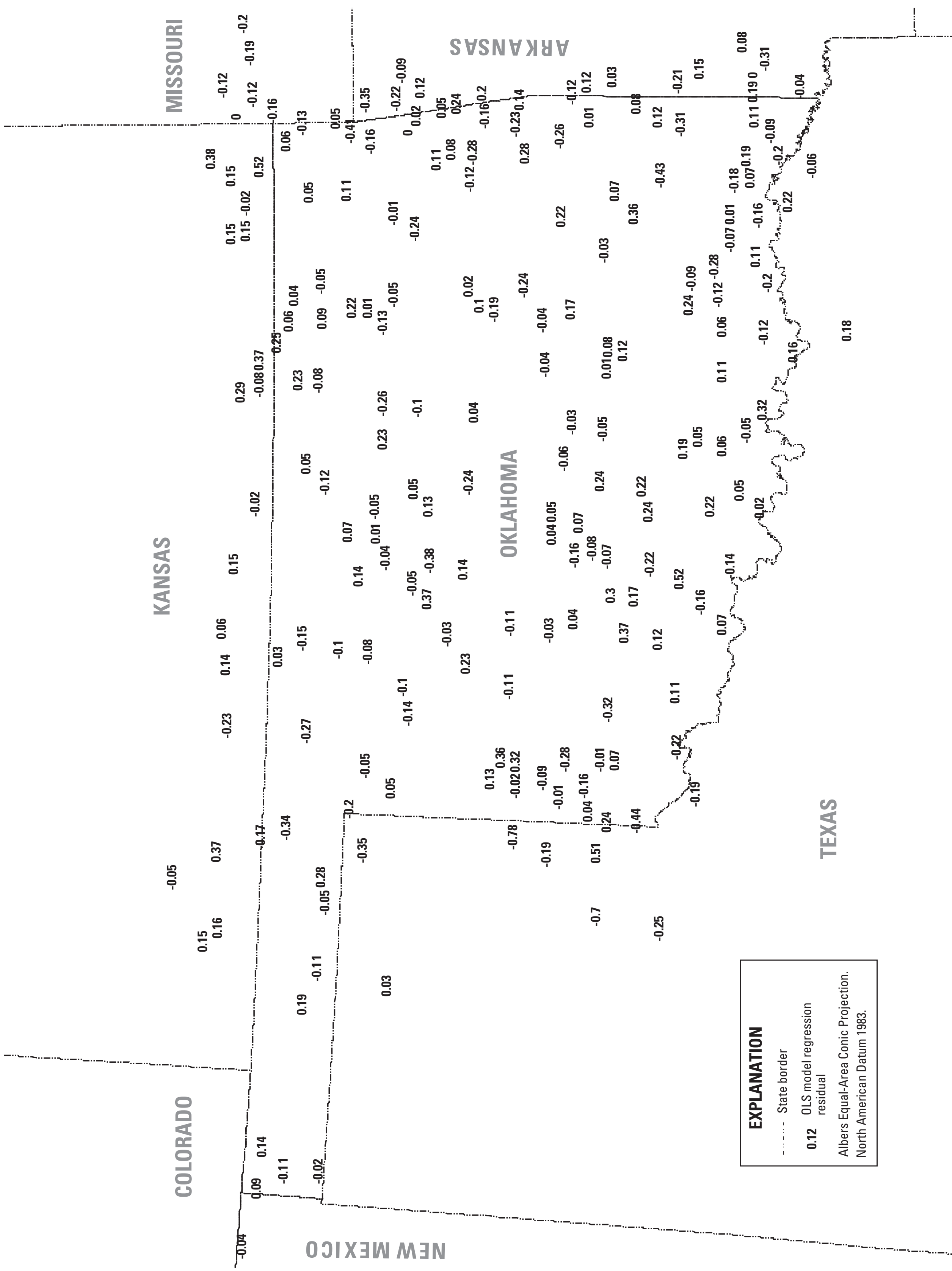


Figure 3. Residuals from the 10-percent chance exceedance ordinary least squares (OLS) regression model for each site.

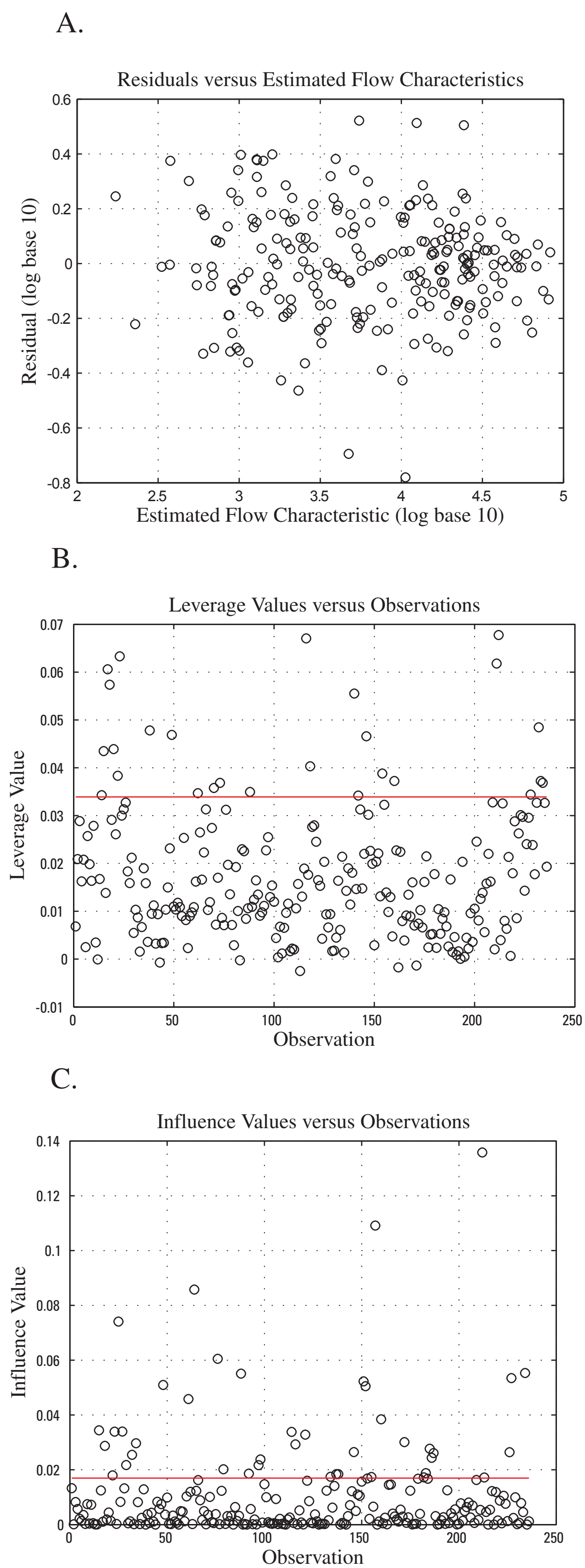


Figure 4. Performance metrics from computer program WREG (**A**) residuals, (**B**) leverage, and (**C**) influence for a 10-percent chance exceedance peak-streamflow regression model.

independent variables at one streamflow-gaging station are from the centroid of values of the same variables at all other streamflow-gaging stations. The influence metric indicates whether a streamflow-gaging station had a large influence on the estimated regression parameter values (Eng and others, 2009). Streamflow-gaging stations, identified as having large influence and leverage, were not necessarily removed because the gaging station may have been the only gaging station in a particular area or because removal did not alter the regression. After examining the leverage and influence plots, the following sites were removed: Dry Cimarron River near Guy, New Mexico, (07153500), Fly Creek near Faulkner, Kansas, (07184600), Lelia Lake Creek below Bell Creek near Hedley, Texas, (07299890), Salt Fork Red River near Wellington, Texas, (07300000), and Sweetwater Creek near Kelton, Texas, (07301410). Caution is needed when estimating peak streamflows in areas near the streamflow-gaging stations listed because of irrigation practices. The final performance metrics for the 10-percent chance exceedance regression model are shown in figure 4.

Regression Equations

Regression equations were developed for use in estimating peak streamflows associated with 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent chance exceedances. Combinations of independent variables that did not have substantially large leverage or influence, and multicollinearity that also provided the lowest estimated error for each percent exceedance, were selected for inclusion in the final regression equations. Contributing drainage area, mean-annual precipitation, and main-channel slope were the most appropriate basin characteristics used to estimate peak-streamflow frequency on unregulated streams. The three characteristics used in the regression equations are listed in table 1 for each streamflow-gaging station used in the analysis.

The following equations were computed for unregulated streams from the results of the GLS regression analysis in WREG and are listed according to percent chance exceedance.

$$Q_{50\%} = 0.064\,(CONTDA)^{0.66}\,(PRECIP)^{2.06}\,(CSL10\_85fm)^{0.16} \quad (4)$$

$$Q_{20\%} = 0.574\,(CONTDA)^{0.66}\,(PRECIP)^{1.63}\,(CSL10\_85fm)^{0.19} \quad (5)$$

$$Q_{10\%} = 1.74\,(CONTDA)^{0.66}\,(PRECIP)^{1.42}\,(CSL10\_85fm)^{0.21} \quad (6)$$

$$Q_{4\%} = 4.90\,(CONTDA)^{0.66}\,(PRECIP)^{1.24}\,(CSL10\_85fm)^{0.23} \quad (7)$$

$$Q_{2\%} = 13.18\,(CONTDA)^{0.66}\,(PRECIP)^{1.05}\,(CSL10\_85fm)^{0.21} \quad (8)$$

$$Q_{1\%} = 26.9\ (CONTDA)^{0.65}\ (PRECIP)^{0.92}\ (CSL10\_85fm)^{0.21} \quad (9)$$

$$Q_{0.2\%} = 126\ (CONTDA)^{0.64}\ (PRECIP)^{0.64}\ (CSL10\_85fm)^{0.19} \quad (10)$$

where

$Q_{50\%}, Q_{20\%}$,……, and $Q_{0.2\%}$ = the peak-streamflows with percent chance exceedances of 50 percent, 20 percent, ……, and 0.2 percent, in cubic feet per second;

CONTDA = the contributing drainage area, in square miles;

PRECIP mean-annual precipitation, the point mean-annual precipitation from the period 1971-2000;

CSL10_85fm = the main-channel slope, measured at the points that are 10 percent and 85 percent upstream from the station or ungaged site, on the main-channel length between the study site and the drainage divide, in feet per mile.

Accuracy and Limitations

Regression equations are statistical models in which the results are inexact. Regression equations needs to be applied within the limits of the data with the understanding that the results are best-fit estimates with associated variances. Three measures that can be used to assess the accuracy of a regression peak-discharge estimate are: the adjusted coefficient of determination (R^2), the average standard error of prediction, and the standard model error.

Residual errors in the model (differences between estimated and measured values) are examined to determine variables that optimize the accuracy of a regression equation, which depends on the model and sampling error. Model errors represent errors that result from an incomplete model. These errors are described by the standard model error. Sampling errors result from the limitations on the number of years of streamflow-gaging station record, the assumption of gaging station record being representative of long-term streamflow, and from hydrologic conditions during the particular period represented by samples. Although the use of GLS methodology allows separation of the sampling error variance from the total mean square error of the residuals, the GLS methodology does not prevent this type of error.

R^2 is the proportion of the variability in the dependent variable (site peak discharge, $Q_{x(s)}$) that is accounted for by the independent variables (the basin characteristics, CONTDA, PRECIP, and CSL10_85fm) — the larger the 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 (Helsel and Hirsch, 2002). Griffis and Stedinger (2007) state that R^2_{pseudo} is a more appropriate performance metric for WLS and GLS regressions. R^2_{pseudo} is based on the variability in the dependent variable explained by the regression, after removing the effect of the time-sampling error (Eng and others, 2009). Table 4 lists all R^2_{pseudo} values for each of the percent exceedance chance peak streamflows.

The standard error of prediction is derived from the sum of the model error variance and the sampling error of the coefficients, and is a measure of the expected accuracy of the regression estimates for the selected percent chance exceedances. The standard model error, which depends on the number and predictive power of the independent variables, measures the ability of these variables to estimate peak-streamflow frequency from the site records that were used to develop the equation. The WREG program reports average standard error of prediction (Sp), standard model error, and R^2_{pseudo} in the model output (fig. 5). The average standard error of prediction ranges from 32 to 47 percent and the standard model error ranges from 31 to 46 percent for the percent chance exceedances computed (table 4).

Equivalent years of record, proposed by Hardison (1971), is another way of measuring the reliability of peak-streamflow regression equations. Equivalent years of record, which is an approximation, is the number of actual years of record needed to provide estimates equal in accuracy to those estimates computed by the regression equations. The accuracy of the regression equations for unregulated streams, expressed as equivalent years, is summarized in table 4.

The regression equations developed in this report are applicable to streams in Oklahoma with drainage areas less than 2,510 mi² that are not substantially affected by regulation. The equations are intended for use on unregulated streams in Oklahoma and should not be used outside the range of the independent variables used in the analysis:

CONTDA	equal to or greater than 0.100 square mile	and less than or equal to 2,510 square miles
PRECIP	equal to or greater than 16.6 inches	and less than or equal to 62.1 inches
CSL10_85fm	equal to or greater than 1.98 foot per mile	and less than or equal to 342 feet per mile

The same cautions are applicable for estimating flows on streams regulated with floodwater retarding structures as with unregulated drainage basin peak-streamflow estimates. The adjusted equations described in “Adjustment for Ungaged Sites on Urban Streams” 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, 1997;

Table 4. Accuracy of peak-streamflows estimated for unregulated streams in Oklahoma.

[R^2; coefficient of determination; %, percent]

Percent chance exceedance	R^2 pseudo	S_p (average standard error of prediction, in %)	Standard model error (%)
50	92.36	46.74	45.89
20	94.98	35.11	34.26
10	95.70	31.80	30.88
4	94.88	34.66	32.98
2	94.98	33.98	32.86
1	94.51	35.72	34.52
0.2	92.36	43.26	41.87

Tortorelli and Bergman, 1985). The adjusted equations are intended for use on parts of a basin with NRCS floodwater retarding structures and not with any other floodwater retarding structures. When the regulated drainage area is greater than 86 percent of the basin, the flow routing techniques in Chow and others (1988) may be used.

Application of Methods

This section presents methods for use of the regression equations to make a weighted peak-streamflow estimate for streamflow-gaging station data on unregulated streams with a drainage area less than 2,510 mi^2 in Oklahoma, and to use this result to make an estimate for a nearby ungaged site on the same stream. For ungaged sites on urban streams and ungaged sites on streams regulated by floodwater retarding structures, an adjustment of the statewide regression equations for unregulated stream can be used to estimate peak-streamflow frequency.

Estimate for a Streamflow-Gaging Station

Interagency Advisory Committee on Water Data (1982) recommends that peak-streamflow frequency estimates for streamflow-gaging station sites on unregulated streams are combinations of streamflow-gaging station data and regression estimates. The estimates weighted by years of record are considered to be more reliable than either the regression estimate or gaging-station data when making estimates of peak-streamflow frequency relations at gaging-station sites (Sauer, 1974a; Thomas and Corley, 1977). The equivalent years of record concept is used to combine gaging-station estimates with regression estimates to obtain weighted estimates of peak-streamflow at a gaging station site.

The locations of the streamflow-gaging stations with unregulated periods of record used in the report are shown in figure 1. Figure 1 is used to obtain the gaging-station number of the gaging station of interest. This number is used to obtain the appropriate station peak-streamflow ($\mathbf{Q}_{x(s)}$), for percent chance exceedance **x**, from table 1. The streamflow-gaging stations that have unregulated periods of record, but are now regulated, are noted with footnote 8 in table 1. If the gaging station of interest is still unregulated, then this peak-streamflow is used with the regression estimate $\mathbf{Q}_{x(r)}$ in a weighting procedure described by Sauer (1974a) and Thomas and Corley (1977):

$$\mathbf{Q}_{x(w)} = [\mathbf{Q}_{x(s)}(\mathbf{N}) + \mathbf{Q}_{x(r)}(\mathbf{E})] / (\mathbf{N} + \mathbf{E}) \qquad (11)$$

where

$\mathbf{Q}_{x(w)}$ = the weighted estimate of peak streamflow, for percent chance exceedance **x**, in cubic feet per second,
$\mathbf{Q}_{x(s)}$ = the gaging station estimate of peak streamflow, for percent chance exceedance **x** (table 1), in cubic feet per second,
$\mathbf{Q}_{x(r)}$ = the regression estimate of peak streamflow, for percent chance exceedance **x** (equations 4-10), in cubic feet per second,
N = number of actual years of record at the gaging station site (table 1),
E = equivalent years of record for percent chance exceedance **x** (table 4).

Example

The following example illustrates how the method described is used to determine weighted peak-streamflow estimates for a streamflow-gaging station on an unregulated stream. The example computation is for Kiamichi River near Big Cedar, Okla., (07335700) and the results are presented in table 5.

The column $\mathbf{Q}_{x(s)}$ in table 5 indicates the computed peak-streamflow frequency relations derived from the 43 years of record (column N) at gaging station 07335700 (site 206, table 1). The values in the column labeled $\mathbf{Q}_{x(r)}$ were estimated by using equations 4–10 and the following basin characteristics (table 1):

CONTDA = 39.6 square miles
PRECIP = 62.1 inches
CSL10_85fm = 54.9 feet per mile

The $\mathbf{Q}_{x(r)}$ estimates computed from equations 4–10 are presented in table 5. The weighted estimates, $\mathbf{Q}_{x(w)}$ were computed from equation 11 by using appropriate years of **E** from table 5.

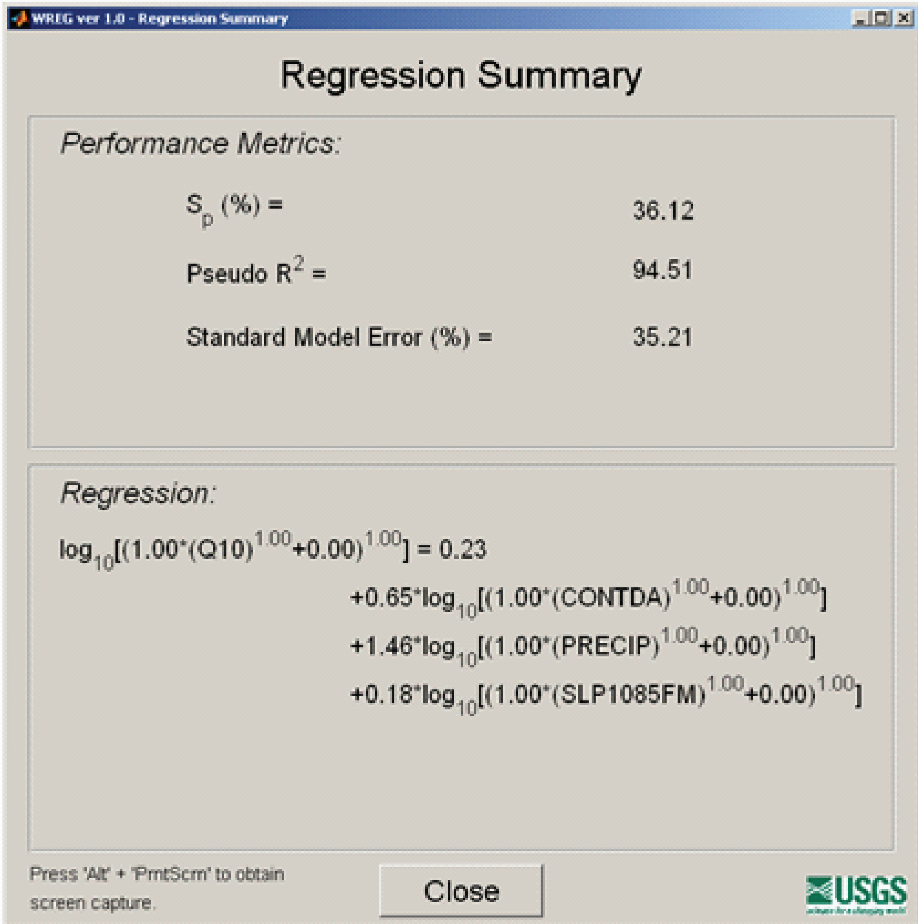


Figure 5. WREG output for the 10-percent chance exceedance peak-streamflow regression model by using the generalized least squares (GLS) method, showing average standard error of prediction (Sp %), the pseudo coefficient of determination (Pseudo R_2), and standard model error, in percent (%). SPL1085FM is CSL10_85fm (main-channel slope), CONTDA is contributing drainage area, and PRECIP is mean-annual precipitation used in regression equations (4–10).

Table 5. Weighted peak-streamflow frequency estimates for Kiamichi River near Big Cedar, Oklahoma (07335700)

[ft³/s, cubic feet per second; %, percent]

Percent chance exceedance (%)	$Q_{x(s)}$[1] (ft³/s)	N[2] (years)	$Q_{x(r)}$[3] (ft³/s)	E[4] (years)	$Q_{x(w)}$[5] (ft³/s)
50	9,200	43	6,800	2	9,090
20	15,100	43	11,700	5	14,700
10	19,300	43	16,100	8	18,800
4	24,800	43	23,300	9	24,500
2	29,000	43	26,400	11	28,500
1	33,300	43	30,400	12	32,700
0.2	43,400	43	39,900	12	42,600

[1] Station estimate of peak discharge, for percent chance exceedance x, table 1.

[2] Number of actual years of streamflow record at streamflow-gaging station, table 1.

[3] Regression estimate of peak discharge, for percent chance exceedance x, equations 4-10.

[4] Equivalent years of unregulated streamflow record for percent chance exceedance x, table 4.

[5] Weighted estimate of peak discharge, for percent chance exceedance x, equation 11.

Estimate for an Ungaged Site near a Streamflow-Gaging Station

The combined use of the regression equations and the gaging-station data can yield an estimate of the peak-streamflow magnitude and frequency for ungaged sites near streamflow-gaging stations on the same stream. The following method is indicated for use if the ungaged site has a drainage area within 50 percent of the drainage area of the gaging station (Sauer, 1974a). 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 streamflow-gaging station:

$$R_w = \frac{Q_{x(w)}}{Q_{x(r)}} \qquad (12)$$

where

$\mathbf{Q}_{x(w)}$ is the weighted estimate of peak streamflow at the gaging-station site, for percent chance exceedance **x** (equation 11), in cubic feet per second, and

$\mathbf{Q}_{x(r)}$ is the regression estimate of peak streamflow at the gaging-station site, for percent chance exceedance **x** (equations 4–10), in cubic feet per second.

$\mathbf{R}_w$ 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 gaging-station site on the same stream,

$$\mathrm{R}_c = R_w - \frac{\Delta CONTDA}{0.5CONTDA_g}(R_w 1.00) \qquad (13)$$

where

ΔCONTDA is the difference between the drainage areas of the gaging-station site and ungaged site, and

$\mathbf{CONTDA}_g$ is the drainage area of the gaging-station 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 gaging-station data. If the drainage area of the ungaged site is within 50 percent of two gaging-station sites, the peak-streamflow frequency estimate for the ungaged site can be made by interpolation of the weighted station peak-streamflow ($\mathbf{Q}_{x(w)}$) for each gaging-station site. Interpolation is on the basis of drainage area. If the peak streamflows for the ungaged site are affected by urbanization, the peak streamflows need to be modified by methods given in the following section "Adjustment for Ungaged Sites on Urban Streams". If the drainage area of the ungaged site is 50 percent more than or less than that of the gaging-station site (that is, **ΔCONTDA**/$\mathbf{CONTDA}_g$ is greater than 0.5), equation 11 is not used and the regression equations 4–10 are used without adjustment.

Example

The following example illustrates how to adjust a weighted estimate calculated for a streamflow-gaging-station site on an unregulated stream for an ungaged site on the same stream. Assume an estimate of the 1 percent chance exceedance flood is needed at an ungaged site upstream from gaging station 07335700 on the Kiamichi River (table 5). Assume the following hypothetical basin characteristics:

CONTDA = 20.5 square miles
PRECIP = 54.0 inches
CSL10_85fm = 42.0 feet per mile

The following data and calculations are needed to estimate $Q_{1\%}$ at the ungaged site.

Gaging station site, 07335700, Kiamichi River near Big Cedar

$\mathbf{CONTDA}_g$ = 39.6 square miles
$\mathbf{Q}_{1\%(r)}$ = 30,400 cubic feet per second, from equation 9, table 5
$\mathbf{Q}_{1\%(w)}$ = 32,700 cubic feet per second, from equation 11, table 5
$\mathbf{R}_w$ **=** $\mathbf{Q}_{1\%(w)}$**/** $\mathbf{Q}_{1\%(r)}$ = 1.08

Ungaged site on Kiamichi River

CONTDA = 20.5 square miles
$\mathbf{Q}_{1\%(r)}$ = 16,500 cubic feet per second, from equation 9
ΔCONTDA = 19.1 square miles
ΔCONTDA/CONTDA$_g$ = 0.48 (Because 0.48 is less than 0.5, $\mathbf{R}_c$ is computed from equation 12 and used to adjust $\mathbf{Q}_{1\%(r)}$)

$$R_c = 1\ 08 - \frac{19.1}{0.5(39.6)}(1.08 - 1.00) \ = 1.00$$

$\mathbf{Q}_{1\%} = \mathbf{Q}_{1\%(r)}\,(\mathbf{R}_c)$ = 16,500 (1.00) = 16,500 cubic feet per second

The estimate of the 1 percent chance exceedance flood at the ungaged site on the Kiamichi River is a discharge of

16,500 ft^3/s, after the regression estimate is adjusted for the data for gaging station 07335700.

Adjustment for Ungaged Sites on Urban Streams

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

After the percentages of the area impervious and area served by storm sewers are obtained, $\mathbf{R}_L$, the urban adjustment factor, is obtained from figure 6 (Leopold, 1968).

The urban adjustment factor, $\mathbf{R}_L$, is the ratio of the mean annual flood in urban areas to that in rural areas. The following equations computed by Sauer (1974b) can be used to adjust estimates from equations 4–10 to urban areas:

$$Q_{50\%(u)} = R_L\, Q_{50\%(r)} \quad (14)$$

$$Q_{20\%(u)} = 1.60\,(R_L\text{-}1)\, Q_{50\%(r)} + 0.167\,(7\text{-}R_L)\, Q_{20\%(r)} \quad (15)$$

$$Q_{10\%(u)} = 1.87\,(R_L\text{-}1)\, Q_{50\%(r)} + 0.167\,(7\text{-}R_L)\, Q_{10\%(r)} \quad (16)$$

$$Q_{4\%(u)} = 2.21\,(R_L\text{-}1)\, Q_{50\%(r)} + 0.167\,(7\text{-}R_L)\, Q_{4\%(r)} \quad (17)$$

$$Q_{2\%(u)} = 2.46\,(R_L\text{-}1)\, Q_{50\%(r)} + 0.167\,(7\text{-}R_L)\, Q_{2\%(r)} \quad (18)$$

$$Q_{1\%(u)} = 2.72\,(R_L\text{-}1)\, Q_{50\%(r)} + 0.167\,(7\text{-}R_L)\, Q_{1\%(r)} \quad (19)$$

$$Q_{0.2\%(u)} = 3.30\,(R_L\text{-}1)\, Q_{50\%(r)} + 0.167\,(7\text{-}R_L)\, Q_{0.2\%(r)} \quad (20)$$

where

$\mathbf{Q}_{x(u)}$ = the adjusted regression estimate of peak discharge for ungaged sites on urban streams, for percent chance exceedance **x**, in cubic feet per second,

$\mathbf{R}_L$ = urban adjustment factor (fig. 6), and

$\mathbf{Q}_{x(r)}$ = the regression estimate of peak discharge for ungaged sites on unregulated streams, for percent chance exceedance **x** (equations 4–10), in cubic feet per second.

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

Example

This example shows how the 1 percent chance exceedance flood can be calculated for a hypothetical stream in an urban environment. The calculation is based on the basin being 50 percent impervious and that 65 percent of the basin is served by storm sewers. The 1 percent chance exceedance flood ($Q_{1\%(u)}$) can be estimated for this hypothetical urban site with the following additional basin characteristic values:

CONTDA = 25.0 square miles
PRECIP = 33.0 inches
CSL10_85fm = 11.5 feet per mile

$Q_{1\%(r)}$ = 9,080 cubic feet per second, from equation 9 (rural areas)
$Q_{50\%(r)}$ = 1,060 cubic feet per second, from equation 4 (rural areas)
$\mathbf{R}_L$ = 3.0, from figure 6
$Q_{1\%(u)}$ = 11,800 cubic feet per second, from equation 19 (urban areas)

The estimate of the 1 percent chance exceedance flood in urban areas for this ungaged watershed is a discharge of 11,800 ft^3/s. This estimate is an increase of 33 percent more than the 1 percent chance exceedance flood for rural areas.

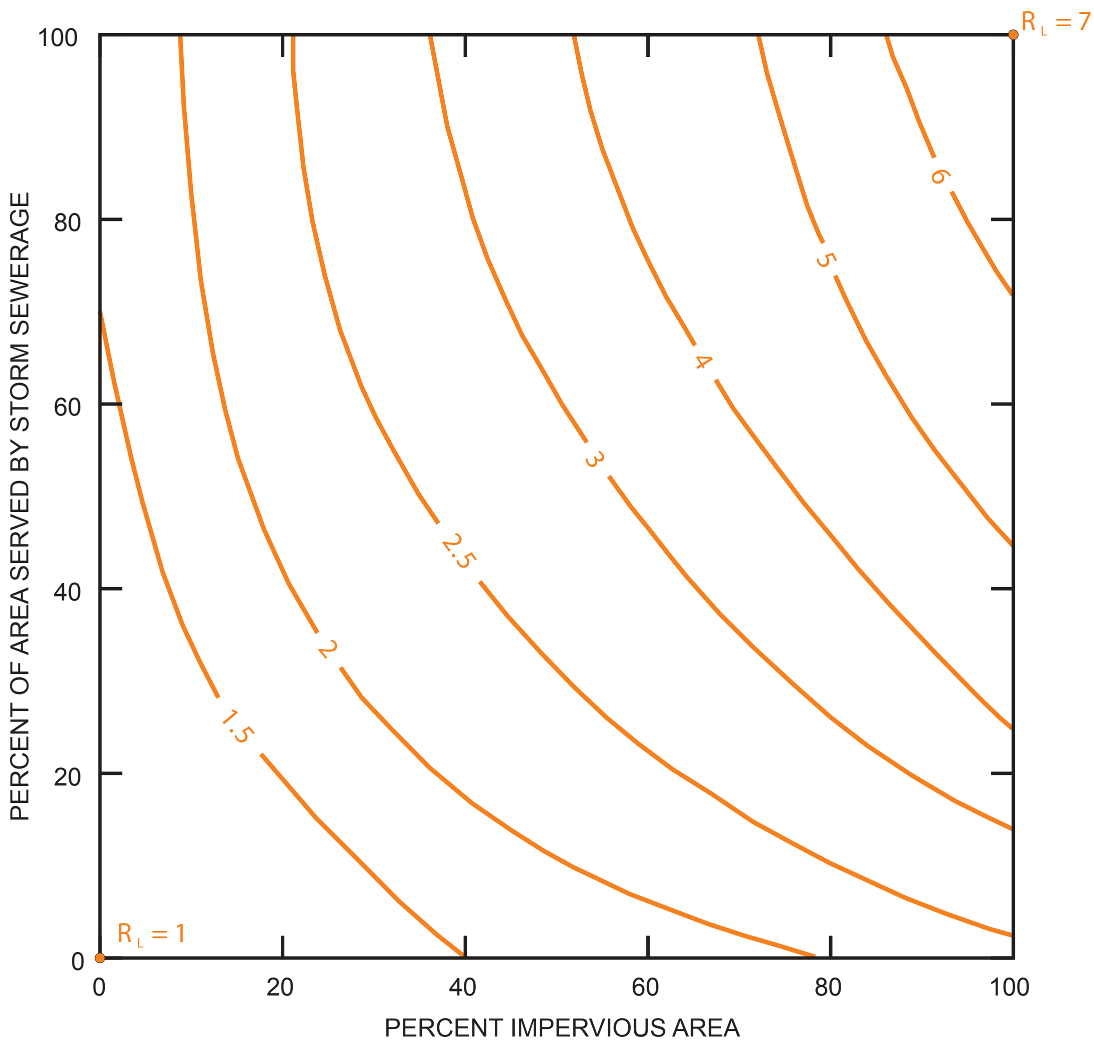
Adjustment for Ungaged Sites on Streams Regulated by Floodwater Retarding Structures

An adjustment needs to be made when estimating peak-streamflow magnitude and frequency in basins regulated by floodwater retarding structures. The regression estimate of peak-streamflow for ungaged sites on regulated streams, or $\mathbf{F}_{x(r)}$, for percent chance exceedance **x**, can be computed from equations 4–10 by substituting the drainage area of the unregulated part of the basin or drainage area downstream from the floodwater retarding structures, **DAUNREG**, for CONTD**A**. A complete discussion of the analysis can be found in Tortorelli and Bergman (1985). These authors indicated that the main-channel slope for the entire basin be used to estimate a conservative result (this method will result in a larger peak streamflow than by using main-channel slope downstream from floodwater retarding structures only).

If floodwater retarding structures regulate less than 86 percent of the basin, the following equations are used to adjust the regression estimate of peak-streamflow of ungaged sites on unregulated streams:

$$F_{50\%(r)} = 0.064\,(DUANREG)^{0.66}\,(PRECIP)^{2.06}(CSL10\_85fm)^{0.16} \quad (21)$$

$$F_{20\%(r)} = 0.574\,(DUANREG)^{0.66}\,(PRECIP)^{1.63}(CSL10\_8\,fm)^{0.19} \quad (22)$$



EXPLANA TION

$$R_L = \frac{\text{discharge after urbanization}}{\text{discharge before urbanization}}$$

Figure 6. Relation of urban adjustment factor, R_L, to the percentage of area impervious,and served by storm sewer (adapted from Leopold, 1968).

$$F_{10\%(r)} = 1.74\ (DAUNREG)^{0.66}\ (PRECIP)^{1.42}(CSL10\_85fm)^{0.21} \quad (23)$$

$$F_{4\%(r)} = 4.90\ (DAUNREG)^{0.66}\ (PRECIP)^{1.24}(CSL10\_85fm)^{0.23} \quad (24)$$

$$F_{2\%(r)} = 13.18\ (DAUNREG)^{0.66}\ (PRECIP)^{1.05}(CSL10\_85fm)^{0.21} \quad (25)$$

$$F_{1\%(r)} = 26.9\ (DAUNREG)^{0.65}\ (PRECIP)^{0.92}(CSL10\_85fm)^{0.21} \quad (26)$$

$$F_{0.2\%(r)} = 126\ (DAUNREG)^{0.64}\ (PRECIP)^{0.64}(CSL10\_85fm)^{0.19} \quad (27)$$

where

$\mathbf{F}_{x(r)}$ = the regression peak-streamflow estimate adjusted for floodwater retarding structures, for percent chance exceedance **x**, in cubic feet per second,

DAUNREG = the contributing drainage area of the unregulated part of the basin or drainage area downstream from the floodwater retarding structures, in square miles,

PRECIP = the point mean-annual precipitation at the station or ungaged site, for the period 1971-2000, in inches, and

CSL10_85fm = the main-channel slope, measured at the points that are 10 percent and 85 percent of the main-channel length between the station or ungaged site and the drainage divide, in feet per mile.

The adjusted equations can be used when the percent of regulated drainage area is not greater than 86 percent of the basin, 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, flow routing techniques, such as outlined in Chow and others (1988), may be used.

Example

This example illustrates how a peak-streamflow estimate is calculated for an ungaged site on a stream regulated by floodwater retarding structures. An estimate of the $Q_{1\%}$ is needed for this example on an ungaged site on Uncle Johns Creek in Kingfisher County that is regulated by floodwater retarding structures.

To obtain the regression flood-frequency estimate for an ungaged site on a stream regulated by floodwater retarding structures, $\mathbf{F}_{1\%(r)}$, equation 26 is used. Equation 26 uses **DAUNREG**, the area of the drainage basin unregulated by floodwater retarding structures, instead of **CONTDA**. The following data and calculations are needed to estimate $Q_{1\%}$ for the ungaged site on a stream regulated by floodwater retarding structures:

CONTDA = 155 square miles
DAUNREG = 65.1 square miles
PRECIP = 31.0 inches
CSL10_85fm = 12.0 feet per mile

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

$\mathbf{F}_{1\%(r)}$ = 16,100 cubic feet per second from equation 26

The estimate of the 1 percent chance exceedance flood with 58 percent of the basin regulated by floodwater retarding structures is a discharge of 16,100 ft^3/s.

Summary

This report presents the results of a cooperative study by the U.S. Geological Survey (USGS) and the Oklahoma Department of Transportation to estimate the magnitude and frequency of peak streamflows from regional regression equations for Oklahoma by using generalized least squares regression methods. Annual-maximum peak flows observed at 231 streamflow-gaging stations through water year 2008 were used for the regression analysis. Gage peak-streamflow estimates were used from previous work unless 2008 gaging-station data were available, in which new peak-streamflow estimates were calculated. The basin characteristics for each site were determined by using a geographical information system and the USGS web application StreamStats. The most statistically significant basin characteristics required to estimate peak-streamflow frequency for unregulated streams in Oklahoma are contributing drainage area, mean-annual precipitation, and main-channel slope. Multiple-regression analyses were used to define the relations between peak-streamflow frequency and basin characteristics. The resulting regression equations can be used to estimate peak discharge and frequency of floods for selected percent chance exceedance floods ranging from 50–0.2 percent.

The regression equations are applicable for basins with a drainage area less than 2,510 square miles that are not substantially affected by regulation. The estimated standard error of prediction for the regression equations ranged from 32 to 47 percent, and standard model error ranged from 31 to 46 percent. This report also presents methods on estimating peak-streamflow magnitude and frequency for ungaged sites on streams with streamflow-gaging stations and for sites on urban streams and streams regulated by floodwater retarding structures. Log-Pearson Type III analysis information, basin characteristics, and the peak-streamflow frequency estimates for 231 streamflow-gaging stations in and near Oklahoma are listed in this report.

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Table 1

Table 1. Peak-streamflow frequency estimates and basin characteristics for selected stations with at least 8 years of annual

[ft³/s, cubic feet per second; LPIII, Log-Pearson Type III; mi², square miles; ft/mi, feet per mile; wt, weighted; Trib., Tributary; Ck, creek; Res., Reservoir;

Site number (fig. 1)	Station number	Station name	Analysis Information				
			Available systematic record[1] (years)	Historical record length[2] (years)	Number of high outliers	High-outlier threshold[3] (ft³/s)	Low-outlier threshold[4] (ft³/s)
1	07148100	Grouse Creek near Dexter, Kans.[7]	30				
2	07148350	Salt Fork Arkansas R. nr Winchester, Okla.[7]	34	37			
3	07148400	Salt Fork Arkansas R. near Alva, Okla.	43	71			
4	07148700	Dog Creek near Deerhead, Kans.	21				
5	07148800	Medicine Lodge River Trib. nr Medicine Lodge, Kans.[7]	21				5
6	07150580	Sand Creek Trib. near Kremlin, Okla.	12		1	11,500	10
7	07150870	Salt Fork Arkansas River Trib. near Eddy, Okla.	22				
8	07151500	Chikaskia River near Corbin, Kans.[7]	59	86			1,000
9	07151600	Rush Creek near Harper, Kans.[7]	33				77
10	07152000	Chikaskia River near Blackwell, Okla.[7]	72	86			2,000
11	07152360	Elm Creek near Foraker, Okla.	12				200
12	07152410	Rock Creek near Shidler, Okla.	8				
13	07152520	Black Bear Creek Trib. near Garber, Okla.	12				10
14	07152842	Subwatershed W–4 near Morrison, Okla.	22				10
15	07152846	Subwatershed W–3 near Morrison, Okla.	25				1
16	07153000	Black Bear Creek at Pawnee, Okla.[7, 8]	20	55	1	30,000	
17	07154400	Carrizozo Creek near Kenton, Okla.	56				
18	07154500	Cimarron River near Kenton, Okla.[7]	20				577
19	07155000	Cimarron River above Ute Creek nr Boise City, Okla.	13	49	1	76,600	
20	07155100	Cold Springs Creek near Wheeless, Okla.	17	21			
21	07156600	Cimarron River Trib. near Moscow, Kans.	33				12
22	07156700	Cimarron River Trib. near Satanta, Kans.	52				
23	07157100	Crooked Creek near Copeland, Kans.[7]	33				15
24	07157400	Crooked Creek Trib. at Meade, Kans.	33				10
25	07157500	Crooked Creek near Englewood, Kans.	21				200
26	07157550	West Fork Creek near Knowles, Okla.	22				25
27	07157900	Cavalry Creek at Coldwater, Kans.[7]	28				
28	07157960	Buffalo Creek near Lovedale, Okla.	28				
29	07158020	Cimarron River Trib. near Lone Wolf, Okla.	12				
30	07158080	Sand Creek Trib. near Waynoka, Okla.	12	24	1	990	

peak-streamflow data from unregulated basins in and near Oklahoma.

L., Little; Lk, Lake; blw, below; SWS, subwatershed; Fk, Fork; R, river; nr, near; %, percent; SH, State highway; N, north; ab, above]

Site number (fig. 1)	Basin characteristics					Peak-streamflow frequency estimates						
	Skew coefficient for LP III distribution[5]		Contributing drainage area (mi^2)	Area-wt mean annual precipitation[6] (inches)	Steam slope (ft/mi)	Peak discharge; in ft^3/s, for indicated percent chance exceedance (%)						
	Station	Weighted				50	20	10	4	2	1	0.02
1	0.185	-0.062	171.34	36.3	8.63	8,730	18,000	26,200	38,900	50,100	62,800	98,900
2	-0.390	-0.118	827.23	26.4	9.40	6,640	16,100	25,200	40,400	54,600	71,200	121,000
3	-0.513	-0.306	982.09	26.7	8.43	6,520	13,300	18,800	26,700	33,100	40,000	57,600
4	-0.145	-0.066	5.05	27.1	64.44	251	924	1,810	3,670	5,780	8,660	19,500
5	-0.730	-0.146	2.15	28.5	38.81	143	477	876	1,650	2,470	3,530	7,150
6	-0.591	0.105	7.13	34.0	14.76	479	1,260	2,110	3,700	5,330	7,440	14,700
7	0.225	0.000	2.51	34.9	19.55	259	525	761	1,130	1,460	1,830	2,910
8	-0.688	-0.160	812.58	30.5	7.67	9,610	18,800	26,400	37,600	46,900	57,200	84,400
9	-1.311	-0.203	11.78	31.0	20.10	1,170	2,280	3,180	4,480	5,560	6,730	9,770
10	-0.500	-0.083	1873.05	31.8	6.58	19,200	38,000	54,100	78,300	99,200	122,000	187,000
11	-0.648	-0.127	18.34	38.7	14.65	2,230	4,590	6,630	9,750	12,400	15,500	23,800
12	-0.014	-0.140	9.06	39.2	33.19	1,640	2,100	2,380	2,700	2,940	3,160	3,650
13	-0.083	0.087	1.02	34.7	24.01	92.5	286	522	1,000	1,530	2,250	4,940
14	-1.240	0.006	0.33	37.1	52.70	134	239	324	447	551	666	975
15	-1.184	0.089	0.08	37.2	182.11	68.9	181	304	530	763	1,060	2,090
16	0.730	0.372	538.32	36.6	3.39	6,030	10,000	13,400	18,500	23,000	28,100	43,100
17	0.313	0.337	112.28	16.6	26.94	1,690	3,920	6,270	10,600	15,100	20,900	41,700
18	-0.617	0.371	1111.58	16.8	23.56	6,860	14,300	21,600	34,400	47,000	62,800	116,000
19	0.251	0.152	1966.87	16.8	19.48	9,660	21,700	33,500	53,900	73,700	98,000	177,000
20	-0.005	0.253	10.70	17.1	27.54	58.2	306	762	2,090	4,100	7,600	27,600
21	-1.028	-0.499	21.42	18.6	23.11	459	1,400	2,360	3,920	5,310	6,870	11,000
22	-0.357	-0.370	4.23	19.3	25.88	152	515	924	1,660	2,380	3,240	5,820
23	-1.203	-0.257	47.74	20.3	13.09	512	1,500	2,560	4,400	6,180	8,310	14,800
24	-0.424	-0.253	6.89	21.6	38.27	294	1,250	2,550	5,300	8,350	12,400	27,000
25	-1.288	-0.266	821.97	21.3	3.98	3,750	7,400	10,400	14,600	18,000	21,700	31,100
26	-0.261	-0.219	4.44	22.7	55.00	108	267	420	667	892	1,150	1,900
27	-0.107	-0.085	41.54	26.1	11.08	470	1,270	2,120	3,640	5,130	6,970	12,900
28	-0.515	-0.428	401.31	25.2	11.77	1,090	4,120	7,750	14,500	21,100	29,200	53,600
29	-0.478	-0.135	4.20	28.4	28.55	534	771	923	1,130	1,280	1,420	1,770
30	-0.281	-0.148	1.77	28.0	57.50	151	358	554	874	1,160	1,500	2,490

Table 1. Peak-streamflow frequency estimates and basin characteristics for selected stations with at least 8 years of annual

[ft³/s, cubic feet per second; LPIII, Log-Pearson Type III; mi², square miles; ft/mi, feet per mile; wt, weighted; Trib., Tributary; Ck, creek; Res., Reservoir;

			Analysis Information				
Site number (fig. 1)	Station number	Station name	Available systematic record[1] (years)	Historical record length[2] (years)	Number of high outliers	High-outlier threshold[3] (ft³/s)	Low-outlier threshold[4] (ft³/s)
31	07158180	Salt Creek Trib. near Okeene, Okla.	12				
32	07158400	Salt Creek near Okeene, Okla.	12				
33	07158500	Preacher Creek near Dover, Okla.	27		1	6,000	
34	07158550	Turkey Creek Trib. near Goltry, Okla.	19				
35	07159000	Turkey Creek near Drummond, Okla.[7]	27	43	1	30,000	
36	07159200	Kingfisher Creek near Kingfisher, Okla.	15	40			
37	07159810	Watershed W–VI near Guthrie, Okla.	14				
38	07160350	Skeleton Creek at Enid, Okla.	12				
39	07160500	Skeleton Creek near Lovell, Okla.[7]	51	77			
40	07160550	West Beaver Creek near Orlando, Okla.	22				
41	07163000	Council Creek near Stillwater, Okla.[7]	60	82			
42	07163020	Corral Creek near Yale, Okla.	12				
43	07165550	Snake Creek near Bixby, Okla.	15				500
44	07170600	Cherry Creek near Cherryvale, Kans.	21		1	15,500	
45	07170700	Big Hill Creek near Cherryvale, Kans.[7]	23	30	1	35,000	
46	07170800	Mud Creek near Mound Valley, Kans.	34				175
47	07171700	Spring Branch near Cedar Vale, Kans.	38				15
48	07171800	Cedar Creek Trib. near Hooser, Kans.	34				
49	07172000	Caney River near Elgin, Kans.[7, 8]	26				
50	07173000	Caney River near Hulah, Okla.[8]	12				
51	07174200	L. Caney River blw Cotton Creek near Copan, Okla.[7, 8]	21				
52	07174570	Dry Hollow near Pawhuska, Okla.	8				
53	07174600	Sand Creek at Okesa, Okla.[7]	34				
54	07174720	Hogshooter Creek Trib. near Bartlesville, Okla.	21				83
55	07176500	Bird Creek at Avant, Okla.[7, 8]	31				1,904
56	07176800	Candy Creek near Wolco, Okla.	12				
57	07177000	Hominy Creek near Skiatook, Okla.[7, 8]	38		1	31,100	1,498
58	07177500	Bird Creek near Sperry, Okla.[7, 8]	46				2,186
59	07178640	Bull Creek near Inola, Okla.	11				
60	07183800	Limestone Creek near Beulah, Kans[7]	33				

peak-streamflow data from unregulated basins in and near Oklahoma.—Continued

L., Little; Lk, Lake; blw, below; SWS, subwatershed; Fk, Fork; R, river; nr, near; %, percent; SH, State highway; N, north; ab, above]

Site number (fig. 1)	Basin characteristics: Skew coefficient for LP III distribution[5] — Station	Skew coefficient — Weighted	Contributing drainage area (mi^2)	Area-wt mean annual precipitation[6] (inches)	Steam slope (ft/mi)	Peak-streamflow frequency estimates: Peak discharge; in ft^3/s, for indicated percent chance exceedance (%) — 50	20	10	4	2	1	0.02
31	-0.038	0.168	8.37	30.9	12.71	687	2,160	4,010	7,890	12,300	18,500	43,100
32	0.433	0.214	181.49	30.9	8.45	4,770	7,690	9,980	13,300	16,100	19,100	27,400
33	0.829	0.348	14.33	32.8	14.47	219	617	1,100	2,120	3,280	4,910	11,500
34	0.149	0.031	4.82	31.8	15.13	342	999	1,760	3,210	4,750	6,760	13,900
35	0.008	0.035	254.76	32.4	4.31	2,630	7,190	12,200	21,600	31,200	43,400	85,400
36	0.035	0.261	165.14	31.8	6.44	2,490	7,740	14,500	29,000	45,900	70,200	170,000
37	-0.097	0.202	0.15	35.9	132.65	30.2	80.3	137	246	362	516	1,080
38	0.406	0.095	69.95	34.0	12.63	3,460	5,720	7,480	10,000	12,100	14,400	20,400
39	0.110	0.146	412.05	33.6	5.67	5,890	15,600	26,500	47,000	68,600	96,700	197,000
40	-0.354	0.035	13.58	35.0	19.55	992	2,170	3,280	5,110	6,800	8,810	14,900
41	0.312	0.368	30.03	38.4	13.88	2,200	4,610	7,000	11,200	15,300	20,600	38,200
42	-0.327	0.183	3.01	38.5	45.65	590	912	1,160	1,500	1,780	2,080	2,880
43	-1.370	0.263	47.69	42.7	9.45	3,280	5,770	7,890	11,100	14,000	17,300	27,000
44	0.578	0.231	15.23	43.2	16.34	2,350	4,590	6,620	9,900	13,000	16,600	27,600
45	1.307	0.020	36.84	43.1	8.80	3,590	6,600	9,090	12,800	16,000	19,500	29,200
46	-0.366	0.228	4.40	44.2	27.39	1,230	2,150	2,930	4,100	5,130	6,310	9,680
47	-1.777	-0.553	3.08	37.9	42.41	832	2,160	3,340	5,100	6,550	8,080	11,800
48	-0.661	-0.410	0.51	37.6	153.63	157	324	457	645	794	950	1,330
49	-0.933	-0.581	428.50	37.7	7.02	14,300	30,500	43,200	60,200	73,200	86,100	116,000
50	-0.336	-0.413	710.78	38.2	5.45	15,400	28,400	37,900	50,500	60,200	69,900	92,600
51	-0.608	-0.428	503.37	40.0	4.92	10,800	21,900	30,500	42,400	51,800	61,400	84,600
52	-0.381	-0.339	1.72	40.1	84.08	316	606	832	1,140	1,390	1,650	2,280
53	-0.821	-0.433	137.83	40.3	9.67	8,140	13,300	16,800	21,100	24,300	27,400	34,200
54	-0.895	-0.244	0.78	40.6	65.71	346	515	627	766	869	970	1,200
55	-1.216	-0.146	368.55	41.4	6.05	12,100	19,800	25,300	32,800	38,600	44,700	59,500
56	-0.482	-0.092	31.35	41.1	15.15	5,080	7,870	9,860	12,500	14,500	16,600	21,700
57	-0.835	0.350	340.11	40.9	4.50	8,400	12,900	16,300	21,400	25,600	30,200	43,000
58	0.216	0.488	906.98	41.1	4.09	14,500	25,600	35,700	51,900	67,100	85,200	142,000
59	-1.052	-0.063	10.83	43.6	13.30	827	1,400	1,840	2,450	2,940	3,470	4,830
60	-0.513	-0.162	13.27	45.1	15.78	3,100	6,520	9,490	14,000	17,900	22,300	34,300

Table 1. Peak-streamflow frequency estimates and basin characteristics for selected stations with at least 8 years of annual

[ft^3/s, cubic feet per second; LPIII, Log-Pearson Type III; mi^2, square miles; ft/mi, feet per mile; wt, weighted; Trib., Tributary; Ck, creek; Res., Reservoir;

Site number (fig. 1)	Station number	Station name	Analysis Information				
			Available systematic record[1] (years)	Historical record length[2] (years)	Number of high outliers	High-outlier threshold[3] (ft^3/s)	Low-outlier threshold[4] (ft^3/s)
61	07184000	Lightning Creek near McCune, Kans.[7]	58				
62	07184500	Labette Creek near Oswego, Kans.[7]	37	56			1,342
63	07185500	Stahl Creek near Miller, Mo.7	34				
64	07185600	South Fork Stahl Creek near Miller, Mo.	28				
65	07185700	Spring River at LaRussell, Mo.[7]	26				
66	07185765	Spring River at Carthage, Mo.	19				
67	07185900	O'Possum Creek at Jasper, Mo.	23				
68	07186000	Spring River near Waco, Mo.[7]	86				
69	07186400	Center Creek near Carterville, Mo.[7]	30				
70	07187000	Shoal Creek above Joplin, Mo.7	85				
71	07188000	Spring River near Quapaw, Okla.[7]	69				
72	07188140	Flint Branch near Peoria, Okla.	22				
73	07188500	Lost Creek at Seneca, Mo.[7]	11				
74	07188900	Butler Creek Trib. near Gravette, Ark.	21				2
75	07189000	Elk River near Tiff City, Mo.[7]	68				
76	07189540	Cave Springs Branch near South West City, Mo.	11				
77	07189542	Honey Creek near South West City, Mo.	10				
78	07190600	Big Cabin Creek near Pyramid Corners, Okla.	15				457
79	07191000	Big Cabin Creek near Big Cabin, Okla.[7]	68	74	4	41,000	
80	07191220	Spavinaw Creek near Sycamore, Okla.[7]	49				
81	07191260	Brushy Creek near Jay, Okla.	8	10	1	4,640	
82	07192000	Pryor Creek near Pryor, Okla.[7]	21				
83	07194515	Mill Creek near Park Hill, Okla.	20				17
84	07194800	Illinois River at Savoy, Ark.	13				
85	07195000	Osage Creek near Elm Springs, Ark.7	59				508
86	07195200	Brush Creek Trib. near Tontitown, Ark.	21				
87	07195430	Illinois River South of Siloam Springs, Ark.	13				5,811
88	07195450	Ballard Creek at Summers, Ark.	24				
89	07195500	Illinois River near Watts, Okla.[7]	53				
90	07195800	Flint Creek at Springtown, Ark.[7]	48				

peak-streamflow data from unregulated basins in and near Oklahoma.—Continued

L., Little; Lk, Lake; blw, below; SWS, subwatershed; Fk, Fork; R, river; nr, near; %, percent; SH, State highway; N, north; ab, above]

Basin characteristics						Peak-streamflow frequency estimates						
Site number (fig. 1)	Skew coefficient for LP III distribution[5]		Contributing drainage area (mi²)	Area-wt mean annual precipitation[6] (inches)	Steam slope (ft/mi)	Peak discharge; in ft³/s, for indicated percent chance exceedance (%)						
	Station	Weighted				50	20	10	4	2	1	0.02
61	0.462	0.216	195.94	44.8	3.43	6,760	15,300	24,000	39,200	54,400	73,300	136,000
62	-1.189	-0.055	213.21	43.0	3.71	8,160	12,900	16,300	20,800	24,400	28,200	37,500
63	-0.554	-0.197	4.02	44.9	27.03	612	1,020	1,310	1,700	2,000	2,320	3,090
64	0.254	0.033	0.96	45.0	45.18	201	392	558	813	1,040	1,300	2,030
65	0.232	0.048	305.59	45.1	6.04	5,850	11,200	15,800	22,800	28,900	35,900	55,700
66	-0.446	-0.122	447.81	45.1	5.18	7,910	17,200	25,600	38,700	50,400	63,600	101,000
67	-0.332	-0.113	9.82	45.1	11.37	1,170	1,860	2,360	3,020	3,540	4,080	5,400
68	-0.159	-0.120	1158.12	45.1	2.51	18,800	36,000	50,000	70,600	87,900	107,000	157,000
69	0.526	0.115	228.93	45.1	7.75	5,430	11,000	16,100	24,200	31,700	40,500	66,900
70	0.028	-0.011	427.45	45.6	5.83	7,260	14,610	21,040	31,020	39,850	49,910	78,660
71	-0.084	-0.080	2515.63	45.2	2.07	35,800	66,400	91,100	127,000	158,000	190,000	279,000
72	0.483	0.038	4.88	44.4	34.84	782	1,480	2,070	2,970	3,750	4,640	7,130
73	0.264	-0.007	40.75	45.1	22.59	892	3,220	6,290	12,800	20,400	30,800	71,200
74	-0.956	-0.359	0.99	46.9	128.02	101	295	494	828	1,140	1,500	2,520
75	-0.411	-0.302	850.68	45.9	6.81	20,100	39,400	54,800	76,500	94,000	112,000	159,000
76	-0.105	-0.215	8.00	45.7	28.52	690	1,240	1,650	2,220	2,680	3,160	4,370
77	0.122	-0.177	48.64	46.1	23.24	1,070	2,490	3,810	5,920	7,820	10,000	16,200
78	-1.380	-0.071	71.06	43.9	9.61	4,710	8,430	11,400	15,600	19,100	22,900	32,800
79	-0.123	-0.137	450.31	44.1	4.45	16,100	28,100	37,300	50,000	60,300	71,200	98,800
80	-0.383	-0.315	131.55	47.2	14.18	3,410	9,510	15,700	26,000	35,500	46,500	78,200
81	1.093	-0.120	16.51	46.6	26.63	854	2,170	3,490	5,740	7,880	10,400	18,200
82	0.193	0.017	227.41	43.5	3.71	5,300	11,700	17,800	27,800	37,200	48,200	81,700
83	-1.584	-0.228	2.10	47.0	99.43	414	896	1,310	1,950	2,490	3,090	4,720
84	0.425	-0.193	167.44	48.1	13.37	11,900	20,700	27,200	36,100	43,200	50,600	69,000
85	-0.547	-0.297	129.96	47.0	15.77	5,540	10,500	14,300	19,700	23,900	28,400	39,500
86	-0.332	-0.317	0.38	46.8	127.96	68.0	177	281	450	601	773	1,250
87	-1.102	-0.371	567.80	47.4	7.08	24,100	35,800	43,300	52,400	58,900	65,100	78,800
88	-1.052	-0.455	14.31	49.0	43.10	1,710	4,010	5,990	8,890	11,300	13,800	20,200
89	-0.549	-0.394	629.77	47.5	6.59	18,800	33,200	43,600	57,100	67,300	77,600	101,000
90	0.115	-0.120	14.72	47.6	38.21	758	1,940	3,130	5,170	7,110	9,430	16,600

Table 1. Peak-streamflow frequency estimates and basin characteristics for selected stations with at least 8 years of annual

[ft³/s, cubic feet per second; LPIII, Log-Pearson Type III; mi², square miles; ft/mi, feet per mile; wt, weighted; Trib., Tributary; Ck, creek; Res., Reservoir;

Site number (fig. 1)	Station number	Station name	Analysis Information				
			Available systematic record[1] (years)	Historical record length[2] (years)	Number of high outliers	High-outlier threshold[3] (ft³/s)	Low-outlier threshold[4] (ft³/s)
91	07195865	Sager Creek near West Siloam Springs, Okla.	12				264
92	07196000	Flint Creek near Kansas, Okla.[7]	53				
93	07196380	Steely Hollow near Tahlequah, Okla.	11				
94	07196500	Illinois River near Tahlequah, Okla.[7]	74	93			
95	07196900	Baron Fork at Dutch Mills, Ark.[7]	51				436
96	07196973	Peacheater Creek at Christie, Okla.	10				109
97	07197000	Baron Fork at Eldon, Okla.[7]	61				1,500
98	07197360	Caney Creek near Barber, Okla.	11				475
99	07228290	Rough Creek near Thomas, Okla.	22				100
100	07228450	Deer Creek Trib. near Hydro, Okla.	12				
101	07228930	Worley Creek near Tuttle, Okla.	15				87
102	07228960	Canadian River Trib. near Newcastle, Okla.	11				
103	07229220	Walnut Creek near Blanchard, Okla.	9				
104	07229300	Walnut Creek at Purcell, Okla.	28		1	67,100	
105	07229420	Julian Creek Trib. near Asher, Okla.	21				55
106	07229430	Arbeca Creek near Allen, Okla.	11				150
107	07230000	Little River blw Lk Thunderbird near Norman, Okla.[8]	12		1	26,400	
108	07230500	Little River near Tecumseh, Okla.[7, 8]	21	33	1	38,190	
109	07231000	Little River near Sasakwa, Okla.[8]	19	23	1	33,000	3,000
110	07231320	Leader Creek Trib. near Atwood, Okla.	22				
111	07231560	Middle Creek near Carson, Okla.	11				300
112	07231950	Pine Creek near Higgins, Okla.	22				650
113	07232000	Gaines Creek near Krebs, Okla.[7]	21	26	1	60,900	
114	07232500	Beaver River near Guymon, Okla.[7]	35				272
115	07232650	Aqua Frio Creek near Felt, Okla.	12				
116	07233000	Coldwater Creek near Hardesty, Okla.[7]	26				100
117	07233500	Palo Duro Creek near Spearman, Tex.[7]	26	36	2	26,100	
118	07234050	North Fork Clear Creek Trib. near Balko, Okla.	22				10
119	07234100	Clear Creek near Elmwood, Okla.	28				
120	07234150	White Woman Creek Trib. near Darrouzett, Tex.	9				

peak-streamflow data from unregulated basins in and near Oklahoma.—Continued

L., Little; Lk, Lake; blw, below; SWS, subwatershed; Fk, Fork; R, river; nr, near; %, percent; SH, State highway; N, north; ab, above]

Site number (fig. 1)	Basin characteristics: Skew coefficient for LP III distribution[5] Station	Skew coefficient for LP III distribution[5] Weighted	Contrib-uting drainage area (mi²)	Area-wt mean annual precip-itation[6] (inches)	Steam slope (ft/mi)	Peak-streamflow frequency estimates: Peak discharge; in ft³/s, for indicated percent chance exceedance (%) 50	20	10	4	2	1	0.02
91	-1.016	-0.239	19.11	47.9	22.45	1,750	2,890	3,710	4,800	5,630	6,480	8,520
92	-0.256	-0.271	115.59	47.8	15.33	3,950	10,300	16,600	26,900	36,200	47,100	78,300
93	-0.292	-0.244	3.84	47.8	78.25	540	1,770	3,180	5,800	8,440	11,700	22,300
94	-0.177	-0.208	950.25	47.6	4.54	19,600	38,100	53,000	74,500	92,300	111,000	161,000
95	-1.436	-0.494	41.09	50.1	39.02	7,140	13,700	18,600	25,100	30,000	34,800	46,000
96	-1.860	-0.383	24.85	48.7	32.83	1,360	2,370	3,100	4,050	4,770	5,480	7,160
97	-1.427	-0.242	311.58	49.4	10.28	15,600	27,500	36,400	48,600	58,100	68,000	92,500
98	-2.588	-0.165	90.21	49.0	21.91	4,990	6,910	8,140	9,650	10,700	11,800	14,200
99	-0.493	0.205	10.19	29.8	39.26	772	2,120	3,690	6,760	10,100	14,600	31,300
100	0.518	0.480	2.32	31.1	62.25	298	534	748	1,100	1,420	1,810	3,050
101	-2.470	0.234	11.22	35.2	17.11	1,240	2,110	2,820	3,880	4,790	5,820	8,730
102	-0.244	0.317	3.27	36.1	44.15	702	1,170	1,560	2,140	2,650	3,220	4,870
103	-0.501	0.317	1.27	34.8	67.78	374	662	911	1,300	1,650	2,060	3,260
104	0.014	0.229	202.13	36.7	6.61	8,670	17,300	25,200	38,200	50,400	64,900	110,000
105	-0.434	0.573	2.30	39.4	27.35	398	740	1,060	1,620	2,160	2,830	5,060
106	-0.584	0.551	2.12	42.4	30.67	653	1,180	1,670	2,490	3,270	4,220	7,310
107	1.396	0.595	257.09	38.0	6.15	5,780	10,600	15,200	23,100	30,700	40,200	71,600
108	1.271	0.855	462.50	38.3	5.54	8,950	16,300	23,600	36,600	49,800	66,900	128,000
109	-0.610	0.327	888.35	39.2	3.30	15,000	26,600	36,800	53,000	67,700	85,000	138,000
110	0.275	0.514	0.73	42.1	75.47	293	583	869	1,370	1,870	2,510	4,680
111	-0.978	0.500	7.34	43.8	27.16	1,630	2,980	4,220	6,280	8,240	10,600	18,300
112	-0.374	0.150	10.83	51.2	48.66	4,120	7,890	11,200	16,400	21,100	26,500	42,500
113	0.609	0.541	585.08	47.9	3.07	12,200	23,200	33,800	52,000	69,800	92,100	167,000
114	-0.825	-0.451	1,611.74	17.3	14.03	8,630	21,500	33,000	50,400	65,000	80,800	121,000
115	-0.356	0.161	31.52	16.6	17.89	124	677	1,690	4,610	8,910	16,300	56,400
116	-0.642	-0.265	1028.81	17.9	9.71	2,730	7,470	12,300	20,300	27,900	36,700	62,600
117	0.257	0.262	624.68	18.2	8.27	2,890	7,410	12,500	22,200	32,700	46,500	97,500
118	-0.483	-0.252	4.30	21.1	25.53	59.4	297	658	1,480	2,460	3,840	9,120
119	-0.779	-0.397	161.87	21.2	11.38	957	5,420	12,400	28,300	46,800	72,000	163,000
120	0.072	-0.191	4.10	23.4	16.30	78.2	210	344	574	793	1,050	1,840

Table 1. Peak-streamflow frequency estimates and basin characteristics for selected stations with at least 8 years of annual

[ft^3/s, cubic feet per second; LPIII, Log-Pearson Type III; mi^2, square miles; ft/mi, feet per mile; wt, weighted; Trib., Tributary; Ck, creek; Res., Reservoir;

Site number (fig. 1)	Station number	Station name	Analysis Information				
			Available systematic record[1] (years)	Historical record length[2] (years)	Number of high outliers	High-outlier threshold[3] (ft^3/s)	Low-outlier threshold[4] (ft^3/s)
121	07234290	Clear Creek Trib. near Catesby, Okla.	20				25
122	07235700	Little Wolf Creek Trib. near Gage, Okla.	11				
123	07236000	Wolf Creek near Fargo, Okla.	16		1	62,300	
124	07237750	Cottonwood Creek near Vici, Okla.	21				22
125	07237800	Bent Creek near Seiling, Okla.	20				
126	07239050	North Canadian River Trib. near Eagle City, Okla.	12				
127	07241880	Sand Creek near Cromwell, Okla.	22				220
128	07242160	Alabama Creek near Weleetka, Okla.	19				1,000
129	07243000	Dry Creek near Kendrick, Okla.[7]	39				
130	07243500	Deep Fork near Beggs, Okla.[7, 8]	29				
131	07243550	Adams Creek near Beggs, Okla.	20				64
132	07244000	Deep Fork near Dewar, Okla.	18	47	2	29,000	
133	07244790	Brooken Creek near Enterprise, Okla.	11				
134	07245500	Sallisaw Creek near Sallisaw, Okla.[7, 8]	22				
135	07246610	Pecan Creek near Spiro, Okla.	12				
136	07246630	Big Black Fox Creek near Long, Okla.	21				250
137	07247000	Poteau River at Cauthron, Ark.[7, 8]	34				
138	07247250	Black Fork below Big Creek near Page, Okla.	16				
139	07247500	Fourche Maline near Red Oak, Okla.[7, 8]	25				
140	07249000	Poteau River at Poteau, Okla.	12	23	3	21,000	
141	07249300	James Fork near Midland, Ark.	20				
142	07249400	James Fork near Hackett, Ark.[7]	51				
143	07249500	Cove Creek near Lee Creek, Ark.[7]	55				
144	07249650	Mountain Fork near Evansville, Ark.	20				
145	07250000	Lee Creek near Van Buren, Ark.[7]	50	62	1	112,000	
146	07299300	Little Red R nr Turkey, Tex.	14				
147	07299670	Groesbeck Creek at S.H. 6 near Quanah, Tex.[7]	46				56
148	07299705	Bitter Creek near Hollis, Okla.	9				
149	07300150	Bear Creek near Vinson, Okla.	22				100
150	07300500	Salt Fork Red River at Mangum, Okla.[7]	71				

peak-streamflow data from unregulated basins in and near Oklahoma.—Continued

L., Little; Lk, Lake; blw, below; SWS, subwatershed; Fk, Fork; R, river; nr, near; %, percent; SH, State highway; N, north; ab, above]

	Basin characteristics					Peak-streamflow frequency estimates						
Site number (fig. 1)	Skew coefficient for LP III distribution[5]		Contributing drainage area (mi²)	Area-wt mean annual precipitation[6] (inches)	Steam slope (ft/mi)	Peak discharge; in ft³/s, for indicated percent chance exceedance (%)						
	Station	Weighted				50	20	10	4	2	1	0.02
121	-0.431	-0.327	8.56	23.6	34.18	119	456	875	1,690	2,540	3,600	7,080
122	0.276	-0.135	17.53	24.4	17.90	504	1,390	2,320	3,960	5,560	7,520	13,700
123	0.756	-0.097	1,473.01	23.0	6.54	7,220	15,900	23,800	36,500	47,800	60,900	98,500
124	-0.977	-0.152	11.65	27.6	40.31	434	1,010	1,540	2,400	3,180	4,070	6,660
125	-0.342	-0.075	129.00	27.4	9.77	2,360	4,480	6,230	8,820	11,000	13,400	20,000
126	-0.080	0.216	0.55	30.0	90.87	88.8	223	370	645	931	1,300	2,630
127	-2.167	0.450	9.52	41.3	24.37	1,400	2,150	2,750	3,640	4,400	5,250	7,660
128	-1.255	0.366	16.21	42.7	19.12	2,080	3,090	3,870	4,980	5,900	6,900	9,620
129	0.141	0.205	68.37	38.4	13.76	3,930	6,990	9,570	13,500	17,000	20,900	32,300
130	0.322	0.364	2,004.26	39.3	2.41	9,400	22,600	37,000	64,300	93,300	132,000	273,000
131	-2.030	0.171	5.69	41.9	37.72	1,080	2,090	2,970	4,380	5,660	7,140	11,600
132	-0.050	0.287	2,295.99	39.8	1.98	11,000	23,500	35,900	57,300	78,400	105,000	192,000
133	-0.418	0.135	5.95	46.9	34.94	1,830	3,380	4,710	6,750	8,540	10,600	16,500
134	0.111	-0.102	181.11	49.3	13.25	13,100	28,800	43,000	65,500	85,600	109,000	175,000
135	-0.095	-0.131	0.92	47.5	44.53	269	409	506	632	728	825	1,060
136	-0.961	-0.300	5.51	48.4	55.79	887	1,410	1,770	2,230	2,570	2,910	3,700
137	-0.319	-0.265	203.56	52.2	8.89	11,400	19,900	26,200	34,700	41,400	48,200	64,900
138	-0.673	-0.303	94.32	59.9	41.18	11,100	20,500	27,500	37,200	44,800	52,700	72,000
139	0.089	-0.039	120.35	49.9	14.67	6,700	14,200	20,900	31,500	41,100	52,100	84,000
140	-0.749	-0.083	1,250.72	51.8	2.82	23,000	46,400	66,500	97,100	124,000	153,000	236,000
141	0.038	-0.148	43.81	52.4	52.27	5,310	11,100	16,100	23,800	30,400	37,800	58,200
142	-0.109	-0.155	146.67	49.4	16.23	6,840	11,700	15,300	20,200	24,100	28,200	38,500
143	-0.147	-0.230	34.84	51.9	34.01	5,000	10,600	15,400	22,600	28,800	35,500	53,600
144	-0.408	-0.315	8.40	52.1	128.70	1,290	2,460	3,380	4,650	5,660	6,720	9,340
145	-0.350	-0.243	437.97	50.2	15.12	24,400	42,900	56,700	75,600	90,400	106,000	144,000
146	-1.063	-0.140	147.54	22.0	23.59	2,470	3,410	4,020	4,780	5,320	5,860	7,100
147	-0.852	0.175	320.00	25.7	7.10	1,860	4,700	7,770	13,500	19,400	27,000	53,700
148	-0.553	-0.072	11.48	25.8	34.08	126	383	679	1,240	1,830	2,580	5,160
149	-0.715	-0.085	7.18	25.9	38.79	668	1,600	2,500	4,010	5,420	7,080	12,100
150	-0.241	-0.154	1,319.45	24.0	11.66	9,560	22,000	33,500	51,900	68,400	87,500	142,000

Table 1. Peak-streamflow frequency estimates and basin characteristics for selected stations with at least 8 years of annual

[ft^3/s, cubic feet per second; LPIII, Log-Pearson Type III; mi^2, square miles; ft/mi, feet per mile; wt, weighted; Trib., Tributary; Ck, creek; Res., Reservoir;

Site number (fig. 1)	Station number	Station name	Analysis Information				
			Available systematic record[1] (years)	Historical record length[2] (years)	Number of high outliers	High-outlier threshold[3] (ft^3/s)	Low-outlier threshold[4] (ft^3/s)
151	07301110	Salt Fork Red River near Elmer, Okla.	29				
152	07301300	N Fk Red R nr Shamrock, Tex.	15				
153	07301455	Turkey Creek near Erick, Okla.	17	22			218
154	07301480	Short Creek near Sayre, Okla.	20				
155	07301500	North Fork Red River near Carter, Okla.[7]	32	59	2	14,300	1,375
156	07303400	Elm Fork of North Fork Red River near Carl, Okla.[7]	34				
157	07303450	Deer Creek near Plainview, Okla.	12				250
158	07303500	Elm Fork of North Fk Red River near Mangum, Okla.[7]	72				
159	07304500	Elk Creek near Hobart, Okla.	20		1	18,300	
160	07309480	Canyon Creek near Medicine Park, Okla.	11				30
161	07311000	East Cache Creek near Walters, Okla.[8]	22				974
162	07311200	Blue Beaver Creek near Cache, Okla.	39				118
163	07311420	Deadman Creek Trib. at Manitou, Okla.	8	11	1	900	
164	07311500	Deep Red Creek near Randlett, Okla.[7]	59				
165	07312850	Nine Mile Beaver Creek near Elgin, Okla.	22				100
166	07312950	Little Beaver Creek near Marlow, Okla.	12				
167	07313000	Little Beaver Creek near Duncan, Okla.	15				
168	07313500	Beaver Creek near Waurika, Okla.[7, 8]	24	26			
169	07313600	Cow Creek at Waurika, Okla.	20	31	1	18,100	
170	07315680	Cottonwood Creek Trib. near Loco, Okla.	21				
171	07315700	Mud Creek near Courtney, Okla.[7]	48	52	1	30,000	211
172	07315880	Demijohn Creek near Wilson, Okla.	10				
173	07316130	Wilson Creek Trib. near McMillan, Okla.	11				
174	07316140	Brier Creek near Powell, Okla.	21				
175	07316500	Washita River near Cheyenne, Okla.[7, 8]	23	27			
176	07317500	Sandstone Creek SWS 16A near Cheyenne, Okla.[9]	21				
177	07318500	Sandstone Creek SWS 14 near Cheyenne, Okla.[9]	12	20	2	1,160	
178	07319000	Sandstone Creek SWS 17 near Cheyenne, Okla.[9]	20				49
179	07320000	Sandstone Creek SWS 10A near Elk City, Okla.[9]	19	21			
180	07321500	Sandstone Creek SWS 3 near Elk City, Okla.[9]	14	19			

peak-streamflow data from unregulated basins in and near Oklahoma.—Continued

L., Little; Lk, Lake; blw, below; SWS, subwatershed; Fk, Fork; R, river; nr, near; %, percent; SH, State highway; N, north; ab, above]

Site number (fig. 1)	Basin characteristics: Skew coefficient for LP III distribution[5]					Peak-streamflow frequency estimates: Peak discharge; in ft^3/s, for indicated percent chance exceedance (%)						
	Station	Weighted	Contributing drainage area (mi^2)	Area-wt mean annual precipitation[6] (inches)	Steam slope (ft/mi)	50	20	10	4	2	1	0.02
151	0.508	0.256	1847.90	25.1	9.77	5,970	13,900	22,200	37,200	52,500	72,000	139,000
152	0.780	-0.024	816.73	22.9	10.36	6,460	10,100	12,700	16,200	19,000	21,900	29,200
153	-1.204	-0.382	21.87	26.1	17.30	1,070	1,910	2,520	3,320	3,930	4,550	6,000
154	0.298	0.044	9.28	26.3	31.62	456	926	1,340	2,010	2,600	3,300	5,320
155	-0.285	-0.151	2072.51	24.1	9.57	8,410	14,800	19,600	26,400	31,900	37,600	52,300
156	-0.202	-0.106	437.96	24.8	15.76	3,810	10,400	17,300	29,600	41,600	56,400	103,000
157	-0.669	-0.086	26.78	26.8	25.58	940	1,660	2,220	3,020	3,670	4,370	6,200
158	-0.548	-0.203	846.33	26.2	10.87	7,300	15,900	23,600	35,200	45,400	56,700	87,800
159	0.818	0.244	549.28	28.7	6.33	3,990	6,880	9,280	12,900	16,100	19,700	30,000
160	-1.697	0.159	3.39	32.8	56.74	762	1,880	3,070	5,230	7,430	10,200	19,800
161	-0.985	0.159	693.50	32.9	5.07	7,590	13,400	18,200	25,500	31,800	38,800	58,900
162	-0.302	0.211	24.67	32.6	35.58	1,650	3,600	5,500	8,780	12,000	15,900	28,700
163	-0.238	0.080	2.58	30.1	31.93	357	771	1,160	1,810	2,410	3,130	5,340
164	-0.044	0.019	604.08	30.8	5.92	7,220	16,800	26,100	41,900	56,900	75,000	131,000
165	-0.589	0.259	6.36	33.9	39.94	703	1,740	2,880	5,000	7,240	10,200	20,600
166	0.238	0.384	34.86	35.6	22.37	799	2,000	3,350	5,990	8,870	12,800	27,600
167	-0.422	-0.365	156.58	35.4	9.11	15,600	29,700	40,500	55,300	66,900	78,800	108,000
168	0.433	0.335	564.36	34.6	3.98	4,350	11,900	20,800	39,000	59,400	87,800	199,000
169	0.054	0.308	192.66	35.3	6.32	3,080	6,410	9,640	15,200	20,600	27,200	49,100
170	-0.419	0.115	1.81	36.3	56.06	486	1,080	1,670	2,650	3,600	4,750	8,400
171	-0.353	0.190	574.41	35.1	3.89	5,920	15,200	25,400	44,530	64,560	90,690	183,400
172	-0.949	0.065	6.44	36.9	30.34	1,880	2,160	2,330	2,530	2,660	2,790	3,070
173	-0.327	0.068	2.95	40.3	43.67	768	1,110	1,350	1,660	1,900	2,150	2,770
174	0.281	0.152	11.99	42.2	25.65	2,930	5,450	7,630	11,000	14,000	17,400	27,400
175	0.108	0.043	762.59	24.2	8.96	5,610	15,500	26,600	47,200	68,700	96,300	192,000
176	0.337	0.066	9.68	25.8	45.39	451	1,070	1,700	2,780	3,830	5,130	9,290
177	-0.220	-0.014	1.01	26.7	116.64	274	632	979	1,560	2,100	2,750	4,740
178	-0.858	-0.095	11.11	26.0	51.32	979	2,370	3,740	6,020	8,150	10,700	18,400
179	-1.300	-0.078	2.79	27.0	75.30	750	1,250	1,620	2,130	2,540	2,970	4,060
180	-1.041	0.116	0.65	27.4	107.51	311	616	890	1,320	1,720	2,180	3,540

Table 1. Peak-streamflow frequency estimates and basin characteristics for selected stations with at least 8 years of annual

[ft^3/s, cubic feet per second; LPIII, Log-Pearson Type III; mi^2, square miles; ft/mi, feet per mile; wt, weighted; Trib., Tributary; Ck, creek; Res., Reservoir;

Site number (fig. 1)	Station number	Station name	Analysis Information				
			Available systematic record[1] (years)	Historical record length[2] (years)	Number of high outliers	High-outlier threshold[3] (ft^3/s)	Low-outlier threshold[4] (ft^3/s)
181	07322000	Sandstone Creek SWS 9 near Elk City, Okla.[9]	18	22			
182	07324000	Sandstone Creek SWS 1 near Cheyenne, Okla.[9]	18	22			
183	07325000	Washita River near Clinton, Okla.[7, 8]	27				
184	07325850	Lake Creek near Eakly, Okla.	13				
185	07326000	Cobb Creek near Fort Cobb, Okla.[8]	19	22	1	32,500	
186	07327150	Salt Creek near Chickasha, Okla.	11				
187	07327420	West Bitter Creek near Tabler, Okla.	15				206
188	07327440	East Bitter Creek near Tabler, Okla.[8]	10				
189	073274406	Little Washita River ab SCS Pond No 26 nr Cyril, Okla.	14				
190	07327490	Little Washita River near Ninnekah, Okla.[7, 8]	22	27	1	24,900	
191	07329000	Rush Creek at Purdy, Okla.[8]	15				
192	07329500	Rush Creek near Maysville, Okla.[8]	11				
193	07329810	Honey Creek near Davis, Okla.	21				37
194	07329900	Rock Creek at Dougherty, Okla.[8]	15				273
195	07330500	Caddo Creek near Ardmore, Okla.	14				926
196	07332070	Rock Creek near Achille, Okla.	10				
197	07332400	Blue River at Milburn, Okla.	22		1	35,000	
198	07332500	Blue River near Blue, Okla.[7]	72				984
199	07332600	Bois D'Arc Ck nr Randolph, Tex.[7]	23				1,800
200	07333500	Chickasaw Creek near Stringtown, Okla.	20				1,800
201	07333800	McGee Creek near Stringtown, Okla.	20				2,900
202	07334000	Muddy Boggy Creek near Farris, Okla.[7, 8]	49				
203	07335000	Clear Boggy Creek near Caney, Okla.[7, 8]	20	24	1	54,600	
204	07335310	Rock Creek near Boswell, Okla.	21				
205	07335320	Bokchito Creek near Soper, Okla.	11				670
206	07335700	Kiamichi River near Big Cedar, Okla.	43				1,428
207	07335760	Kiamichi River Trib. near Albion, Okla.	8				
208	07336000	Tenmile Creek near Miller, Okla.	29		1	9,810	
209	07336500	Kiamichi River near Belzoni, Okla.[7]	47	57			
210	07336520	Frazier Creek near Oleta, Okla.	22				

peak-streamflow data from unregulated basins in and near Oklahoma.—Continued

L., Little; Lk, Lake; blw, below; SWS, subwatershed; Fk, Fork; R, river; nr, near; %, percent; SH, State highway; N, north; ab, above]

Site number (fig. 1)	Basin characteristics: Skew coefficient for LP III distribution[5]: Station	Weighted	Contributing drainage area (mi^2)	Area-wt mean annual precipitation[6] (inches)	Steam slope (ft/mi)	Peak-streamflow frequency estimates: Peak discharge; in ft^3/s, for indicated percent chance exceedance (%): 50	20	10	4	2	1	0.02
181	-0.197	0.010	3.36	27.4	60.09	868	1,580	2,160	3,010	3,740	4,550	6,740
182	-0.340	0.082	5.39	27.5	46.93	812	1,930	3,070	5,050	7,000	9,400	17,200
183	0.678	0.507	1,948.58	26.4	6.79	7,650	18,200	30,000	53,100	78,500	113,000	247,000
184	0.413	0.459	52.46	31.6	15.90	935	2,840	5,380	11,100	18,200	28,800	76,500
185	0.851	0.556	310.72	31.4	7.23	4,220	10,200	17,200	31,200	47,000	68,900	157,000
186	0.089	0.436	23.79	34.1	13.17	694	1,620	2,620	4,530	6,560	9,260	19,300
187	-1.523	0.270	59.70	34.0	10.89	1,630	3,080	4,380	6,470	8,380	10,600	17,600
188	-0.582	0.338	35.38	34.6	12.23	1,710	2,990	4,100	5,820	7,360	9,150	14,500
189	-0.717	0.263	3.65	33.4	37.74	391	1,350	2,660	5,670	9,380	14,900	39,200
190	0.413	0.544	207.96	34.4	8.52	3,250	7,430	12,000	20,900	30,500	43,500	93,300
191	0.244	0.344	139.68	36.6	9.97	10,000	16,100	21,000	28,300	34,500	41,500	61,200
192	0.003	0.280	201.75	36.9	8.78	9,390	17,800	25,300	37,400	48,600	61,900	102,000
193	-2.175	0.132	18.75	39.6	41.48	1,940	4,610	7,340	12,200	16,900	22,900	42,600
194	-1.027	0.226	136.76	41.2	13.71	4,650	10,500	16,500	27,000	37,400	50,500	94,200
195	-1.260	0.054	296.30	38.0	5.81	8,300	15,500	21,600	30,800	38,800	47,800	73,200
196	0.587	0.199	0.71	43.5	27.10	397	684	919	1,270	1,580	1,920	2,890
197	-0.426	-0.120	203.19	42.3	10.26	8,700	17,300	24,500	35,300	44,600	54,800	82,700
198	-0.216	0.367	477.45	43.5	6.98	9,300	17,100	24,000	35,300	45,650	58,000	96,200
199	-2.187	-0.322	72.09	43.3	8.38	8,880	12,500	14,700	17,400	19,300	21,000	25,000
200	-1.184	0.177	32.62	45.5	25.39	7,570	10,800	13,200	16,300	18,700	21,300	27,700
201	-1.761	0.113	88.76	47.4	6.10	6,840	8,630	9,770	11,200	12,200	13,200	15,600
202	-0.164	0.056	1088.92	45.0	3.18	19,200	29,800	37,600	48,300	56,900	65,900	88,900
203	0.050	0.167	713.37	43.4	3.37	14,000	28,600	42,200	64,400	85,200	110,000	186,000
204	-0.685	-0.067	1.01	46.0	33.38	249	427	564	756	912	1,080	1,510
205	-1.270	-0.071	17.48	47.1	15.74	3,230	5,090	6,430	8,230	9,640	11,100	14,700
206	-0.647	-0.258	39.63	62.1	54.89	9,200	15,100	19,300	24,800	29,000	33,300	43,400
207	0.530	-0.511	1.51	55.9	342.93	246	549	797	1,150	1,420	1,710	2,400
208	0.617	0.281	68.31	48.1	12.21	3,620	5,080	6,120	7,530	8,650	9,830	12,800
209	-0.147	-0.059	1415.94	51.3	3.35	34,300	49,400	59,600	72,700	82,500	92,500	116,000
210	-0.184	-0.061	18.54	50.8	25.32	2,480	4,560	6,250	8,710	10,800	13,000	19,100

Table 1. Peak-streamflow frequency estimates and basin characteristics for selected stations with at least 8 years of annual

[ft^3/s, cubic feet per second; LPIII, Log-Pearson Type III; mi^2, square miles; ft/mi, feet per mile; wt, weighted; Trib., Tributary; Ck, creek; Res., Reservoir;

Site number (fig. 1)	Station number	Station name	Analysis Information				
			Available systematic record[1] (years)	Historical record length[2] (years)	Number of high outliers	High-outlier threshold[3] (ft^3/s)	Low-outlier threshold[4] (ft^3/s)
211	07336710	Rock Creek near Sawyer, Okla.	11				
212	07336750	Little Pine Creek near Kanawha, Tex.	12				
213	07336780	Perry Creek near Idabel, Okla.	10				714
214	07336785	Bokchito Creek near Garvin, Okla.	12				240
215	07336800	Pecan Bayou near Clarksville, Tex.	16				
216	07337220	Big Branch near Ringold, Okla.	11				
217	07337500	Little River near Wright City, Okla.[7, 8]	26				
218	07337900	Glover River near Glover, Okla.7	48				
219	07338500	Little River blw Lukfata Creek near Idabel, Okla.[7, 8]	39				
220	07338520	Yanubbee Creek near Broken Bow, Okla.	22				
221	07338700	Twomile Creek near Hatfield, Ark.	21				
222	07338780	Mountain Fork Trib. near Smithville, Okla.	20		1	1,017	
223	07339000	Mountain Fork near Eagletown, Okla.[7, 8]	39	54		67,500	
224	07339500	Rolling Fork near DeQueen, Ark.[7, 8]	25	27	1	87,700	
225	07339800	Pepper Creek near DeQueen, Ark.	26				
226	07340200	West Flat Creek near Foreman, Ark.	20	22			
227	07340300	Cossatot River near Vandervoort, Ark.[7]	41	48	1	48,000	
228	07340500	Cossatot River near DeQueen, Ark.[7, 8]	37				
229	07340530	Mill Slough Trib. near Locksburg, Ark.	24				
230	07341000	Saline River near Dierks, Ark.[7, 8]	34	53	2	42,000	
231	07341100	Rock Creek near Dierks, Ark.	23				350

[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 2008 water year.

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

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

[5]Reflects weighting adjusted station skew with skew value from Oklahoma generalized skew map (fig. 2; Lewis and Esralew, 2009).

[6]Values at station location derived from geographical information system using gridded mean-annual precipitation based on 1971-2000 data.

[7]Station used in construction of Oklahoma generalized skew map (fig. 2; Lewis and Esralew, 2009).

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

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

peak-streamflow data from unregulated basins in and near Oklahoma.—Continued

L., Little; Lk, Lake; blw, below; SWS, subwatershed; Fk, Fork; R, river; nr, near; %, percent; SH, State highway; N, north; ab, above]

Basin characteristics						Peak-streamflow frequency estimates						
Site number (fig. 1)	Skew coefficient for LP III distribution[5]		Contributing drainage area (mi²)	Area-wt mean annual precipitation[6] (inches)	Steam slope (ft/mi)	Peak discharge; in ft³/s, for indicated percent chance exceedance (%)						
	Station	Weighted				50	20	10	4	2	1	0.02
211	0.156	-0.022	3.33	49.4	33.06	794	1,170	1,430	1,770	2,040	2,310	2,960
212	-0.142	-0.118	75.27	48.8	5.24	6,180	12,600	18,200	26,600	33,900	42,000	64,500
213	-0.955	0.054	7.60	51.1	22.72	2,240	3,020	3,540	4,190	4,680	5,180	6,350
214	-1.071	-0.172	2.89	51.1	22.67	731	1,020	1,200	1,430	1,600	1,760	2,130
215	-0.422	-0.201	98.91	49.2	4.30	4,060	8,050	11,300	16,100	20,200	24,500	36,000
216	0.385	0.023	1.99	52.2	72.35	448	856	1,200	1,730	2,190	2,710	4,160
217	-0.042	-0.047	648.22	53.9	9.74	30,500	49,700	64,100	83,800	99,500	116,000	158,000
218	0.150	0.033	320.28	55.3	13.52	27,700	45,100	58,300	76,800	91,700	108,000	149,000
219	-0.055	-0.058	1,228.14	53.9	5.67	27,600	46,100	60,000	79,400	95,100	112,000	154,000
220	-0.394	-0.145	9.03	53.8	42.27	1,770	3,100	4,130	5,550	6,700	7,920	11,000
221	0.394	-0.070	16.22	60.0	44.03	2,040	3,570	4,760	6,460	7,850	9,340	13,200
222	0.505	-0.020	0.65	56.1	69.96	203	359	482	660	808	968	1,400
223	-0.469	-0.223	799.80	57.4	6.82	37,400	62,900	81,600	106,000	126,000	146,000	194,000
224	0.139	-0.098	183.37	56.4	17.52	16,300	31,600	44,300	63,100	79,200	96,800	145,000
225	-0.503	-0.138	6.27	55.9	41.72	976	2,410	3,800	6,130	8,300	10,800	18,500
226	-0.633	-0.151	10.65	50.8	10.62	1,540	2,640	3,470	4,610	5,520	6,480	8,880
227	-0.525	-0.253	89.10	62.0	28.55	14,300	24,000	31,000	40,300	47,500	54,800	72,400
228	0.225	0.076	361.22	58.7	15.46	28,100	46,800	61,300	82,100	99,200	118,000	168,000
229	-0.351	-0.079	0.69	54.7	55.83	183	344	476	669	838	1,010	1,490
230	0.113	0.009	120.21	59.1	20.90	9,740	18,500	26,000	37,200	46,900	57,900	88,500
231	-0.552	-0.027	9.39	56.9	41.95	2,220	4,280	6,020	8,640	10,900	13,400	20,500

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