In cooperation with the Texas Commission on Environmental Quality

Statewide Analysis of the Drainage-Area Ratio Method for 34 Streamflow Percentile Ranges in Texas

Scientific Investigations Report 2006–5286

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

Cover. Unnamed tributary to Honey Creek at Honey Creek State Natural Area, Comal County, Texas, April 2001.

Statewide Analysis of the Drainage-Area Ratio Method for 34 Streamflow Percentile Ranges in Texas

By William H. Asquith, Meghan C. Roussel, and Joseph Vrabel

In cooperation with the Texas Commission on Environmental Quality

Scientific Investigations Report 2006–5286

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

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark Myers, Director

U.S. Geological Survey, Reston, Virginia: 2006

For more information about the USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: http://www.usgs.gov/

Suggested citation:

Asquith, W.H., Roussel, M.C., and Vrabel, Joseph, 2006, Statewide analysis of the drainage-area ratio method for 34 streamflow percentile ranges in Texas: U.S. Geological Survey Scientific Investigations Report 2006–5286, 34 p., 1 appendix.

Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)

Statewide Analysis of the Drainage-Area Ratio Method for 34 Streamflow Percentile Ranges in Texas

By William H. Asquith, Meghan C. Roussel, and Joseph Vrabel

Abstract

The drainage-area ratio method commonly is used to estimate streamflow for sites where no streamflow data are available using data from one or more nearby streamflow-gaging stations. The method is intuitive and straightforward to implement and is in widespread use by analysts and managers of surface-water resources. The method equates the ratio of streamflow at two stream locations to the ratio of the respective drainage areas. In practice, unity often is assumed as the exponent on the drainage-area ratio, and unity also is assumed as a multiplicative bias correction. These two assumptions are evaluated in this investigation through statewide analysis of daily mean streamflow in Texas. The investigation was made by the U.S. Geological Survey in cooperation with the Texas Commission on Environmental Quality. More than 7.8 million values of daily mean streamflow for 712 U.S. Geological Survey streamflow-gaging stations in Texas were analyzed. To account for the influence of streamflow probability on the drainage-area ratio method, 34 percentile ranges were considered. The 34 ranges are the 4 quartiles (0–25, 25–50, 50–75, and 75–100 percent), the 5 intervals of the lower tail of the streamflow distribution (0–1, 1–2, 2–3, 3–4, and 4–5 percent), the 20 quintiles of the 4 quartiles (0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, 35–40, 40–45, 45–50, 50–55, 55–60, 60–65, 65–70, 70–75, 75–80, 80–85, 85–90, 90–95, and 95–100 percent), and the 5 intervals of the upper tail of the streamflow distribution (95–96, 96–97, 97–98, 98–99 and 99–100 percent). For each of the 253,116 (712×711/2) unique pairings of stations and for each of the 34 percentile ranges, the concurrent daily mean streamflow values available for the two stations provided for station-pair application of the drainage-area ratio method. For each station pair, specific statistical summarization (median, mean, and standard deviation) of both the exponent and bias-correction components of the drainage-area ratio method were computed. Statewide statistics (median, mean, and standard deviation) of the station-pair specific statistics subsequently were computed and are tabulated herein. A separate analysis considered conditioning station pairs to those stations within 100 miles of each other and with the absolute value of the logarithm (base-10) of the ratio of the drainage areas greater than or equal to 0.25. Statewide statistics of the conditional station-pair specific statistics were computed and are tabulated. The conditional analysis is preferable because of the anticipation that small separation distances reflect similar hydrologic conditions and the observation of large variation in exponent estimates for similar-sized drainage areas. The conditional analysis determined that the exponent is about 0.89 for streamflow percentiles from 0 to about 50 percent, is about 0.92 for percentiles from about 50 to about 65 percent, and is about 0.93 for percentiles from about 65 to about 85 percent. The exponent decreases rapidly to about 0.70 for percentiles nearing 100 percent. The computation of the bias-correction factor is sensitive to the range analysis interval (range of streamflow percentile); however, evidence suggests that in practice the drainage-area method can be considered unbiased. Finally, for general application, suggested values of the exponent are tabulated for 54 percentiles of daily mean streamflow in Texas; when these values are used, the bias correction is unity.

Introduction

Analysts and managers of surface-water resources often require streamflow data for locations where no data were collected or for streamflow-gaging stations for periods during which the gage was not in operation. Techniques used to estimate streamflow for locations where no streamflow data were collected include the drainage-area ratio method, regional statistics, regression (in various forms), and rainfall-runoff modeling. Only the drainage-area ratio method is considered here. The method is considered in the specific context of estimating daily mean streamflow at ungaged locations using daily mean streamflow from gaged locations. The term ungaged requires specific clarification. An ungaged location has no historical streamflow information.

The drainage-area ratio method is a technique that statistically transfers same-day streamflow information from one location to another on the basis of the drainage areas of the two locations. The method is algebraically simple and is the most straightforward of the techniques to implement. In one formulation, the drainage-area ratio method is (Emerson and others, 2005)

$$Y = X\left(\frac{A_Y}{A_X}\right)^{\phi}, \qquad (1)$$

where Y is the streamflow for the ungaged location, X is the streamflow at a gaging station, and A_Y and A_X are the drainage areas for the ungaged location and the streamflow-gaging station, respectively. In widespread practice the exponent $\phi = 1$, and therefore the drainage-area ratio method is a direct proration of flow based on streamflow per unit area (square kilometers or square miles).

Analysts at the Texas Commission on Environmental Quality (TCEQ) use streamflow estimates for regulatory stream locations lacking a gaging station (ungaged locations). For example, if water-quality data are collected for the regulatory stream location and a concurrent streamflow measurement is not made, then the streamflow at the location requires estimation. The drainage-area ratio method often is applied and uses concurrent-in-time (same day) streamflow for one or more nearby and operating streamflow-gaging stations. The drainage-area ratio method also is used for numerous other applications requiring streamflow transference. Therefore, examination of the drainage-area ratio method for daily streamflow estimation in Texas is needed. Beginning in 2005, the U.S. Geological Survey (USGS), in cooperation with TCEQ, initiated an investigation of the exponent and bias-correction factor (to be discussed) of the drainage-area ratio method in Texas.

Finally, emphasis is needed that the primary purpose of the drainage-area ratio method reported here is for daily mean streamflow estimation for ungaged locations. For circumstances in which limited streamflow data exist for a location of interest not gaged on a day for which a streamflow estimate is required, alternative techniques that utilize the limited streamflow information should be used to provide a calibrated drainage-area ratio method or a regression between the same-day streamflow for data for the location of interest and a nearby streamflow-gaging station.

Purpose and Scope

The purpose of this report is to summarize the results of a statewide analysis of the exponent and bias-correction factor of the drainage-area ratio method in Texas. This report also offers values of the exponent and bias-correction factor for general application of the drainage-area ratio method for statistically transferring daily mean streamflow from gaged locations to ungaged locations in Texas. The analysis for this report uses nearly the entire database of daily mean streamflow values available for more than 700 USGS streamflow-gaging stations in Texas. The analysis is statewide in nature and does not address regional or seasonal variations in the drainage-area ratio method should such variations exist.

Previous Studies

Hirsch (1979) evaluates the drainage-area ratio method with $\phi = 1$, regional regression equations, linear regression equations, and log-log regression equations to reconstruct streamflow record. Although streamflow reconstruction nominally is not the purpose of the drainage-area ratio method considered here, there is considerable analytical overlap with the objective of streamflow transference and streamflow reconstruction. Hirsch (1979) concludes that the other techniques are superior to the drainage-area ratio method for gages with some historical record. If streamflow is being estimated for a historically ungaged location, however, then the streamflow characteristics at the location are unknown, and how well the drainage-area ratio method works also is unknown.

In the context of estimating low-flow statistics for Massachusetts streams, Ries and Friez (2000, p. 1) conclude that "the drainage-area ratio method [generally] is as accurate or more accurate than regression estimates when the drainage-area ratio for [the] ungaged [location] is between 0.3 and 1.5 times the drainage area of the [streamflow-gaging station]." Ries and Friez consider the drainage-area ratio method with $\phi = 1$.

Wurbs (2005) provides a reference manual for a computer software program used for water-right evaluation for the State of Texas. This program is in widespread use in Texas. Within the algorithms of the program, the drainage-area ratio method is used under a variety of circumstances to transfer streamflow data from one location to another. The method has $\phi = 1$.

A cursory search of the drainage-area ratio method on the Internet finds numerous documents referencing the use of the method with $\phi = 1$. Four examples are provided. Perry and others (2002) apply the drainage-area ratio method with $\phi = 1$ for estimation of median streamflow values in Kansas. In the context of streamflow estimation for drought conditions, the Michigan Department of Environmental Quality (2005) states that "[the drainage-area ratio method] is used for gaged or ungaged watersheds. The drought flows at a specific site are computed based on the ratio of the drainage areas between that site and a USGS [streamflow-] gaging station. A USGS station with similar watershed characteristics is used for this method." California Environmental Protection Agency, State Water Resources Control Board, Water Rights (2005) suggests the use of the drainage-area ratio method with $\phi = 1$ for purposes of water-right evaluation and permitting in California. Oregon State University (2005) suggests techniques for streamflow estimation at ungaged locations in Oregon in which the drainage-area ratio method is used with $\phi = 1$.

Emerson and others (2005) describe an evaluation of the drainage-area ratio method for the Red River of the North Basin in North Dakota and Minnesota in the context of the estimation of winter (January, February, November, and December), spring (March, April, and May), and summer (June, July, August, September, and October) monthly mean streamflow. They also included a detailed explanation of the general mathematics of the drainage-area ratio. The ϕ exponents on the winter, spring, and summer equations are 0.85, 0.91, and 1.02, respectively. Bias-correction factors (not indicated in equation 1 but shown in equation 10) for the winter, spring, and summer equations are 1.24, 1.02, and 1.06, respectively.

Asquith and Thompson (2005) provide statewide regression analysis of the 2-, 5-, 10-, 25-, 50-, and 100-year annual peak streamflow for Texas using data considered by Asquith and Slade (1997). Asquith and Thompson (2005) develop regression equations for each of the six T-year recurrence intervals that use only logarithms of streamflow and drainage area. The exponent on drainage area is mathematically compatible with the ϕ exponent of the drainage-area ratio method considered in section "Statewide Analysis of the Drainage-Area Ratio Method in Texas" of this report. The general value of the exponent from Asquith and Thompson (2005) is about 0.51. In this report, the value of 0.51 for the exponent is compared to the results of the current (2006) investigation. For additional perspective, Stamey and Hess (1993) report numerous equations for annual peak streamflow frequency estimation in Georgia using drainage area; a general value for the exponent on drainage area is about 0.6.

In general, the literature is synthesized as follows: The drainage-area ratio method is almost universally used with $\phi = 1$, and the method is considered unbiased. Further, the majority of the literature appears to involve the application of the method and not evaluation of the method in a statistical sense. Emerson and others (2005) appears to be an exception.

Database

The statewide analysis of the drainage-area ratio method reported here is based on the period of record of daily mean streamflow and the (contributing) drainage areas for 712 USGS streamflow-gaging stations (fig. 1). The stations and ancillary information are listed in table 1 (at end of report). The geographic distance between each station pair was computed. The mean distance is about 221 miles and the standard deviation is about 116 miles.

The stations have at least 1 year (365 days) of daily mean streamflow record and a documented drainage area. The data and drainage areas for the 712 stations were acquired from U.S. Geological Survey (2005). The year in which the first daily mean streamflow record occurs is 1898. The last water year[1] of record is 2004. The total number of daily values available is 7,844,761. Streamflow-gaging stations that monitor spring flow or only stage (water level) were not used. Further, partial record streamflow-gaging stations were not used because complete flow-duration curves are needed.

For the statewide analysis reported here, no further subselection of stations according to streamflow regulation or general land use of the watershed (undeveloped, developed, regulated, urban, and other) was made. In addition, the entire period of record for each station was used. Graphical review or statistical evaluation of potential temporal trends with the purpose of rejecting (or accepting) specific stations or specific portions of the data record for some stations was not made. Whereas the rigorous review of the time series of the data for differing combinations of watersheds is useful and particularly important for evaluation of the drainage-area ratio method on a localized or site-specific basis, the analysis in this report is intended to establish a general parameterization of the drainage-area ratio method in Texas.

Streamflow for a particular location generally exhibits considerable variation. Because the primary purpose of the drainage-area ratio method is to transfer streamflow from a gaging station to an ungaged location, a specific drainage-area ratio equation for the streamflow regime exhibited at the streamflow-gaging station is needed. For this report streamflow regime is specified through selection of a range of streamflow percentile (nonexceedance probability) using flow-duration curves. Flow-duration curves are a common statistical concept and graph that show the fraction or percent of time that the daily mean streamflow magnitude exceeds a specified value (Dingman, 2002). Flow-duration curves are thoroughly discussed by Vogel and Fennessey (1994 and 1995).

At the beginning of this investigation, four primary ranges of streamflow percentile [100×(nonexceedance probability)] were considered and are the four quartiles of streamflow or the ranges of 0–25, 25–50, 50–75, and 75–100 percent; however, further subdivision was deemed necessary. A particularly acute problem for TCEQ analysts and others is the transference of streamflow for low-flow conditions; therefore, the first quartile (0–25 percent) was further subdivided into quintiles to form the 0–5, 5–10, 10–15, 15–20, and 20–25 percent ranges. A common problem for analysts involved in infrastructure design (such as bridge and culverts) is the transference of high magnitude streamflow values (annual peak streamflow). Although this investigation is limited to daily mean streamflow values and not peak streamflow, to facilitate comparison of the drainage-area ratio method to existing equations for estimation of peak streamflow (see Asquith and Thompson, 2005) and other large values of streamflow, the fourth quartile (75–100 percent) was subdivided into quintiles to form the 75–80, 80–85, 85–90, 90–95, and 95–100 percent ranges.

From exploratory data analysis conducted between August 2005 and November 2005, further subdivision of the flow-duration curve far into the lower and upper tails was deemed necessary. The 95–96, 96–97, 97–98, 98–99, and 99–100

[1] Water year is the 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2004, is called the "2004 water year."

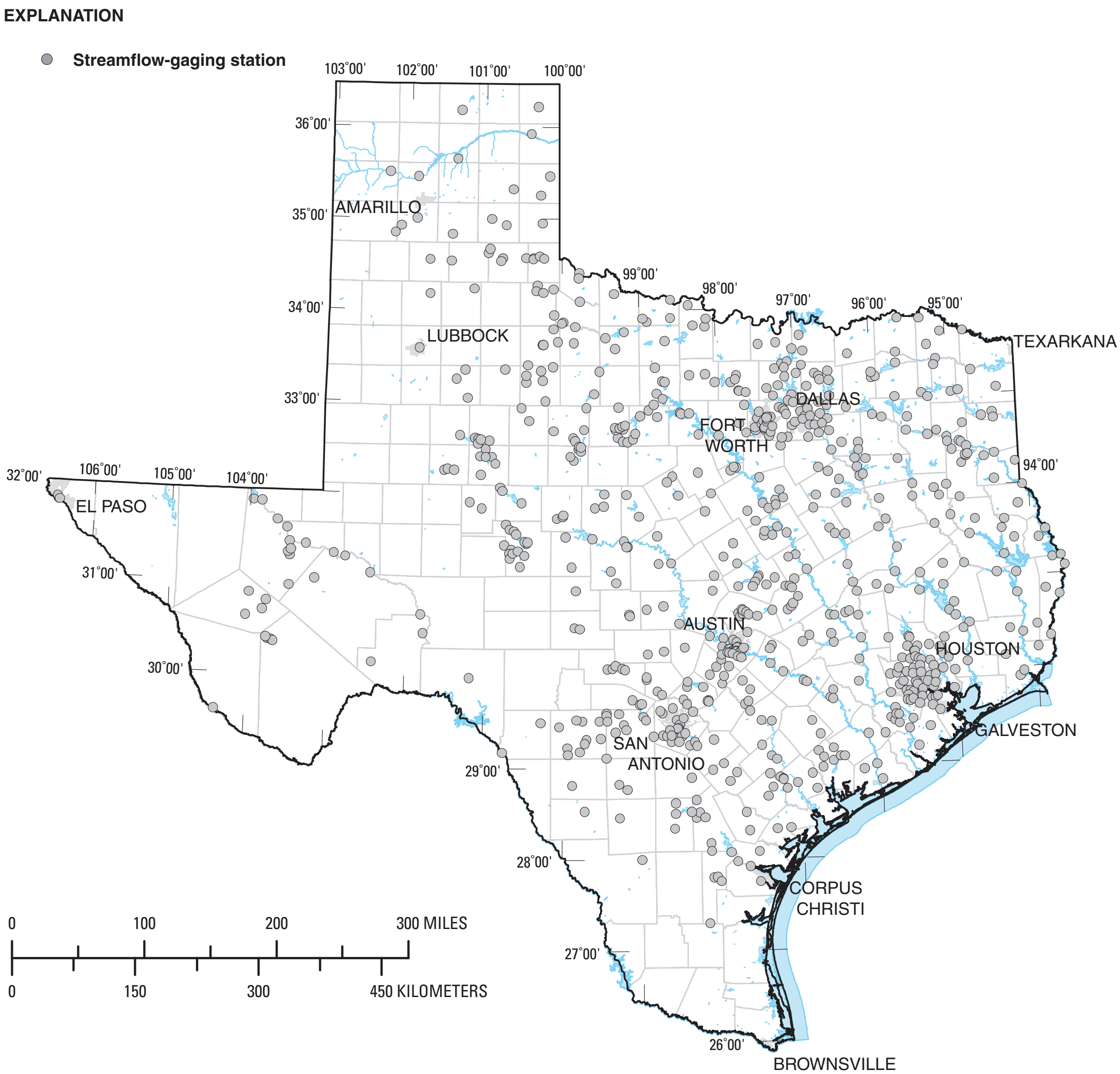


Figure 1. Locations of U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data.

percent ranges also were selected to provide more detailed analysis for the upper tail of the streamflow distribution, and in order to maintain symmetry, the lower tail of the streamflow distribution was subdivided into the 0–1, 1–2, 2–3, 3–4, and 4–5 percent ranges.

Finally, for purposes of continuity of analysis, the middle two quartiles also were subdivided into quintiles to form the 25–30, 30–35, 35–40, 40–45, 45–50, 50–55, 55–60, 60–65, 65–70, and 70–75 percent ranges. Thus, the entire spectrum of streamflow frequency is represented through 20 5-percent wide ranges. Thus, a total of 34 streamflow percentile ranges are considered.

Mathematics of the Drainage-Area Ratio Method

Generalized Drainage-Area Ratio Method

The simplest drainage-area ratio method is based on the assumption that the streamflow for a site of interest can be estimated by multiplying the ratio of the drainage area for the site of interest and the drainage area for a nearby streamflow-gaging station by the streamflow for the nearby gaging station. Thus, the simplest drainage-area ratio method has an exponent of unity and is given by

$$\widehat{Q_1} = Q_2\left(\frac{A_1}{A_2}\right)^1, \quad (2)$$

where $\widehat{Q_1}$ is the estimated streamflow, in cubic length per time for the ungaged location; Q_2 is the streamflow, in cubic length per time for the streamflow-gaging station; A_1 is the drainage area, in units of square length, for ungaged location; and A_2 is the drainage area, in units of square length, for the streamflow-gaging station. Following the nomenclature shown, the actual streamflow for the site of interest is denoted as Q_1 and estimated streamflow for the gaging station is denoted as $\widehat{Q_2}$.

For the simplest drainage-ratio method (equation 2), assumptions are made that the exponent ϕ of (A_1/A_2) is 1, and the equation is unbiased. The term unbiased implies that the expected value of the estimated streamflow equals the true streamflow value. To evaluate the simplest drainage-ratio method, a generalized drainage-area ratio method can be formulated. The streamflow for the ungaged location is estimated from drainage area by using the following

$$\log(\widehat{Q_1}) = c + \phi\log(A_1), \quad (3)$$

where the $\log(x)$ function is a base-10 logarithm, c represents a constant or intercept, and ϕ represents a slope. By generality, the streamflow for the gaging station is estimated by

$$\log(\widehat{Q_2}) = c + \phi\log(A_2). \quad (4)$$

To obtain an unbiased estimate of streamflow for the site of interest, consideration of an error (residual) term is required

$$\log(Q_1) = c + \phi\log(A_1) + \varepsilon_1, \quad (5)$$

where $\varepsilon_1 = \log(Q_1) - \log(\widehat{Q_1})$ is the residual. Again by generality, the unbiased streamflow for the gaging station is given by

$$\log(Q_2) = c + \phi\log(A_2) + \varepsilon_2, \quad (6)$$

where $\varepsilon_2 = \log(Q_2) - \log(\widehat{Q_2})$ is the residual. For unbiased estimation of streamflow in linear-space (non log), the expectation of the linear-space residuals is

$$E[10^{\varepsilon}] = 1. \quad (7)$$

Therefore, after converting equations 5 and 6 to linear-space and forming ratios, the following result

$$\frac{Q_1}{Q_2} = \kappa_1\left(\frac{A_1}{A_2}\right)^{\phi} \text{ and} \quad (8)$$

$$\frac{Q_2}{Q_1} = \kappa_2\left(\frac{A_2}{A_1}\right)^{\phi}, \quad (9)$$

where κ_1 and κ_2 represent bias correction terms that have the same statistical properties. Each bias-correction factor is chosen such that $E[10^{\varepsilon_1}] = E[10^{\varepsilon_2}] = 1$. The ratio in linear-linear space between equations 8 and 9 represents a generalized drainage-area ratio method and is

$$\frac{Q_1}{Q_2} = K\left(\frac{A_1}{A_2}\right)^{\phi}, \quad (10)$$

where K is a single bias correction term. Using symmetry arguments, the expected values of κ_1 and κ_2 are the same and the bias-correction factor is defined as the expected value of either variable or for smaller sampling variance the expected value of the combination of κ_1 and κ_2 values.

Parameter Estimation for Generalized Drainage-Area Ratio Method

In practice the drainage-area ratio method is used to estimate streamflow at an ungaged location by using streamflow from a nearby gaging station; however, the analysis of K and ϕ requires joint analysis of the streamflow for two gaging stations. The choice of the subscript 1 for the site of interest and subscript 2 for the streamflow-gaging station is arbitrary. Furthermore, one station can be used to estimate streamflow at the other and in turn the other station can be used to estimate streamflow for the former. With the bias correction, the streamflow for each of the two stations were estimated by using the following

$$\widehat{Q_1} = KQ_2\left(\frac{A_1}{A_2}\right)^{\phi} \text{ and} \quad (11)$$

$$\widehat{Q_2} = KQ_1\left(\frac{A_2}{A_1}\right)^{\phi}. \quad (12)$$

The parameter ϕ can be estimated from daily mean streamflow data with assumption that K initially is 1. The ϕ_i for the i th day that streamflow data are available for each station is

$$\phi_i = \frac{\log(Q_{1i}/Q_{2i})}{\log(A_1/A_2)}. \quad (13)$$

The mean or expected value of ϕ is

$$\bar{\phi} = \frac{1}{n}\sum_{i=1}^{n}\phi_i, \quad (14)$$

where n is the sample size (number of days of record). After the mean exponent is estimated by equation 14, the residuals of equations 11 and 12 are computed, and in turn, the two estimates for the bias-correction term for the i th day of record are computed from $\bar{\phi}$ by

$$_{12}\kappa_i = \frac{Q_{1i}}{Q_{2i}\left(\frac{A_1}{A_2}\right)^{\bar{\phi}}} \text{ for station 1 to station 2 and} \quad (15)$$

$$_{21}\kappa_i = \frac{Q_{2i}}{Q_{1i}\left(\frac{A_2}{A_1}\right)^{\bar{\phi}}} \text{ for station 2 to station 1.} \quad (16)$$

```
                   .. additional output ..
# DISCHARGE-AREA CALCULATOR
#   STATION 1 08069000 CYPRESS CK NR WESTFIELD, TX; 285 square miles
#   STATION 2 08069500 W FK SAN JACINTO RV NR HUMBLE, TX; 1741 square miles
#   Qs are in cubic feet per second
STATION1 AREA1 STATION2 AREA2 PERCENTILE_RANGE Q1_RANGE   Q2_RANGE     PHI    PHI_STD RECORD_SIZE  BIASCOR
08069000 285   08069500 1741  %0.98-0.99%      1880-2730  9321.2-14000 0.8927 0.003   8             1.004
08069000 285   08069500 1741  %0.99-1.00%      2730-15600 14000-154000 0.9153 0.045   25            1.073
# DISCHARGE-AREA CALCULATOR
#   STATION 1 08069000 CYPRESS CK NR WESTFIELD, TX; 285 square miles
#   STATION 2 08070000 E FK SAN JACINTO RV NR CLEVELAND, TX; 325 square miles
#   Qs are in cubic feet per second
STATION1 AREA1 STATION2 AREA2 PERCENTILE_RANGE Q1_RANGE   Q2_RANGE     PHI    PHI_STD RECORD_SIZE  BIASCOR
08069000 285   08070000 325   %0.98-0.99%      1880-2730  2230-3310    1.344  1.197   36            1.010
08069000 285   08070000 325   %0.99-1.00%      2730-15600 3310-44200   2.458  23.55   78            1.229
                   .. additional output ..
```

Figure 2. Example output from drainage-area ratio computation run for an arbitrary station pair and the 98–99 and 99–100 percentile ranges.

The mean or expected value of the bias-correction factor is

$$K = \frac{1}{2n}\sum_{i=1}^{n} {}_{12}\kappa_i + {}_{21}\kappa_i \,. \tag{17}$$

The corrections for bias with algebraic adjustment are known as “smearing estimates” (Duan, 1983; Helsel and Hirsch, 1992). Finally, equations 14 and 17 represent statistically estimated parameters of the generalized drainage-area ratio method.

Example Calculations of Parameter Estimation

To demonstrate how $\bar{\phi}$ and K can be estimated from two streamflow-gaging stations, example calculations for four values of daily streamflow are listed in table 2. The notation [#] refers to the vector of data values in the indicated column number. For example, a vector of the logarithms of column 2 is denoted as log([2]). Column 4 is computed by log([2]/[3])/log(839/10.9) where 839 and 10.9 are drainage areas for stations 1 and 2, respectively. The mean of column 4 is 0.9194. Column 5 is computed by $[3]\times(839/10.9)^{0.9194}$; likewise column 6 is computed by $[2]\times(10.9/839)^{0.9194}$. Column 7 is computed by [2]/[5]; likewise column 8 is computed by [3]/[6]. The means of columns 7 and 8 are 1.987 and 1.442 for ${}_{12}\bar{\kappa}$ and ${}_{21}\bar{\kappa}$, respectively. The mean of these is (1.987+1.442)/2 = 1.715. Thus, the generalized drainage-area ratio method for these two stations from the sample of 4 days is

$$\frac{Q_1}{Q_2} = 1.715\left(\frac{A_1}{A_2}\right)^{0.9194} . \tag{18}$$

Statewide Analysis of the Drainage-Area Ratio Method in Texas

The daily mean streamflow data available for Texas constitute a very large data set from which ϕ and K can be estimated to develop a framework by which the drainage-area ratio method can be implemented in Texas. To estimate the ϕ and K parameters from a statewide perspective, the period-of-record streamflow and drainage areas for 712 stations were used. For each of the 34 streamflow percentile ranges, the streamflow for each of the 712 stations was compared to the streamflow for the remaining 711 stations. As a result, for each of the 34 percentile ranges, 253,116 (712×711/2) unique pairings of stations were made. Thus, 8,605,944 (34×253,116) pairings were considered. Given that the total number of daily values analyzed is in excess of 7.8 million, considerable computational resources were required[2]. Example output for an arbitrary station pair is shown in figure 2.

The figure shows an abbreviated output pertinent to the investigation of the drainage-area ratio method. Each station pair is separated by a repetitive header (lines beginning with `#`) and label line (lines beginning with `STATION1`). Within the output for each station pair, an ensemble of computations for the selected values of the percentile ranges of daily mean streamflow is present. For brevity, the figure only shows the 98–99 and 99–100 percentile ranges (`PERCENTILE_RANGE`). The `Q1_RANGE` and `Q2_RANGE` fields show the range in daily mean streamflow comprising the end points of the corresponding percentile range. The $\bar{\phi}$ value and its standard deviation are listed under the `PHI` and `PHI_STD` fields. The record size

[2] Just over a week of computer time using four computers and eight parallel processes was needed to complete a computation run. Four processes (two per computer) were run on a RedHat Linux WS4 2×2.0GHz Xeon CPU with 512MB memory and a MacOSX 10.4 2×2.0GHz G5 CPU with 4GB memory, each equipped with two hard drives (one process per hard drive). The remaining four processes were run on a RedHat Linux 9 2×2.2GHz Athlon CPU with 512MB memory and a SuSE Linux 9.1, 2×3.2GHz Xeon CPU, and 1GB memory computer. The aggregated output file for a computation run is about 1.96 GB.

Table 2. Example of parameter estimation for the generalized drainage-area ratio method.

[[#], column number; ft^3/s, cubic feet per second; mi^2, square miles]

Day	Observed daily mean streamflow (ft^3/s)		Exponent ϕ_i	Estimated streamflow without correction for bias (ft^3/s)		Bias-correction factors	
	Station 1 (839 mi^2)	Station 2 (10.9 mi^2)		Station 1	Station 2	$_{12}\kappa_i$	$_{21}\kappa_i$
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
1	1,470	4.3	1.343	233.2	27.10	6.304	0.1587
2	158	4.3	.8300	233.2	2.913	.6775	1.476
3	154	6.0	.7471	325.4	2.839	.4733	2.113
4	145	5.4	.7575	292.9	2.673	.4950	2.020
		$\bar{\phi}$	**.9194**		$_{12}\bar{\kappa}$ **and** $_{21}\bar{\kappa}$	1.987	1.442
					K	**1.715**	

(RECORD_SIZE, total number of daily values processed) is listed next. The line terminates with K (BIASCOR). The supporting values $_{12}\bar{\kappa}$ and $_{21}\bar{\kappa}$ are not listed. To clarify the contents of the output, the $\bar{\phi}$ value of 0.9153 for the station 08069000 to 08069500 comparison and the 99–100 percentile range was computed from 25 same-day and same-percentile range daily streamflow values for the stations. In turn, the computed bias correction (K) was 1.073.

Data Analysis

Two types of analysis are performed on the database of $\bar{\phi}$ and K (analogous to output shown in fig. 2). The first analysis uses the $\bar{\phi}$ and K parameters for all applicable station pairs. The second analysis uses the $\bar{\phi}$ and K parameters for station pairs conditional on separation distance between the stations and relative difference in drainage area. The term "applicable" means that at least five nonzero values for same-day streamflow and same streamflow percentile range for the two gaging stations were available for computation of $\bar{\phi}$ and K.

The first analysis style establishes a foundational perspective of the magnitude and variability of the two parameters in Texas. A statistical summary of the first analysis is listed in table 3. The table lists for each of the 34-streamflow percentile ranges the sample size (count of applicable station pairings) and the total number of daily values processed within the station pairings. The median and mean statistics of the mean $\bar{\phi}$ values are listed in the table; the standard deviation of the $\bar{\phi}$ values are listed as well. To clarify on the sample size, the mean ϕ listed in the table is the mean of the "sample size" number (column 2) of $\bar{\phi}$ values. The table also lists both the median, mean, and standard deviation statistics of the mean bias-correction factor K values.

Several interpretations of values listed in table 3 are made. First, sample size increases with increase of absolute percentile. The primary reason is that zero values of daily streamflow are more likely for small percentiles than for large percentiles. Because the drainage-area ratio method is based in log-space, zero values are incompatible and thus particular station pairs are meaningless because of the presence of all zero values. Second, the means are much less than the medians suggesting a left-skewed distribution of ϕ. Third, the standard deviation of ϕ is so large that the reliability of the mean or median ϕ values is questionable and further investigation is needed, which is provided through the second analysis.

The second analysis (hereafter referred to as the "conditional analysis") is based on the concept that as separation distance between the site of interest and the streamflow-gaging station increases the applicability of the drainage-area ratio method decreases. Conceptually, the applicability of the drainage-area ratio method diminishes as separation distance increases for reasons including (1) increasingly larger differences in hydrologic conditions, (2) increasingly larger differences in climate, and (3) increasingly larger differences in geology or other components of physiographic regions.

The relation between separation distance and mean $\bar{\phi}$ for the fourth quartile (75–100 percent range) of streamflow is shown in figure 3. From the figure, the large variation in $\bar{\phi}$ values is seen, and the variation is consistent with the large standard deviation values listed in table 3. A cone-shape trend in $\bar{\phi}$ values is evident in which convergence (from right to left) towards a $\bar{\phi}$ value slightly less than 1 as separation distance decreases is seen. Because of the concept that stations which are increasingly far apart are expected to have diverging same-day hydrologic conditions, it is logical to limit analysis by separation distance. An upper limit of 100 miles was chosen. For distances greater than 100 miles, the variation in $\bar{\phi}$ rapidly becomes large. Similar relations between separation distance

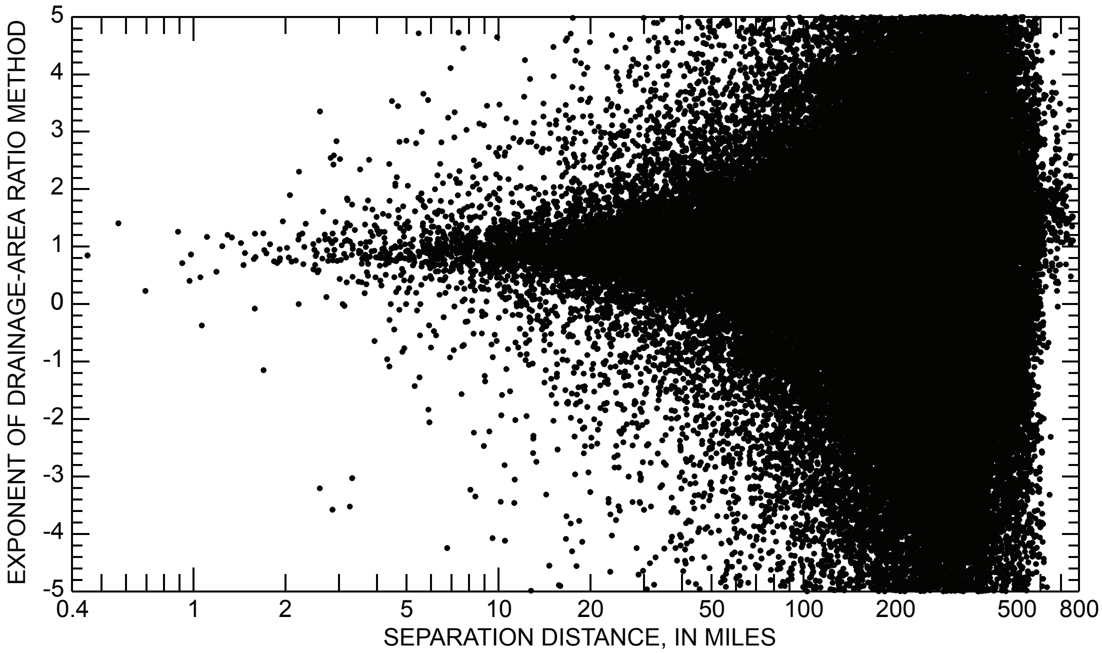


Figure 3. Relation between separation distance and exponent of drainage-area ratio method for the fourth quartile (75–100 percentile range) of daily streamflow in Texas.

and $\bar{\phi}$ for the other percentile ranges were evaluated (not presented in this report), and the conclusion consistently was made that 100 miles is an appropriate, albeit an ad hoc, upper limit.

Comparison of relative differences in drainage area to $\bar{\phi}$ values provides further insight into the relation between drainage area and $\bar{\phi}$. The relation between the relative difference in drainage area, measured by the absolute value of the logarithm (base-10) of the ratio of drainage areas, and the mean $\bar{\phi}$ for the fourth quartile (75–100 percent range) of streamflow is shown in figure 4. The horizontal axis depicts the number of log cycles separating the two drainage areas. Instead of plotting all available station pairs, subselection or conditioning for stations with separation distance less than or equal to 100 miles was performed. As evident in the figure, there is large variation in $\bar{\phi}$ for similar magnitude drainage areas. A cone-shape trend in $\bar{\phi}$ values is evident in which convergence (from left to right) towards a $\bar{\phi}$ value slightly less than 1 is seen. A critical observation of the figure is that variation in $\bar{\phi}$ values rapidly reduces for drainage areas differing by more than about 0.25-log cycles. The large variation in $\bar{\phi}$ as drainage areas become similar (identical) occurs because as the ratio of the drainage areas approaches 1, $\bar{\phi}$ necessarily exhibits increasing sample variability because $\bar{\phi}$ often acquires large values to account for streamflow differences between the two stations. In other words

$$\lim_{A_1 \to A_2} \frac{A_1}{A_2} = 1 \,, \tag{19}$$

so ϕ becomes increasingly arbitrary. Hence, in the spirit of increasing the reliability of statistical estimation, the following relative drainage area criteria was established for the conditional analysis

$$0.25 \le \left|\log\left(\frac{A_1}{A_2}\right)\right| . \tag{20}$$

Because of the smooth convergence of ϕ from left to right in figure 4, no upper limit to relative drainage area difference is established.

The separation distance and relative drainage-area criteria were developed in an iterative, but still ad hoc, fashion through exploratory data analysis culminating with interpretations of graphs such as those shown in figures 3 and 4. The reliability of statistical estimates of ϕ and K is increased by conditioning the station pairs and using the two criteria.

A statistical summary of the conditional analysis is listed in table 4, which lists for each of the 34 percentile ranges the sample size (count of applicable station pairings) and the total number of daily values processed within the station pairings. The median, mean, and standard deviation statistics of the mean $\bar{\phi}$ values are listed in the table. To clarify on the sample size, the mean ϕ listed in the table is the mean of the "sample size" number (column 2) of $\bar{\phi}$ values. The table also lists both the median and mean statistics of the mean bias-correction factor K values; the standard deviations of the K values are listed as well.

Comparison of the statistics listed in table 4 to corresponding values in table 3 indicates that mean and median values are considerably closer in magnitude after the separation distance and relative drainage-area criteria are applied. The median

Table 3. Summary statistics of drainage-area ratio method for each of the 34 percentile ranges of streamflow in Texas.

Streamflow percentile range	Sample size (count of applicable station pairs)	Total number of daily values processed	Exponent ϕ			Bias-correction factor K		
			Median	Mean	Standard deviation	Median	Mean	Standard deviation
Quartiles								
0–25	105,614	53,644,385	0.790	0.490	48.4	1.84	2.53	2.45
25–50	144,138	72,076,225	.808	.703	49.2	1.15	1.35	.628
50–75	163,891	79,607,258	.821	.760	37.7	1.14	1.33	.824
75–100	183,644	124,502,596	.786	.662	41.9	2.98	8.18	72.8
Lower tail								
0–1	6,884	120,393	.720	1.68	57.5	1.03	1.16	.417
1–2	11,854	93,906	.766	.535	65.6	1.00	1.04	.122
2–3	16,017	94,744	.805	.0971	62.9	1.00	1.03	.125
3–4	19,712	99,315	.859	.320	64.8	1.00	1.01	.0667
4–5	22,875	104,709	.830	.700	35.8	1.00	1.01	.0557
Quintiles of first quartile								
0–5	37,700	2,340,594	.777	.252	58.9	1.17	1.50	1.02
5–10	57,338	2,330,925	.808	.366	45.0	1.03	1.12	.277
10–15	73,479	2,353,238	.812	.484	45.2	1.01	1.07	.203
15–20	86,781	2,544,805	.811	.388	52.1	1.01	1.04	.119
20–25	95,643	2,635,428	.807	.570	44.6	1.01	1.03	.0955
Quintiles of second quartile								
25–30	105,248	2,688,949	.810	.589	39.4	1.00	1.02	.0636
30–35	115,631	2,928,715	.829	.657	45.5	1.00	1.02	.0425
35–40	123,501	3,012,915	.815	.778	39.0	1.00	1.02	.133
40–45	125,596	3,038,213	.796	.767	36.3	1.00	1.01	.0356
45–50	131,185	3,126,384	.809	.712	38.9	1.00	1.01	.033
Quintiles of third quartile								
50–55	133,017	3,131,395	.802	.752	39.8	1.00	1.01	.0486
55–60	138,695	3,211,017	.809	.831	37.5	1.00	1.01	.0226
60–65	142,796	3,190,527	.810	.728	38.8	1.00	1.02	.109
65–70	145,964	3,420,121	.812	.698	37.8	1.00	1.02	.0906
70–75	152,138	3,602,955	.818	.797	36.4	1.01	1.02	.0640
Quintiles of fourth quartile								
75–80	155,744	3,979,760	.820	.772	42.5	1.01	1.01	.026
80–85	158,048	4,390,667	.822	.772	35.6	1.01	1.04	.150
85–90	163,889	5,150,742	.819	.728	38.6	1.02	1.04	.117
90–95	168,848	6,438,618	.786	.663	42.2	1.05	1.08	.166
95–100	173,571	11,335,377	.694	.608	37.9	1.61	2.45	10.2
Upper tail								
95–96	105,722	330,178	.761	.848	29.7	1.00	1.00	.0162
96–97	108,936	371,788	.738	.761	28.1	1.00	1.01	.0251
97–98	114,679	449,496	.716	.615	28.6	1.00	1.01	.0361
98–99	118,510	574,368	.687	.587	38.1	1.01	1.02	.0593
99–100	120,641	1,034048	.643	.596	18.0	1.13	1.27	.481

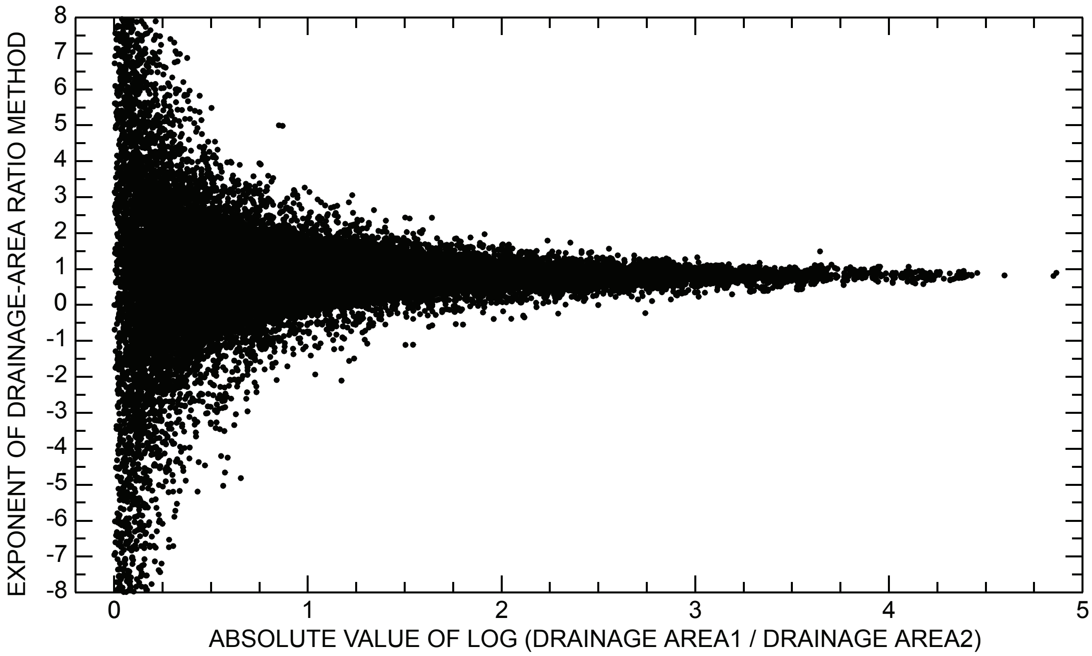


Figure 4. Relation between absolute value of logarithm of ratio of drainage areas and exponent of drainage-area ratio method for fourth quartile (75–100 percentile range) of daily streamflow in Texas for station pairs with separation distance less than or equal to 100 miles.

remains slightly larger than the mean; however, a more symmetrical distribution of ϕ is evident. The standard deviations are dramatically smaller after the criteria are applied. Hence, more reliable characterization of ϕ and K is made.

A graphical depiction of the mean ϕ values listed in table 4 is shown in figure 5. In this figure, the general value of about 0.9 is seen except for the very largest streamflow percentiles. For the largest streamflow percentiles, ϕ decreases substantially to about 0.7. The trend is consistent with ϕ acquiring a value of about 0.5 for annual peak (instantaneous) streamflow in Texas (Asquith and Thompson, 2005). Annual peak streamflow values are generally larger than most daily mean streamflow values and hence corresponding ϕ values are in the region near and “beyond” the right-most portion of the horizontal axis. The smoothed relation between ϕ and streamflow percentile shown in the figure is discussed in section “Implementation of the Drainage-Area Ratio Method in Texas.”

The bias-correction factor is about 1.00–1.01 for most percentile ranges. A graphical depiction of the mean K values listed in table 4 is shown in figure 6, wherein a “U” shape to K is evident for the quartiles and the 5-percent-wide intervals. A similar U-shape, although subtle, is evident if the lower and upper tails are considered together. In general, K increases into the tails of the streamflow distribution for a given width of percentile interval. For example, observe how K values for the 0-25 and 75–100 percentile range are larger than the nearly equal values for the 25–50 percentile and 50–75 percentile range. Further, the largest K values are seen when the interval of analysis is large. For example, the 75–100 percentile range is larger than the 75–80 percentile range. As the interval becomes small (for example, the 97–98 percentile range), the bias of the drainage-area ratio method becomes small.

The authors make an explicit interpretation that the bias correction is about unity as the interval of analysis becomes small. This conclusion is strongly supported by the biases observed for the 5-percent-wide intervals (grey circles, exclusive of the lower and upper 10th percentiles on fig. 6) and augmented by the 1-percent-wide lower and upper tails (see open circles on fig. 6). The authors conclude, therefore, that the drainage-area ratio method is either inherently unbiased or the bias is less than 1 or 2 percent when a suitably narrow region of the flow-duration curve is analyzed. No mathematical proof for this conclusion is made; however, the authors speculate that the bias is exhibited computationally because the typical daily mean streamflow distribution exhibits considerable curvilinearity in both the lower and upper quartiles. If the interval of analysis is large and the interval is in the tails of the distribution, the curvilinearity produces the bias.

Implementation of the Drainage-Area Ratio Method in Texas

Additional interpretation and refinement of the analysis results for implementation of the drainage-area ratio method for daily mean streamflow estimation in Texas is made.

1. The analysis strongly indicates that same-day and same-percentile streamflow does not scale by per-unit drainage area basis ($\phi = 1$) but instead scales according to a fractional power of drainage area ($\phi < 1$). The

Table 4. Summary statistics of drainage-area ratio method conditional on separation distance and relative drainage area for each of the 34 percentile ranges of streamflow in Texas.

[Separation distance between station pairs was less than or equal to 100 miles; the absolute value of the logarithm of the ratio of the drainage area was greater than or equal to 0.25]

Streamflow percentile range	Sample size (count of applicable station pairs)	Total number of daily values processed	Exponent ϕ			Bias-correction factor K		
			Median	Mean	Standard deviation	Median	Mean	Standard deviation
Quartiles								
0–25	15,521	9,266,530	0.952	0.876	1.78	1.72	2.30	2.17
25–50	20,409	11,554,604	.941	.886	1.61	1.13	1.31	.496
50–75	22,835	12,458,079	.947	.940	1.31	1.13	1.31	.922
75–100	24,584	21,617,656	.883	.874	.856	2.38	4.99	22.72
Lower Tail								
0–1	1,386	32,339	.824	.829	1.76	1.03	1.16	.410
1–2	2,278	22,065	.902	.908	1.76	1.00	1.03	.103
2–3	2,883	20,199	.920	.916	1.83	1.00	1.03	.101
3–4	3,544	20,485	.980	.979	1.82	1.00	1.02	.0711
4–5	3,964	20,930	.950	.914	1.72	1.00	1.01	.0600
Quintiles of first quartile								
0–5	6,137	500,060	.919	.875	1.91	1.17	1.50	1.08
5–10	8,735	445,235	.948	.888	1.81	1.03	1.11	.242
10–15	10,921	425,884	.958	.898	1.81	1.01	1.06	.175
15–20	12,780	440,074	.957	.902	1.77	1.01	1.04	.0934
20–25	14,182	452,190	.940	.895	1.64	1.01	1.03	.0958
Quintiles of second quartile								
25–30	15,550	455,011	.930	.871	1.68	1.00	1.02	.0712
30–35	16,829	482,096	.951	.910	1.62	1.00	1.02	.0357
35–40	17,818	491,931	.947	.908	1.58	1.00	1.02	.0882
40–45	18,036	494,047	.931	.880	1.48	1.00	1.01	.0363
45–50	18,818	504,954	.935	.899	1.42	1.00	1.01	.0316
Quintiles of third quartile								
50–55	18,862	501,167	.928	.891	1.33	1.00	1.01	.0481
55–60	19,771	513,828	.934	.926	1.34	1.00	1.01	.0219
60–65	20,298	520,049	.934	.924	1.30	1.00	1.02	.128
65–70	20,479	554,689	.938	.934	1.22	1.00	1.02	.0838
70–75	21,326	591,767	.936	.935	1.16	1.01	1.01	.0539
Quintiles of fourth quartile								
75–80	21,763	669,295	.932	.933	1.10	1.01	1.01	.0257
80–85	22,122	769,374	.930	.933	1.02	1.01	1.02	.0993
85–90	22,831	947,795	.920	.925	.990	1.02	1.04	.117
90–95	23,264	1,285,919	.880	.886	.979	1.05	1.07	.138
95–100	23,747	2,627,616	.757	.768	.677	1.52	2.01	3.33
Upper tail								
95–96	16,723	72,330	.828	.850	.826	1.00	1.00	.0175
96–97	17,342	84,083	.804	.819	.777	1.00	1.01	.0227
97–98	18,091	105,355	.781	.802	.692	1.01	1.01	.0180
98–99	18,755	144,517	.747	.765	.617	1.01	1.02	.0346
99–100	20,203	322,824	.693	.702	.566	1.19	1.31	.540

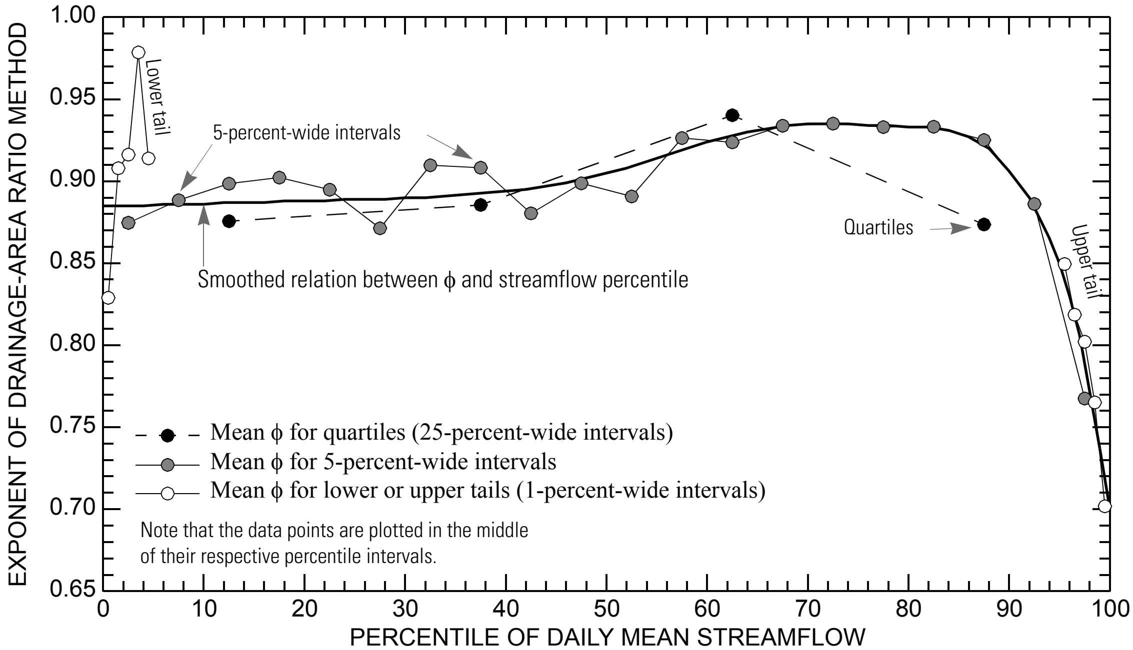


Figure 5. Relation between conditional exponents (ϕ) of drainage-area ratio method and percentile of daily mean streamflow in Texas by streamflow-frequency width interval.

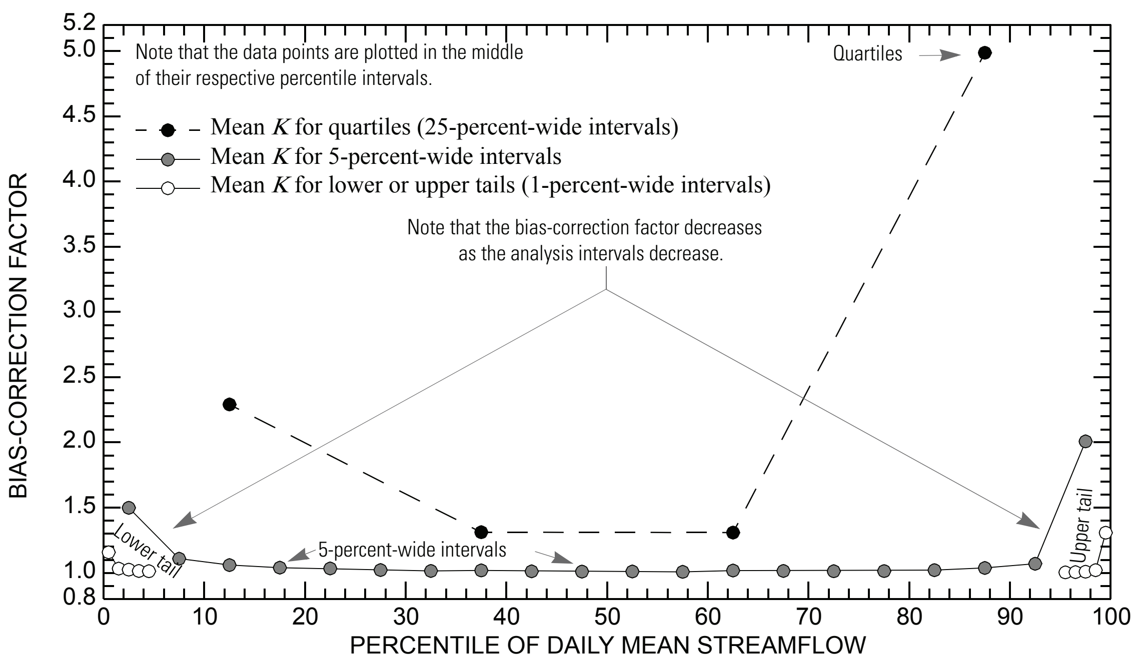


Figure 6. Relation between conditional bias-correction factors (κ) of drainage-area ratio method and percentile of daily mean streamflow in Texas by streamflow-frequency width interval.

precise value of ϕ is a function of streamflow percentile (probability).

2. The authors explicitly conclude that the quartiles of streamflow are too wide for reliable estimation of both values for ϕ or K and that the 5-percent-wide intervals are too wide for the lower and upper 10th percentiles of streamflow.

3. More specific interpretations of ϕ values in figure 5 and table 4 are possible. Values for ϕ are about 0.89 for streamflow percentiles from 0 to about 50 percent, are

Table 5. Suggested exponents for the drainage-area ratio method in Texas.

Streamflow percentile	Exponent ϕ	Streamflow percentile	Exponent ϕ	Streamflow percentile	Exponent ϕ	Streamflow percentile	Exponent ϕ
0	0.885	28	.889	56	.916	84	.931
2	.885	30	.890	58	.920	86	.927
4	.885	32	.890	60	.924	88	.920
6	.886	34	.891	62	.927	90	.906
8	.886	36	.892	64	.930	92	.890
10	.886	38	.893	66	.932	94	.865
12	.887	40	.894	68	.934	95	.850
14	.887	42	.895	70	.935	96	.830
16	.887	44	.897	72	.935	97	.806
18	.888	46	.899	74	.935	98	.773
20	.888	48	.902	76	.934	99	.737
22	.888	50	.905	78	.934	100	.700
24	.889	52	.908	80	.933		
26	.889	54	.912	82	.933		

about 0.92 for percentiles from about 50 to about 65 percent, and are about 0.93 for percentiles from about 65 to about 85 percent. The exponent decreases rapidly to about 0.70 for percentiles nearing 100 percent. The authors conclude by intuition and observation that ϕ smoothly varies throughout the flow-duration curve. A smoothed relation between ϕ and streamflow percentile is depicted in figure 5, and the smoothed values are listed in table 5. These smoothed values were graphically determined. The lower tail data points (open circles, fig. 5) were not used because of the markedly smaller sample sizes relative to the 5-percent-wide interval and the upper tail data points. The smoothed relation is suggested for implementation of the drainage-area ratio method for daily mean streamflow values in Texas.

4. The variability of ϕ is considerable as evidenced by the large standard deviation values listed in tables 3 and 4. Coefficients of variation are often near 1.5 (coefficient of variation equals the standard deviation divided by the mean). There is considerable uncertainty in ϕ, but the central tendency of ϕ is well established in this report. Further, it is important to consider that streamflow exhibits much variation in time and space; therefore, use of the ϕ with more than two decimal places likely implies precision intrinsically not present in the drainage-area ratio method.

The drainage-area ratio method is straightforward to use. For example, suppose the ungaged location has a drainage area of 45 square miles and a nearby streamflow-gaging station is operational and has a drainage area of 450 square miles. The streamflow at the gaging station is 62 cubic feet per second. From the flow-duration curve for the station, 62 cubic feet per second is approximately the 33rd percentile of streamflow. The appropriate ϕ value (table 5) is 0.89 and the bias-correction factor is 1. The same-day streamflow for the ungaged location is assumed to be at the 33rd percentile streamflow; therefore, the magnitude of the flow is

$$\widehat{Q_1} = 62 \times 1\left(\frac{45}{450}\right)^{0.89} = 8.0 \text{ cubic feet per second.} \quad (21)$$

An inherent complication in use of the drainage-area ratio method for specific ungaged locations is that two or more hydrologically similar streamflow-gaging stations satisfying the 100-mile maximum separation distance criteria could be used. Development of a hierarchal or decision tree to decide which candidate stations should be used is difficult, and judgment on the part of the analyst on the basis of hydrologic familiarity with the watersheds in question is required.

There are several concepts to consider when evaluating stations for use in the drainage-area ratio method: (1) Degree of watershed development—comparison of undeveloped to undeveloped or similarly developed watersheds is more favorable than comparison of a highly regulated watershed to an undeveloped watershed or a comparison of an urban watershed to a highly regulated watershed. (2) Soil types, vegetation, and geologic setting—comparison of watersheds having similar soil type, vegetation, and geologic setting are more favorable. (3) Water use characteristics—return and diversion flows complicate application of the drainage-area ratio method. As evidenced by this list, many caveats exist and numerous judgments must be made with site-specific application of the drainage-area ratio method.

In practice, if the analyst decides that multiple stations are applicable, then the authors suggest that the arithmetic mean of the estimated streamflow for all appropriate stations be used. However, the median might be preferable to some analysts. For example, if three stations are deemed applicable to an ungaged location, three estimates of streamflow for the ungaged location would result from application of the method. The mean or median of the three estimates for the ungaged location would be preferable. An example of the method with multiple applicable stations available is provided in figure 7.

Sensitivity of the Drainage-Area Ratio Method

The sensitivity of the drainage-area ratio method to ϕ is informative. Because ϕ is an exponent in the method, estimated flows are particularly sensitive to the value of ϕ. Viewing equation 10 as a function of ϕ and differentiating with respect to ϕ produces

$$\frac{d\widehat{Q_1}}{d\phi} = KQ_2 \ln\left(\frac{A_1}{A_2}\right)\left(\frac{A_1}{A_2}\right)^{\phi}, \tag{22}$$

where all variables are defined as in equation 10. The derivative shows that the estimated streamflow changes (left-hand side of equation 22) proportionally to the "ϕ-power" of the drainage-area ratio (right-hand side of equation 22). The derivative implies that a linear variation in ϕ exponentially affects streamflow. To illustrate, increasing ϕ to 1 from 0.89 (used in the previous example) increases ϕ by 12 percent [(1-0.89)/0.89]; however, the estimated streamflow changes from 8.0 to 6.2 cubic feet per second, which is a 22-percent decrease. Conversely, decreasing ϕ to 0.8 from 0.89 decreases ϕ by 10 percent [(0.80-0.89)/0.89]; however the estimated streamflow changes from 8.0 to 9.83 cubic feet per second, which is a 23-percent increase.

For the illustration chosen here, increases in ϕ correspond to decreases in estimated streamflow because the drainage-area ratio ($A_1/A_2 = 45/450$) is less than 1 and the factor $\ln(A_1/A_2)$ in equation 22 is less than 0, which results in an overall negative rate of change (derivative). Otherwise, increases of estimated streamflow would occur with increasing ϕ when the drainage-area ratio is more than 1. In summary, the derivative of the drainage-area ratio method shows that substantial underestimation or overestimation of streamflow can occur with apparently minor changes in ϕ. The suggested values of ϕ listed in table 5 should, therefore, be used instead of $\phi = 1$. Finally, as depicted in figure 5, ϕ changes most rapidly for large percentiles so sensitivity of streamflow estimates with ϕ is greatest for large magnitude streamflow. The applicability of the method is dependent on the hydrologic similarity between the two sites. For example, similar drainage area, slope, climate, and hydrologic response of the watersheds increases the likelihood of reliably estimating discharge at an ungaged location using the drainage-area ratio method.

Limitations of the Drainage-Area Ratio Method

Following is a list of enumerated limitations of the drainage-area ratio method:

1. The analysis is based on daily mean streamflow. The reliability of the method for other streamflow durations (monthly or annual mean streamflow) or classifications (annual peak streamflow) is uncertain or inappropriate, respectively. For example, use of the method for the 7Q2, often a regulatory critical low flow condition, is appropriate because the 7Q2 is derived from daily streamflow values. Conversely, the method would not be appropriate for peak streamflow values as they are not derived from daily streamflow values.

2. In general, for continuous daily mean streamflow-gaging stations the USGS reports 0.01 cubic foot per second as the smallest nonzero daily mean streamflow value. Lacking the contribution of additional information for application of the method or alternative techniques at a given ungaged location, it is uncertain how the method performs for streamflow estimation at values less than 0.01 cubic foot per second. Users might consider setting an estimate to zero if the method predicts less than 0.01 cubic foot per second. The authors explicitly recognize, however, that such a practice might not be suitable for universal application.

3. Other factors being equal, small separation distances between the ungaged location and the streamflow-gaging station are preferable to large separation distances.

4. To increase the reliability of summary statistics, the minimum absolute value of the logarithm of the drainage-area ratio was 0.25-log cycles. This criteria is used because much uncertainty in estimation of ϕ from data exists when the drainage areas are similar. For application, however, the minimum drainage-area ratio should not be used. Specifically, similar or exactly equal watershed areas for nearby stations are expected to be most appropriate. For example, if the two drainage areas are equal then the drainage-area ratio method equates the streamflow for the ungaged site to the streamflow for the gaging station.

5. Contrary to our expectation, selection of an upper bound of drainage-area ratio is not made or used in data processing; however, relatively large differences in drainage area imply differences in daily mean streamflow during storm events (large magnitude events) because of differences in lag or response time of the watersheds. It is suggested that drainage-area difference greater than about 1.5-log cycles be cautiously used. This criteria is used in common practice for daily streamflow statistics (Reis and Friez, 2000; Hortness, 2006) and peak streamflow statistics (Kjelstrom, 1998; Berenbrock, 2002; Parrett and Johnson, 2004).

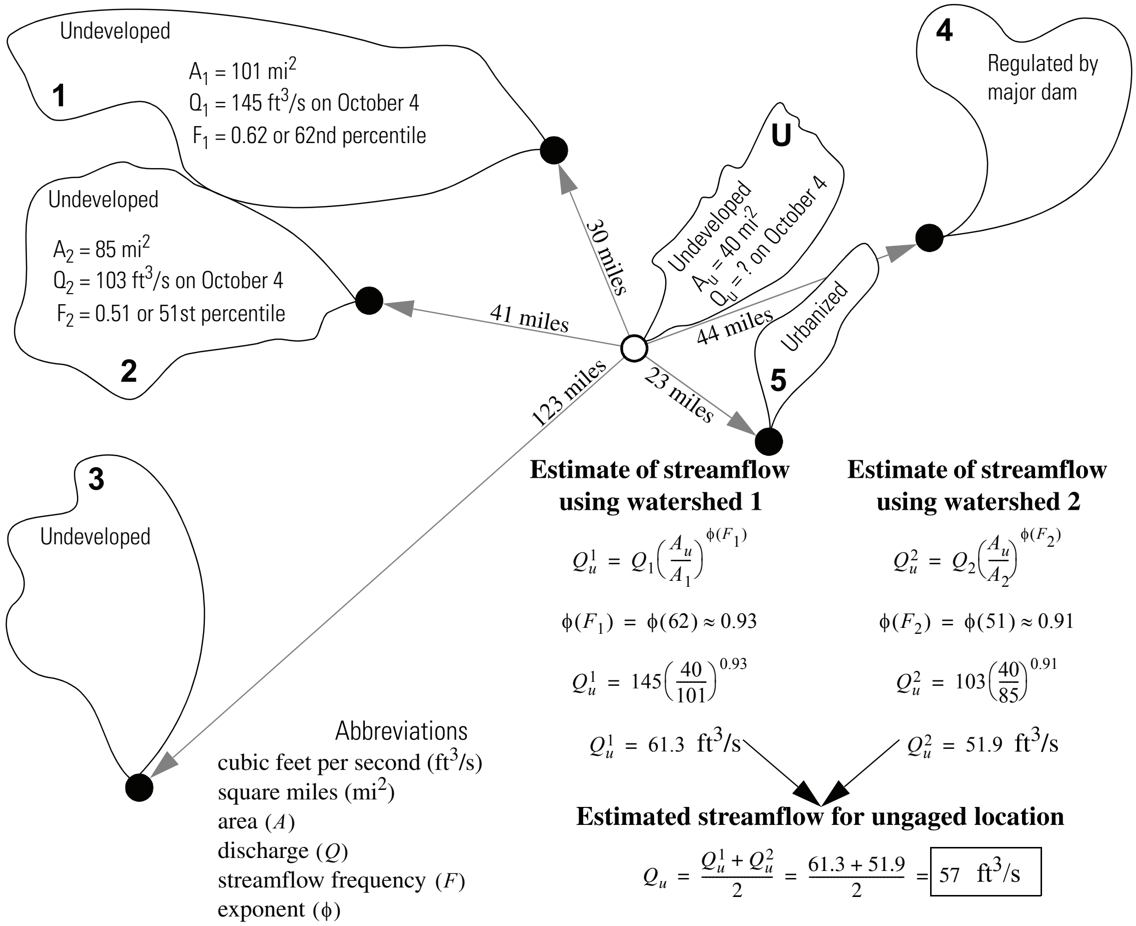


Figure 7. Example application of the drainage-area ratio method.

6. The preferred investigation of the drainage-area ratio method considered a maximum of 100-mile separation distance between stations; hence, it is suggested that users of the method presented here limit the distance between the streamflow-gaging station and the ungaged location to less than about 100 miles.

7. The drainage-area ratio method reported here is designed for estimation of daily mean streamflow for individual ungaged locations. For the method it is inappropriate to subdivide a watershed into two or more subwatersheds, apply the method to each subwatershed, and compute the sum of the estimates. It is inappropriate because the ϕ are not equal to 1. For example, suppose watershed A has a drainage area of 100 square miles and a discharge of 300 cubic feet per second. A nearby ungaged watershed B also has a drainage area of 100 square miles. Using a general value of $\phi = 0.90$, the estimate of the discharge for watershed B = $(300)(100/100)^{0.90}$ = 300 cubic feet per second. If watershed B instead is subdivided into two subwatersheds (B_1 and B_2) with drainage areas of 25 and 75 square miles, respectively, the estimated discharges are 86 cubic feet per second and 232 cubic feet per second. The sum of the discharges does not equal 300 cubic feet per second. The inappropriateness of subdivision is thus demonstrated.

Example Application of Drainage-Area Ratio Method

A diagrammatic representation (fig. 7) of drainage-area ratio method for Texas is illustrated to clarify several concepts presented herein. A hypothetical ungaged watershed (U) requires an estimate of streamflow in cubic feet per second for October 4. The 40-square mile watershed is undeveloped. Five candidate streamflow-gaging stations are available. Watershed 3 is not used because it is more than 100 miles away and other applicable watersheds (1 and 2) are nearby. Watershed 4 is not used because the analyst considers the basin highly regulated and dissimilar to the ungaged watershed. Watershed 5 is not used because the analyst considers the basin too urbanized and dissimilar to the ungaged watershed. Hence, watersheds 1 and 2 can be used to estimate the streamflow for the ungaged watershed. Each watershed provides a separate estimate of streamflow for the ungaged watershed. As anticipated for a given day, watersheds 1 and 2 are exhibiting streamflow at different percentiles. Therefore, the suggested ϕ value (table 5) differs for each watershed. The computations are shown in the lower right corner of the diagram. The arithmetic mean of the two estimates is used for the final estimate of about 57 cubic feet per second. Appendix 1 provides a summary of the drainage-area ratio method that includes some illustrative examples of estimating streamflow for selected USGS stations and TCEQ sites.

Summary

Analysts and managers of surface-water resources often require streamflow data for stream locations where no data were collected or for streamflow-gaging stations for periods during which the gage was not in operation. For example, if water-quality data are collected for the regulatory stream location and a concurrent streamflow measurement is not made, then the streamflow of the location requires estimation. This estimation often is made by using the drainage-area ratio method and is based on concurrent-in-time (same day) streamflow for one or more nearby and operating streamflow-gaging stations. Examination of the drainage-area ratio method for daily streamflow estimation is needed.

The drainage-area ratio method commonly is used to estimate streamflow for sites where no streamflow data are available by using data from a nearby streamflow-gaging station. The method is intuitive and straightforward to implement, and the method is in widespread use by analysts and managers of surface-water resources. The method equates the ratio of streamflow at two stream locations to the ratio of the respective drainage areas. In practice, unity often is assumed as the exponent on the drainage-area ratio, and unity is assumed as a multiplicative bias correction. These two assumptions are evaluated in this investigation through statewide analysis of daily mean streamflow in Texas. The investigation was made by the U.S. Geological Survey in cooperation with the Texas Commission on Environmental Quality.

The analysis of the drainage-area ratio method reported here is based on the period of record of daily mean streamflow and the (contributing) drainage areas for 712 USGS streamflow-gaging stations. The total number of daily values available is in excess of 7.8 million. For the analysis reported here, no further subselection of stations according to streamflow regulation or general land use (developed or undeveloped) was made. Also, the entire period of record for each station was used. Graphical review or statistical tests for temporal trends with the purpose of rejecting (or accepting) specific stations or specific portions of the data record for some stations were not made.

To account for the influence of streamflow probability on the drainage-area ratio method, 34 percentile ranges of daily mean streamflow were considered. The 34 ranges are the 4 quartiles (0–25, 25–50, 50–75, and 75–100 percent), the 5 intervals of the lower tail of the streamflow distribution (0–1, 1–2, 2–3, 3–4, and 4–5 percent), the 20 quintiles of the 4 quartiles (0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, 35–40, 40–45, 45–50, 50–55, 55–60, 60–65, 65–70, 70–75, 75–80, 80–85, 85–90, 90–95, and 95–100 percent), and the 5 intervals of the upper tail of the streamflow distribution (95–96, 96–97, 97–98, 98–99 and 99–100 percent). For each of the 253,116 (712×711/2) unique pairings of stations and for each of the 34 percentile ranges, the concurrent daily mean streamflow values available for the two stations provided for station-pair specific statistical summarization (median, mean, and standard deviation) of both the exponent and bias-correction components of the drainage-area ratio method. Statewide statistics (median, mean, and standard deviation) of the station-pair specific statistics subsequently were computed and are tabulated.

A separate analysis considered conditioning station pairs to those stations within 100 miles of each other and with the absolute value of the logarithm (base-10) of the ratio of the drainage areas greater than or equal to 0.25. Statewide statistics of the conditional station-pair specific statistics were computed and are tabulated. The conditional analysis is preferable primarily because of the anticipation that small separation distances reflect similar hydrologic conditions and the large variation in exponent estimates for similar drainage areas.

The conditional analysis strongly indicates that same-day and same-percentile streamflow does not scale by per-unit drainage area basis ($\phi = 1$), but instead scales on a fractional power of drainage area ($\phi < 1$). Further, ϕ is a function of streamflow percentile (probability). The analysis also indicates that quartiles of streamflow are too wide for reliable estimation of both values for ϕ or K.

The analysis demonstrates that the exponent is about 0.89 for streamflow percentiles from 0 to about 50 percent, is about 0.92 for percentiles from about 50 to about 65 percent, and is about 0.93 for percentiles from about 65 to about 85 percent. The exponent decreases rapidly to about 0.70 for percentiles nearing 100 percent. The bias-correction factor is about 1.00–1.01 for most percentiles ranges, but it is considerably larger as the interval of analysis (for example, the 75–100 percentile range of streamflow) becomes large. Finally, for general application, suggested values of the exponent are tabulated for 54 percentiles of daily mean streamflow in Texas; when these values are used, the bias correction is unity.

References

Asquith, W.H., and Slade, R.M., 1997, Regional equations for estimation of peak-streamflow frequency for natural basins in Texas: U.S. Geological Survey Water-Resources Investigations Report 96–4307, 68 p.

Asquith, W.H., and Thompson, D.B., 2005, Alternative regression equations for estimation of annual peak-streamflow frequency for undeveloped watersheds in Texas using PRESS minimization: Texas Tech University, Center for Multidisciplinary Research in Transportation, Texas Department of Transportation Research Report 0–4405–2, 27 p.

Asquith, W.H., Vrabel, Joseph, and Roussel, M.C., 2007a, Summary of percentages of zero daily mean streamflow for 712 U.S. Geological Survey streamflow-gaging stations in Texas through 2003: U.S. Geological Survey Data Series 247, 721 p. Available online.

Asquith, W.H., Vrabel, Joseph, and Roussel, M.C., 2007b, Summary of annual mean, maximum, minimum, and L-scale statistics of daily mean streamflow for 712 U.S. Geological Survey streamflow-gaging stations in Texas through 2003: U.S. Geological Survey Data Series 248, 721 p. Available online.

Berenbrock, C., 2002, Estimating the magnitude of peak flows at selected recurrence intervals for streams in Idaho: U.S. Geological Survey Water-Resources Investigations Report 02–4170, 59 p.

California Environmental Protection Agency, State Water Resources Control Board, Water Rights, 2005, Example format for WAA/CFII report: accessed on November 2, 2005 at http://www.waterrights.ca.gov/forms/waa_cfii_report_format_example_aug042004pdf

Dingman, S.L., 2002, Physical hydrology: New Jersey, Prentice Hall, 646 p.

Duan, N., 1983, Smearing estimate—A nonparametric retransformation method: Journal of the American Statistical Association, v. 78, p. 605–610.

Emerson, D.G., Vecchia, A.V., and Dahl, A.L., 2005, Evaluation of drainage-area ratio method used to estimate streamflow for the Red River of the North basin, North Dakota and Minnesota: U.S. Geological Survey Scientific Investigations Report 2005–5017, 13 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources—Studies in environmental science 49: New York, Elsevier, 522 p.

Hirsch, R.M., 1979, An evaluation of some record reconstruction techniques: Water Resources Research, v. 18, no. 4, p. 1,081–1,088.

Hortness, J., 2006, Estimating low-flow frequency statistics for unregulated streams in Idaho: U.S. Geological Survey Scientific Investigations Report 2006–5035, 31 p.

Kjelstrom, L.C., 1998, Methods for estimating selected flow-duration and flood-frequency characteristics at ungaged sites in central Idaho: U.S. Geological Survey Water-Resources Investigations Report 94–4120, 10 p.

Michigan Department of Environmental Quality, 2005, Drought flow fact sheet: accessed on October 28, 2005 at http://www.deq.state.mi.us/documents/deq-lwm-hydro-drought_flow_fact_sheet.pdf

Oregon State University, 2005, Streamflow evaluations for watershed restoration planning and design: accessed on November 2, 2005 at http://water.oregonstate.edu/streamflow/manipulation

Parrett, C., and Johnson, D.R., 2004, Methods for estimating flood frequency in Montana based on data through water year 1998: U.S. Geological Survey Water-Resources Investigations Report 03–4308, 101 p., 1 pl.

Perry, C.A., Wolock, D.M., and Artman, J.C., 2002, Estimates of median flows for streams on the Kansas surface water register: U.S. Geological Survey Water-Resources Investigations Report 02–4292, 107 p.

Ries, K.G., and Friez, P.J., 2000, Methods for estimating low-flow statistics for Massachusetts streams: U.S. Geological Survey Water-Resources Investigations Report 00–4135, 81 p.

Stamey, T.C., and Hess, G.W., 1993, Techniques for estimating magnitude and frequency of floods in rural basins of Georgia: U.S. Geological Survey Water-Resources Investigations Report 93–4016, 75 p.

U.S. Geological Survey, 2005, National Water Information System: accessed on various days in July 2005 at http://nwis.waterdata.usgs.gov/nwis/discharge

Vogel, R.M., and Fennessey, N.M., 1994, Flow-duration curves, I—New interpretation and confidence intervals: Journal of Water Resources Planning and Management, v. 120, p. 485–504.

Vogel, R.M., and Fennessey, N.M., 1995, Flow-duration curves, II—A review of applications in water resources planning: Water Resources Bulletin, v. 31, p. 1,029–1,039.

Wurbs, R.A., 2005, Water Rights Analysis Package (WRAP) modeling system reference manual: College Station, Texas, Texas Water Resources Institute Technical Report No. 255, 229 p.

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data.

[USGS, U.S. Geological Survey; no., number; mi^2, square miles]

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
07227470	Canadian River at Tascosa, Tex.	14,713	35°31'08"	102°15'35"
07227500	Canadian River near Amarillo, Tex.	15,376	35°28'13"	101°52'45"
07227920	Dixon Creek near Borger, Tex.	134	35°39'53"	101°21'02"
07228000	Canadian River near Canadian, Tex.	18,178	35°56'06"	100°22'13"
07233500	Palo Duro Creek near Spearman, Tex.	556	36°12'08"	101°18'20"
07235000	Wolf Creek at Lipscomb, Tex.	475	36°14'19"	100°16'31"
07295500	Tierra Blanca Creek above Buffalo Lake near Umbarger, Tex.	538	34°50'55"	102°10'32"
07296100	Tierra Blanca Creek below Buffalo Lake near Umbarger, Tex.	2,075	34°55'27"	102°05'57"
07297500	Prairie Dog Town Fork Red River near Canyon, Tex.	711	35°00'38"	101°53'29"
07297910	Prairie Dog Town Fork Red River near Wayside, Tex.	930	34°50'15"	101°24'49"
07298000	North Tule Draw at Reservoir near Tulia, Tex.	65	34°33'34"	101°42'33"
07298200	Tule Creek near Silverton, Tex.	190	34°32'36"	101°25'46"
07298500	Prairie Dog Town Fork Red River near Brice, Tex.	1,581	34°37'40"	100°56'25"
07299000	Mulberry Creek near Brice, Tex.	534	34°40'30"	100°55'00"
07299200	Prairie Dog Town Fork Red River near Lakeview, Tex.	2,023	34°34'23"	100°44'43"
07299300	Little Red River near Turkey, Tex.	139	34°32'27"	100°46'13"
07299500	Prairie Dog Town Fork Red River near Estelline, Tex.	4,769	34°34'20"	100°26'10"
07299512	Jonah Creek at Weir near Estelline, Tex.	65.5	34°34'20"	100°20'00"
07299514	Jonah Creek below Weir near Estelline, Tex.	66.6	34°33'33"	100°20'21"
07299530	Salt Creek near Estelline, Tex.	142	34°35'26"	100°15'08"
07299540	Prairie Dog Town Fork Red River near Childress, Tex.	2,958	34°34'09"	100°11'37"
07299570	Red River near Quanah, Tex.	3,552	34°24'48"	99°44'07"
07299670	Groesbeck Creek at State Highway 6 near Quanah, Tex.	303	34°21'16"	99°44'24"
07299850	Salt Fork Red River near Clarendon, Tex.	266	35°00'10"	100°53'30"
07299890	Lelia Lake Creek below Bell Creek near Hedley, Tex.	74	34°56'08"	100°41'46"
07300000	Salt Fork Red River near Wellington, Tex.	1,013	34°57'27"	100°13'14"
07301200	McClellan Creek near McLean, Tex.	460	35°19'45"	100°36'32"
07301300	North Fork Red River near Shamrock, Tex.	703	35°15'51"	100°14'29"
07301410	Sweetwater Creek near Kelton, Tex.	267	35°28'23"	100°07'14"
07307500	Quitaque Creek near Quitaque, Tex.	35	34°14'24"	101°07'03"
07307600	North Pease River near Childress, Tex.	1,434	34°16'30"	100°17'05"
07307750	Middle Pease River at Highways 62 and 83 near Paducah, Tex.	1,021	34°12'31"	100°18'03"
07307760	Middle Pease River near Paducah, Tex.	1,058	34°11'28"	100°12'38"
07307800	Pease River near Childress, Tex.	2,195	34°13'39"	100°04'24"
07308000	Pease River near Crowell, Tex.	2,478	34°05'45"	99°43'47"
07308200	Pease River near Vernon, Tex.	2,929	34°10'45"	99°16'40"
07308500	Red River near Burkburnett, Tex.	14,634	34°06'36"	98°31'53"
07311600	North Wichita River near Paducah, Tex.	540	33°57'02"	100°03'52"
07311622	North Wichita River near Crowell, Tex.	591	33°52'12"	99°56'48"
07311630	Middle Wichita River near Guthrie, Tex.	50.3	33°47'45"	100°04'29"
07311648	Middle Wichita River near Truscott, Tex.	161	33°51'12"	99°57'44"
07311700	North Wichita River near Truscott, Tex.	937	33°49'14"	99°47'10"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
07311780	South Wichita River near Guthrie, Tex.	219	33°37'29"	100°13'04"
07311782	South Wichita River at Low Flow Dam near Guthrie, Tex.	223	33°37'19"	100°12'31"
07311783	South Wichita River below Low Flow Dam near Guthrie, Tex.	223	33°37'19"	100°12'31"
07311790	South Wichita River at Ross Ranch near Benjamin, Tex.	499	33°39'18"	100°00'49"
07311800	South Wichita River near Benjamin, Tex.	584	33°38'39"	99°48'02"
07311900	Wichita River near Seymour, Tex.	1,874	33°42'01"	99°23'18"
07312100	Wichita River near Mabelle, Tex.	2,086	33°45'36"	99°08'33"
07312130	Wichita River at State Highway 25 near Kamay, Tex.	2,246	33°52'09"	98°50'20"
07312200	Beaver Creek near Electra, Tex.	652	33°54'21"	98°54'17"
07312500	Wichita River at Wichita Falls, Tex.	1,054	33°54'34"	98°32'00"
07312700	Wichita River near Charlie, Tex.	3,439	34°03'11"	98°17'47"
07314500	Little Wichita River near Archer City, Tex.	481	33°39'45"	98°36'46"
07314900	Little Wichita River above Henrietta, Tex.	1,037	33°49'36"	98°14'23"
07315200	East Fork Little Wichita River near Henrietta, Tex.	178	33°48'46"	98°05'05"
07315400	Little Wichita River near Ringgold, Tex.	1,350	33°53'55"	98°04'05"
07316200	Mineral Creek near Sadler, Tex.	26	33°42'08"	96°50'51"
07332600	Bois D' Arc Creek near Randolph, Tex.	72	33°28'32"	96°12'52"
07335400	Sanders Creek near Chicota, Tex.	175	33°51'09"	95°32'40"
07336750	Little Pine Creek near Kanawha, Tex.	75.4	33°50'26"	95°15'55"
07336800	Pecan Bayou near Clarksville, Tex.	100	33°41'07"	94°59'41"
07336820	Red River near De Kalb, Tex.	41,412	33°41'15"	94°41'39"
07342465	South Sulphur River at Commerce, Tex.	150	33°12'42"	95°54'50"
07342470	South Sulphur River near Commerce, Tex.	189	33°13'11"	95°51'45"
07342480	Middle Sulphur River at Commerce, Tex.	44.1	33°15'59"	95°54'55"
07342500	South Sulphur River near Cooper, Tex.	527	33°21'23"	95°35'41"
07343000	North Sulphur River near Cooper, Tex.	276	33°28'29"	95°35'15"
07343200	Sulphur River near Talco, Tex.	1,405	33°23'26"	95°03'44"
07343300	Cuthand Creek near Bogata, Tex.	69	33°32'51"	95°10'22"
07343500	White Oak Creek near Talco, Tex.	494	33°19'20"	95°05'33"
07344000	Sulphur River near Darden, Tex.	2,774	33°15'00"	94°37'00"
07344482	Big Cypress Creek near Winnsboro, Tex.	27.2	33°01'24"	95°16'12"
07344486	Brushy Creek at Scroggins, Tex.	23.4	32°58'32"	95°11'03"
07344500	Big Cypress Creek near Pittsburg, Tex.	370	33°01'15"	94°52'55"
07345000	Boggy Creek near Daingerfield, Tex.	72	33°02'10"	94°47'15"
07346000	Big Cypress Creek near Jefferson, Tex.	850	32°44'58"	94°29'55"
07346045	Black Cypress Bayou at Jefferson, Tex.	365	32°46'40"	94°21'26"
07346050	Little Cypress Creek near Ore City, Tex.	383	32°40'21"	94°45'03"
07346070	Little Cypress Creek near Jefferson, Tex.	675	32°42'46"	94°20'45"
07346140	Frazier Creek near Linden, Tex.	48	33°03'14"	94°17'24"
08017200	Cowleech Fork Sabine River at Greenville, Tex.	77.7	33°07'58"	96°04'36"
08017300	South Fork Sabine River near Quinlan, Tex.	78.7	32°53'52"	96°15'11"
08017410	Sabine River near Wills Point, Tex.	756	32°48'22"	95°55'09"
08017500	Sabine River near Emory, Tex.	888	32°46'23"	95°47'56"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08018500	Sabine River near Mineola, Tex.	1,357	32°36'49"	95°29'08"
08018730	Burke Creek near Yantis, Tex.	33.1	32°59'26"	95°37'18"
08019000	Lake Fork Creek near Quitman, Tex.	585	32°45'47"	95°27'46"
08019200	Sabine River near Hawkins, Tex.	2,259	32°33'35"	95°12'23"
08019500	Big Sandy Creek near Big Sandy, Tex.	231	32°36'14"	95°05'29"
08020000	Sabine River near Gladewater, Tex.	2,791	32°31'37"	94°57'36"
08020200	Prairie Creek near Gladewater, Tex.	48.9	32°28'45"	94°57'14"
08020450	Sabine River above Longview, Tex.	2,943	32°28'47"	94°48'15"
08020500	Sabine River near Longview, Tex.	2,947	32°28'00"	94°46'50"
08020700	Rabbit Creek at Kilgore, Tex.	75.8	32°23'17"	94°54'11"
08020900	Sabine River below Longview, Tex.	3,155	32°25'00"	94°42'35"
08020960	Mill Creek near Henderson, Tex.	20.3	32°14'02"	94°46'54"
08020980	Mill Creek near Longview, Tex.	47.9	32°18'18"	94°43'41"
08020990	Tiawichi Creek near Longview, Tex.	62.7	32°19'14"	94°43'57"
08021000	Cherokee Bayou near Elderville, Tex.	120	32°20'00"	94°42'00"
08022040	Sabine River near Beckville, Tex.	3,589	32°19'38"	94°21'12"
08022070	Martin Creek near Tatum, Tex.	148	32°17'44"	94°29'29"
08022300	Murvaul Bayou near Gary, Tex.	134	32°02'54"	94°22'31"
08022400	Socagee Creek near Carthage, Tex.	82.6	32°13'54"	94°05'31"
08022500	Sabine River at Logansport, La.	4,839	31°58'20"	94°00'22"
08023200	Tenaha Creek near Shelbyville, Tex.	97.8	31°45'56"	94°05'02"
08024400	Sabine River near Milam, Tex.	6,508	31°28'01"	93°44'41"
08024500	Palo Gaucho Bayou near Hemphill, Tex.	123	31°23'10"	93°50'08"
08025307	Mill Creek near Burkeville, Tex.	18	31°09'23"	93°40'35"
08025360	Sabine River at Toledo Bend Reservoir near Burkeville, Tex.	7,178	31°10'25"	93°33'57"
08026000	Sabine River near Burkeville, Tex.	7,482	31°03'50"	93°31'10"
08028500	Sabine River near Bon Wier, Tex.	8,229	30°44'49"	93°36'30"
08029500	Big Cow Creek near Newton, Tex.	128	30°49'08"	93°47'08"
08030000	Cypress Creek near Buna, Tex.	69.2	30°25'52"	93°54'28"
08030500	Sabine River near Ruliff, Tex.	9,329	30°18'13"	93°44'37"
08031000	Cow Bayou near Mauriceville, Tex.	83.3	30°11'10"	93°54'30"
08031200	Kickapoo Creek near Brownsboro, Tex.	232	32°18'34"	95°36'19"
08031500	Neches River near Reese, Tex.	851	32°01'30"	95°25'40"
08032000	Neches River near Neches, Tex.	1,145	31°53'32"	95°25'50"
08032500	Neches River near Alto, Tex.	1,945	31°34'45"	95°09'55"
08033000	Neches River near Diboll, Tex.	2,724	31°07'58"	94°48'35"
08033300	Piney Creek near Groveton, Tex.	79	31°08'25"	95°05'11"
08033500	Neches River near Rockland, Tex.	3,636	31°01'30"	94°23'58"
08033700	Striker Creek near Summerfield, Tex.	146	32°00'10"	94°59'35"
08033900	East Fork Angelina River near Cushing, Tex.	158	31°51'36"	94°49'23"
08034500	Mud Creek near Jacksonville, Tex.	376	31°58'35"	95°09'38"
08035000	Mud Creek at Ponta, Tex.	475	31°53'21"	95°05'19"
08036500	Angelina River near Alto, Tex.	1,276	31°40'10"	94°57'24"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08037000	Angelina River near Lufkin, Tex.	1,600	31°27'26"	94°43'34"
08037050	Bayou Lanana at Nacogdoches, Tex.	31.3	31°36'58"	94°38'28"
08037500	Arenoso Creek near San Augustine, Tex.	75.3	31°35'48"	94°16'06"
08038000	Attoyac Bayou near Chireno, Tex.	503	31°30'15"	94°18'15"
08038500	Angelina River near Zavalla, Tex.	2,892	31°12'41"	94°17'40"
08039100	Ayish Bayou near San Augustine, Tex.	89	31°23'46"	94°09'03"
08039500	Angelina River near Ebenezer, Tex.	3,486	31°00'54"	94°09'07"
08040600	Neches River near Town Bluff, Tex.	7,574	30°47'27"	94°09'03"
08041000	Neches River at Evadale, Tex.	7,951	30°21'20"	94°05'35"
08041500	Village Creek near Kountze, Tex.	860	30°23'52"	94°15'48"
08041700	Pine Island Bayou near Sour Lake, Tex.	336	30°06'21"	94°20'04"
08042000	Taylor Bayou near LaBelle, Tex.	262	29°52'30"	94°09'34"
08042500	Hillebrandt Bayou near Lovell Lake, Tex.	128	29°55'44"	94°06'35"
08042700	North Creek near Jacksboro, Tex.	21.6	33°16'57"	98°17'53"
08042800	West Fork Trinity River near Jacksboro, Tex.	683	33°17'30"	98°04'49"
08042900	Beans Creek at Wizard Wells, Tex.	29.6	33°11'59"	97°58'01"
08043500	West Fork Trinity River at Bridgeport, Tex.	1,147	33°12'05"	97°45'21"
08043950	Big Sandy Creek near Chico, Tex.	312	33°16'27"	97°40'42"
08044000	Big Sandy Creek near Bridgeport, Tex.	333	33°13'54"	97°41'40"
08044135	Garrett Creek near Paradise, Tex.	52.5	33°06'18"	97°39'17"
08044140	Salt Creek near Paradise, Tex.	52.7	33°05'54"	97°38'59"
08044500	West Fork Trinity River near Boyd, Tex.	1,725	33°05'07"	97°33'30"
08044800	Walnut Creek at Reno, Tex.	75.6	32°56'44"	97°34'58"
08045500	West Fork Trinity River at Lake Worth Dam above Fort Worth, Tex.	2,069	32°47'27"	97°24'54"
08045850	Clear Fork Trinity River near Weatherford, Tex.	121	32°44'25"	97°39'06"
08046000	Clear Fork Trinity River near Aledo, Tex.	251	32°38'28"	97°33'51"
08047000	Clear Fork Trinity River near Benbrook, Tex.	431	32°39'54"	97°26'30"
08047050	Marys Creek at Benbrook, Tex.	54	32°41'42"	97°26'49"
08047500	Clear Fork Trinity River at Fort Worth, Tex.	518	32°43'56"	97°21'31"
08048000	West Fork Trinity River at Fort Worth, Tex.	2,615	32°45'39"	97°19'56"
08048520	Sycamore Creek at Interstate Highway 35 West, Fort Worth, Tex.	17.7	32°39'55"	97°19'16"
08048530	Sycamore Creek Tributary above Semenary South Shopping Center, Fort Worth, Tex.	.97	32°41'08"	97°19'44"
08048540	Sycamore Creek Tributary at Interstate Highway 35 West, Fort Worth, Tex.	1.35	32°41'18"	97°19'11"
08048543	West Fork Trinity River at Beach Street, Fort Worth, Tex.	2,685	32°45'06"	97°17'21"
08048600	Dry Branch at Fain Street at Fort Worth, Tex.	2.15	32°46'34"	97°17'18"
08048800	Big Fossil Creek at Haltom City, Tex.	52.8	32°48'26"	97°14'54"
08048850	Little Fossil Creek at Mesquite Street, Fort Worth, Tex.	12.3	32°48'33"	97°17'28"
08048970	Village Creek at Everman, Tex.	84.5	32°36'12"	97°15'53"
08048980	Village Creek at Kennedale, Tex.	100	32°38'28"	97°14'31"
08049000	Village Creek near Handley, Tex.	126	32°42'00"	97°13'00"
08049500	West Fork Trinity River at Grand Prairie, Tex.	3,065	32°47'55"	97°01'46"
08049550	Big Bear Creek near Grapevine, Tex.	29.6	32°54'48"	97°07'44"
08049553	Big Bear Creek at Euless/Grapevine Road near Grapevine, Tex.	38.6	32°53'41"	97°04'56"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08049556	Unnamed Tributary Big Bear Creek (Outflow 19) near Euless, Tex.	1.04	32°52'19"	97°03'24"
08049565	Trigg Branch at DFW Airport near Euless, Tex.	2.62	32°52'02"	97°02'20"
08049569	Big Bear Creek at State Highway 183 near Euless, Tex.	76.9	32°50'08"	97°02'09"
08049580	Mountain Creek near Venus, Tex.	25.5	32°29'27"	97°07'22"
08049600	Mountain Creek near Cedar Hill, Tex.	119	32°35'03"	97°01'23"
08049700	Walnut Creek near Mansfield, Tex.	62.8	32°34'51"	97°06'06"
08050000	Mountain Creek near Grand Prairie, Tex.	273	32°42'20"	96°58'00"
08050100	Mountain Creek at Grand Prairie, Tex.	298	32°44'51"	96°55'32"
08050300	Elm Fork Trinity River near Muenster, Tex.	46	33°36'36"	97°22'57"
08050400	Elm Fork Trinity River at Gainesville, Tex.	174	33°37'27"	97°09'22"
08050500	Elm Fork Trinity River near Sanger, Tex.	381	33°23'11"	97°05'05"
08050800	Timber Creek near Collinsville, Tex.	38.8	33°33'16"	96°56'49"
08050840	Range Creek near Collinsville, Tex.	29.2	33°31'34"	96°48'25"
08051000	Isle Du Bois Creek near Pilot Point, Tex.	266	33°24'23"	97°00'45"
08051130	Elm Fork Trinity River near Pilot Point, Tex.	692	33°21'01"	97°02'49"
08051500	Clear Creek near Sanger, Tex.	295	33°20'10"	97°10'45"
08052000	Elm Fork Trinity River near Denton, Tex.	1,084	33°15'02"	97°02'42"
08052650	Little Elm Creek near Celina, Tex.	46.7	33°21'55"	96°49'25"
08052700	Little Elm Creek near Aubrey, Tex.	75.5	33°17'00"	96°53'33"
08052780	Hickory Creek at Denton, Tex.	129	33°09'06"	97°08'30"
08053000	Elm Fork Trinity River near Lewisville, Tex.	1,673	33°02'44"	96°57'39"
08053500	Denton Creek near Justin, Tex.	400	33°07'08"	97°17'25"
08054000	Denton Creek near Roanoke, Tex.	621	33°02'24"	97°12'17"
08055000	Denton Creek near Grapevine, Tex.	705	32°59'13"	97°00'45"
08055500	Elm Fork Trinity River near Carrollton, Tex.	2,459	32°57'57"	96°56'39"
08055700	Bachman Branch at Dallas, Tex.	10	32°51'37"	96°51'13"
08056500	Turtle Creek at Dallas, Tex.	7.98	32°48'26"	96°48'08"
08057000	Trinity River at Dallas, Tex.	6,106	32°46'29"	96°49'18"
08057100	White Rock Creek at Keller Springs Road, Dallas, Tex.	29.4	32°58'13"	96°48'19"
08057200	White Rock Creek at Greenville Avenue, Dallas, Tex.	66.4	32°53'21"	96°45'23"
08057300	White Rock Creek at White Rock Lake, Dallas, Tex.	100	32°48'31"	96°43'32"
08057410	Trinity River below Dallas, Tex.	6,278	32°42'27"	96°44'08"
08057445	Prairie Creek at U.S. Highway 175, Dallas, Tex.	9.03	32°42'17"	96°40'11"
08057448	Trinity River near Wilmer, Tex.	6,387	32°37'03"	96°37'19"
08057450	Tenmile Creek at State Highway 342 at Lancaster, Tex.	52.8	32°34'42"	96°45'21"
08058500	Honey Creek near McKinney, Tex.	39	33°16'42"	96°39'27"
08058900	East Fork Trinity River at McKinney, Tex.	164	33°14'38"	96°36'31"
08059000	East Fork Trinity River near McKinney, Tex.	190	33°12'13"	96°35'44"
08059400	Sister Grove Creek near Blue Ridge, Tex.	83.1	33°17'40"	96°28'58"
08059500	Sister Grove Creek near Princeton, Tex.	113	33°11'35"	96°28'32"
08060000	East Fork Trinity River above Pilot Grove near Lavon, Tex.	324	33°01'23"	96°28'32"
08061000	East Fork Trinity River near Lavon, Tex.	773	33°01'25"	96°28'31"
08061500	East Fork Trinity River near Rockwall, Tex.	840	32°55'25"	96°30'20"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08061540	Rowlett Creek near Sachse, Tex.	120	32°57'35"	96°36'51"
08061700	Duck Creek near Garland, Tex.	31.6	32°49'58"	96°35'43"
08061750	East Fork Trinity River near Forney, Tex.	1,118	32°46'27"	96°30'12"
08061950	South Mesquite Creek at Mercury Road, North Mesquite, Tex.	23	32°43'32"	96°34'12"
08062000	East Fork Trinity River near Crandall, Tex.	1,256	32°38'19"	96°29'06"
08062500	Trinity River near Rosser, Tex.	8,147	32°25'35"	96°27'46"
08062650	Cedar Creek Reservoir Spillway Outflow near Trinidad, Tex.	1,007	32°14'16"	96°08'36"
08062700	Trinity River at Trinidad, Tex.	8,538	32°08'05"	96°06'20"
08062800	Cedar Creek near Kemp, Tex.	189	32°30'18"	96°06'57"
08062900	Kings Creek near Kaufman, Tex.	233	32°30'48"	96°19'44"
08062980	Lacey Fork near Mabank, Tex.	118	32°25'27"	96°06'33"
08063000	Cedar Creek near Mabank, Tex.	733	32°19'45"	96°10'05"
08063003	South Twin Creek near Eustace, Tex.	27.4	32°19'18"	96°01'43"
08063020	Cedar Creek at Trinidad, Tex.	1,011	32°09'24"	96°03'45"
08063100	Richland Creek near Dawson, Tex.	333	31°56'18"	96°40'52"
08063200	Pin Oak Creek near Hubbard, Tex.	17.6	31°48'01"	96°43'02"
08063500	Richland Creek near Richland, Tex.	734	31°57'02"	96°25'16"
08063800	Waxahachie Creek near Bardwell, Tex.	178	32°14'36"	96°38'24"
08064100	Chambers Creek near Rice, Tex.	807	32°11'54"	96°31'12"
08064500	Chambers Creek near Corsicana, Tex.	963	32°06'29"	96°22'14"
08064700	Tehuacana Creek near Streetman, Tex.	142	31°50'54"	96°17'23"
08064800	Catfish Creek near Tennessee Colony, Tex.	207	31°52'51"	95°52'07"
08065000	Trinity River near Oakwood, Tex.	12,833	31°38'54"	95°47'21"
08065200	Upper Keechi Creek near Oakwood, Tex.	150	31°34'11"	95°53'17"
08065350	Trinity River near Crockett, Tex.	13,911	31°20'18"	95°39'22"
08065500	Trinity River near Midway, Tex.	14,450	31°04'28"	95°41'57"
08065700	Caney Creek near Madisonville, Tex.	112	30°56'12"	95°56'07"
08065800	Bedias Creek near Madisonville, Tex.	321	30°53'05"	95°46'40"
08066000	Trinity River at Riverside, Tex.	15,589	30°51'33"	95°23'55"
08066100	White Rock Creek near Trinity, Tex.	222	31°03'06"	95°22'40"
08066170	Kickapoo Creek near Onalaska, Tex.	57	30°54'25"	95°05'18"
08066191	Livingston Reservoir Outflow Weir near Goodrich, Tex.	16,583	30°37'55"	95°01'11"
08066200	Long King Creek at Livingston, Tex.	141	30°42'58"	94°57'31"
08066250	Trinity River near Goodrich, Tex.	16,844	30°34'19"	94°56'55"
08066300	Menard Creek near Rye, Tex.	152	30°28'53"	94°46'47"
08066500	Trinity River at Romayor, Tex.	17,186	30°25'30"	94°51'02"
08067000	Trinity River at Liberty, Tex.	17,468	30°03'27"	94°49'05"
08067500	Cedar Bayou near Crosby, Tex.	64.9	29°58'21"	94°59'08"
08067525	Goose Creek at Baytown, Tex.	15.8	29°46'14"	94°59'58"
08067610	Lake Conroe Outflow Weir near Conroe, Tex.	445	30°21'23"	95°33'37"
08067650	West Fork San Jacinto River below Lake Conroe near Conroe, Tex.	451	30°20'31"	95°32'34"
08067700	Caney Creek near Dobbin, Tex.	40.4	30°21'13"	95°48'35"
08067900	Lake Creek near Conroe, Tex.	291	30°15'12"	95°34'43"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08068000	West Fork San Jacinto River near Conroe, Tex.	828	30°14'40"	95°27'25"
08068090	West Fork San Jacinto River above Lake Houston near Porter, Tex.	962	30°05'09"	95°17'59"
08068275	Spring Creek near Tomball, Tex.	186	30°07'11"	95°38'45"
08068325	Willow Creek near Tomball, Tex.	41	30°06'19"	95°32'47"
08068390	Bear Branch at Research Boulevard, The Woodlands, Tex.	15.4	30°11'26"	95°29'28"
08068400	Panther Branch at Gosling Road, The Woodlands, Tex.	25.9	30°11'31"	95°29'01"
08068450	Panther Branch near Spring, Tex.	34.5	30°07'51"	95°28'52"
08068500	Spring Creek near Spring, Tex.	409	30°06'37"	95°26'10"
08068520	Spring Creek at Spring, Tex.	419	30°05'31"	95°24'21"
08068720	Cypress Creek at Katy-Hockley Road near Hockley, Tex.	110	29°57'00"	95°48'29"
08068740	Cypress Creek at House-Hahl Road near Cypress, Tex.	131	29°57'32"	95°43'03"
08068780	Little Cypress Creek near Cypress, Tex.	41	30°00'57"	95°41'50"
08068800	Cypress Creek at Grant Road near Cypress, Tex.	214	29°58'24"	95°35'54"
08068900	Cypress Creek at Stuebner-Airline Road near Westfield, Tex.	248	30°00'23"	95°30'42"
08069000	Cypress Creek near Westfield, Tex.	285	30°02'08"	95°25'43"
08069500	West Fork San Jacinto River near Humble, Tex.	1,741	30°01'37"	95°15'28"
08070000	East Fork San Jacinto River near Cleveland, Tex.	325	30°20'11"	95°06'14"
08070200	East Fork San Jacinto River near New Caney, Tex.	388	30°08'43"	95°07'27"
08070500	Caney Creek near Splendora, Tex.	105	30°15'34"	95°18'08"
08071000	Peach Creek at Splendora, Tex.	117	30°13'57"	95°10'05"
08071280	Luce Bayou above Lake Houston near Huffman, Tex.	218	30°06'34"	95°03'35"
08071500	San Jacinto River near Huffman, Tex.	2,800	29°59'40"	95°08'00"
08072300	Buffalo Bayou near Katy, Tex.	63.3	29°44'35"	95°48'24"
08072730	Bear Creek near Barker, Tex.	21.5	29°49'50"	95°41'12"
08072760	Langham Creek at West Little York Road near Addicks, Tex.	24.6	29°52'01"	95°38'47"
08073500	Buffalo Bayou near Addicks, Tex.	293	29°45'42"	95°36'20"
08073600	Buffalo Bayou at West Belt Drive at Houston, Tex.	307	29°45'43"	95°33'27"
08073700	Buffalo Bayou at Piney Point, Tex.	317	29°44'48"	95°31'24"
08074000	Buffalo Bayou at Houston, Tex.	336	29°45'36"	95°24'30"
08074020	Whiteoak Bayou at Alabonson Road at Houston, Tex.	34.5	29°52'14"	95°28'49"
08074150	Cole Creek at Deihl Road, Houston, Tex.	7.5	29°51'04"	95°29'16"
08074250	Brickhouse Gully at Costa Rica Street, Houston, Tex.	11.4	29°49'40"	95°28'09"
08074500	Whiteoak Bayou at Houston, Tex.	86.3	29°46'30"	95°23'49"
08074760	Brays Bayou at Alief, Tex.	12.9	29°42'39"	95°35'13"
08074780	Keegans Bayou at Keegan Road near Houston, Tex.	8.63	29°39'55"	95°35'42"
08074800	Keegans Bayou at Roark Road near Houston, Tex.	12.7	29°39'23"	95°33'43"
08074810	Brays Bayou at Gessner Drive, Houston, Tex.	52.5	29°40'21"	95°31'41"
08075000	Brays Bayou at Houston, Tex.	94.9	29°41'49"	95°24'43"
08075400	Sims Bayou at Hiram Clarke Street, Houston, Tex.	20.2	29°37'07"	95°26'45"
08075500	Sims Bayou at Houston, Tex.	63	29°40'27"	95°17'21"
08075650	Berry Bayou at Forest Oaks Street, Houston, Tex.	10.7	29°40'35"	95°14'37"
08075730	Vince Bayou at Pasadena, Tex.	8.26	29°41'40"	95°12'58"
08075770	Hunting Bayou at Interstate Highway 610, Houston, Tex.	16.1	29°47'35"	95°16'04"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08075780	Greens Bayou at Cutten Road near Houston, Tex.	8.65	29°56'56"	95°31'10"
08075900	Greens Bayou near U.S. Highway 75 near Houston, Tex.	36.6	29°57'24"	95°25'04"
08076000	Greens Bayou near Houston, Tex.	68.7	29°55'05"	95°18'24"
08076180	Garners Bayou near Humble, Tex.	31	29°56'03"	95°14'02"
08076500	Halls Bayou at Houston, Tex.	28.7	29°51'42"	95°20'05"
08076700	Greens Bayou at Ley Road, Houston, Tex.	182	29°50'13"	95°13'59"
08077000	Clear Creek near Pearland, Tex.	38.8	29°35'50"	95°17'11"
08077540	Clear Creek at Friendswood, Tex.	99.6	29°32'31"	95°11'48"
08078000	Chocolate Bayou near Alvin, Tex.	87.7	29°22'09"	95°19'14"
08079000	Oyster Creek near Angleton, Tex.	171	29°09'30"	95°28'32"
08079500	North Fork Double Mountain Fork Brazos River at Lubbock, Tex.	200	33°35'08"	101°49'40"
08079575	North Fork Double Mountain Fork Brazos River near Post, Tex.	438	33°14'55"	101°20'17"
08079600	Double Mountain Fork Brazos River at Justiceburg, Tex.	244	33°02'18"	101°11'50"
08080000	Double Mountain Fork Brazos River near Rotan, Tex.	1,604	32°55'49"	100°29'16"
08080500	Double Mountain Fork Brazos River near Aspermont, Tex.	1,864	33°00'29"	100°10'49"
08080540	McDonald Creek near Post, Tex.	79.2	33°21'03"	101°13'36"
08080700	Running Water Draw at Plainview, Tex.	382	34°10'44"	101°42'08"
08080950	Duck Creek near Girard, Tex.	279	33°21'22"	100°42'17"
08081000	Salt Fork Brazos River near Peacock, Tex.	1,985	33°12'43"	100°25'53"
08081200	Croton Creek near Jayton, Tex.	290	33°17'18"	100°25'52"
08081500	Salt Croton Creek near Aspermont, Tex.	64.3	33°24'03"	100°24'29"
08082000	Salt Fork Brazos River near Aspermont, Tex.	2,496	33°20'02"	100°14'16"
08082100	Stinking Creek near Aspermont, Tex.	88.8	33°14'00"	100°12'47"
08082180	North Croton Creek near Knox City, Tex.	251	33°22'59"	100°04'51"
08082500	Brazos River at Seymour, Tex.	5,972	33°34'51"	99°16'02"
08082700	Millers Creek near Munday, Tex.	104	33°19'45"	99°27'53"
08083000	Brazos River near Graham, Tex.	7,264	33°04'55"	98°43'36"
08083100	Clear Fork Brazos River near Roby, Tex.	228	32°47'15"	100°23'18"
08083230	Clear Fork Brazos River near Noodle, Tex.	1,176	32°40'28"	100°04'20"
08083240	Clear Fork Brazos River at Hawley, Tex.	1,416	32°35'53"	99°48'53"
08083245	Mulberry Creek near Hawley, Tex.	205	32°34'04"	99°47'32"
08083300	Elm Creek near Abilene, Tex.	133	32°21'08"	99°48'27"
08083400	Little Elm Creek near Abilene, Tex.	39.1	32°23'29"	99°51'08"
08083420	Cat Claw Creek at Abilene, Tex.	13	32°28'31"	99°44'56"
08083430	Elm Creek at Abilene, Tex.	422	32°30'29"	99°44'27"
08083470	Cedar Creek at Abilene, Tex.	119	32°26'56"	99°43'13"
08083480	Cedar Creek at Interstate Highway 20, Abilene, Tex.	136	32°29'58"	99°42'57"
08084000	Clear Fork Brazos River at Nugent, Tex.	2,199	32°41'24"	99°40'09"
08084800	California Creek near Stamford, Tex.	478	32°55'51"	99°38'32"
08085000	Paint Creek near Haskell, Tex.	914	33°04'39"	99°32'36"
08085500	Clear Fork Brazos River at Fort Griffin, Tex.	3,988	32°56'04"	99°13'27"
08086000	Clear Fork Brazos River at Crystal Falls, Tex.	4,323	32°54'00"	98°50'00"
08086015	Hubbard Creek near Sedwick, Tex.	128	32°36'06"	99°14'20"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08086050	Deep Creek at Moran, Tex.	235	32°33'33"	99°10'11"
08086100	Hubbard Creek near Albany, Tex.	454	32°41'21"	99°09'52"
08086120	Salt Prong Hubbard Creek at U.S. Highway 380 near Albany, Tex.	65.2	32°41'01"	99°16'05"
08086150	North Fork Hubbard Creek near Albany, Tex.	39.3	32°42'27"	99°16'29"
08086200	Salt Prong Hubbard Creek near Albany, Tex.	115	32°42'02"	99°12'42"
08086210	Snailum Creek near Albany, Tex.	22.9	32°43'15"	99°10'30"
08086212	Hubbard Creek below Albany, Tex.	613	32°43'58"	99°08'25"
08086235	Battle Creek near Moran, Tex.	108	32°33'10"	99°06'32"
08086260	Pecan Creek near Eolian, Tex.	26.4	32°35'01"	99°01'57"
08086290	Big Sandy Creek above Breckenridge, Tex.	280	32°38'54"	99°00'15"
08086500	Hubbard Creek near Breckenridge, Tex.	1,089	32°50'13"	98°56'52"
08087300	Clear Fork Brazos River at Eliasville, Tex.	5,697	32°57'36"	98°45'59"
08088000	Brazos River near South Bend, Tex.	13,107	33°01'27"	98°38'37"
08088100	Salt Creek at Olney, Tex.	11.8	33°22'13"	98°44'40"
08088200	Salt Creek near Newcastle, Tex.	120	33°13'00"	98°38'55"
08088300	Briar Creek near Graham, Tex.	24.2	33°12'43"	98°37'06"
08088450	Big Cedar Creek near Ivan, Tex.	97	32°49'39"	98°43'25"
08088600	Brazos River at Morris Sheppard Dam near Graford, Tex.	14,030	32°52'19"	98°25'32"
08088610	Brazos River near Graford, Tex.	14,030	32°51'29"	98°24'41"
08089000	Brazos River near Palo Pinto, Tex.	14,245	32°51'45"	98°18'08"
08090500	Palo Pinto Creek near Santo, Tex.	573	32°37'51"	98°10'50"
08090800	Brazos River near Dennis, Tex.	15,671	32°36'56"	97°55'32"
08091000	Brazos River near Glen Rose, Tex.	16,252	32°15'32"	97°42'08"
08091500	Paluxy River at Glen Rose, Tex.	410	32°13'53"	97°46'37"
08091750	Squaw Creek near Glen Rose, Tex.	70.3	32°16'12"	97°43'56"
08092000	Nolan River at Blum, Tex.	282	32°09'02"	97°24'09"
08092600	Brazos River at Whitney Dam near Whitney, Tex.	17,623	31°52'00"	97°22'00"
08093100	Brazos River near Aquilla, Tex.	17,678	31°48'44"	97°17'51"
08093250	Hackberry Creek at Hillsboro, Tex.	57.9	32°00'20"	97°08'59"
08093360	Aquilla Creek above Aquilla, Tex.	255	31°53'43"	97°12'10"
08093400	Cobb Creek near Abbott, Tex.	12.4	31°55'11"	97°05'57"
08093500	Aquilla Creek near Aquilla, Tex.	308	31°50'40"	97°12'04"
08093700	North Bosque River at Stephenville, Tex.	95.9	32°12'56"	98°11'55"
08094800	North Bosque River at Hico, Tex.	359	31°58'41"	98°02'04"
08095000	North Bosque River near Clifton, Tex.	968	31°47'09"	97°34'04"
08095200	North Bosque River at Valley Mills, Tex.	1,146	31°40'10"	97°28'09"
08095300	Middle Bosque River near McGregor, Tex.	182	31°30'33"	97°21'56"
08095400	Hog Creek near Crawford, Tex.	78.2	31°33'20"	97°21'22"
08095500	South Bosque River near Speegleville, Tex.	386	31°31'00"	97°15'00"
08095600	Bosque River near Waco, Tex.	1,656	31°36'04"	97°11'36"
08096500	Brazos River at Waco, Tex.	19,993	31°32'09"	97°04'23"
08097500	Brazos River near Marlin, Tex.	20,645	31°17'18"	96°58'10"
08098000	Deer Creek at Chilton, Tex.	84.5	31°15'58"	97°03'30"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08098290	Brazos River near Highbank, Tex.	20,870	31°08'02"	96°49'29"
08098300	Little Pond Creek near Burlington, Tex.	23	31°01'35"	96°59'17"
08099100	Leon River near De Leon, Tex.	479	32°10'25"	98°31'58"
08099300	Sabana River near De Leon, Tex.	264	32°06'50"	98°36'19"
08099500	Leon River near Hasse, Tex.	1,261	31°57'28"	98°27'32"
08100000	Leon River near Hamilton, Tex.	1,891	31°47'19"	98°07'16"
08100500	Leon River at Gatesville, Tex.	2,342	31°25'58"	97°45'42"
08101000	Cowhouse Creek at Pidcoke, Tex.	455	31°17'05"	97°53'05"
08101500	Cowhouse Creek near Killeen, Tex.	667	31°12'21"	97°42'55"
08102500	Leon River near Belton, Tex.	3,542	31°04'12"	97°26'28"
08102600	Nolan Creek at Belton, Tex.	112	31°03'06"	97°27'25"
08103800	Lampasas River near Kempner, Tex.	818	31°04'54"	98°00'59"
08103900	South Fork Rocky Creek near Briggs, Tex.	33.3	30°54'41"	98°02'12"
08104000	Lampasas River at Youngsport, Tex.	1,240	30°57'26"	97°42'30"
08104100	Lampasas River near Belton, Tex.	1,321	31°00'06"	97°29'32"
08104310	Salado Creek below Salado Springs at Salado, Tex.	136	30°57'07"	97°31'26"
08104500	Little River near Little River, Tex.	5,228	30°57'59"	97°20'45"
08104700	North Fork San Gabriel River near Georgetown, Tex.	248	30°39'42"	97°42'40"
08104900	South Fork San Gabriel River at Georgetown, Tex.	133	30°37'32"	97°41'27"
08105000	San Gabriel River at Georgetown, Tex.	405	30°39'14"	97°39'18"
08105095	Berry Creek at Airport Road near Georgetown, Tex.	71.4	30°42'11"	97°39'58"
08105100	Berry Creek near Georgetown, Tex.	83.1	30°41'28"	97°39'21"
08105200	Berry Creek at State Highway 971 near Georgetown, Tex.	117	30°40'33"	97°36'51"
08105300	San Gabriel River near Weir, Tex.	563	30°38'45"	97°35'06"
08105400	San Gabriel River near Circleville, Tex.	599	30°37'43"	97°28'23"
08105700	San Gabriel River at Laneport, Tex.	738	30°41'39"	97°16'43"
08106300	Brushy Creek near Rockdale, Tex.	505	30°41'38"	97°04'42"
08106310	San Gabriel River near Rockdale, Tex.	1,359	30°43'39"	97°02'19"
08106350	Little River near Rockdale, Tex.	6,959	30°45'38"	97°00'49"
08106500	Little River at Cameron, Tex.	7,065	30°50'06"	96°56'47"
08107000	Big Elm Creek near Temple, Tex.	74.7	31°02'58"	97°14'08"
08107500	Big Elm Creek near Buckholts, Tex.	171	30°56'50"	97°06'14"
08108000	North Elm Creek near Ben Arnold, Tex.	32.2	30°57'00"	97°03'00"
08108200	North Elm Creek near Cameron, Tex.	44.8	30°55'52"	97°01'13"
08108700	Brazos River at State Highway 21 near Bryan, Tex.	29,483	30°37'36"	96°32'38"
08109000	Brazos River near Bryan, Tex.	29,949	30°36'50"	96°29'11"
08109700	Middle Yegua Creek near Dime Box, Tex.	236	30°20'21"	96°54'16"
08109800	East Yegua Creek near Dime Box, Tex.	244	30°24'26"	96°49'02"
08110000	Yegua Creek near Somerville, Tex.	1,009	30°19'18"	96°30'26"
08110100	Davidson Creek near Lyons, Tex.	195	30°25'10"	96°32'24"
08110200	Brazos River at Washington, Tex.	31,626	30°21'40"	96°09'18"
08110325	Navasota River above Groesbeck, Tex.	239	31°34'27"	96°31'14"
08110400	Navasota River near Groesbeck, Tex.	311	31°30'44"	96°27'01"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08110430	Big Creek near Freestone, Tex.	97.2	31°30'24"	96°19'28"
08110500	Navasota River near Easterly, Tex.	968	31°10'12"	96°17'51"
08110800	Navasota River at Old Spanish Road near Bryan, Tex.	1,287	30°58'25"	96°14'29"
08111000	Navasota River near Bryan, Tex.	1,454	30°52'10"	96°11'32"
08111010	Navasota River near College Station, Tex.	1,809	30°36'26"	96°10'53"
08111025	Burton Creek at Villa Maria Road at Bryan, Tex.	1.33	30°38'47"	96°20'58"
08111050	Hudson Creek near Bryan, Tex.	1.94	30°39'37"	96°17'58"
08111500	Brazos River near Hempstead, Tex.	34,314	30°07'44"	96°11'15"
08111700	Mill Creek near Bellville, Tex.	376	29°52'51"	96°12'18"
08114000	Brazos River at Richmond, Tex.	35,541	29°34'56"	95°45'27"
08114500	Brazos River near Juliff, Tex.	35,623	29°27'19"	95°31'58"
08115000	Big Creek near Needville, Tex.	42.8	29°28'35"	95°48'45"
08115500	Fairchild Creek near Needville, Tex.	26.2	29°26'45"	95°45'41"
08116000	Big Creek near Guy, Tex.	116	29°24'45"	95°42'36"
08116400	Dry Creek near Rosenberg, Tex.	8.65	29°30'42"	95°44'48"
08116500	Dry Creek near Richmond, Tex.	12.2	29°30'19"	95°42'41"
08116650	Brazos River near Rosharon, Tex.	35,773	29°20'58"	95°34'56"
08117500	San Bernard River near Boling, Tex.	727	29°18'48"	95°53'37"
08117900	Big Boggy Creek near Wadsworth, Tex.	10.3	28°48'26"	95°57'02"
08117995	Colorado River near Gail, Tex.	498	32°37'43"	101°17'06"
08118500	Bull Creek near Ira, Tex.	26.3	32°36'00"	101°05'38"
08119000	Bluff Creek near Ira, Tex.	42.6	32°35'29"	101°03'02"
08119500	Colorado River near Ira, Tex.	1,112	32°32'18"	101°03'12"
08120500	Deep Creek near Dunn, Tex.	188	32°34'25"	100°54'27"
08120700	Colorado River near Cuthbert, Tex.	1,531	32°28'38"	100°56'58"
08121000	Colorado River at Colorado City, Tex.	1,585	32°23'33"	100°52'42"
08121500	Morgan Creek near Westbrook, Tex.	230	32°23'42"	101°01'32"
08122000	Graze Creek near Westbrook, Tex.	21.7	32°35'03"	101°01'10"
08122500	Morgan Creek near Colorado City, Tex.	270	32°23'17"	100°56'59"
08123500	Champion Creek near Colorado City, Tex.	177	32°19'01"	100°49'28"
08123650	Beals Creek above Big Spring, Tex.	1,505	32°15'01"	101°29'26"
08123700	Beals Creek at Big Spring, Tex.	1,527	32°15'45"	101°26'30"
08123720	Beals Creek near Coahoma, Tex.	1,569	32°14'56"	101°21'42"
08123800	Beals Creek near Westbrook, Tex.	1,988	32°11'57"	101°00'49"
08123850	Colorado River above Silver, Tex.	4,650	32°03'13"	100°45'42"
08123900	Colorado River near Silver, Tex.	4,737	32°01'10"	100°44'08"
08124000	Colorado River at Robert Lee, Tex.	5,047	31°53'07"	100°28'49"
08126380	Colorado River near Ballinger, Tex.	6,098	31°42'55"	100°01'34"
08126500	Colorado River at Ballinger, Tex.	6,160	31°43'58"	99°57'13"
08127000	Elm Creek at Ballinger, Tex.	450	31°44'57"	99°56'51"
08128000	South Concho River at Christoval, Tex.	354	31°11'13"	100°30'06"
08128400	Middle Concho River above Tankersley, Tex.	1,116	31°25'38"	100°42'39"
08128500	Middle Concho River near Tankersley, Tex.	1,685	31°22'35"	100°36'50"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08129300	Spring Creek above Tankersley, Tex.	405	31°19'48"	100°38'24"
08130500	Dove Creek at Knickerbocker, Tex.	218	31°16'26"	100°37'50"
08130700	Spring Creek above Twin Buttes Reservoir near San Angelo, Tex.	657	31°19'51"	100°36'02"
08131000	Spring Creek near Tankersley, Tex.	671	31°21'30"	100°32'05"
08131400	Pecan Creek near San Angelo, Tex.	81.1	31°18'32"	100°26'44"
08132500	South Concho River at San Angelo, Tex.	2,688	31°26'45"	100°25'30"
08133250	North Concho River above Sterling City, Tex.	201	31°53'50"	101°06'17"
08133500	North Concho River at Sterling City, Tex.	568	31°49'48"	100°59'36"
08133900	Chalk Creek near Water Valley, Tex.	26.9	31°38'47"	100°41'25"
08134000	North Concho River near Carlsbad, Tex.	1,191	31°35'33"	100°38'12"
08134230	Grape Creek near Grape Creek, Tex.	109	31°34'30"	100°35'07"
08134250	North Concho River near Grape Creek, Tex.	1,325	31°32'33"	100°33'17"
08135000	North Concho River at San Angelo, Tex.	1,450	31°27'57"	100°26'51"
08136000	Concho River at San Angelo, Tex.	4,411	31°27'16"	100°24'37"
08136500	Concho River at Paint Rock, Tex.	5,443	31°30'57"	99°55'09"
08136700	Colorado River near Stacy, Tex.	12,802	31°29'37"	99°34'25"
08138000	Colorado River at Winchell, Tex.	13,788	31°28'04"	99°09'43"
08139500	Deep Creek near Mercury, Tex.	43.9	31°24'08"	99°07'17"
08140500	Dry Prong Deep Creek near Mercury, Tex.	8.31	31°24'09"	99°08'13"
08140700	Pecan Bayou near Cross Cut, Tex.	532	31°58'21"	99°07'48"
08140800	Jim Ned Creek near Coleman, Tex.	333	31°58'59"	99°24'52"
08141500	Hords Creek near Valera, Tex.	54.2	31°50'03"	99°32'04"
08142000	Hords Creek near Coleman, Tex.	107	31°50'50"	99°25'25"
08143500	Pecan Bayou at Brownwood, Tex.	1,660	31°43'54"	98°58'25"
08143600	Pecan Bayou near Mullin, Tex.	2,073	31°31'02"	98°44'25"
08144500	San Saba River at Menard, Tex.	1,128	30°55'08"	99°47'07"
08144600	San Saba River near Brady, Tex.	1,626	31°00'14"	99°16'07"
08144800	Brady Creek near Eden, Tex.	101	31°11'03"	99°50'27"
08145000	Brady Creek at Brady, Tex.	588	31°08'17"	99°20'05"
08146000	San Saba River at San Saba, Tex.	3,039	31°12'47"	98°43'09"
08147000	Colorado River near San Saba, Tex.	19,819	31°13'04"	98°33'51"
08148500	North Llano River near Junction, Tex.	914	30°31'02"	99°48'21"
08150000	Llano River near Junction, Tex.	1,849	30°30'15"	99°44'03"
08150700	Llano River near Mason, Tex.	3,242	30°39'38"	99°06'32"
08150800	Beaver Creek near Mason, Tex.	215	30°38'36"	99°05'44"
08151000	Llano River near Castell, Tex.	3,747	30°43'00"	98°53'00"
08151500	Llano River at Llano, Tex.	4,192	30°45'04"	98°40'10"
08152000	Sandy Creek near Kingsland, Tex.	346	30°33'27"	98°28'19"
08152900	Pedernales River near Fredericksburg, Tex.	369	30°13'13"	98°52'10"
08153000	Pedernales River at Stonewall, Tex.	647	30°15'00"	98°40'00"
08153500	Pedernales River near Johnson City, Tex.	901	30°17'30"	98°23'57"
08154000	Pedernales River near Spicewood, Tex.	1,294	30°25'15"	98°04'50"
08154510	Colorado River below Mansfield Dam, Austin, Tex.	27,352	30°23'30"	97°54'28"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08154700	Bull Creek at Loop 360 near Austin, Tex.	22.3	30°22'19"	97°47'04"
08155200	Barton Creek at State Highway 71 near Oak Hill, Tex.	89.7	30°17'46"	97°55'31"
08155240	Barton Creek at Lost Creek Boulevard near Austin, Tex.	107	30°16'26"	97°50'40"
08155260	Barton Creek near Camp Craft Road near Austin, Tex.	109	30°16'12"	97°49'43"
08155300	Barton Creek at Loop 360, Austin, Tex.	116	30°14'40"	97°48'07"
08155400	Barton Creek above Barton Springs at Austin, Tex.	125	30°15'48"	97°46'19"
08156700	Shoal Creek at Northwest Park at Austin, Tex.	6.52	30°20'50"	97°44'41"
08156800	Shoal Creek at West 12th Street, Austin, Tex.	12.3	30°16'35"	97°45'00"
08157000	Waller Creek at 38th Street, Austin, Tex.	2.31	30°17'49"	97°43'36"
08157500	Waller Creek at 23rd Street, Austin, Tex.	4.13	30°17'08"	97°44'01"
08157600	East Bouldin Creek at South 1st Street, Austin, Tex.	2.4	30°15'07"	97°45'14"
08157700	Blunn Creek near Little Stacy Park, Austin, Tex.	1.2	30°14'50"	97°44'37"
08158000	Colorado River at Austin, Tex.	27,606	30°14'40"	97°41'39"
08158050	Boggy Creek at U.S. Highway 183, Austin, Tex.	13.1	30°15'47"	97°40'20"
08158600	Walnut Creek at Webberville Road, Austin, Tex.	51.3	30°16'59"	97°39'17"
08158700	Onion Creek near Driftwood, Tex.	124	30°04'58"	98°00'27"
08158800	Onion Creek at Buda, Tex.	166	30°05'09"	97°50'52"
08158810	Bear Creek below Farm to Market Road 1826 near Driftwood, Tex.	12.2	30°09'19"	97°56'23"
08158840	Slaughter Creek at Farm to Market Road 1826 near Austin, Tex.	8.24	30°12'32"	97°54'11"
08158920	Williamson Creek at Oak Hill, Tex.	6.3	30°14'06"	97°51'36"
08158922	Williamson Creek at Brush Country Boulevard, Oak Hill, Tex.	6.79	30°13'34"	97°50'28"
08158930	Williamson Creek at Manchaca Road, Austin, Tex.	19	30°13'16"	97°47'36"
08158970	Williamson Creek at Jimmy Clay Road, Austin, Tex.	27.6	30°11'21"	97°43'56"
08159000	Onion Creek at U.S. Highway 183, Austin, Tex.	321	30°10'40"	97°41'18"
08159150	Wilbarger Creek near Pflugerville, Tex.	4.61	30°27'16"	97°36'02"
08159165	Big Sandy Creek near McDade, Tex.	38.7	30°18'18"	97°17'48"
08159170	Big Sandy Creek near Elgin, Tex.	63.8	30°15'54"	97°19'39"
08159200	Colorado River at Bastrop, Tex.	28,576	30°06'16"	97°19'09"
08159500	Colorado River at Smithville, Tex.	28,968	30°00'45"	97°09'42"
08160400	Colorado River above La Grange, Tex.	29,471	29°54'44"	96°54'13"
08160500	Colorado River at La Grange, Tex.	27,550	29°53'45"	96°52'15"
08160700	Colorado River above Columbus, Tex.	29,910	29°43'09"	96°34'16"
08160800	Redgate Creek near Columbus, Tex.	17.3	29°47'56"	96°31'55"
08161000	Colorado River at Columbus, Tex.	30,237	29°42'22"	96°32'12"
08162000	Colorado River at Wharton, Tex.	30,600	29°18'32"	96°06'13"
08162500	Colorado River near Bay City, Tex.	30,837	28°58'26"	96°00'44"
08162600	Tres Palacios River near Midfield, Tex.	145	28°55'40"	96°10'15"
08164000	Lavaca River near Edna, Tex.	817	28°57'35"	96°41'10"
08164300	Navidad River near Hallettsville, Tex.	332	29°28'00"	96°48'45"
08164350	Navidad River near Speaks, Tex.	437	29°19'18"	96°42'32"
08164370	Navidad River at Morales, Tex.	549	29°08'07"	96°44'39"
08164390	Navidad River at Strane Park near Edna, Tex.	579	29°03'55"	96°40'26"
08164450	Sandy Creek near Ganado, Tex.	289	29°09'36"	96°32'46"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08164500	Navidad River near Ganado, Tex.	1,062	29°01'32"	96°33'08"
08164503	West Mustang Creek near Ganado, Tex.	178	29°04'17"	96°28'01"
08164504	East Mustang Creek near Louise, Tex.	90.8	29°04'14"	96°25'01"
08164600	Garcitas Creek near Inez, Tex.	91.7	28°53'28"	96°49'08"
08164800	Placedo Creek near Placedo, Tex.	68.3	28°43'30"	96°46'07"
08165300	North Fork Guadalupe River near Hunt, Tex.	169	30°03'50"	99°23'12"
08165500	Guadalupe River at Hunt, Tex.	288	30°04'11"	99°19'17"
08166000	Johnson Creek near Ingram, Tex.	114	30°06'00"	99°16'58"
08166140	Guadalupe River above Bear Creek at Kerrville, Tex.	494	30°04'10"	99°11'42"
08166200	Guadalupe River at Kerrville, Tex.	510	30°03'11"	99°09'47"
08166500	Guadalupe River near Comfort, Tex.	762	29°56'57"	98°53'32"
08167000	Guadalupe River at Comfort, Tex.	839	29°58'10"	98°53'33"
08167500	Guadalupe River near Spring Branch, Tex.	1,315	29°51'37"	98°23'00"
08167600	Rebecca Creek near Spring Branch, Tex.	10.9	29°55'06"	98°22'10"
08167800	Guadalupe River at Sattler, Tex.	1,436	29°51'32"	98°10'47"
08168500	Guadalupe River above Comal River at New Braunfels, Tex.	1,518	29°42'53"	98°06'35"
08169000	Comal River at New Braunfels, Tex.	130	29°42'21"	98°07'20"
08169500	Guadalupe River at New Braunfels, Tex.	1,652	29°41'52"	98°06'23"
08170500	San Marcos River at San Marcos, Tex.	48.9	29°53'20"	97°56'02"
08171000	Blanco River at Wimberley, Tex.	355	29°59'39"	98°05'19"
08171300	Blanco River near Kyle, Tex.	412	29°58'45"	97°54'35"
08172000	San Marcos River at Luling, Tex.	838	29°39'58"	97°39'02"
08172400	Plum Creek at Lockhart, Tex.	112	29°55'22"	97°40'44"
08172500	Plum Creek near Lockhart, Tex.	189	29°49'17"	97°35'02"
08173000	Plum Creek near Luling, Tex.	309	29°41'58"	97°36'12"
08173500	San Marcos River at Ottine, Tex.	1,249	29°35'36"	97°35'22"
08173900	Guadalupe River at Gonzales, Tex.	3,490	29°29'03"	97°27'00"
08174600	Peach Creek below Dilworth, Tex.	460	29°28'26"	97°18'59"
08175000	Sandies Creek near Westhoff, Tex.	549	29°12'54"	97°26'57"
08175800	Guadalupe River at Cuero, Tex.	4,934	29°05'25"	97°19'46"
08176000	Guadalupe River below Cuero, Tex.	4,923	29°03'05"	97°15'52"
08176500	Guadalupe River at Victoria, Tex.	5,198	28°47'34"	97°00'46"
08176550	Fifteenmile Creek near Weser, Tex.	167	28°53'51"	97°21'17"
08176900	Coleto Creek at Arnold Road near Schroeder, Tex.	357	28°51'41"	97°13'34"
08176990	Coleto Creek Reservoir Inflow (Guadalupe Diversion) near Schroeder, Tex.	357	28°50'21"	97°11'20"
08177000	Coleto Creek near Schroeder, Tex.	369	28°49'53"	97°11'10"
08177300	Perdido Creek at Farm to Market Road 622 near Fannin, Tex.	28	28°45'05"	97°19'01"
08177500	Coleto Creek near Victoria, Tex.	514	28°43'51"	97°08'18"
08177700	Olmos Creek at Dresden Drive, San Antonio, Tex.	21.2	29°29'56"	98°30'36"
08177860	San Antonio River at Woodlawn Ave, San Antonio, Tex.	36.4	29°27'04"	98°28'42"
08178000	San Antonio River at San Antonio, Tex.	41.8	29°24'34"	98°29'41"
08178050	San Antonio River at Mitchell Street, San Antonio, Tex.	42.4	29°23'34"	98°29'40"
08178500	San Pedro Creek at Furnish Street, San Antonio, Tex.	2.64	29°24'22"	98°30'38"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08178565	San Antonio River at Loop 410 at San Antonio, Tex.	125	29°19'19"	98°27'00"
08178585	Salado Creek at Wilderness Road at San Antonio, Tex.	23	29°37'50"	98°33'55"
08178700	Salado Creek at Loop 410 at San Antonio, Tex.	137	29°30'57"	98°25'51"
08178800	Salado Creek at Loop 13 at San Antonio, Tex.	189	29°21'25"	98°24'45"
08178880	Medina River at Bandera, Tex.	328	29°43'25"	99°04'11"
08179000	Medina River near Pipe Creek, Tex.	474	29°40'31"	98°58'33"
08179100	Red Bluff Creek near Pipe Creek, Tex.	56.3	29°40'51"	98°57'19"
08179520	Medina River below Medina Lake near San Antonio, Tex.	635	29°32'02"	98°56'06"
08180500	Medina River near Riomedina, Tex.	650	29°29'53"	98°54'16"
08180640	Medina River at La Coste, Tex.	805	29°19'26"	98°48'46"
08180700	Medina River near Macdona, Tex.	885	29°20'05"	98°41'22"
08180750	Medio Creek at Pearsall Road at San Antonio, Tex.	47.9	29°19'40"	98°38'19"
08180800	Medina River near Somerset, Tex.	967	29°15'43"	98°34'52"
08181400	Helotes Creek at Helotes, Tex.	15	29°34'42"	98°41'29"
08181410	Ranch Creek near Helotes, Tex.	.39	29°36'06"	98°43'26"
08181450	Leon Creek Tributary at Kelly Air Force Base, Tex.	1.19	29°23'12"	98°36'00"
08181480	Leon Creek at Interstate Highway 35 at San Antonio, Tex.	219	29°19'47"	98°35'02"
08181500	Medina River at San Antonio, Tex.	1,317	29°15'50"	98°29'26"
08181800	San Antonio River near Elmendorf, Tex.	1,743	29°13'19"	98°21'20"
08182500	Calaveras Creek near Elemendorf, Tex.	77.2	29°15'38"	98°17'34"
08183000	San Antonio River at Calaveras, Tex.	1,786	29°12'54"	98°15'39"
08183500	San Antonio River near Falls City, Tex.	2,113	28°57'05"	98°03'50"
08183850	Cibolo Creek at Interstate Highway 10 above Boerne, Tex.	29	29°48'52"	98°45'12"
08183900	Cibolo Creek near Boerne, Tex.	68.4	29°46'26"	98°41'50"
08184000	Cibolo Creek near Bulverde, Tex.	198	29°43'33"	98°25'37"
08184500	Cibolo Creek above Bracken, Tex.	250	29°40'30"	98°23'00"
08185000	Cibolo Creek at Selma, Tex.	274	29°35'38"	98°18'39"
08185500	Cibolo Creek at Sutherland Springs, Tex.	665	29°16'47"	98°03'10"
08186000	Cibolo Creek near Falls City, Tex.	827	29°00'50"	97°55'48"
08186500	Ecleto Creek near Runge, Tex.	239	28°55'12"	97°46'19"
08187500	Escondido Creek at Kenedy, Tex.	72.4	28°49'11"	97°51'32"
08188500	San Antonio River at Goliad, Tex.	3,921	28°38'58"	97°23'04"
08189200	Copano Creek near Refugio, Tex.	87.8	28°18'12"	97°06'44"
08189300	Medio Creek near Beeville, Tex.	204	28°28'58"	97°39'23"
08189500	Mission River at Refugio, Tex.	690	28°17'30"	97°16'44"
08189700	Aransas River near Skidmore, Tex.	247	28°16'56"	97°37'14"
08189800	Chiltipin Creek at Sinton, Tex.	128	28°02'48"	97°30'13"
08190000	Nueces River at Laguna, Tex.	737	29°25'42"	99°59'49"
08190500	West Nueces River near Brackettville, Tex.	694	29°28'21"	100°14'10"
08191500	Nueces River near Uvalde, Tex.	1,833	29°11'44"	99°53'45"
08192000	Nueces River below Uvalde, Tex.	1,861	29°07'25"	99°53'40"
08192500	Nueces River near Cinonia, Tex.	2,102	28°47'00"	99°50'00"
08193000	Nueces River near Asherton, Tex.	4,082	28°30'00"	99°40'54"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08194000	Nueces River at Cotulla, Tex.	5,171	28°25'34"	99°14'23"
08194200	San Casimiro Creek near Freer, Tex.	469	27°57'53"	98°58'00"
08194500	Nueces River near Tilden, Tex.	8,093	28°18'31"	98°33'25"
08194600	Nueces River at Simmons, Tex.	8,561	28°25'16"	98°17'03"
08195000	Frio River at Concan, Tex.	389	29°29'18"	99°42'16"
08196000	Dry Frio River near Reagan Wells, Tex.	126	29°30'16"	99°46'52"
08196500	Dry Frio River at Knippa, Tex.	179	29°17'30"	99°39'30"
08197500	Frio River below Dry Frio River near Uvalde, Tex.	631	29°14'44"	99°40'27"
08198000	Sabinal River near Sabinal, Tex.	206	29°29'27"	99°29'33"
08198500	Sabinal River at Sabinal, Tex.	241	29°18'05"	99°28'46"
08199700	Frio River near Frio Town, Tex.	1,460	29°05'08"	99°24'30"
08200000	Hondo Creek near Tarpley, Tex.	95.6	29°34'10"	99°14'47"
08200500	Hondo Creek near Hondo, Tex.	132	29°27'05"	99°11'07"
08200700	Hondo Creek at King Waterhole near Hondo, Tex.	149	29°23'26"	99°09'04"
08201500	Seco Creek at Miller Ranch near Utopia, Tex.	45	29°34'23"	99°24'10"
08202000	Seco Creek near Utopia, Tex.	53.2	29°33'01"	99°24'22"
08202500	Seco Creek near D'Hanis, Tex.	87.4	29°29'20"	99°23'16"
08202700	Seco Creek at Rowe Ranch near D'Hanis, Tex.	168	29°22'14"	99°17'15"
08204005	Leona River near Uvalde, Tex.	132	29°09'15"	99°44'35"
08204500	Leona River near Divot, Tex.	565	28°47'34"	99°14'27"
08205500	Frio River near Derby, Tex.	3,429	28°44'11"	99°08'40"
08206600	Frio River at Tilden, Tex.	4,493	28°28'02"	98°32'50"
08206700	San Miguel Creek near Tilden, Tex.	783	28°35'14"	98°32'44"
08206910	Choke Canyon Reservoir OWC near Three Rivers, Tex.	5,490	28°29'09"	98°14'29"
08207000	Frio River at Calliham, Tex.	5,491	28°29'31"	98°20'47"
08207500	Atascosa River near McCoy, Tex.	530	28°51'53"	98°20'17"
08208000	Atascosa River at Whitsett, Tex.	1171	28°37'19"	98°16'52"
08210000	Nueces River near Three Rivers, Tex.	15,427	28°25'38"	98°10'40"
08210300	Ramirena Creek near George West, Tex.	84.4	28°08'30"	98°06'11"
08210400	Lagarto Creek near George West, Tex.	155	28°03'34"	98°05'48"
08211000	Nueces River near Mathis, Tex.	16,660	28°02'17"	97°51'36"
08211200	Nueces River at Bluntzer, Tex.	16,772	27°56'15"	97°46'32"
08211500	Nueces River at Calallen, Tex.	16,920	27°52'58"	97°37'30"
08211520	Oso Creek at Corpus Christi, Tex.	90.3	27°42'40"	97°30'06"
08211800	San Diego Creek at Alice, Tex.	319	27°45'59"	98°04'31"
08211900	San Fernando Creek at Alice, Tex.	507	27°46'20"	98°02'00"
08212000	San Fernando Creek near Alice, Tex.	518	27°43'30"	97°59'15"
08212400	Los Olmos Creek near Falfurrias, Tex.	476	27°15'51"	98°08'08"
08365600	McKelligon Canyon at El Paso, Tex.	2.3	31°49'20"	106°28'09"
08365800	Government Ditch at El Paso, Tex.	6.4	31°47'02"	106°26'41"
08373200	Cibolo Creek near Presidio, Tex.	276	29°34'50"	104°21'55"
08376300	Sanderson Creek at Sanderson, Tex.	195	30°07'42"	102°23'04"
08411500	Salt Screwbean Draw near Orla, Tex.	464	31°52'40"	103°56'50"

Table 1. U.S. Geological Survey streamflow-gaging stations in Texas with at least 1 year of daily mean streamflow data—Continued.

USGS station no.	USGS station name	Contributing drainage area (mi^2)	Latitude	Longitude
08412500	Pecos River near Orla, Tex.	21,210	31°52'21"	103°49'52"
08414000	Pecos River near Mentone, Tex.	21,650	31°40'07"	103°37'34"
08416500	Pecos River above Barstow (Barstow Canal), Tex.	21,800	31°35'00"	103°30'00"
08420500	Pecos River at Pecos, Tex.	22,100	31°26'11"	103°28'01"
08424500	Madera Canyon near Toyahvale, Tex.	53.8	30°52'04"	103°58'09"
08431000	Toyah Creek near Pecos, Tex.	1,024	31°16'50"	103°27'31"
08431500	Salt Draw near Pecos, Tex.	1,882	31°18'54"	103°29'07"
08431700	Limpia Creek above Fort Davis, Tex.	52.4	30°36'48"	104°00'04"
08431800	Limpia Creek below Fort Davis, Tex.	227	30°40'52"	103°47'30"
08432000	Limpia Creek near Fort Davis, Tex.	303	30°47'00"	103°45'00"
08433000	Barrilla Draw near Saragosa, Tex.	612	30°57'28"	103°27'33"
08434000	Toyah Creek below Toyah Lake near Pecos, Tex.	3709	31°21'00"	103°24'00"
08435500	Pecos River below Barstow, Tex.	25,980	31°25'00"	103°15'00"
08435600	Toronto Creek near Alpine, Tex.	27.9	30°21'30"	103°42'48"
08435620	Alpine Creek at Alpine, Tex.	18.1	30°21'06"	103°40'00"
08435660	Moss Creek near Alpine, Tex.	11.3	30°20'10"	103°38'24"
08435700	Sunny Glen Canyon near Alpine, Tex.	29.7	30°22'52"	103°44'08"
08435800	Coyanosa Draw near Fort Stockton, Tex.	1,182	31°02'27"	103°08'15"
08438100	Pecos River near Grandfalls, Tex.	27,810	31°19'18"	102°53'33"
08441500	Pecos River below Grandfalls, Tex.	27,820	31°17'00"	102°44'32"
08446500	Pecos River near Girvin, Tex.	29,560	31°06'47"	102°25'02"
08447000	Pecos River near Sheffield, Tex.	31,600	30°39'34"	101°46'11"
08447020	Independence Creek near Sheffield, Tex.	763	30°27'07"	101°43'58"
08449000	Devils River near Juno, Tex.	2,730	29°57'48"	101°08'42"
08455000	Pinto Creek near Del Rio, Tex.	249	29°08'45"	100°43'05"

Appendix 1—Summary of the Drainage-Area Ratio Method for Daily Mean Streamflow in Texas

Blank Page

This appendix provides a summary of the drainage-area ratio method. We summarize the method, demonstrate application for selected U.S. Geological Survey (USGS) streamflow-gaging stations, and demonstrate application for selected partial-record sites provided by the Texas Commission on Environmental Quality (TCEQ). The method is summarized below; additional limitations of the method are described in section “Limitations of the Drainage-Area Ratio Method.”

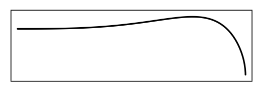
1. DRAINAGE-AREA RATIO METHOD EQUATION—The drainage-area ratio method, when applied in accordance with the conclusions in the report, is represented by

$$\frac{Q_2}{Q_1} = \left(\frac{A_2}{A_1}\right)^{\phi(F)},$$

   where Q_1 and Q_2 are streamflow (concurrent in time), in cubic length per time, for site 1 (gaged) and 2 (ungaged); A_1 and A_2 are drainage area, in square length, for site 1 and 2; and $\phi(F)$ is an exponent that is a function of cumulative streamflow percentile (F = streamflow percentile/100) of site 1. The method explicitly assumes that the daily mean streamflow percentile for site 2 equals that of site 1 for a given date. For the discussion in this appendix, gaged site 1 is always the USGS station that provides the continuous streamflow data for estimation of the streamflow for ungaged site 2. This convention holds for circumstances in which site 2 is another USGS station.

2. METHOD EXPONENT—The exponent ϕ of the method is a function of streamflow percentile $F/100$. For this appendix the authors have fit an equation to ordinates listed in table 5 for convenient support of automated computations involving the method. The equation for this “variable ϕ” [$\phi_{\mathrm{var}}(F)$] follows, and the shape for $\phi_{\mathrm{var}}(F_{0\to1})$ is in the small graphic below

$$\phi_{\mathrm{var}}(F) = \frac{741.66 + 2827.7\left(1 - \left(\frac{1-F^{3.0181}}{3.0181}\right)^{1.8447}\right)}{220.55 + 4991.4\left(1 - \left(\frac{1-F^{9.8835}}{9.8835}\right)^{0.49762}\right)}\,.$$



   It can be shown that this equation provides a close representation of the ordinates listed in table 5 and the smoothed relation between ϕ and streamflow percentile in figure 5. The limits of the $\phi(F)$ are $\phi_{\mathrm{var}}(0) = 0.8853$ and $\phi_{\mathrm{var}}(1) = 0.6848$.

3. CANDIDATE STATIONS—The drainage-area ratio method requires selection of one or more USGS streamflow-gaging stations to provide streamflow estimation for ungaged site 2. The applicability of the method depends on the hydrologic similarity between the two sites. For example, similar drainage area, slope, climate, recent weather patterns, and hydrologic response of the watersheds increase the likelihood of reliably estimating discharge at an ungaged site using the drainage-area ratio method. The judgment that two watersheds are hydrologically similar is not straightforward. Two recent reports by Asquith and others (2007a,b; `http://pubs.usgs.gov/ds/2007/247` and `http://pubs.usgs.gov/ds/2007/248`) provide a comprehensive summary of daily mean streamflow statistics in Texas. These reports can be used to guide or support an analyst’s choice of streamflow-gaging stations to use in the drainage-area ratio method to estimate streamflow at ungaged site 2. Two general restrictions or criteria for candidate stations are identified in the report.

   (a) RESTRICTION ON DRAINAGE AREA—To increase the reliability of statistical development of the method, the minimum absolute value of the logarithm of the drainage-area ratio was 0.25-log cycle. For application, however, the minimum drainage-area ratio should not be used when the method is used in practice. Specifically, similar or exactly equal watershed areas for nearby stations are expected to be most appropriate. For example, if the two drainage areas are equal then the drainage-area ratio method equates streamflow for the ungaged site to streamflow for the gaging station. However, an upper limit on the drainage-area ratio is suggested:

$$\left|\log_{10}\left(\frac{A_2}{A_1}\right)\right| \le 1.5 \text{ or } \frac{A_2}{A_1} < 31.6 \mid 0.0316 \text{ depending on whether } A_2 > A_1 \mid A_2 < A_1.$$

   (b) SEPARATION DISTANCE—To increase the hydrologic similarity of two watersheds, a maximum of 100-mile separation distance between stations was identified. Therefore, it is suggested that users of the method limit the distance between the streamflow-gaging station (site 1) and ungaged site 2 to less than about 100 miles. Analysts might have additional information regarding watershed similarity, and therefore relaxation of the separation-distance limit might be necessary.

Demonstration of the Drainage-Area Ratio Method—Estimating Streamflow for Selected USGS Streamflow-Gaging Stations

To provide a brief demonstration of the drainage-area ratio method, five pairs of selected USGS streamflow-gaging stations were selected. These pairs represent various geographic and hydrologic characteristics of Texas watersheds. The stations are listed in table 1.1, and each evaluation is shown in figures 1.1–1.10.

The drainage-area ratio method can be applied from one station to another and the reverse; therefore, the table lists the stations as ensemble pairings. The right arrow in the table indicates that the station on the left was used to estimate the daily mean streamflow for the station on the right. For each application of the method the streamflow percentiles for the left station were computed. Next, the temporal intersection of the common record of the two stations was determined. From this intersected record, values of observed ϕ were computed and are shown in figures 1.1–1.10. A LOWESS smooth line was computed from the data points and is shown in the figures. For computational purposes the smooth line represents a generalized ϕ for the two stations. Superimposed on each figure are lines that depict $\phi = 1$ and $\phi_{\mathrm{var}}(F)$. Sequences of residuals (errors) between the LOWESS smooth line and each of the two ϕ lines were computed for each streamflow percentile of the data. The mean for each sequence subsequently was determined; two numbers result. The ratio of these means represents the relative performance of the $\phi = 1$ and $\phi_{\mathrm{var}}(F)$ estimation methods. The ratios are listed in table 1.1.

One-half the ratios listed in the table are greater than 1, and one-half are less than 1, which indicates that either $\phi = 1$ or $\phi_{\mathrm{var}}(F)$ can be a better approximation of observed ϕ. However, the data for these stations show that either method of ϕ estimation might not be a reliable model of streamflow estimation for any particular site pairing. The figures show tremendous and complex variability in observed ϕ. The figures also show that there is an inherent dependency of ϕ on streamflow probability, a feature of the data that figure 5 and $\phi_{\mathrm{var}}(F)$ seek to represent.

Table 1.1. Summary of comparison of drainage-area ratio method using $\phi = 1$ and $\phi_{\mathrm{var}}(F)$ for selected USGS streamflow-gaging stations.

Station used to estimate (→) streamflow at other station	Ratio of mean error of $\phi = 1$ to mean error of $\phi_{\mathrm{var}}(F)$
07299670 → 07301410	1.04
07301410 → 07299670	.90
08019000 → 08019500	1.06
08019500 → 08019000	1.07
08037050 → 08039100	.81
08039100 → 08037050	.80
08167000 → 08171000	1.31
08171000 → 08167000	1.35
08198000 → 08200000	.68
08200000 → 08198000	.77

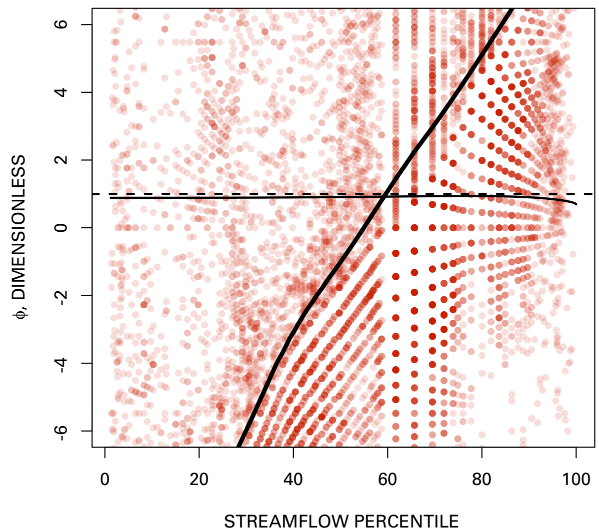


Figure 1.1. Comparison of $\phi(F)$ values using station 07299670 to estimate daily mean streamflow at station 07301410.

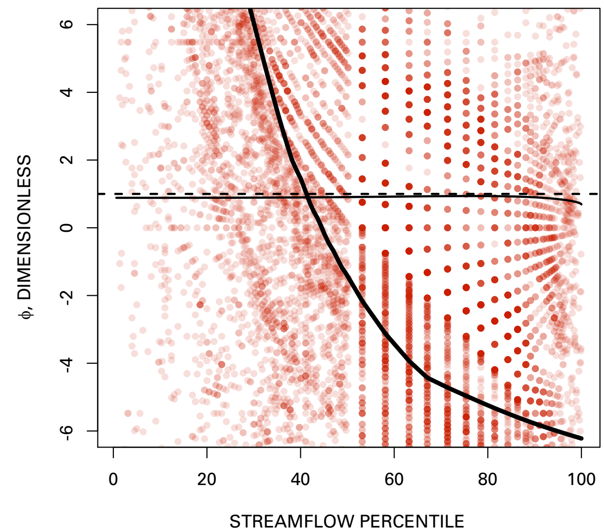


Figure 1.2. Comparison of $\phi(F)$ values using station 07301410 to estimate daily mean streamflow at station 07299670.

EXPLANATION (figs. 1.1–1.10)

LOWESS smooth

$\phi = 1$

$\phi_{\mathrm{var}}(F)$

Observed ϕ

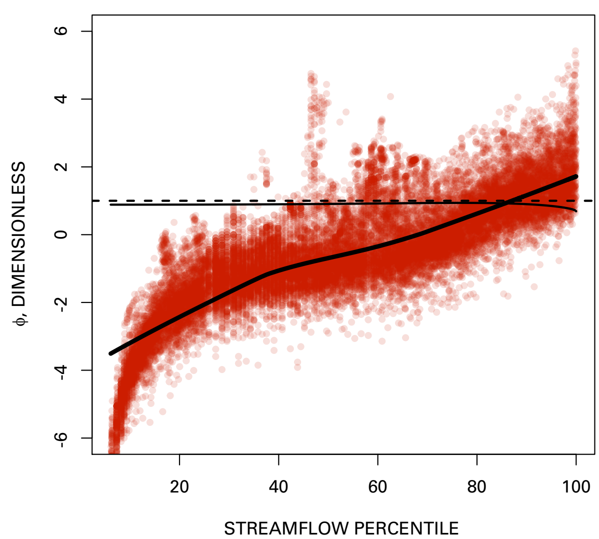


Figure 1.3. Comparison of $\phi(F)$ values using station 08019000 to estimate daily mean streamflow at station 08019500.

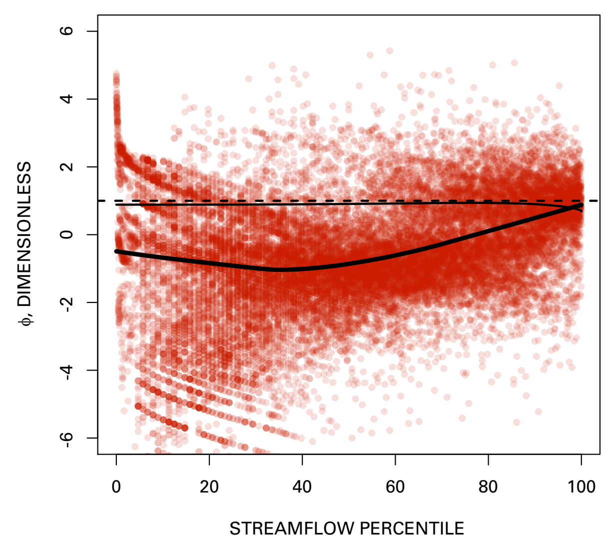


Figure 1.4. Comparison of $\phi(F)$ values using station 08019500 to estimate daily mean streamflow at station 08019000.

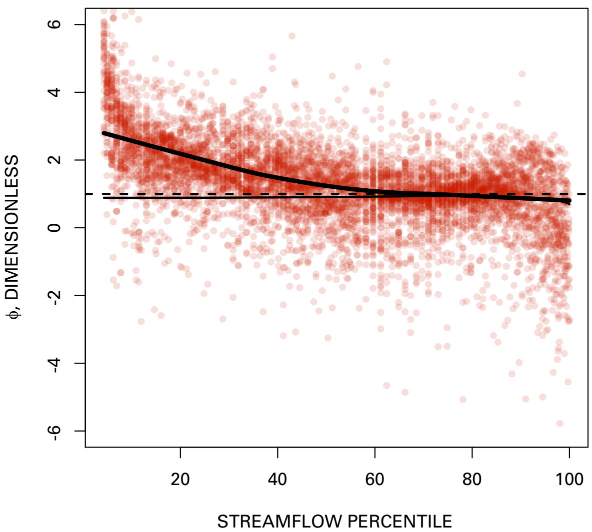


Figure 1.5. Comparison of $\phi(F)$ values using station 08037050 to estimate daily mean streamflow at station 08039100.

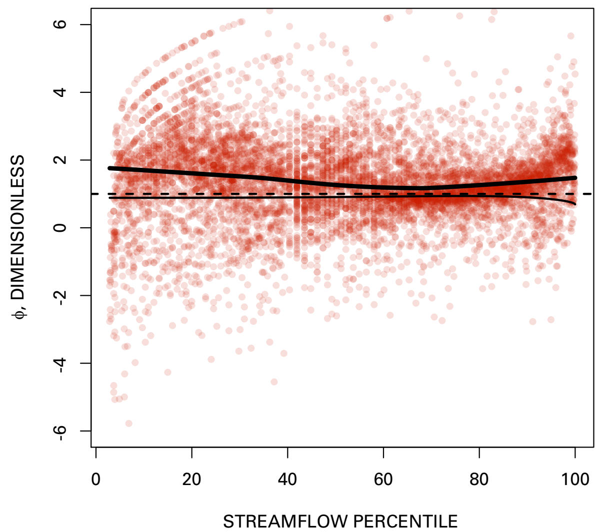


Figure 1.6. Comparison of $\phi(F)$ values using station 08039100 to estimate daily mean streamflow at station 08037050.

EXPLANATION (figs. 1.1–1.10)

LOWESS smooth

$\phi = 1$

$\phi_{\text{var}}(F)$

Observed ϕ

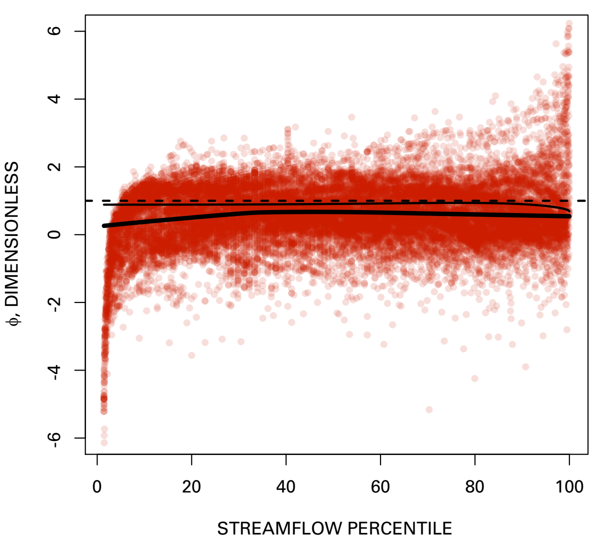


Figure 1.7. Comparison of $\phi(F)$ values using station 08167000 to estimate daily mean streamflow at station 08171000.

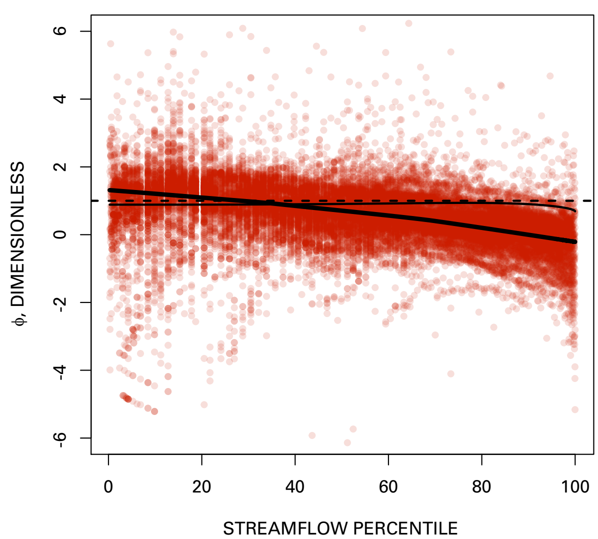


Figure 1.8. Comparison of $\phi(F)$ values using station 08171000 to estimate daily mean streamflow at station 08167000.

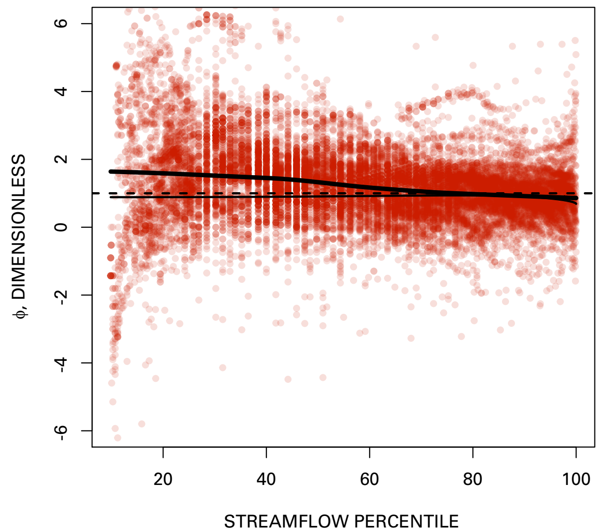


Figure 1.9. Comparison of $\phi(F)$ values using station 08198000 to estimate daily mean streamflow at station 08200000.

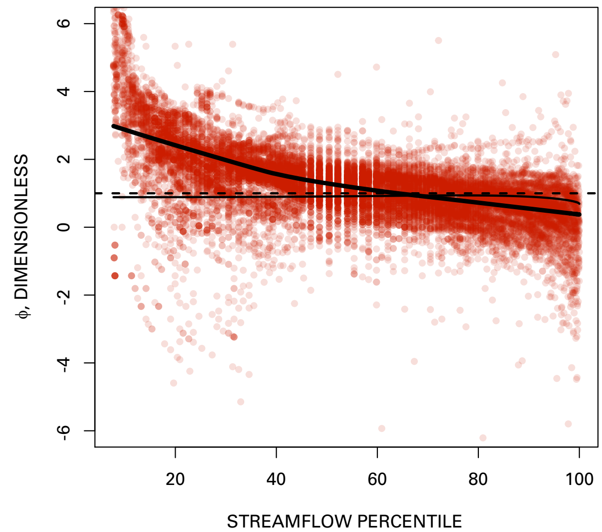


Figure 1.10. Comparison of $\phi(F)$ values using station 08200000 to estimate daily mean streamflow at station 08198000.

EXPLANATION (figs. 1.1–1.10)

LOWESS smooth

$\phi = 1$

$\phi_{\text{var}}(F)$

Observed ϕ

Demonstration of the Drainage-Area Ratio Method—Estimating Streamflow for Selected Monitoring Sites of the Texas Commission on Environmental Quality

Nine (ungaged) sites, which periodically are monitored by TCEQ, were identified by TCEQ for inclusion in this demonstration of the drainage-area ratio method. The site numbers, names, and drainage areas are listed in table 1.2. The site number and site name are specific to TCEQ. The drainage areas were determined using a 30-meter digital elevation model. The table also lists the number of flow values and USGS stations used for the computations. The number of flow values represents the number of concurrent nonzero flow days at the comparison USGS station. The USGS station number represents the station used in the drainage-area ratio method to estimate streamflow at the TCEQ station. For this demonstration both $\phi_{\text{var}}(F)$ and $\phi = 1$ were considered.

A residual ε is defined as the number of $\log_{10}$ cycles between streamflow measured by TCEQ and concurrent daily mean streamflow of the indicated USGS station, specifically $\varepsilon = \log_{10}(Q_{\text{TCEQ}}/Q_{\text{USGS}})$, where Q represents the streamflow for the respective agency. The quantity $\varepsilon[\phi_{\text{var}}(F)]$ represents the mean $\log_{10}$ residual of streamflow with the $\pm$ indicating the standard deviation. Similarly, $\varepsilon[\phi = 1]$ represents the mean $\log_{10}$ residual of streamflow with the $\pm$ indicating the standard deviation. The USGS stations were selected on the basis of regional proximity, hydrologic similarity with the site, and the other criteria identified for application of the drainage-area ratio method. For several of the TCEQ sites, those with less than about four USGS stations shown, too few residuals could be computed because of zero flow values at some USGS stations. Zero streamflow is incompatible with the drainagea-area ratio method. These stations were not used to compute summary statistics of the residuals and are not listed in the table.

The mean residual statistics indicate that considerable average bias for streamflow estimation by the drainage-area ratio method is expected, and the standard deviation statistics indicate that considerable uncertainty in application of the drainage-area ratio method also exists. The residual statistics also indicate, as expected, that the estimates of site streamflow are sensitive to USGS station selection. However, the residual statistics can be interpreted. If a site has generally positive mean residuals then the site has larger-than-expected flow from a regional perspective; whereas, if a site has generally negative mean residuals then the site has smaller-than-expected flow. The residual statistics in the table indicate that neither $\phi_{\mathrm{var}}(F)$ or $\phi = 1$ are preferable. For some sites, such as 12377, $\phi = 1$ performs better; whereas, for other sites, such as 14942, $\phi_{\mathrm{var}}(F)$ performs better. Therefore, the statistics indicate that considerable ambiguity in application of the drainage-area ratio method exists.

In conclusion, we emphasize that application of the drainage-area ratio method discussed in this report is for ungaged sites lacking any streamflow data. Therefore in actual practice, it would not be known whether $\phi_{\mathrm{var}}(F)$ or $\phi = 1$ is more appropriate. However, $\phi_{\mathrm{var}}(F)$ is determined by large-scale computations of the historical USGS streamflow database in Texas. The evidence is clear that on average $\phi < 1$. For circumstances in which streamflow data actually exist, the ϕ of the drainage-area ratio could be computed specific to the ungaged site. However for those circumstances involving streamflow data at an ungaged site, alternative methods of streamflow estimation as noted in the text is preferred.

Table 1.2. Ungaged sites provided by the Texas Commission on Environmental Quality for inclusion in demonstration of the drainage-area ratio method.

[$\varepsilon[\phi_{\mathrm{var}}(F)]$ represents mean $\log_{10}$ residual of streamflow with $\pm$ indicating standard deviation. Similarly, $\varepsilon[\phi = 1]$ represents mean $\log_{10}$ residual of streamflow with $\pm$ indicating standard deviation.]

Site number	Site name	Drainage area (square miles)	Number of flow values	USGS station used for computation	$\varepsilon[\phi_{\mathrm{var}}(F)]$	$\varepsilon[\phi = 1]$
12377	Pedernales River	440	32	08150800	0.574 ± 0.663	0.544 ± 0.622
			27	08152000	0.612 ± 0.862	0.603 ± 0.680
			26	08152900	0.049 ± 0.278	0.042 ± 0.278
			32	08153500	-0.105 ± 0.512	-0.077 ± 0.515
12805	Cibolo Creek at Farm to Market Road 539	644	18	08183500	-0.343 ± 0.381	-0.297 ± 0.385
			18	08186000	0.090 ± 0.403	0.099 ± 0.404
12841	Leon Creek at Ruiz Ranch	204	12	08181400	-0.197 ± 1.178	-0.315 ± 1.204
			36	08181480	-0.050 ± 0.280	-0.047 ± 0.280
			32	08181500	-0.452 ± 0.404	-0.410 ± 0.399
13239	Devils River near Dolan Creek	2,897	11	08128000	0.053 ± 0.373	-0.028 ± 0.363
			11	08148500	0.191 ± 0.417	0.149 ± 0.414
			13	08150000	-0.194 ± 0.332	-0.211 ± 0.331
			13	08190000	-0.589 ± 0.441	-0.654 ± 0.457
			8	08447020	0.006 ± 0.425	-0.047 ± 0.431
14942	Dolan Springs at Devils River confuence	178	13	08128000	0.771 ± 0.316	0.799 ± 0.316
			13	08148500	0.866 ± 0.375	0.926 ± 0.379
			13	08150000	0.431 ± 0.366	0.510 ± 0.372
			9	08447020	0.804 ± 0.320	0.861 ± 0.326
15449	Frio River South of Sabinal	880	16	08192000	-0.827 ± 0.648	-0.796 ± 0.651
			12	08193000	-0.504 ± 0.836	-0.446 ± 0.834
			16	08198500	-0.231 ± 0.721	-0.284 ± 0.716
			10	08204005	-1.387 ± 0.503	-1.470 ± 0.517
			14	08205500	-0.218 ± 0.655	-0.163 ± 0.658
15820	San Felipe Creek at West Springs	37.4	10	08190000	0.548 ± 0.341	0.688 ± 0.330
			10	08198000	1.076 ± 1.026	1.151 ± 1.033
15821	San Felipe Creek at Blue Hole Gate	37.6	7	08190000	0.858 ± 0.361	0.994 ± 0.340
			7	08198000	1.054 ± 0.637	1.128 ± 0.640
16701	South Llano River on County Road 408	504	12	08148500	-0.518 ± 0.803	-0.492 ± 0.803
			14	08150000	-1.018 ± 0.647	-0.965 ± 0.646
			14	08150800	-0.390 ± 0.875	-0.423 ± 0.872
			14	08165300	-1.304 ± 0.630	-1.348 ± 0.633
			14	08165500	-1.346 ± 0.642	-1.369 ± 0.643
			14	08166000	-1.426 ± 0.646	-1.481 ± 0.645

Information regarding water resources in Texas is available at
http: //tx.usgs.gov/