Computer Programs for Obtaining and Analyzing Daily Mean Streamflow Data from the U.S. Geological Survey National Water Information System Web Site

Appendix 4.   Streamflow (Q) Statistics (QSTATS—Version 1.0)—A program for calculating population statistics for daily mean streamflow data retrieved from the U.S. Geological Survey National Water Information System Web Site

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Conversion Factors and Abbreviations

Multiply	By	To obtain
Area		
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]

Abbreviations

1B3	1-day 3-year biological low flow
4B3	4-day 3-year biological low flow
7Q10	7-day 10-year low flow
ADAPS	USGS Automated Data Processing System
BCF	bias correction factor
BMP(s)	best management practice(s)
CD-ROM	computer disk-read only memory
dv	daily value
dd	data descriptor
EMC	event mean concentration
FHWA	Federal Highway Administration
GNWISQ	Get National Water Information System Streamflow (Q)
KTRLine	Kendall-Theil robust line
log10	common logarithm
MkDF	Make U.S. Environmental Protection Agency DFLOW3 batch input Files
MkPP	Make plotting position file
MOVE	maintenance of variance
NWIS	National Water Information System
NWISWeb	National Water Information System Web
PC	Personal Computer
Q	Streamflow
QSTATS	Streamflow (Q) Statistics
RDB	relational database
ROS	regression-on-order statistics
SELDM	stochastic empirical loading and dilution model
SQL	structured query language
SREF	Streamflow Record Extension Facilitator
TMDL(s)	Total Maximum Daily Load(s)
USGS	U.S. Geological Survey

Appendix 4.   Streamflow (Q) Statistics (QSTATS—Version 1.0)—A program for calculating population statistics for daily mean streamflow data retrieved from the U.S. Geological Survey National Water Information System Web Site

By Gregory E. Granato

Abstract

The Microsoft Visual Basic 6.0 Streamflow (Q) Statistics (QSTATS Version 1.0) program was developed by the U.S. Geological Survey (USGS) in cooperation with the Federal Highway Administration to facilitate analysis of daily mean streamflow data. The QSTATS program uses daily value data files that are obtained from the USGS National Water Information System Web site and reformatted to a common format by use of the program GNWISQ (appendix 1). QSTATS can be used to calculate the average, standard deviation, skew, and median of daily mean streamflow values in arithmetic and common logarithmic ($\log_{10}$) space for one station or multiple stations. The program provides the option to calculate probability-weighted moments and L-moments in arithmetic and $\log_{10}$ space. The program also calculates the total number of daily mean streamflow values, the number of gaps in the record (each of which may be one day to several decades long), and the fraction of zero flows recorded in the data file. This computer program has a graphical user interface that follows standard Microsoft Windows interface conventions.

Introduction

Streamflow information is important for many planning and design activities including water-supply analysis, habitat protection, bridge and culvert design, calibration of surface- and ground-water models, and water-quality assessments. Streamflow information is especially critical for water-quality assessments (Warn and Brew, 1980; Di Toro, 1984; Driscoll and others, 1989; Driscoll and others 1990a, b). Calculation of streamflow statistics for receiving waters is necessary to estimate the potential effects of point sources such as wastewater-treatment plants and nonpoint sources such as highway and urban-runoff discharges on receiving water. Streamflow statistics indicate the amount of flow that may be available for dilution and transport of contaminants (U.S. Environmental Protection Agency, 1986; Driscoll and others, 1990a, b). Streamflow statistics also may be used to indicate receiving-water quality because concentrations of water-quality constituents commonly vary naturally with streamflow. For example, concentrations of suspended sediment and sediment-associated constituents (such as nutrients, trace elements, and many organic compounds) commonly increase with increasing flows, and concentrations of many dissolved constituents commonly decrease with increasing flows in streams and rivers (O'Connor, 1976; Glysson, 1987; Vogel and others, 2003, 2005).

Reliable, efficient and repeatable methods are needed to access and process streamflow information and data. For example, the Nation's highway infrastructure includes an innumerable number of stream crossings and stormwater-outfall points for which estimates of stream-discharge statistics may be needed. The U.S. Geological Survey (USGS) streamflow data-collection program is designed to provide streamflow data at gaged sites and to provide information that can be used to estimate streamflows at almost any point along any stream in the United States (Benson and Carter, 1973; Wahl and others, 1995; National Research Council, 2004). The USGS maintains the National Water Information System (NWIS), a distributed network of computers and file servers used to store and retrieve hydrologic data (Mathey, 1998; U.S. Geological Survey, 2008). NWISWeb is an on line version of this database that includes water data from more than 24,000 streamflow-gaging stations throughout the United States (U.S. Geological Survey, 2002, 2008). Information from NWISWeb is commonly used to characterize streamflows at gaged sites and to help predict streamflows at ungaged sites.

Streamflow Analysis

Streamflow statistics are used to summarize the information in long streamflow records. Long records (years to decades) are commonly needed to characterize variations in streamflow through time. For example, at least one decade—preferably two to four decades—is considered necessary to develop a reliable estimate of the 7-day 10-year (7Q10) hydrologic low flow (U.S. Environmental Protection Agency, 1986), and at least 20 years of data are recommended for analysis of the 1-day 3-year biological low flow (1B3) and the 4-day 3-year biological low flow (4B3), which are used for setting water-quality criteria and TMDL waste-load allocations (Rossman, 1990; Saunders and others, 2004). One 40-year record may include about 14,610 daily mean streamflow values and require about 400,000 bytes of computer-disk space. Hundreds to thousands of such data files are necessary to characterize national variations in streamflow to the degree necessary to frame defensible planning-level estimates of streamflow at almost any point along any stream in the United States (Benson and Carter, 1973). For this reason, the streamflow statistics program QSTATS was designed to reduce a data set of more than 38,225,000 daily mean streamflow values into a set of summary statistics that would be useful for the estimation of streamflow characteristics in different areas of the Nation.

Basic streamflow statistics including the average, standard deviation, skew, and median of daily mean streamflow values, and the number of zero flow values in the record are used for characterizing streamflow records. These statistics also may be useful for a stochastic analysis of potential effects of runoff on receiving waters. Streamflow statistics can be calculated by using standard product-moment estimators, probability weighted moments, and L-moments in arithmetic and logarithmic space (Stedinger and others, 1993). Streamflow statistics that are normalized by drainage area commonly are used to compare streamflows from different basins and to estimate streamflows at ungaged sites. Many different software packages can be used to calculate summary statistics, but QSTATS is optimized to calculate these streamflow-statistics from many different stations in batch mode.

Purpose and Scope

This manual describes the implementation, use, and interpretation of results from the Streamflow (Q) Statistics (QSTATS version 1.0) program. The QSTATS program was developed by the USGS in cooperation with the Federal Highway Administration (FHWA) for use in the analysis of regional and national hydrologic data sets. The program was developed as part of a suite of tools to download and process streamflow information from the conterminous United States in support of a stochastic empirical loading and dilution model for planning-level estimates of the effects of highway runoff on receiving waters. QSTATS uses streamflow and station-information files

retrieved from NWISWeb by use of the Get NWIS streamflow (GNWISQ) program (Appendix 1). This program was used to calculate stream-discharge statistics for 2,783 USGS streamflow-gaging stations within the 84 U.S. Environmental Protection Agency Level III nutrient ecoregions with nominal drainage areas ranging from 10–500 mi^2 and at least 24 years of streamflow data collected during the period 1961–2004. Methods and governing equations for estimating streamflow statistics in the QSTATS program are described. The formats of input data and output statistics are described. Step-by-step use of the program's graphical user interface is illustrated. The program code written in Microsoft Visual Basic 6.0 is documented as individual files in a Visual Basic project directory on the computer disk containing this manual.

Governing Equations and Statistical Methods

The objective of this streamflow analysis is to provide an estimate of the probability of occurrence of any random streamflow value (a value in what is commonly referred to as the parent population) from a statistical analysis of observed streamflow values (commonly referred to as samples of the parent population). Streamflow estimates are commonly made by selecting a statistical model that represents the relation between streamflow magnitude and the probability of occurrence for the parent population. Sample statistics are used as estimates of population statistics in fitting a theoretical distribution to the available data.

Historically, many of different distributions have been used to estimate different streamflow values, but the lognormal and log-Pearson type III (three-parameter gamma) distributions are most commonly used for hydrologic analysis of streamflow records (Marcovic, 1965; Haan, 1977; U.S. Interagency Advisory Committee on Water Data, 1982; Chow and others, 1988; Bobee and Ashkar, 1991; Hirsch and others, 1993; Stedinger and others, 1993; U.S. Army Corps of Engineers, 1993, 1994; Helsel and Hirsch, 2002; McCuen and others, 2002). This manual will focus on the common logarithm (base 10) because it is commonly used for hydrologic studies (Stedinger and others, 1993). In some cases, analysts use a three-parameter lognormal distribution to resolve slight departures from normality (Stedinger and others, 1993), but the flexibility of the log-Pearson type III allows use of this distribution under substantial departures from (log) normality (Bobee and Ashkar, 1991). For example, if the skew coefficient of the logarithm of the data is equal to zero, the log-Pearson type III distribution is equivalent to the lognormal distribution (Bobee and Ashkar, 1991). The lognormal and log-Pearson type III distributions can be modeled by use of sample statistics such as the mean, standard deviation, and skew of the logarithms of the data.

The summary statistics that are used to describe the location and spread of a random data set are estimates of the properties of the true underlying distribution of values. The QSTATS program uses classical product-moment estimators prevalent in the literature and recommended for hydrologic applications (Marcovic, 1965; Haan, 1977; Water Resources Council, Hydrology Committee, 1982; Chow and others, 1988; Bobee and Ashkar, 1991; Hirsch and others, 1993; Stedinger and others, 1993; U.S. Army Corps of Engineers, 1993, 1994; U.S. Natural Resources Conservation Service, 2000; Helsel and Hirsch, 2002; McCuen and others, 2002). Although linear or L-moments have some distinct advantages for some data sets (Stedinger and others, 1993) methods for calculation of the mean and median are equivalent to classical product-moment estimators. The uncertainties or potential bias introduced by the use of familiar product-moment estimators were judged to be less critical than the uncertainties or potential bias introduced by the selection of a representative probability distribution and extrapolation of available data to ungaged sites.

Governing Equations

The mean describes the location (central tendency) of a random variable, and is calculated by dividing the sum of all measurements by the number of samples. The mean $\overline{X}$ is expressed mathematically as

$$\overline{X} = \sum_{i=1}^{N} \frac{X_i}{N},$$ (1)

where

X_i is the value for each data point i; and
N is the total number of data points in the sample.

The standard deviation S describes the width (scale) of a distribution and is calculated as the square root of the variance. The standard deviation is expressed mathematically as

$$S = \left(\sum_{i=1}^{N} (X_i - \overline{X})^2 / (N-1) \right)^{0.5}.$$ (2)

In arithmetic space, the standard deviation has the same units as the input data set. In logarithmic space, however, the difference of the logarithms of two numbers is equal to the quotient of the two numbers. The standard deviation in logarithmic space, therefore, is a dimensionless number that is proportional to the mean.

In arithmetic space, the coefficient of variation is commonly used as the dimensionless number to express variability of the data in proportion to the mean. The coefficient of variation (CV) of the data describes the normalized width of the distribution and is expressed mathematically as

$$CV = S / \overline{X}.$$ (3)

The value of the coefficient of variation calculated with equation 3 approaches infinity as the mean value approaches zero (as in the standard normal distribution); this equation will produce a division-by-zero error in QSTATS when the mean does equal zero. The CV of arithmetic statistics is commonly used to estimate other statistics of the lognormal distribution, but the CV is not commonly used for statistics in logarithmic space (Chow, 1954; Driscoll and others, 1990a,b; Stedinger and others, 1993).

The coefficient of skewness G describes the relative asymmetry of a sample in comparison to the skewness of the normal distribution. The coefficient of skewness is expressed mathematically as

$$G = N \left(\sum_{i=1}^{N} (X_i - \overline{X})^3 / ((N-1)(N-2)S^3) \right).$$ (4)

Theoretically, the 95-percent confidence interval for the coefficient of skewness for data that are randomly sampled from a population with a normal distribution, CI_G, may be expressed as

$$CI_G = \pm 2 \left(\frac{6}{N} \right)^{0.5},$$ (5)

and therefore may indicate the applicability of a lognormal or log-Pearson type III distribution to characterize the streamflow statistics. This relation, however, is approximate because the skew coefficient calculated by use of equation 4 with data for an individual station may be biased by a few measurements at extremely low or extremely high flows (Stedinger and others, 1993; W.S. Kirby, U.S. Geological Survey, Office of Surface Water, written commun., 2004). Because these extreme flows are relatively rare, there may be fewer available stage-discharge measurements to extend the stage-discharge rating curves used to predict streamflow from measured stage values. In smaller streams, debris or vegetation growth may have transient effects on stage-discharge relations. High streamflows that exceed bankfull conditions are difficult to measure and commonly have a different stage-discharge relation than the most flows. As a result, streamflow values in the tails of the distribution commonly have the greatest uncertainties in the stage-discharge rating curves used to compute these flows.

Equations 1, 2, and 4 may be used as population estimators for values of streamflow in arithmetic space (the untransformed values) or in logarithmic space (the log-transformed values). Log transformations are commonly used to normalize data and reduce the relative weight of high outliers (Stedinger and others, 1993). The lognormal or log-Pearson type III distribution may be used with either the natural log transformation ($X = \ln(Y)$ in which Y is the untransformed streamflow) or the $\log_{10}$ transformation ($X = \log_{10}(Y)$). The QSTATS program uses the $\log_{10}$ base because this is the transformation

commonly used for hydrologic analysis (U.S. Interagency Advisory Committee on Water Data, 1982; Stedinger and others, 1993; U.S. Army Corps of Engineers, 1993, 1994; McCuen and others, 2002). The equation to convert from one base to another is

$$\log_a X = \log_b X / \log_b a ,\qquad(6)$$

where

X is the variable of interest,

a is the base of the logarithm of interest (for example, 10 for the common log or "*e*"—about 2.71828—for the natural log), and

b is the base of the logarithm to be converted.

Thus, the natural and common logarithms may be converted with simple proportionality factors (for example, $\ln X = 2.302585 * \log_{10} X$ or $\log_{10} X = 0.4342945 * \ln X$). In either case, the mean of the logarithms of the values is the geometric mean, which is not equal to the arithmetic mean. The mean of the lognormal distribution is equivalent to the median in log space. If the geometric mean is retransformed, the resulting value also is equivalent to the arithmetic median of the original data set if it is approximately a lognormal distribution (Helsel and Hirsch, 2002).

Chow (1954) published approximate conversions from population statistics for a lognormal distribution to the arithmetic statistics of the retransformed data. Stedinger and others (1993) recalculated these conversions for the common logarithms used for hydrologic applications. The conversion from the mean $\overline{X}$ and standard deviation S_X of the common logarithm of the data to the arithmetic mean $\overline{Y}$ is

$$\overline{Y} = 10^{(\overline{X}+0.5\ln(10)S_X^2)} .\qquad(7)$$

To calculate the arithmetic standard deviation, the arithmetic mean $\overline{Y}$ and the standard deviation of the common logarithms S_X are used as follows:

$$S_Y = \overline{Y}(10^{\ln(10)S_x^2} - 1)^{0.5} .\qquad(8)$$

These relations, however, are just approximations unless the skew of the sampled population approaches zero in common-log space. QSTATS calculates the arithmetic and log-transformed statistics directly for each sample. Equations 7 and 8 are provided for independent assessment of the lognormal population as a model for streamflow value.

QSTATS calculates arithmetic statistics for all streamflow-data points and log-transformed statistics for all nonzero streamflow-data points because only positive, nonzero values may be converted into log space. A conditional-probability adjustment approach (Haan, 1977; Chow and others, 1988; Stedinger and others, 1993) is used for zero flows in QSTATS. Streamflow records commonly have a minimum measurable flow, depending on the size of the stream and channel

geometry, below which flows are reported as zero. For low-flow analysis, the use of censoring methods for data below detection limits may be warranted (Stedinger and others, 1993; Helsel and Hirsch, 2002). It should be noted, however, that zero flows may be common in arid areas, areas with large ground-water withdrawals, and in headwater areas of watersheds throughout the nation. For example, Croker and others (2003) used conditional-probability methods to develop flow-duration curves for daily flows at gaged ephemeral streams in Portugal and then used these statistics to estimate streamflows (or the lack thereof) at ungaged sites. The use of a conditional-probability adjustment approach for the purpose of calculating dilutions in receiving waters is more conservative than for estimating nonzero streamflow values below some measurement threshold (W.S., Kirby, U.S. Geological Survey, Office of Surface Water, written commun., 2004). The conditional-probability adjustment approach is based on the theorem of total probability (Haan, 1977), according to which the probability of zero values is the fraction of zero values, and the probability of nonzero values is determined by use of standard analysis (with a lognormal or log-Pearson type III distribution) with the sample size equal to the number of nonzero values. The probability of any flow, therefore, may be expressed as

$$P_x(X) = f_z + (1 - f_z)P_{nzX}(X),\qquad(9)$$

where

$P_x(X)$ is the cumulative probability distribution of X,

f_Z is the fraction of zero values in the total sample, and

$P_{nzX}(X)$ is the cumulative probability distribution of nonzero values of X.

To predict a value based on population statistics and a given probability of occurrence, one would use the desired probability and a normal or Pearson Type III variate as a frequency factor (Chow, 1954; U.S. Interagency Advisory Committee on Water Data, 1982; Stedinger and others, 1993). If the probability were less than or equal to the fraction of zero flow, the streamflow of interest would equal zero. Otherwise, the nonzero streamflow Y would be calculated as

$$Y = 10^{(\overline{X}+S\cdot K)} ,\qquad(10)$$

where

$\overline{X}$ is the mean of the values in $\log_{10}$ space;

S is the standard deviation of the values in $\log_{10}$ space; and

K is the standard normal variate or the Pearson Type III variate.

These variates (K) are commonly available in table form (Harter, 1969, 1971; Haan, 1977; U.S. Interagency Advisory Committee on Water Data, 1982; Chow and others, 1988; U.S. Natural Resources Conservation Service, 1998) or

may be calculated with various approximations (for example, Kirby, 1972; Haan, 1977; U.S. Interagency Advisory Committee on Water Data, 1982; Chow and others, 1988; Bobee and Ashkar, 1991; U.S. Army Corps of Engineers, 1993, 1994). The CD-ROM containing this manual includes tables for percentage points of the Pearson type III distribution in tabular (U.S. Interagency Advisory Committee on Water Data, 1982; U.S. Natural Resources Conservation Service, 1998) and Microsoft Access database table formats.

QSTATS also calculates probability-weighted moment estimators (Greenwood and others, 1979; Hosking, 1990; Stedinger and others, 1993) and linear moment (L-moment) estimators (Hosking, 1990; Stedinger and others, 1993; Hosking and Wallis, 1997) for all streamflow values and the common logarithms of all nonzero streamflow values in the data set. L-moment estimators are considered unbiased because they are not calculated with the squared and cubed terms used to calculate the product-moment standard deviation and skew, respectively. L-moment ratios, which include coefficients of variation, skewness, and kurtosis are used to identify a probability distribution that best fits a data set (Hosking, 1990; Stedinger and others, 1993; Hosking and Wallis, 1997).

The first four probability-weighted moments, commonly designated as b_0 through b_3, are used to calculate the L-moment estimators, which in turn are used to calculate the L-moment ratios. The first step in calculating probability-weighted moments, and therefore L-moments, is to sort the data in descending order so X_1 is the largest value in the data set and X_n is the smallest. The first probability-weighted moment, b_0, is equal to the mean of the data (equation 1). The remaining probability-weighted moments are calculated as

$$b_1 = \sum_{i=1}^{N-1} ((N-i)X_i) / (N(N-1)) , \tag{11}$$

$$b_2 = \sum_{i=1}^{N-2} ((N-i)(N-i-1)X_i) / (N(N-1)(N-2)) , \text{ and} \tag{12}$$

$$b_3 = \sum_{i=1}^{N-3} ((N-i)(N-i-1)(N-i-2)X_i) / (N(N-1)(N-2)(N-3)) , \tag{13}$$

where

b_j is the jth probability-weighted moment value;
X_i is the value for each data point i; and
N is the total number of data points in the sample (Greenwood and others, 1979; Hosking, 1990; Stedinger and others, 1993).

Although the equations for higher moments indicate the summation from i to N-1, N-2, or N-3, the computer implementation of the method does not require separate calculation loops because the numerators of the equations for b_1, b_2, and b_3 produce a value of zero as i approaches N.

L-moments are linear (not squared or cubed) combinations of the probability-weighted moments (Hosking, 1990; Stedinger and others, 1993; Hosking and Wallis, 1997). The first four L-moments, designated in this manual as L_1 through L_4, are used to calculate the L-moment estimators. As is true for the probability-weighted moments, the first L-moment, L_1, is equal to the mean of the data (equation 1). The remaining L-moments are calculated as

$$L_2 = 2b_1 - b_0 , \tag{14}$$

$$L_3 = 6b_2 - 6b_1 + b_0 , \text{ and} \tag{15}$$

$$L_4 = 20b_3 - 30b_2 + 12b_1 - b_0 . \tag{16}$$

The L-moment coefficient of variation CV_L, coefficient of skewness CS_L and coefficient of kurtosis CK_L are calculated as

$$CV_L = \frac{L_2}{L_1}, \tag{17}$$

$$CS_L = \frac{L_3}{L_2}, \text{ and} \tag{18}$$

$$CK_L = \frac{L_4}{L_2}. \tag{19}$$

Hosking (1990) and Hosking and Wallis (1997) provide equations and computer programs that can be used to select a suitable probability distribution by graphical examination of L-moment ratios.

Statistical Methods

The QSTATS program uses standard methods to calculate streamflow statistics with the applicable governing equations defined above. The program is written with the assumption that it will read streamflows in units of cubic feet per second, drainage areas in square miles, and print out statistics in units of cubic feet per second and cubic feet per second per square mile. (Only 15 streamflow-gaging stations near the Canadian border have streamflow values in cubic meters per second in the NWISWeb database.) The program, however, may be used with any internally consistent set of units because only the file-header explanatory information is dependent on the use of English units. The user may select individual or batch processing, but input, processing, and output are done in series, station by station, by the program. The results of calculations by QSTATS were tested for a random sample of five stations from different parts of the country by use of the S-Plus 6.1 statistical package. The tests confirmed that each calculation was being done correctly for this data.

As the program reads each sample of streamflow data from each station, it calculates the total number of daily mean streamflow measurements, the number of missing days during the period of record, and the number of zero flows. The number of nonzero values is calculated as the total number of recorded values minus the number of zero values. The fraction of zero flows is calculated as one minus the quotient of the number of nonzero values and the total number of recorded values.

The program calculates statistics in arithmetic and $\log_{10}$ space. Arithmetic statistics, including the average, standard deviation, skew, median, and L-moments values, are calculated for all flows in the data set. These statistics also are calculated for the nonzero-flow values that are transformed into $\log_{10}$ space. The average, median, and standard deviation of the nonzero-flow values are retransformed directly into a power of 10 (for example, $X = 10^Y$) to provide a sense of scale in arithmetic space. The coefficient of skew, however, is not retransformed because the retransformation is not meaningful; and the user may wish to assess the degree of normalization achieved by transformation by comparison of the logarithmic and arithmetic coefficients of skew. The logarithmic coefficient of skew also may be evaluated in terms of the confidence limit of the sample (eq. 5) to determine if the lognormal or log-Pearson Type III distribution would be more appropriate for analysis. Because of the sensitivity of the skew coefficient to extreme values, however, selection of a distribution may be improved by visual inspection of a probability plot of the data (Riggs, 1968; U.S. Interagency Advisory Committee on Water Data, 1982; Vogel and Kroll, 1989; Chow and others, 1988; Vogel and McMartin, 1991; Stedinger and others, 1993). The Make Plotting Position File (MkPP) program (Appendix 2) was designed to provide a condensed file of the plotting position and normal score of data from the NWISWeb streamflow data files to facilitate graphing and examination of this data.

QSTATS calculates the flow per unit area (cubic feet per second per square mile) for selected flow statistics. To use these statistics to estimate streamflow at an ungaged site with similar basin characteristics, the user would multiply the geometric-mean flow per unit area statistic by the drainage area of the site of interest. The geometric standard deviation and skew are dimensionless and therefore should not be multiplied by the drainage area of interest. The user would then transform the geometric mean and standard deviation into the associated common logarithm and apply equation 10 with the standard normal or Pearson type 3 variate that corresponds to the probability of interest. If used for stochastic modeling of a population of random streamflow values, a population of variate values would be obtained from an appropriate random-number generator for application in equation 10 with the population statistics (Haan, 1977).

Flows per unit area are calculated with the best available estimate of contributing area to minimize the potential effects of natural and anthropogenic influences on regional statistics. The NWIS database includes values of total drainage area and contributing drainage area. The total drainage area is the geographic watershed defined by topographic surface-water divides above the streamflow-gaging station. The contributing drainage area is the effective drainage area above the streamflow-gaging station that contributes flow. This value is assigned by local USGS data chiefs who are knowledgeable about factors that may affect streamflow measured at a given location. Factors that may affect the contributing drainage area include differences in surface and ground-water contributing areas (natural) as well as withdrawals and diversions (anthropogenic) that affect the watershed above a given station. If a contributing drainage area is listed in the station header file QSTATS uses this value to calculate flows per unit watershed area; otherwise, the total drainage area is used.

Use of the QSTATS Program

The QSTATS program is a Visual Basic program that provides several choices for processing NWISWeb data that were retrieved with output options specified by the GNWISQ program (Appendix 1). QSTATS is used to calculate streamflow statistics with prespecified NWISWeb station-information and stream-discharge files. The user interface consists of one interactive form that identifies the program and provides input- and output-file information. This form provided the graphical user interface controls necessary to specify user input and provide feedback on the data-analysis operations. QSTATS can be run to analyze streamflow statistics for an individual station or to analyze streamflow statistics in batch mode for multiple stations. The program outputs tab-delimited text files that can be used with many computer applications including text editors, spreadsheets, graphing software, and statistical software. QSTATS, if installed properly, should be compatible with commonly used Microsoft Windows operating systems.

Installation and Removal

The QSTATS program depends on a number of software drivers and dynamic-link libraries that may not be installed and available on the user's computer. This program must be installed by someone who has administrative rights on the program user's computer. The administrator must test the installation with the user's profile to ensure that all permissions are set properly. A readme.txt file with installation instructions and three installation files are in the folder QSTATSInstall on the CD-ROM containing this manual. Three files—setup.exe, setup.LST, and QSTATSv1.CAB—are needed to install the program. The file setup.exe is the installation program. The setup.LST file is a text file that provides the necessary installation specifications. The file QSTATSv1.CAB is the file containing the program and support files. The setup program is a standard Microsoft installation wizard that should be familiar to the user or system administrator. These three files must be located in the same directory on the CD-ROM or in a directory on the user's computer. The person installing the program should follow all the standard choices for installation. The installation program creates the directory C:\Program Files\FHWA\HEP\QSTATS\ and includes the QSTATS program in the computer's registry. If desired, a shortcut to the program can be added to the desktop manually after installation. Sample files are saved on the CD-ROM containing this manual and should be copied to a directory in which the user has read, write, and execute rights. The user may uninstall the QSTATS program and its support files by use of the standard Microsoft Windows Add or Remove Programs wizard on the control panel of the user's computer.

Input-File Formats

The QSTATS program uses several input-file formats to retrieve streamflow-gaging station information and associated daily mean streamflow data to calculate streamflow statistics (table 4-1). Input data files include a station-list file, one or more station information files, and one or more daily mean streamflow data files. The user specifies the input file directory by selecting the station-list file in the directory with the data files. QSTATS uses the station-list file to identify all of the input files. QSTATS uses the station-description files, and one or more daily mean streamflow data files to calculate the statistics of interest. Examples of each type of file are provided in the example data directory for QSTATS on the CD-ROM containing this manual.

Data from the NWISWeb database is transmitted in a tab-delimited RDB format (Manis and others, 1988). RDB files are tab-delimited ASCII text files that can be imported into many software packages. The USGS RDB file format begins with comment lines that are intended to describe the source of the data and the content of the file. These comment lines are denoted by a pound symbol (#) in the first character location of each line. The comments are followed by a line of NWIS variable names for each type of information in the file. The variable name line is followed by a data-format line which indicates the maximum character length for each variable and the type of variable ("d" for date, "n" for number, and "s" for string). All remaining lines in the RDB files contain the daily mean streamflow data. If data elements are qualified, such as being estimated, being less than a listed value, or being greater than a listed value, a numerical value will appear within a data field with an additional character code; alternatively, if the measurement cannot be quantified, the data field may contain just the character code (U.S. Geological Survey, 2008). The documentation and format lines in these files and the qualification codes associated with the data are essential for transmitting meaningful data in an efficient format. Example daily mean streamflow files also are provided in the QSTATS example-data directory on the CD-ROM containing this manual.

Station-List File Format

Streamflow data for multiple stations can be processed in batch mode to facilitate the analysis of local, regional, and national hydrologic data sets. In batch mode, the program reads a station-list file. This list file does not contain any header lines. The list file consists of 8- to 12-character streamflow-gaging-station numbers on separate lines without leading or following spaces. The station-list file should not include any text except the station numbers of interest and should not end in a blank line. The station numbers in this file are used with a

Table 4-1.   Summary of input and output files for the Streamflow (Q) Statistics (QSTATS—Version 1.0) program.

[GIS, Geographic Information System; GNWISQ, Get NWIS streamflow (Q) software version 1; NWIS, National Water Information System; RDB, relational database]

File type	Example files on the CD-ROM directory: CDROM:\Applications\GNWISQEx\	Comments
Input files		
Station-list input file	IndexStations.txt	Lists long-term index-station numbers
Station-information file	01117500H.txt	NWISWeb RDB file for selected streamflow-gaging-station information
NWISWeb daily value RDB streamflow data file	01117500Q.txt	The 2005 daily value format NWISWeb RDB file, formatted by GNWISQ
Output files		
Streamflow statistics (dat) file	QSTATSDatFile0.txt	Tab-delimited RDB ouput file with station information and streamflow statistics
GIS file format	QSTATSGISFile0.txt	Tab-delimited RDB ouput file formatted for input to a GIS database to facilitate spatial analysis of station information and streamflow statistics; statistics are normalized by drainage area to facilitate station comparisons
L-moment file	QSTATSLMomFile0.txt	Tab-delimited RDB ouput file with probability-weighted moments, L-moments, and L-moment ratios for all the daily mean streamflow values
Common logarithm L-moment file	QSTATSLMomLogFile0.txt	Tab-delimited RDB ouput file with probability-weighted moments, L-moments, and L-moment ratios of the common logarithm of nonzero daily mean streamflow values
Error output file	QSTATSErrFile.txt	File containing errors or warnings generated during the analysis process

"H.txt" suffix to identify NWISWeb station information files and a "Q.txt" suffix to identify NWISWeb data files for each streamflow-gaging station.

Station-Information File Format

The station-information files (or header files) provide information about the streamflow-gaging station that can be used for analysis of streamflow data. Station-information file-names include the station number followed by the letter "H" and the suffix ".txt" (for example, 01022500H.txt). The default station information includes the site-identification number, site name, decimal latitude, decimal longitude, latitude-longitude accuracy, latitude-longitude datum, state code, altitude of gaging station or land surface, altitude accuracy, altitude datum, hydrologic unit code, drainage area, contributing drainage area, daily mean streamflow-data begin date, daily mean streamflow-data end date, and daily mean streamflow-data count. Not all of these station-information parameters are available for every station. The GNWISQ program (Appendix 1) is designed to obtain these station-information files in the proper format from NWISWeb. Examples of the station-information files are provided in the QSTATS example-data directory of the CD-ROM containing this manual.

Streamflow-Data File Format

The streamflow-data file in NWISWeb daily value (dv) format provides the daily mean streamflow values for statistical analysis. The streamflow-data file names include the station number followed by the letter "Q" (a common abbreviation for streamflow in the hydrologic literature) and the suffix ".txt" (for example, 01022500Q.txt). QSTATS is designed to read an NWISWeb daily value table with columns for the agency code (typically the USGS), the 8- to 12-digit USGS streamflow-gaging-station number, the measurement date of the daily mean streamflow (in a YYYY-MM-DD format), the daily mean streamflow (in cubic feet per second), and data-value qualification codes (for example, "A" for approved, "e" for estimated, ">" for greater than a listed value, "<" for less than a listed value, or "P" for provisional data). Alternatively, if the measurement cannot be quantified, the data field may be blank and the comment field will contain just the character code (U.S. Geological Survey, 2008). The GNWISQ program (Appendix 1) is designed to obtain stream-discharge-data files from NWISWeb (in the new post 2006 RDB format) and reformat these files into the older, more consistent dv RDB format. Examples of the stream-discharge-data files are provided in the QSTATS directory of the CD-ROM containing this manual.

Output-File Formats

The QSTATS program will create two to five output files depending on user-selected options and the occurrence of data-processing errors (table 4-1). The output files include a statistics (dat) file, a geographic information system (GIS) file, an arithmetic L-moment file, a common logarithm L-moment file and, if necessary, an error file. The dat files are named QSatsDatFile*N*.txt, and the GIS files are named QSatsGIS-File*N*.txt. The files containing L-moment arithmetic statistics and common logarithm statistics are named QStatsLMom-File*N*.txt and QStatsLMomLogFile*N*.txt, respectively. Each error file is named QStatsErrFile*N*.txt. An error file is written only if there is a data-processing error. The letter "*N*" in these filenames denotes the sequential number of each dat file in the order the dat files are generated in the target directory from zero and to the number of separate analyses that are run. The sequence numbers for all the other output and error files are synchronized to the dat file number to facilitate identification of related files from each QSTATS run. If statistics for multiple stations are calculated in one analysis session, all results are saved in the output files for that QSTATS session. The file-creation and modification dates and the station numbers listed in the input and output files will indicate a correspondence between files. If an error file is generated, the filename will be denoted in the current-status text box on the program's graphical user interface form.

Streamflow-Statistics Output File Formats

All the statistical output files are designed to emulate the NWISWeb RDB file format. These files begin with comment lines denoted by a pound symbol (#) in the first character location of each line. The comments are followed by a line of variable names for each type of information in the file. The station files and the statistical output files, however, do not include a data-format line following the variable name line because a data-format line is not necessary for use of the information and statistics presented. All remaining lines contain information and statistics for each individual streamflow-gaging station that is included in the statistical analysis. The dat and GIS files contain station information and calculated population statistics. In the geographical information system (GIS) file format, the longitude and latitude of each station are listed in the first and second columns, respectively, to facilitate import and use in GIS software. In the GIS-file format, the statistics are expressed in cubic feet per second per square mile so that flow statistics that are normalized to drainage area can be compared to statistics at nearby stations with different drainage areas.

Error Output File Format

The error file is designed to provide the information necessary for the user to find and solve problems with the input files. If the station-information file is not found, the program will print the station number and the message "Error bad file name" in the error file. If the streamflow-data file is not found, the program will print the station number and the message "Error bad file name or empty file" in the error file. An empty data file may be generated if there are some data for a streamflow gaging station, but not in the interval specified in the NWISWeb data retrieval. If there is an error within the station-information file, QSTATS will print the header-file name and an error message such as "Error in header file, Check Data," "Station number in header file does not match specified station number" or "Warning problem with header file station drainage area does not exist please check." If there is an error in a streamflow-data file, QSTATS will print the flow-file name and an error message such as "Warning problem with data file please check line" or "Fatal Error: Data file not read please try again. See line: N" where N represents the line number on which the error occurred.

Graphical User Interface

The graphical user-interface consists of one interactive form and two file-specification dialog forms. The program is initiated by double clicking on the program file or a Microsoft Windows shortcut to the executable program-file location. Initially, the user is presented with two command buttons, an

individual NWIS RDB file or a batch file (fig. 4-1). If the user selects the individual-file option, the program requires that the user enter a valid 8- to 12-digit USGS streamflow-gaging station identification number (fig. 4-2) and select the associated header file (for example, 01117500H.txt) and streamflow-data file (for example, 01117500Q.txt) by use of the respective file-specification dialog boxes (fig. 4-3). These files must be in the format specified within the GNWISQ program (appendix 1). If the user selects the batch-file option, a file-specification dialog box appears so that the user may select the name of a file containing one valid station number per line (fig. 4-3). In either case, the form indicates the choice and waits for the command to process data (fig. 4-4). The number of stations to be processed is specified in the "Number of files:" text box.

Two check boxes are provided for the user to select the supplementary statistics to be generated by the program. By default, the "Calculate Arithmetic L-Moments" and the "Calculate Log10 L-Moments," are checked (fig. 4-4A), and the program will calculate and print the associated statistics. The user may click on the check boxes to deselect these options. The time required to calculate the additional statistics is minor unless there are hundreds of stations to be processed because the data are already sorted to determine the median values.

When the user clicks the "Process Data" button, the program reads the input files, does the necessary calculation, updates the output files, and prints the status to the "Current Status" text box (fig. 4-5). If the input files are processed without error, the path and filename of the output file are displayed in the status text box; however, if an error occurs, the user is notified with a message box and the path and filename of the error file are displayed in the status text box. At any time in the data-specification process, the user may click the "Close" button to terminate the program, but this button will not be active while the program is processing, input files. If large amounts of data are processed, the user interface may appear frozen. However, the program will process the data and return control to the user if it is left alone.

and median of daily mean streamflow values by use of standard product-moment estimators in arithmetic and common logarithmic (log_{10}) space. The program provides the option to calculate probability-weighted moments and L-moments in arithmetic and log_{10} space. The program also calculates the total number of daily mean streamflow values, the number of daily flows missing from the record, and the fraction of zero flows recorded in the data file. The basic streamflow statistics (average and median) are printed to the output files in terms of streamflows in cubic feet per second in the dat file and streamflows per unit area cubic feet per second per square mile in the GIS file. The results of calculations by QSTATS were tested for a random sample of five stations from different parts of the country by use of the S-Plus 6.1 statistical package; these tests confirmed that each calculation was being done correctly for this data. In individual-file mode, the program retrieves station information and daily mean streamflow files for the station associated with the USGS streamflow-gaging station identification number that the user enters in the text box. In batch mode, the program reads a series of station numbers from a user-specified input file and processes the information and data sequentially. The output file formats include a statistics (dat) file, a geographic information system (GIS) file, and, if necessary, an error file.

This manual describes the implementation, use, and interpretation of results from QSTATS (Version 1.0) program. QSTATS was written in Microsoft Visual Basic 6.0 and has a graphical user interface that follows standard Microsoft Windows interface conventions. The program uses daily mean streamflow files that can be obtained from U.S. Geological Survey National Water Information System Web site. The program outputs tab-delimited text files that can be used with many computer applications including text editors, spreadsheets, graphing software, and statistical software. An executable version of the program, example files, and the Visual Basic source code are documented in the QSTATS directory on the computer disk containing this manual.

Summary

The streamflow (Q) statistics (QSTATS—Version 1.0) program was developed by the U.S. Geological Survey (USGS) in cooperation with the Federal Highway Administration to calculate statistics for daily mean streamflow value files retrieved from the USGS National Water Information System Web site. Streamflow statistics are important for many planning and design activities including water-supply, habitat protection, bridge and culvert design, surface and ground-water models, and water-quality assessments. The program can be used to calculate the average, standard deviation, skew,
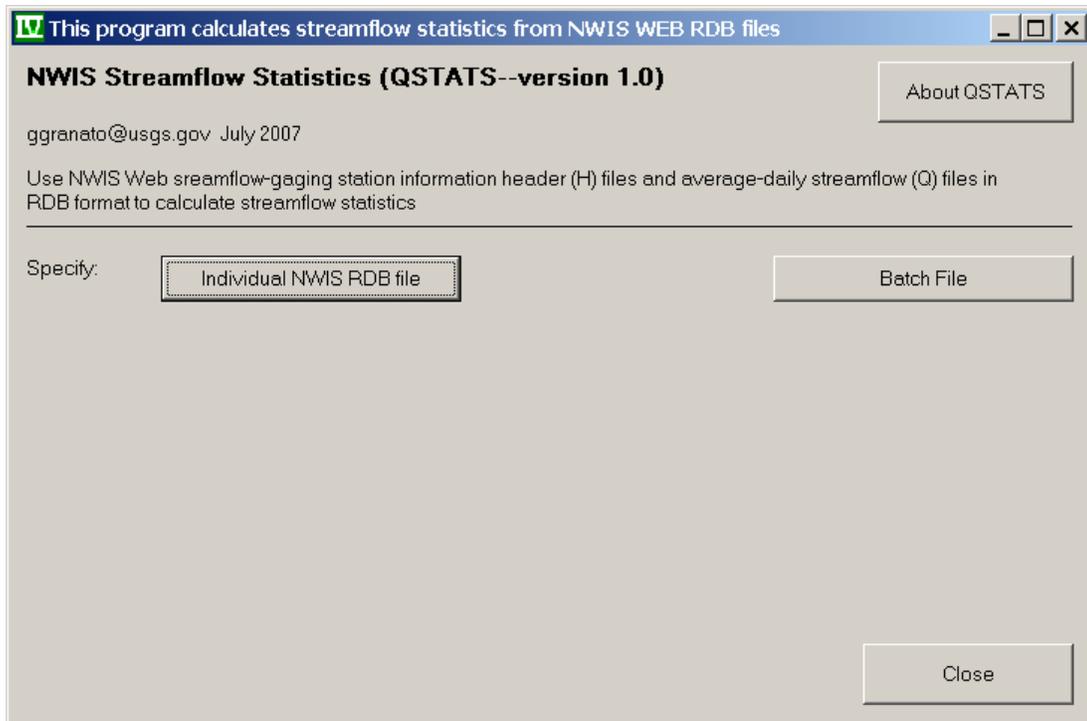
Acknowledgments

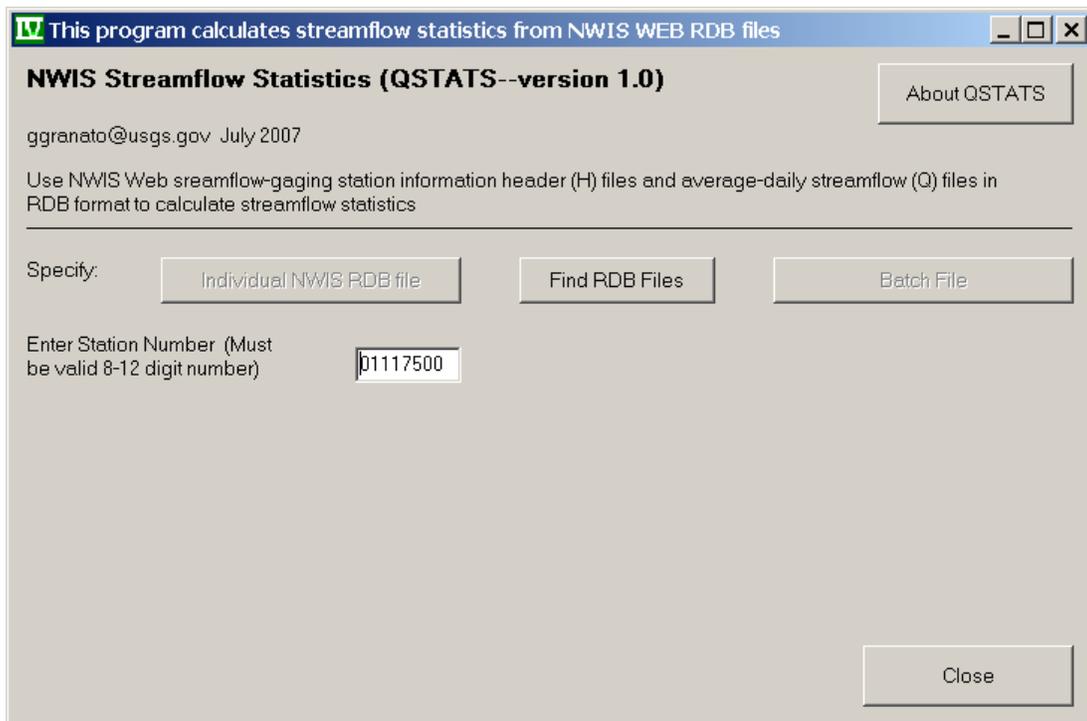**Figure 4-1.** Initial appearance of the QSTATS program input form.

Figure 4-2. Example of the QSTATS program input form as configured for specification of data-retrieval options for an individual streamflow-gaging station.
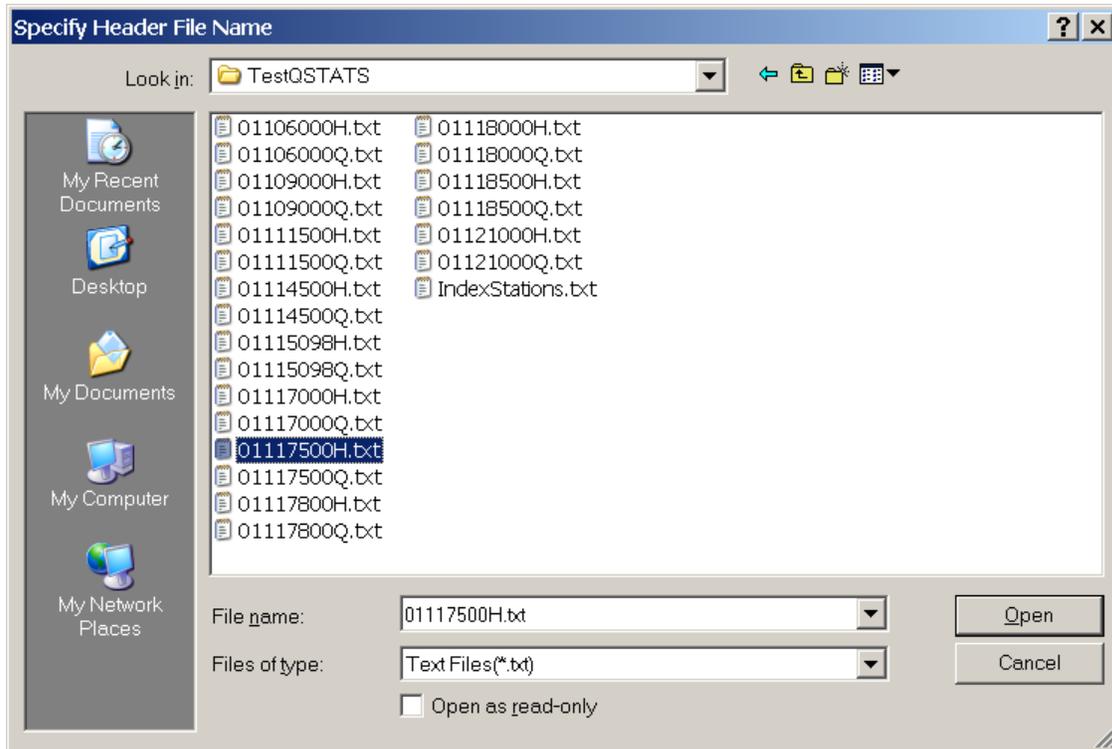
Figure 4-3.   Example of the QSTATS program file-specification dialog box.

Figure 4-4. Example of the QSTATS program input form as configured for (*A*) individual or (*B*) batch processing of U.S. Geological Survey daily mean streamflow data.

A

B

Figure 4-5.   Examples of the QSTATS program input form after (*A*) individual or (*B*) batch processing of U.S. Geological Survey daily mean streamflow data.

References Cited

Benson, M.A., and Carter, R.W., 1973, A national study of the streamflow data-collection program: United States Geological Survey Water-Supply Paper 2028, 44 p.

Bobee, Bernard, and Ashkar, Fahim, 1991, The gamma family and derived distributions applied in hydrology: Littleton, CO, Water Resource Publications, 203 p.

Chow, V.T., 1954, The log-probability law and its engineering applications: Proceedings of the American Society of Civil Engineers, v. 80, Separate No. 536, 25 p.

Chow, V.T., Maidment, D.R., Mays, L.W., 1988, Applied Hydrology: New York, McGraw-Hill Publishing Company, 572 p.

Croker, K.M., Young, A.R., Zaidman, M.D., and Rees, H.G., 2003, Flow duration curve estimation in ephemeral catchments in Portugal: Hydrological Sciences Journal, v. 48, no. 3, p. 427–440.

DiToro, D.M., 1984, Probability model of stream quality due to runoff: Journal of Environmental Engineering, v. 110, no. 3, p. 607–628.

Driscoll, E.D., Shelley, P.E., Gaboury, D.R., and Salhotra, Atul, 1989, A probabilistic methodology for analyzing water quality effects of urban runoff on rivers and streams: U.S. Environmental Protection Agency, Office of Water, EPA 841-R89-101, 128 p.

Driscoll, E.D., Shelley, P.E., and Strecker, E.W., 1990a, Pollutant loadings and impacts from highway stormwater runoff volume I: design procedure: Federal Highway Administration Final Report FHWA-RD-88-006, 67 p.

Driscoll, E.D., Shelley, P.E., and Strecker, E.W., 1990b, Pollutant loadings and impacts from highway stormwater runoff, volume III—Analytical investigation and research report: Federal Highway Administration Final Report FHWA-RD-88-008, 160 p.

Glysson, G.D., 1987, Sediment-transport curves: United States Geological Survey Open-File Report 87-218, 47 p.

Granato, G.E., and Barlow, P.M., 2005, Effects of alternative instream-flow criteria and water-supply demands on ground-water development options in the Big River Area, Rhode Island: U.S. Geological Survey Scientific Investigations Report 2004-5301, 110 p.

Granato, G.E., Barlow, P.M., and Dickerman, DC, 2003, Hydrogeology and simulated effects of ground-water withdrawals in the Big River Area, Rhode Island: U.S. Geological Survey Water-Resources Investigations Report 03-4222, 76 p.

Greenwood, J.A., Landwehr, J.M., Matalas, N.C., and Wallis, J.R., 1979, Probability weighted moments—definitions and relation to parameters of several distributions expressible in inverse form: Water Resources Research, v. 15, no. 6, p. 1049–1054.

Haan, C.T., 1977, Statistical Methods in Hydrology: Ames, IA, The Iowa State University Press, 378 p.

Harter, H.L. 1969, A new table of percentage points of the Pearson type III distribution: Technometrics, v. 11, no. 1, p. 177–187.

Harter, H.L. 1971, More percentage points of the Pearson distribution: Technometrics, v. 13, no. 1, p. 203–204.

Helsel D.R., and Hirsch, R.M., 2002, Statistical methods in water resources—Hydrologic analysis and interpretation: Techniques of Water-Resources Investigations of the U.S. Geological Survey, chap. A3, book 4, 510 p.

Hirsch, R.M., Helsel D.R., Gilroy, E.J., and Cohn, T.A., 1993, Chapter 17—Statistical analysis of hydrologic data, *in* Maidment, D.R., ed., Handbook of hydrology: New York, McGraw-Hill Book Company, p. 17.1–17.55.

Hosking, J.R.M., 1990, L-moments—analysis and estimation of distributions using linear combinations of order statistics: Journal of the Royal Statistical Society, B, v. 52, no. 2, p. 105–124.

Hosking, J.R.M., and Wallis, J.R., 1997, Regional frequency analysis—An approach based on L-moments: New York, Cambridge University Press, 224 p.

Kirby, W.H., 1972, Computer-oriented Wilson-Hilferty transformation that preserves the first three moments and the lower bound of the Pearson Type 3 distribution: Water Resources Research, v. 8, no. 5, p. 1251–1254.

Manis, Rod, Schaffer, Evan, and Jorgensen, Robert, 1988, Unix relational database management—application and development in the Unix environment: Englewood Cliffs NJ, Prentice Hall, 476 p.

Marcovic, R.D., 1965, Probability functions of best fit to distributions of annual precipitation and runoff: Fort Collins, CO, Colorado State University Hydrology Papers, no. 8, 33 p.

Mathey, S.B., ed., 1998, National Water Information System: U.S. Geological Survey Fact Sheet FS-027-98, 2 p.

McCuen, R.H., Johnson P.A., Ragan, R.M., 2002, Highway hydrology—Hydraulic design series No. 2, 2d ed.: U.S. Department of Transportation, Federal Highway Administration, FHWA-NHI-02-001, 424 p.

National Research Council, 2004, Assessing the National Streamflow Information Program: Washington, DC, The National Academies Press, 164 p.

O'Connor, D.J., 1976, The concentration of dissolved solids and river flow: Water Resources Research, v. 12, n. 2, p. 279–294.

Riggs, H.C., 1968, Frequency curves: Techniques of Water-Resources Investigations of the United States Geological Survey, chap. A2, book 4, 15 p.

Rossman, L.A. 1990, DFLOW user's manual: Cincinnati, OH, U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory, 26 p.

Saunders J.F., III, Murphy, Marylee, Clark, Martyn, and Lewis, W.M., 2004, The influence of climate variation on the estimation of low flows used to protect water quality—a nationwide assessment: Journal of the American Water Resources Association, v. 40, no. 5, p. 1339–1349.

Stedinger, J.R., Vogel, R.M., Georgiou, E.F., 1993, Chapter 18—Frequency analysis of extreme events, *in* Maidment, D.R., ed., Handbook of hydrology: New York, McGraw-Hill Book Company, p. 18.1–18.68.

U.S. Army Corps of Engineers, 1993, Engineering and Design—Hydrologic frequency analysis: Washington, DC, Department of the Army, CECW-EH-Y, U.S. Army Corps of Engineers, Engineer Manual No. 1110-2-1415, 147 p.

U.S. Army Corps of Engineers, 1994, Engineering and Design—Flood-runoff analysis: Washington, DC, Department of the Army, CECW-EH-Y, U.S. Army Corps of Engineers Engineer Manual No. 1110-2-1417, 214 p.

U.S. Environmental Protection Agency, 1986, Technical guidance manual for performing wasteload allocation—Book 6, Design conditions, Chapter I Stream design flow for steady-state modeling: Washington, DC, U.S. Environmental Protection Agency: Report EPA 440/4-86-014, 64 p.

U.S. Geological Survey, 2002, NWIS Web—New site for the Nation's water data: U.S. Geological Survey Fact Sheet FS-128-02, 2 p.

U.S. Geological Survey, 2008, NWISWeb data for the Nation, accessed February 12, 2008, at *http://waterdata.usgs.gov/nwis/*

U.S. Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency, Bulletin 17B of the Hydrology Subcommittee: Reston, VA, U.S. Geological Survey, Office of Water Data Coordination, 185 p.

U.S. Natural Resources Conservation Service, 1998, Tables of percentage points of the Pearson Type III distribution: U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division, Technical Release 38, 17 p.

U.S. Natural Resources Conservation Service, 2000, Selected statistical methods: Washington, DC, United States Department of Agriculture, Natural Resources Conservation Service, National Engineering Handbook, Part 630, Hydrology, Chapter 18, 91 p.

Vogel R.M., and Kroll, C.N., 1989, Low-flow frequency analysis using probability-plot correlation coefficients: Journal of Water Resources Planning and Management, v. 115, no. 3, p. 338–357.

Vogel R.M., and McMartin D.E., 1991, Probability plot goodness of fit and skewness estimation for the Pearson type 3 distribution: Water Resources Research, v. 27, no. 12, p. 3149–3158.

Vogel, R.M., Rudolph, B.E., and Hooper, R.P., 2005, Probabilistic behavior of water-quality loads: Journal of Environmental Engineering, v. 131, no. 7, p. 1081–1089.

Vogel R.M., Stedinger, J.R., and Hooper, R.P., 2003, Discharge indices for water-quality loads: Water Resources Research, v. 39, no. 10, p. 1273–1281.

Wahl, K.L., Thomas, W.O., Jr., and Hirsch, R.M., 1995, Stream-gaging program of the U.S. Geological Survey: U.S. Geological Survey Circular 1123, 22 p.

Warn, A.E., and Brew, J.S., 1980, Mass balance: Water Research, v. 14, p. 1427–1434.